Responses by Breeding Xantus's Murrelets Eight Years after Eradication of Black Rats from Anacapa Island, California

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EXECUTIVE SUMMARY

- In 2010, California Institute of Environmental Studies (CIES) conducted the 11th consecutive year of Xantus's Murrelet (*Synthliboramphus hypoleucus*) nest monitoring at Anacapa Island, California, with funding from the American Trader Trustee Council (ATTC). In 2001-02, Black Rats (*Rattus rattus*) were eradicated from Anacapa Island. In 2000-03, Humboldt State University, CIES, Hamer Environmental and Channel Islands National Marine Sanctuary designed and implemented a program to gather pre-eradication and immediate post-eradication data (including nest monitoring, spotlight surveys and radar monitoring) on Xantus's Murrelets. In 2004-10, CIES continued post-eradication nest monitoring to document population recovery and expanded use of breeding habitats.

- Preliminary nest searches began in ten sea caves on West and Middle Anacapa islands in 2000. Standardized annual nest monitoring was conducted in these caves from 2001-10. In 2003 and again in 2005, we expanded nest monitoring to include plots in accessible cliff, shoreline and offshore rock habitats ("non-cave plots") where murrelets were not known to nest in 1991-2002.

- Several murrelet breeding indices were highest in 2010, with more clutches laid (n = 57 overall, 34 in sea caves, 23 in other plots) and higher nest occupancy (68% overall, 65% in sea caves, 72% in non-cave plots) than in any year since monitoring began. Mean egg-laying (1 April ± 29 d) in 2010 was the earliest recorded during this study.

- Overall hatching success in 2010 was 80% for all clutches (n =56), 79% for first clutches (n = 43) and 85% (n = 13) for "second clutches" (i.e., replacement, second or different pair clutches). Overall hatching success was 79% in sea caves (n = 34) and 82% in the non-cave plots (n = 22). This was the first year that hatching success in non-cave plots exceeded that in sea caves since adequate samples (> 10 clutches) became available in the non-cave plots in 2007.

- Significant positive trends in site occupancy in sea caves and non-cave plots provided strong evidence of improved breeding conditions that permitted murrelet population growth at Anacapa Island post-eradication.

- Signs of growth in the murrelet breeding population were first evident in 2003 and 2005, the first and third years after rat eradication. However, growth was not consistent in the first four years with a reduction in the number of occupied sites in 2004 and 2006. Consistent but weak growth in 2007 and 2008 was followed by strong to moderate increases in the number of occupied sites in 2009 and 2010. Clearly, the eradication of rats created conditions that allowed for population growth, but murrelets also required favorable prey conditions for sustained growth to occur.

- With an adequate time series in 2010, we conducted a preliminary analysis of the murrelet population growth rate in sea caves (2002-10), non-cave plots (2003-10) and all monitored areas (2003-10). Times series regressions generated from the log-transformed data estimated 14.0% to 15.8% annual growth in the number of occupied sites in all plots. Growth was 10.3% in sea caves and 24.3% to 36.6% in non-cave plots.

- Nest monitoring provided limited data to assess whether murrelet population increases resulted from local recruitment or other factors (e.g., immigration, increased proportion of breeding adults), but recruitment of local cohorts surely became an increasingly important factor in the dynamics of the breeding population over time as larger post-eradication cohorts reached maturity (likely 3-4 years of age).

- Increased hatching success has been a key factor allowing post-eradication population growth. Post-eradication (2003-10) hatching success in sea caves was 85% (range = 69-89%) compared to just 30% (range = 22-36%) pre-eradication (2001-02).

- Mammalian depredation has been nearly eliminated as a cause of nest failure at Anacapa since the removal of rats. Over half (60%) of all pre-eradication clutches (2001-02) were depredated by rats, but only 4% of clutches in sea caves and 7% of clutches in non-cave plots were depredated or scavenged post-eradication, likely by endemic deer mice (*Peromyscus maniculatus anacapae*).

- Annual mean clutch initiation dates (all clutches) ranged from 1 April (± 29 d) in 2010 to 20 May (± 29 d) in 2007.

- Nest searches conducted at Anacapa in October 2009 failed to find evidence of murrelets breeding in upper island habitats, suggesting that recent colony growth has been limited to sea caves and localized shoreline, cliff and offshore rock habitats.

- Possible factors impeding murrelet colony expansion into upper island habitats include: 1) upper island habitats are not suitable for widespread breeding and have never been used by murrelets to any great extent; 2) post-eradication population increase has not been sufficient to saturate currently occupied breeding habitats and stimulate more widespread colony expansion; 3) long-term extirpation of murrelets from upper island habitats has resulted in an absence of social stimuli and traditional visitation patterns necessary for rapid recolonization; and 4) lingering evidence of former occupation by rats may discourage pioneering murrelets from breeding in upper island habitats.

- Twenty-seven sequential clutches and one simultaneous clutch were laid in 20 nest sites during this study, with the annual number of sequential clutches increasing as the number of occupied sites increased. Determining the origin of sequential clutches has important implications in the interpretation of monitoring data and assessments of murrelet population trends at Anacapa and other colonies.

- The small but growing Cassin's Auklet (*Ptychoramphus aleuticus*) population now breeds in at least four separate locations on Anacapa Island, providing additional evidence of the benefits of rat eradication program for the island's marine avifauna.

- Funding from ATTC for annual nest monitoring at Anacapa ended after the 2010 breeding season. Continued nest monitoring beyond 2010 is desirable to best document continued recovery of Xantus's Murrelets at Anacapa Island, currently one of only two US colonies of this state-threatened species that are monitored annually for reproductive success. Population monitoring using spotlight surveys should also be conducted in the future to better assess island-wide changes in population size.

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INTRODUCTION

In February 1990, the *American Trader* oil spill occurred off Huntington Beach, California, killing about 3,400 seabirds (ATTC 2001, Carter 2003). With funds from the 1998 litigation settlement, the American Trader Trustee Council (ATTC), in collaboration with Channel Islands National Park (CINP), developed a restoration plan to enhance seabird breeding habitat on Anacapa Island, California, by eradicating non-native Black Rats (*Rattus rattus*) (ATTC 2001; Howald et al. 2005, 2009). The Xantus's Murrelet (*Synthliboramphus hypoleucus*) was identified as the seabird species expected to benefit most from rat eradication. The Anacapa murrelet colony apparently had been severely impacted by rats since at least the early 1900s (Hunt et al. 1979, Carter et al. 1992, McChesney and Tershy 1998, McChesney et al. 2000, Whitworth et al. 2003a) and ATTC determined that rat eradication would prevent possible loss of this important colony and promote murrelet population recovery. In December 2004, Xantus's Murrelet was listed as threatened by the California Fish and Game Commission. The expected recovery of the Anacapa murrelet colony was considered a significant step toward increasing the probability of maintaining viable populations in California (Burkett et al. 2003). Since 2004, Xantus's Murrelet has also been listed as a candidate species under the federal Endangered Species Act.

Island Conservation and CINP successfully eradicated rats from Anacapa Island in two phases: 1) East Anacapa and the eastern end of Middle Anacapa in December 2001; and 2) West Anacapa and the remainder of Middle Anacapa in November 2002 (Howald et al. 2005). While non-native introduced 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), little effort had been made to document the benefits of cat eradication for murrelets or other seabirds.

In 2000, ATTC sponsored Humboldt State University (HSU), California Institute of Environmental Studies (CIES), Hamer Environmental and Channel Islands National Marine Sanctuary (CINMS) to design and implement a Xantus's Murrelet monitoring program for Anacapa Island. The primary goals of this monitoring program were to: 1) determine baseline levels of murrelet population size and reproductive success prior to eradication; and 2) measure expected increases in population size and reproductive success immediately after eradication. Innovative population monitoring techniques (including nest monitoring in sea caves, nocturnal spotlight surveys of at-sea congregations, and radar monitoring) were employed in 2000-03 to provide reliable baseline indices of murrelet population size and reproductive success (Whitworth et al. 2003a, 2005a; Hamer et al. 2005).

In 2004, ATTC decided that baseline data collection was completed but annual nest monitoring was still needed for a sufficient period of time after eradication to measure the rate of recovery and extent of reoccupation of breeding habitats. In 2004-06, CIES and CINMS were funded by ATTC to continue nest searches and monitoring in sea caves and other nesting habitats at Anacapa Island. CIES continued nest monitoring from 2007-10 but CINMS could not participate in these efforts due to staff changes and other priorities.

In 2000-10, nest monitoring has provided standardized data for: 1) measuring number of clutches, site occupancy and hatching success; and 2) detecting expansion of the colony into habitats previously occupied by rats (Whitworth et al. 2009). Efforts at Anacapa Island in 2010 marked the 11th and final year of murrelet nest monitoring supported by ATTC. In this report, we present the results of 2010 nest monitoring with comparison to previous years. In Appendix 1, we also summarize and discuss the results of nest searches conducted in October 2009 in upper island habitats where surface nesting seabirds (e.g., pelicans and cormorants) prevented access to potential murrelet breeding habitats during the seabird breeding season.

METHODS

Study Area

Anacapa Island is the easternmost and smallest of the northern four California Channel Islands and is located 15 km southwest of Ventura. It is comprised of three 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 three islets (Fig. 2), followed by Middle Anacapa (0.6 km^2, 99 m; Fig. 3), and East Anacapa (0.5 km^2, 73 m; Fig. 4). 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. Surrounding waters are managed by CINMS (out to 9.7 km [6 miles] from shore), California Department of Fish and Game (out to 4.8 km [3 miles] from shore), and CINP (out to 1.6 km [1 mile] from shore).

Nest Monitoring

In March-August 2010, CIES conducted nest searches and monitoring in 10 sea caves previously monitored in 2000-09, and cliff, shoreline and offshore rock habitats ("non-cave plots") where monitoring began in 2003 or 2005 (Figs. 1-4). Caves were named by Bunnell (1993). All 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 27 May, but less frequently later in the breeding season on 25-26 June and 1 August.

With reduced funds and extended nesting beyond June in 2004-10, nest monitoring was changed from the weekly schedule used in 2001-04 to a less frequent schedule in 2005-08 (biweekly) and 2009-10 (every 10-15 days). We now consider the 10-15 day checks to be the most efficient long-term monitoring schedule for obtaining adequate data at Anacapa Island with available time, funds, and boat support. While less frequent checks can result in less exact breeding phenology data for some clutches, the accuracy of hatching success is not affected (usually determined by presence of 1-2 hatched eggshell fragments after evidence of full-term

incubation). 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 standardized compared to 2001-10 data.

Systematic efforts to survey potential murrelet nesting habitat in the non-cave plots began in 2003 and were expanded in 2005. Using methods similar to sea cave nest monitoring, non-cave plots were thoroughly searched as follows: 1) cliffs in Landing Cove on East Anacapa (2003-10; Fig. 4); 2) Cat Rock off West Anacapa (2003-10; Fig. 2); and 3) Rockfall Cove on the south side of Middle Anacapa (2005-10; Fig. 3). Previously tagged sites in these plots were checked every 10-15 days as for sea cave sites. More extensive nest searches of non-cave plots were conducted periodically during the breeding season after egg laying had progressed substantially in most sea caves. By monitoring some areas outside of sea caves, we aimed to detect the reoccupation of former murrelet nesting areas that have not been used for decades due to presence of rats.

Monitored nest sites were identified as suitable crevices or sheltered sites, containing evidence of past or present breeding. Such evidence included an incubating or brooding adult, whole unattended eggs, broken or hatched eggshell fragments, or eggshell membranes. 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, one or two unattended eggs, incubating or brooding adult, abandoned eggs, broken or hatched eggshell fragments) and searched for new nest sites. 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 one egg was observed because murrelets are prone to abandonment when handled or prodded on nests and we did not consider hatched or broken eggshells a reliable indicator of clutch size.

Hatching Success – As in 2000-09, hatching success was determined as the percent of all clutches that successfully hatched at least one 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. 5) in or near the nest site.

Failed clutches were classified as depredated, abandoned or usurped 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 shell edges inflicted by rats (larger bite marks on shell edges or greater crushing of eggshells) or mice (smaller bite marks on shell edges with little or no crushing; Fig. 6). 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 two consecutive nest checks. Because egg neglect is known for Xantus's Murrelets, unattended eggs were not removed until after three or more nest checks to ensure that eggs were definitely abandoned. "Usurped" nests were included as a possible clutch fate in 2008 after considerable numbers of murrelet eggs were broken or ejected from sites by Pigeon Guillemots (*Cepphus columba*) in 2007-08. The few

clutches with unknown nest fates were excluded from calculations of hatching success and rates of depredation and abandonment.

Occupancy – Annual site occupancy was calculated as the percentage of all monitored nest sites (regardless of the year when the site was first tagged) in which at least one clutch was detected that year. Potential nest sites were not tagged until evidence of egg laying was first observed, but because all habitats in sea caves and non-cave plots were thoroughly searched each year, we believe that 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 nest sites were added to the sample of monitored sites. This technique increases 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 one 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 or tidal surges in 2008 (one site) and 2010 (two sites) were excluded from occupancy analyses in subsequent years.

A nest site with a single egg found near the East Fish Camp Anchorage in 2004 had been included as a monitored site in previous reports, but was excluded from all analyses in this report because we considered the infrequent nest searches in this area not standardized compared to sea caves and other plots. This nest site was destroyed by a rockslide the following winter and nest searches during the breeding season in this area ceased after 2005.

Single eggs (one each in 2005 and 2008) found in what were considered unsuitable nest sites in sea caves were excluded from estimates of nest occupancy, but were included as abandoned eggs for calculations of hatching success in those years. These unsuitable sites were located in brightly lighted open areas on the cave floor in Lava Bench #1 Cave in 2005 and Lonely at the Top Cave in 2008. We did not consider these eggs to be intentionally laid at these locations and eggs were not laid in these sites in subsequent years.

Sequential Clutches – In some years, particularly 2009 and 2010, a considerable number of nest sites had more than one clutch laid within a breeding season. In most cases, the latter clutch was laid after hatching or failure of the first clutch in the site ("sequential clutches"), although one 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), second 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 two sequential clutches is simply referred to as a second clutch (not to be confused with second clutches by the same breeding pair as described

above) because we could not determine the parentage of sequential clutches, although we suspect at least a few second clutches were laid by different pairs.

Timing of Breeding - A range of possible clutch initiation dates (i.e., laying date of the first 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 first egg of the clutch, such as: 1) one unattended egg prior to the laying of the second egg (i.e., between 1-7 days since laying); 2) two unattended eggs prior to the start of incubation (i.e., between 7-9 days since laying); 3) the first observation in a series of repeated checks with incubating birds (i.e., 10-14 days since laying); or 4) "chicks in nest" (i.e., between 0-3 days since hatching). The number of days subtracted took into account: a) mean time between the laying of two 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 (range = 27- 44 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 nest. However, with nest checks every 10-15 days in 2005-10, slightly greater error was involved in this process than with weekly nest checks in 2001-04.

Data Analysis

We calculated annual hatching success for all clutches, as well as first clutches and second clutches separately, but treated second clutches as independent (i.e., pooled first and second clutches in samples) for most statistical comparisons. We considered this to be the best approach for assessing the benefits of rat eradication in the improvement of breeding conditions at Anacapa. We used a Yates corrected Chi-square test (χ_c^2) to examine differences in the relative frequencies of hatched and failed clutches between: 1) first versus second clutches (sites with sequential clutches only) in 2010 and all years; 2) pre-eradication (2001-02) versus post-eradication (2003-10) periods; and 3) sea caves versus non-cave plots in 2010 and post-eradication. We also tested for differences in frequencies of depredated or scavenged clutches and other failed clutch fates in sea caves pre- versus post-eradication.

We used linear regression (Pearson *r*) to examine trends in nest site occupancy in the sea caves (2002-10) and non-cave plots (2003-10). Time series regression using log-transformed counts of the annual number of occupied sites (an index of breeding population size) provided preliminary estimates of population growth rates (Nur 1999, Eberhardt and Simmons 1992) in the sea caves (2002-10), non-cave plots (2003-10) and pooled data from all monitored areas (combined plots; 2003-10). Population growth rates were estimated based on the slope of the log-linear regression line. Regression analyses of occupancy trends and population growth in seas caves were conducted using 2002, the last year rats were present on the island, as the baseline year. We used 2003, the first year of monitoring outside sea caves, as the baseline year for regression analyses in non-cave plots. Regression analysis of non-cave plot data was complicated by the fact that monitoring in the Rockfall Cove plot did not begin until 2005. Because we could not confirm whether nesting occurred in Rockfall Cove in 2003-04, we performed separate regression analyses based on what we considered to be the minimum and maximum levels of

nesting possible in this plot. The minimum level of nesting assumed no occupied nests in Rockfall Cove in 2003-2004. The maximum level of nesting assumed two occupied nests found in Rockfall Cove in 2005 were occupied in both 2003 and 2004.

RESULTS

Nest Monitoring in 2010

Nesting Effort and Site Occupancy - In 2010, we monitored a total of 65 sites, including 40 in 10 sea caves and 25 in the non-cave plots (Table 1). A total of 57 clutches (34 in sea caves and 23 in non-cave plots) were recorded in 44 sites (26 in sea caves and 18 in non-cave plots). Clutches were laid in eight of 10 sea caves (all except Confusion Cave and Keyhole Cave) and in all three non-cave plots (Landing Cove cliffs, Rockfall Cove and Cat Rock; Table 1). Occupancy of monitored sites was 68% over the entire island (n = 65; Table 1), 65% (n = 40) in sea caves (Table 2) and 72% (n = 25) in non-cave plots (Table 3). Sequential clutches were recorded in 13 sites (Table 1), eight in sea caves and five in non-cave plots. We found no evidence of simultaneous clutches (i.e, three or more eggs found at the same time in a site) in 2010.

A total of eight new murrelet sites were established in 2010. Five sites were established in sea caves (Table 2), including three in Pinnacle Cave and one each in Lava Bench Cave #1 and Lonely at the Top Cave. Three sites were also established in non-cave plots (Table 3), including two nest sites in Rockfall Cove and one new site on Cat Rock. Two sites near the entrance of Pinnacle Cave (Nests #7 and #9) were lost due to a winter storm surge that inundated the sites and apparently moved the boulders in which the crevices were located.

Hatching Success - Overall hatching success was 80% (n = 56 clutches with known fates; Table 1); 79% (n = 43 clutches) for first clutches and 85% (n = 13 clutches) for second clutches. Overall hatching success was 79% in sea caves (n = 34 clutches; Table 2) and 82% in non-cave plots (n = 22 clutches; Table 3). There were no significant differences ($\chi^2_c = 0.05$, $p > 0.80$) in the relative frequencies of hatched and failed fates between sea caves and non-cave plots. Hatched eggshell fragments were found in or near the site for all 45 hatched clutches in 2010, although six clutches hatched only one egg, as based on single intact eggs left in the site. None of these eggs were opened to determine the degree of embryo development. Adults brooding chicks were not observed in 2010. One dead chick was observed near Lonely at the Top Nest #2 on 17 May when hatched eggshell fragments were found in the site, but we could not determine clutch size to assess whether a second chick may have departed the site.

In 13 sites with sequential clutches in 2010, first and second clutches both hatched in seven sites (54%), first clutch hatched and second clutch failed in one site (8%), first clutches failed and second clutches hatched in three sites (23%), first and second clutches both failed in one site (8%), and first clutch fate was unknown and the second clutch hatched in one site (8%). There were no significant differences ($\chi^2_c = 0.34$, $p > 0.50$) in the relative frequencies of hatched and failed fates between first (n = 12) and second (n = 13) clutches with known fates. Depredation of at least one adult murrelet from each pair was responsible for both clutch failures in the site

where the first and second clutches both failed.

Only 11 failed clutches (20%; n = 56) were recorded at Anacapa in 2010, with seven failed clutches in the sea caves and four in non-cave plots (Table 1). Six clutches (55% of failed clutches) failed due to possible depredation or scavenging, including three clutches in which depredation of adults led to clutch failure and three clutches in which eggs were broken or missing but no sign of adult depredation was evident. Failed clutches with broken eggshells were assumed to have been depredated or scavenged by endemic deer mice (*Peromyscus maniculatus anacapae*).

Five failed clutches (45%) were abandoned. We could not determine the causes of clutch abandonment, although one clutch in the Landing Cove cliffs (Nest #15) was incubated over a two month period (28 March – 27 May) before being abandoned, possibly due to early embryo death or infertility. Marine debris deposited near Pinnacle Cave Nest #10 suggested the first clutch was abandoned when the site was inundated by high water during storms in early April. We considered this clutch to have been abandoned due to natural disturbance.
One murrelet clutch was assigned an unknown fate in 2010, but no usurped nests were documented this year (Table 1).

Timing of Breeding - Murrelet clutches (first and second clutches) were initiated over 112 days between 19 February and 10 June, with an overall mean initiation date of 1 April (± 29 d, n = 57). Peak egg laying occurred from early to late March, although smaller numbers of first clutches and second clutches were initiated through April and May (Fig. 7). Mean initiation date was 21 March (± 22 d, n = 44) for first clutches and 7 May (± 18 d, n = 13) for second clutches.

Cassin's Auklet – Cassin's Auklets (*Ptychoramphus aleuticus*) were found nesting at four locations on Anacapa Island in 2010, including five occupied sites on Rat Rock, three sites in Landing Cove, two sites along the north shore of West Anacapa near Portuguese Rock, and one site on Cat Rock. Adult auklets were seen in all 11 occupied sites, but the sites were checked only sporadically and we were able to observe eggs or chicks in only three sites. Observations of adult auklets in two sites (Nests #1 and #2) on Rat Rock from late March through late June suggested successful nesting and possibly second clutches in these sites. Three auklet sites on Rat Rock (Nest #4-6) and the two sites at Portuguese Rock were not found until late May or June and may have been active for several months before being discovered. We suspect auklets also may have nested in several other sites on Rat Rock and the north shore of West Anacapa where auklet guano and odor were detected, but sites were too deep to observe an adult, egg or chick.

Ashy Storm-Petrel – We found no evidence of Ashy Storm-Petrels (*Oceanodroma homochroa*) breeding in any sea cave or monitored plot at Anacapa Island in 2010.

Pigeon Guillemot - Five guillemot sites were found in 2010, including four in Keyhole Cave and one in Aerie Cave. We did not determine hatching or fledging success, but guillemot chicks were observed in three sites in Keyhole Cave (Fig. 8) and one site in Aerie Cave on 26 June, while 2 abandoned eggs were found in one site in Keyhole Cave. None of these sites contained

live chicks on 1 August, although one dead guillemot chick was found below Aerie Cave Nest #1. Keyhole Cave Nest #2 and Aerie Cave Nest #1 were former Xantus's Murrelet nest sites which had been usurped by guillemots in previous years and were occupied by guillemots again in 2010.

Inter-Annual Trends in Sea Caves

Annual Number of Clutches and Site Occupancy – Overall, a total of 184 clutches were found in 42 monitored sites (including two sites destroyed by tidal surges in early spring 2010) in sea caves since 2001 (Table 2). Since rat eradication, the number of monitored sites in sea caves has increased from 16 sites in 2002 to 40 sites in 2010. Annual site occupancy ranged from 24% in 2002 to 65% in 2010 (Table 2, Fig. 9), while the total number of clutches increased from 11 clutches (2001, 2002 and 2004) to 34 clutches (2010) (Table 2, Fig. 10). Significant increases in annual site occupancy were noted from 2002-10 ($r = 0.89$, $p < 0.002$).

Although the number of clutches and nest occupancy in 2000 were similar to other pre-eradication years (2001-02), infrequent monitoring in 2000 resulted in data that were less standardized than in subsequent years. Furthermore, our analysis of 2000 data excluded six rat depredated eggs found away from sites in sea caves. Since these depredated eggs may have come from sites that were later monitored, we probably underestimated the number of clutches found (n = 9) and site occupancy (24%), and overestimated hatching success (86% - considerably higher than other pre-eradication years) to some degree in 2000.

Hatching Success – Excluding unknown clutch fates and data from 2000 (*see Methods and above*), hatching success in sea caves post-eradication (85%, n = 158 clutches with known fates) was nearly three times that observed pre-eradication (30%; n = 20 clutches). The relative frequency of hatched versus failed clutches was significantly higher ($\chi^2_c = 29.86$, $p < 0.0001$) post-eradication (Fig. 11). Hatching success in sea caves was highest in 2009 (96%), but has been consistently high (range 73-96%) since 2003 (Table 2; Fig. 12).

Post-eradication clutch failures in the sea caves (n = 23 clutches) have been attributed primarily to abandonment (n = 14 clutches; 61% of all failed clutches), with smaller numbers of depredated or scavenged (n = 6; 26%) and usurped or disturbed (n = 3; 13%) fates (Table 2). In contrast, pre-eradication (2001-02) clutch failures (n = 14) were attributed primarily to depredation by rats or depredation/scavenging by mice (n = 12; 86%), with few (n = 2; 14%) abandoned clutches (Table 2). The relative frequencies of depredated or scavenged clutches compared to other failed clutch fates differed significantly between pre- and post-eradiation periods ($\chi^2_c = 10.11$, $p < 0.002$).

Four of the six depredated or scavenged clutches in sea caves since rat eradication were associated with depredated adult murrelets, presumably victims of avian predators as evidenced by feather piles found near the site. Up to three abandoned clutches (4-20% of total clutches) have been found in sea caves each year since 2001.

Colony Expansion in Non-Cave Plots

In 2003-10, a total of 84 clutches were found in 26 monitored sites (including one site destroyed by falling rocks during the 2008 breeding season) in non-cave plots (Table 3). No evidence of breeding had been found during periodic nest searches in these areas from 1991 to 2002. The number of monitored sites in non-cave plots increased from two in 2003 to 25 in 2010. Annual site occupancy ranged from 4-12% in 2004 to 72% in 2010 (Table 3, Fig. 9), while the annual number of clutches increased from two in 2003 to 23 in 2010 (Table 3, Fig. 10).

Different potential levels of nesting (i.e., 0-2 clutches) in the Rockfall Cove plot in 2003-2004 (Table 3) had little effect on trends in site occupancy. Strong increases in occupancy from 2003 to 2010 were noted in non-cave plots for both the minimum ($r = 0.97$, $p < 0.0001$) and maximum ($r = 0.96$, $p < 0.0002$) levels of nesting (Fig. 13).

Overall hatching success (excluding three clutches with unknown fates) in non-cave plots was 80% (n = 81 clutches), with only 20% failed in 2003-10 (Table 3). Extremely high hatching success in non-cave plots from 2003 to 2006 (86-100%; Table 3, Fig. 14) was affected by small annual samples (n = 2-8 clutches per year). Hatching success has decreased somewhat (64-82%) since 2007 when larger samples (> 10 clutches per year) were found. Hatching success was much higher at Cat Rock (100%; n = 9 clutches) and Rockfall Cove (95%; n = 20 clutches), compared to Landing Cove (71%; n = 52 clutches), although smaller samples of clutches at Cat Rock and Rockfall Cove allowed for only rough comparisons.

Clutch failures in non-cave plots (n = 16) have been due primarily to abandonment (n = 9; 56%), with only six depredated/scavenged clutches (38%) and one site usurped by Pigeon Guillemots (6%).

Colony expansion has been most evident in the Landing Cove plot (Fig. 15) where the number of monitored sites increased from one in 2003 to 15 in 2010 (not including one site destroyed in spring 2008). The Rockfall Cove plot has shown moderate growth from two sites in 2005 to seven sites in 2010 (Fig. 16). In contrast, only two sites have been added since 2003 in the Cat Rock plot where breeding habitat is limited (Fig. 17).

Hatching Success and Nest Depredation in Sea Caves and Non-Cave Plots

No significant differences were found in the frequencies of hatched and failed clutches ($\chi^2_c = 0.71$, $p > 0.05$) between the sea caves and non-cave plots since 2003 (Tables 2-3). Hatching success appeared to be somewhat greater (16-25% higher) in sea caves in 2007-09 (Fig. 18) when adequate samples (> 10 clutches) became available in non-cave plots, but this difference was not observed in 2010 when hatching success in non-cave plots (82%) slightly exceeded that in sea caves (79%). The relative frequencies of depredated or scavenged clutches compared to other failed fates did not differ ($\chi^2_c = 0.17$, $p > 0.05$) between non-cave plots and sea caves during the post-eradication period.

Multiple Clutches in Sites

Twenty-seven instances of sequential clutches and one instance of simultaneous clutches were noted in 20 different nest sites during this study (Tables 4-5). Hatching success (clutches with known fates) for second clutches was 88% (n = 25) compared to 73% for first clutches (n = 26). We found no significant difference ($\chi_c^2 = 0.98$, $p > 0.05$) in the relative frequencies of hatched and failed fates between first and second clutches.

The annual number of sequential clutches increased dramatically in 2009-10 (nine in 2009 and 13 in 2010) compared to only 0-2 sequential clutches each year from 2002 to 2008 (Fig. 19). Nineteen second clutches (73%) were laid after first clutches hatched (although survival of chicks after nest departure to independence was not determined), while seven (27%) were laid after first clutches failed and one after an unknown first clutch fate. Twenty-two (88%) second clutches with known fates hatched, while three (12%) failed and two had unknown fates (both in 2009). The only case of two simultaneous clutches at Anacapa Island occurred in 2009.

Use of Individual Nest Sites

Since 2000, breeding has been noted at least once in all but one monitored site (Nest #2 marked in Refuge Cave in 1994; Tables 4-5). Excluding new sites found in 2010, twenty-one sites have been occupied each year since breeding was first documented, including four sea cave sites active each year since 2000. In contrast, four sites have not been used since at least 2003, although intervals of as few as one year and as many as seven years have passed without documented clutches in other sites. Seven of 12 new sites established in 2009 were occupied in 2010, but three of these sites were destroyed in the interceding winter.

Colony Growth Rate Post-Eradication

Log-linear regression analysis demonstrated strong overall growth of occupied sites in combined plots from 2003 to 2010 whether minimum ($r = 0.91$, $p < 0.002$) or maximum ($r = 0.92$, $p < 0.002$) levels of nesting were assumed in Rockfall Cove in 2003-04 (Fig. 20). Slopes of the regression lines (Fig. 20) differed little and had little effect on per annum growth rates (14.0% versus 15.8%).

Significant increases in the number of occupied sites in sea caves ($r = 0.90$, $p < 0.001$) resulted in 10.3% per annum growth from 2002 to 2010. However, much greater growth occurred in non-cave plots from 2003 to 2010 regardless of the assumptions concerning minimum (36.6%; $r = 0.88$, $p < 0.005$) or maximum (24.3%; $r = 0.94$, $p < 0.0005$) levels of nesting in Rockfall Cove in 2003-04 (Fig. 21).

Timing of Breeding

Annual mean clutch initiation ranged from 1 April (± 29 d) in 2010 to 20 May (± 29 d) in 2007 (Fig. 22; Table 6). The earliest clutch initiation occurred in 2009 (18 February), while the latest

clutch initiation (not a second clutch) 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. Excluding second clutches reduced the mean clutch initiation date by 11 days in both 2009 (28 March ± 21 d) and 2010 (21 March ± 22 d).

DISCUSSION

Xantus's Murrelet Recovery at Anacapa Island

Xantus's Murrelet nest monitoring provided solid evidence of improved breeding conditions on Anacapa Island following the eradication of Black Rats (Howald et al. 2005, 2009; Whitworth et al. 2005a). Poor pre-eradication hatching success in Anacapa sea caves was in stark contrast to the consistently high hatching success noted immediately after eradication in 2003 and every year since through 2010. The chief reason for this improvement in hatching success appeared to be the elimination of egg depredation by rats, as other colony-based factors (i.e, avian predators, deer mouse scavenging or predation) did not appear to change to any great degree between pre-eradication and post-eradication periods. High post-eradication hatching success also occurred in non-cave plots where murrelets had not been documented breeding since 1991 and likely had not nested to any great extent for a century or more. Rapid expansion of nesting into non-cave habitats indicated that murrelets quickly responded to the greater availability of suitable breeding habitat in some coastal areas, although little or no breeding has occurred yet in upper island habitats (*see Appendix 1*). Significant positive trends in nest occupancy in both sea cave and non-cave habitats suggested that considerable growth has occurred in the murrelet breeding population at Anacapa post-eradication. This is the first study to carefully document the immediate response of an alcid population after eradication of an introduced predator from an entire breeding island. We discuss various aspects of these responses in greater detail below.

Annual Variation in Murrelet Breeding Post-Eradication

While nest monitoring has documented improved hatching success and impressive overall population growth after eradication, increases in the annual number of occupied nest sites in monitored areas have not been consistent. Signs of growth in the number of breeding murrelets were first evident in 2003 and 2005, the first and third years after rat eradication. However, the intervening and subsequent years saw only weak growth (2007 and 2008) or even decreases (2004 and 2006) in the number of occupied sites. This period of weak growth and decline was followed by strong to moderate increases in 2009 and 2010, respectively. Evidently, the eradication of rats allowed for population growth given favorable environmental conditions, but factors other than reduced nest depredation (e.g., prey availability and abundance, adult survival and recruitment) clearly had major effects on the dynamics of the murrelet breeding population during the first decade after eradication.

We have not explored relationships between murrelet breeding indexes at Anacapa and factors

such as local prey and oceanographic conditions because such relationships have been shown to be rather weak and difficult to interpret for Xantus's Murrelets at Santa Barbara Island (Roth et al. 2005). However, timing of breeding is considered to be an indirect indicator of prey conditions for Xantus's Murrelets and other alcids in the California Current System, with late breeding often associated with poor reproduction and reduced prey (Hunt and Butler 1980, Ainley and Boekelheide 1990, Roth et al. 2005). Late egg-laying in 2004-2007 (Fig. 6) apparently reflected poor foraging conditions that generally coincided with weak growth or decline (with the notable exception of 2005) in the number of occupied nests. In contrast, early egg-laying in 2003 and 2008-2010 coincided with often large increases in occupied nests, particularly in 2003 (70%) and 2009 (38%). Early nesting was also observed in 2001-02, but rat predation probably prevented increased breeding by murrelets despite apparently favorable prey conditions during the pre-eradication years.

The poorest post-eradication breeding season (based on annual changes in the number of occupied nests) occurred in 2004, when late mean egg laying (2 May) coincided with the greatest inter-annual decrease (29%) in occupied nests and the lowest annual hatching success (73%) in sea caves during the post-eradication period (2003-10). Another poor breeding year occurred in 2006, with even later timing of breeding (17 May) than in 2004, although the annual decrease in occupied sites (8%) was less severe. Data from individual nest sites suggested poor prey conditions may have caused some experienced adult murrelets to refrain from breeding in 2004 and 2006. However, adult survival did not appear to be affected as breeding resumed in most of the vacant nests in 2005 and 2007. Poor foraging conditions can result in adults refraining from breeding (Erikstad et al. 1998), particularly in long-lived birds with low annual reproductive output such as alcids (Ashcroft 1979, Hudson 1985, Ainely and Boekelheide 1990).

Direct relationships between timing of breeding and murrelet breeding indexes were not evident in all years. Years with the latest (2007) and earliest (2010) mean egg-laying dates showed similar modest increases in occupied nests from the previous year, while the two years that experienced the highest annual decrease (2004) and highest annual increase (2005) in occupied nests shared very similar and relatively late mean egg-laying dates. Clearly, murrelet breeding indexes were dependent on rather complex interactions between prey, oceanography and colony-based factors that require more study.

Factors in Population Growth

Recruitment - Nest monitoring alone could not provide definitive data confirming the source of increased nesting at Anacapa Island from 2003-10. However, strong natal philopatry, which has not been studied in Xantus's Murrelet but has been documented in many other seabirds and alcids (e.g., Hudson 1985, Harris et al. 1996, Gaston and Jones 1998, Pyle 2001, Breton et al. 2006, Lavers et al. 2007; but see Coulson and Coulson 2008), makes it highly likely that most if not all new murrelet nests at Anacapa were initiated by local recruits. Strong philopatry has been found in the congeneric Ancient Murrelet (*S. antiquus*; Gaston 1992), while first-time breeding by Cassin's Auklets, another small crevice/burrow nesting alcid, commonly occurred within a few meters of their natal burrows at Southeast Farallon Island, California (Pyle 2001). Assuming

strong natal philopatry also occurs in Xantus's Murrelet, hatching success and recruitment of local chicks were probably among the most important factors in the dynamics of the breeding population at Anacapa prior to and after rat eradication. The small numbers of murrelets nesting in sea caves and isolated cliff refugiums while rats were present on Anacapa likely provided a source of recruits that maintained the remnant population and prevented extirpation of the colony. These same birds also contributed, at least in part, to the increase in the number of occupied nests during the early recovery period (*see below*). Since 2005, recruitment of larger post-eradication cohorts surely contributed to impressive increases in the breeding population when more favorable foraging conditions prevailed (e.g., 2009). These larger cohorts also may have limited decreases and even permitted weak growth in years with poor foraging conditions (e.g., 2006-2008).

The timing and local distribution of new nests established at Anacapa in 2005 were consistent with local recruitment as the primary factor responsible for increased nesting. Age at first breeding has not been studied in Xantus's Murrelet, but deferred sexual maturity is another trait shared among most seabirds and probably all Alcidae (Lack 1968, Hudson 1985). Deferred maturity in Xantus's Murrelets (probably 3-4 years as in the Ancient Murrelet; Gaston 1990, 1992) would have precluded increased nesting through local recruitment of post-eradication cohorts until 2005 at the earliest (the first phase of rat eradication was conducted on East and eastern Middle Anacapa in December 2001). In fact, a significant increase in nesting did occur in 2005 after a 3 year lag period that corresponded with the presumed age of first breeding for the first post-eradication cohort. Interestingly, most (70%) of the new nests established in 2005 were found on the Landing Cove cliffs on East Anacapa and sea caves on the eastern end of Middle Anacapa, as would be expected if a relatively large number of highly philopatric chicks had hatched in these areas beginning in 2002.

Immediate Post-Eradication Response (2002 to 2003) - Factors other than local recruitment may have led to the increased number of nests on the island from 2002 to 2003, given: (1) the small number of birds breeding in isolated refugiums; (2) poor hatching success prior to rat eradication (as measured in 2000-02); and (3) lack of any recruitment of larger post-eradication cohorts. We speculate that this increase may have reflected increased breeding by subadults and non-breeding adults which regularly attend at-sea congregations. Rat occupation in most breeding habitats at Anacapa (McChesney et al. 2000, Jones et al. 2005) may have: (1) inhibited egg-laying by some adults; or (2) increased age at first breeding for some subadults. For example, repeated disturbances or altercations with rats while prospecting for nest sites may have discouraged certain individuals from breeding in that year. Older subadults also might have had great difficulty finding first mates or rat-free nest sites near occupied habitats containing their natal nest sites which may have delayed the age of first breeding. With the sudden eradication of rats, greater breeding may have been encouraged in such individuals. Regehr et al. (2007) also speculated that a greater proportion of non-breeding adult Ancient Murrelets may have existed prior to rat eradication at Langara Island, British Columbia, and that an increase in the proportion of breeding adults was expected post-eradication.

It is also possible that the increase in the number of occupied sites from 2002 to 2003 was not as

drastic as the data suggest because we may have underestimated nesting in sea caves in 2001-02 by failing to detect some undocumented clutches that were depredated by rats before or between monitoring visits. We did find small numbers of depredated or scavenged eggs (1-3 clutches each year) in open sites far from suitable nest crevices in 2000-02 that were moved from nest sites by rats or mice (Whitworth et al. 2002a,b). These undocumented clutches could explain part (but not all) of the increase in the number of occupied sites in sea caves from 2002 to 2003, but could not explain the increase from 2004 to 2005 as depredated eggs were not found in open sites in 2004.

Immigration - Genetic studies from all known Xantus's Murrelet breeding islands (including Anacapa) have demonstrated sufficient gene flow within the two subspecies to maintain genetic continuity among the relatively isolated populations (Birt et al., in press). Thus, some form of infrequent or periodic immigration must occur among islands. Potential sources of gene flow between colonies is limited to: 1) established breeders changing breeding sites (breeding dispersal); or 2) birds nesting at a colony other than the natal colony (natal dispersal; Greenwood and Harvey 1982). Banding studies in highly philopatric alcids suggest that breeding dispersal occurs much less frequently than natal dispersal. Many hundreds of adult and subadult Xantus's Murrelets (and a few chicks) have been banded at Santa Barbara and Anacapa Islands, but despite their proximity (< 70 km) and the relatively high recapture rate at both islands (> 6%), movements between these colonies have never been documented (Whitworth et al. 1997, unpubl. data). These data indicate breeding dispersal was probably not a factor in the increase in the number of Xantus's Murrelets breeding at Anacapa.

Natal dispersal has been documented in a number of alcid species (Harris 1983, Hudson 1985, Halley and Harris 1993, Gaston and Jones 1998, Lavers et al. 2007), including considerable inter-colony movements by immature Ancient Murrelets (Gaston 1992). Even though infrequent natal dispersal events must have occurred at a sufficient rate to maintain genetic continuity between Xantus's Murrelet colonies, we do not believe it was a significant factor in the post-eradication population increases observed at Anacapa. Banding studies of birds captured in at-sea congregations are warranted to further examine murrelet movements and aspects of demography. Unfortunately, documenting immigration, recruitment of local chicks, or increased breeding in the adult population is complicated by the sensitivity of Xantus's Murrelets to handling when taken from nest sites and difficulties in capturing and banding large samples of chicks.

Population Growth Rates

With eight monitoring years since the final eradication of rats in fall 2002, we measured the rate of increase in the annual number of occupied nest sites and assumed these nests were representative of the overall population. Using 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, with estimated overall growth of 14.0% to 15.8% per annum since 2003. Some studies have surmised that the low reproductive potential of most alcids that lay one egg clutches limits large population increases from local recruitment alone,

and immigration must be a factor when such increases do occur (Leslie 1966, Hudson 1985, Harris and Wanless 1991). However, the two egg clutch of *Synthliboramphus* murrelets may increase their reproductive potential compared to most other alcids, making relatively large population increases more feasible. Strong growth without significant immigration was not unreasonable if the long-term impacts from rats reduced the murrelet population to an extremely low baseline level (effectively zero in some plots and caves) that, given favorable foraging conditions, recovered quickly once rats were eradicated. In fact, occupied site data fit an exponential growth model, particularly since 2006 (Fig. 20).

It is difficult to assess whether observed population growth rates in the combined plots were representative of the entire island. The overall growth rate may be higher than data from the combined plots indicated, as our data were weighted heavily toward sea cave habitats where the growth rate was much lower, when in fact, proportionally much more breeding habitat is available in shoreline and cliff habitats over the entire island. The actual rate of overall population growth at Anacapa may be closer to that observed in the non-cave plots (24-36%).

Growth rates based on the number of occupied nests may have been somewhat conservative if any sequential clutches were laid by different pairs. If future studies verify use of the same nest site by different pairs within a breeding season, growth rates would be better represented by the overall number of clutches. Strongly philopatric (*see above*) post-eradication cohorts returning to natal breeding habitats and first-time breeders responding to social cues from active breeding areas (e.g, Major and Jones 2011) may have resulted in increased competition for limited nesting sites, possibly leading to delayed nesting and sequential clutches by different pairs in some sites. Nest monitoring provided some evidence that competition for nest sites may have increased as the murrelet population grew in the absence of rats, primarily in sea caves and other habitats where the remnant murrelet population persisted prior to rat eradication. Increased numbers of sequential clutches coinciding with higher nest occupancy in 2009-10 was certainly suggestive that some second clutches were laid by second pairs. The high hatching success of first clutches (73%) makes it more likely that second clutches were laid by different pairs, rather than replacement clutches laid after first clutch failure (although no data are available to assess whether any second clutches were laid following failure to raise to chicks to independence). Furthermore, sequential clutches in a nest where one of the first clutch adults was killed by an avian predator provided convincing evidence for nesting by different pairs in a site within a breeding season. The parentage of sequential clutches merits much further study (*see below*). Simultaneous clutches in a sea cave nest on Anacapa also suggest competition for nest sites has occurred. Simultaneous clutches laid by different pairs are not uncommon at the larger murrelet colonies on the Coronado Islands (Whitworth et al 2008) and Santa Barbara Island, where two competing pairs were observed scuffling and laying eggs in a site (L. Harvey, unpubl. data).

Differences in census/monitoring techniques, sampling, within-colony variation, analyses, time periods, and various natural or anthropogenic factors affecting populations make direct comparisons of population growth rates among alcid species and colonies difficult. However, the overall growth rate per annum in monitored areas at Anacapa from 2002-10 was higher than the highest rates (10-12%) reported for Common Murre (*Uria aalge*), Thick-billed Murre (*U.*

lomvia), and Atlantic Puffin (*Fratercula arctica*) colonies in the Atlantic Ocean prior to 1985 (Hudson 1985).

Only one other study examining the post-eradication response of a *Synthliboramphus* murrelet has been conducted - Ancient Murrelet burrow counts and monitoring following the eradication of rats from Langara Island, British Columbia in 1995 (Regehr 2007). Direct comparisons with our results are difficult because methods differed and Langara surveys were only conducted in the fourth and ninth years after eradication. In contrast to the immediate benefits of rat eradication for Xantus's Murrelets at Anacapa Island, pre-eradication population declines for Ancient Murrelets at Langara Island apparently continued for at least four years post-eradication. Environmental conditions or a time lag before normalization of breeding activities were suggested as possible causes of the continued decline, but potential effects of inter-annual variation were not examined. Breeding conditions eventually improved, with increased burrow occupancy and a doubling of the overall population between 1999 and 2004 (Regehr 2007). However, little or no reoccupation of nearby vacant breeding habitats had occurred by 2004. While adequate data was lacking to make reliable assessments, increased adult survival, reduced emigration, increased burrow philopatry and a greater proportion of breeding adults in the total population were all suggested as possible factors in the population growth at Langara Island. Local recruitment was not believed to have increased markedly post-eradication. Annual growth rates were not reported at Langara for comparison with Anacapa.

Colony Expansion

Limited colony expansion at Anacapa in 2003-10 was made possible by the sudden increase in the amount of suitable nesting crevices. The higher growth rate observed in the non-cave plots (Fig. 21) likely resulted from the zero baseline level of nesting in these plots compared to sea caves where some nesting occurred pre-eradication. Murrelet use of Anacapa breeding habitats in 1994 to 2002 represented many decades of island occupation by rats during which murrelets were essentially extirpated from most if not all rat-accessible breeding habitats outside sea caves. Despite rat presence on the island, murrelets had continued to breed in sea caves refugiums which rats apparently did not access on a regular basis (McChesney et al. 2000). Newly available breeding habitats in non-cave plots were adjacent to long-occupied but limited habitats in sea caves, as well as at-sea congregation areas where relatively large numbers of adult and subadult murrelets served as a source of pioneers to explore and eventually use these largely vacant habitats.

Murrelet nesting in the Cat Rock and Landing Cove plots since 2003 represented reoccupation of these cliff and offshore rock habitats after many decades of absence. Infrequent or partial searches in Cat Rock and Landing Cove plots from 1991 to 2002 found no evidence of breeding murrelets (Carter et al. 1992, unpubl. data; McChesney et al. 2000; Whitworth et al. 2003a). First nesting occurred in 2003 in both plots (within one year of rat eradication at Cat Rock and two years at Landing Cove). The small number of nests found in 2003 also suggested no nesting occurred in the accessible portions of these plots pre-eradication. Egg specimens in museum collections confirmed that murrelets nested on Cat Rock and the Landing Cove cliffs in the early

20th century, though the extent of breeding in these areas could not be determined (McChesney et al. 2000). Egg records specified Cat Rock as the location of eight collected clutches, while Landing Cove could be inferred (e.g., "eggs laid in crevice in small cave near the lighthouse ladder on the northeast end of the east island" and "at the foot of the big cave on the northeast side of the east island") for four collected clutches. The role of egg collectors in the extirpation of murrelets from these habitats is difficult to assess. As far as we know, nest searches had never been conducted in the Rockfall Cove plot prior to 2003.

Certainly, the recent and current conditions at Anacapa makes this a rather unique situation with respect to most other alcid colonies – a remnant breeding population of Xantus's Murrelets that could increase in size and expand into unoccupied breeding habitats with few constraints after being suddenly freed from the heavy impacts of an introduced terrestrial predator (Black Rats). This early period of population growth (2003-10) is undoubtedly a temporary phase as suitable breeding habitats reach capacity and the island returns to a natural equilibrium. It is uncertain how long this period of strong colony growth at Anacapa Island will continue. The rate of colony recovery will change over time and will likely depend on continued high hatching success, high survival and colony size, as well as the timing and degree of colony expansion into currently unoccupied upper island habitats. We expect annual increases in the number of occupied sites in sea caves to slow as monitored breeding habitats become saturated. Indeed, high numbers of sequential clutches in 2009-10 may be related to decreases in the availability of sites in sea caves and non-cave plots (Fig. 19), although further study is needed (*see below*). Clutch failure rates in the monitored sea caves and non-cave plots also may increase with greater competition among murrelet pairs and development of new predator-prey relationships with avian predators and the deer mouse population. Recent nest monitoring data suggested that avian predators are having more of an impact on nesting murrelets than in previous years, with adult murrelets depredated from at least three nest sites in 2010. Heightened avian predation of adults (or chicks during the nest departure period) also may account for some sequential clutches involving the same or different mates.

Other Seabird Species

The small but growing number of Cassin's Auklet nests found at Anacapa Island in 2010 provided additional evidence of recovery of this species in the absence of rats. Eleven occupied auklet nests were found in four separate locations in 2010. Thus, the benefits of the rat eradication program have not been limited to murrelets, but have also improved the breeding prospects for Cassin's Auklets. While no active auklet nests had been found on Anacapa prior to 2003, strong evidence of pre-eradication breeding included: 1) one broken eggshell found at the west end of West Anacapa in July 1991 (F. Gress and H. Carter, unpubl. data); 2) eight auklets captured in mist nets on East Anacapa (6 auklets) and Rat Rock (2 auklets) in April-May 1994 (H. Carter, unpubl. data); and 3) an eggshell fragment found in the open on the floor of Pinnacle Cave in 1997 (McChesney et al. 2000).

Unfortunately, no evidence of breeding by Ashy Storm-Petrels was found in any of the areas searched during this study. However, the first active storm-petrel nest was discovered at

Anacapa in 2011 during searches in habitats that we did not regularly monitor (L. Harvey, unpubl. data). Breeding by storm-petrels in habitats inaccessible to rats had been suspected (Carter et al. 2008) based on capture of 50 Ashy Storm-Petrels in mist nets on East and West Anacapa in April-May 1994 (H. Carter, unpubl. data) and radar observations of storm-petrels circling upper cliff areas at Middle Anacapa in 2000-02 (Hamer et al. 2005).

Future Murrelet Monitoring at Anacapa

In fall 2007, the ATTC and CINP decided to discontinue funding for Xantus's Murrelet nest monitoring by CIES after the 2010 breeding season. Unfortunately, alternate funds to continue CIES participation in murrelet nest monitoring at Anacapa have not yet been obtained, although CINP conduct limited nest monitoring in 2011 with funding from the Montrose Settlements Trustee Council (L. Harvey, unpubl. data). Continuation of Anacapa nest monitoring using a method comparable to 2001-10 efforts is critical for best documentation of the rate and pattern of recovery of this colony until it approaches a "recovered" condition. While this program has gathered three years of pre-eradication data (2000-02) and eight years of post-eradication data (2003-10), the long-term value of rat eradication will not be well documented without continued annual monitoring for at least the next two decades. From a scientific perspective, high-quality annual data is needed to reliably measure the nature and rate of recovery of this colony after rat eradication. If low-quality data or no data are gathered annually, a great opportunity to measure the response of this state-threatened and federal candidate species to rat eradication will have been lost forever. However, periodic or sporadic monitoring efforts certainly would be better than a lack of monitoring for a general assessment of restoration progress in the future.

In previous reports, we identified and discussed a number of other pertinent issues for Xantus's Murrelets monitoring at Anacapa Island that merit further investigation. Two major issues to emphasize here are:

Sequential clutches - Further studies that examine parentage of sequential and simultaneous clutches are sorely needed to determine whether annual number of clutches or occupied sites provide the best estimates of population trends. Multiple clutches were laid in a significant number of sites in 2009 (25%) and 2010 (30%). As discussed thoroughly in the 2009 annual report (Whitworth et al. 2009), determining whether these multiple clutches were laid by the same breeding pair or different pairs has important implications in the interpretation of monitoring data and assessments of murrelet population trends at Anacapa and other colonies.

Spotlight Surveys - Although Xantus's Murrelet nest monitoring was selected by the ATTC for monitoring colony recovery since 2003, benefits to the overall murrelet population at Anacapa cannot be properly quantified using only nest monitoring in localized sea caves and non-cave plots. Extensive baseline data on numbers of murrelets attending at-sea congregations were gathered in 2001-04 (Whitworth et al. 2003c, 2004a). Additional spotlight surveys should also be conducted in the future to better assess island-wide population trends, allowing for confirmation and comparison to trends determined from nest monitoring.

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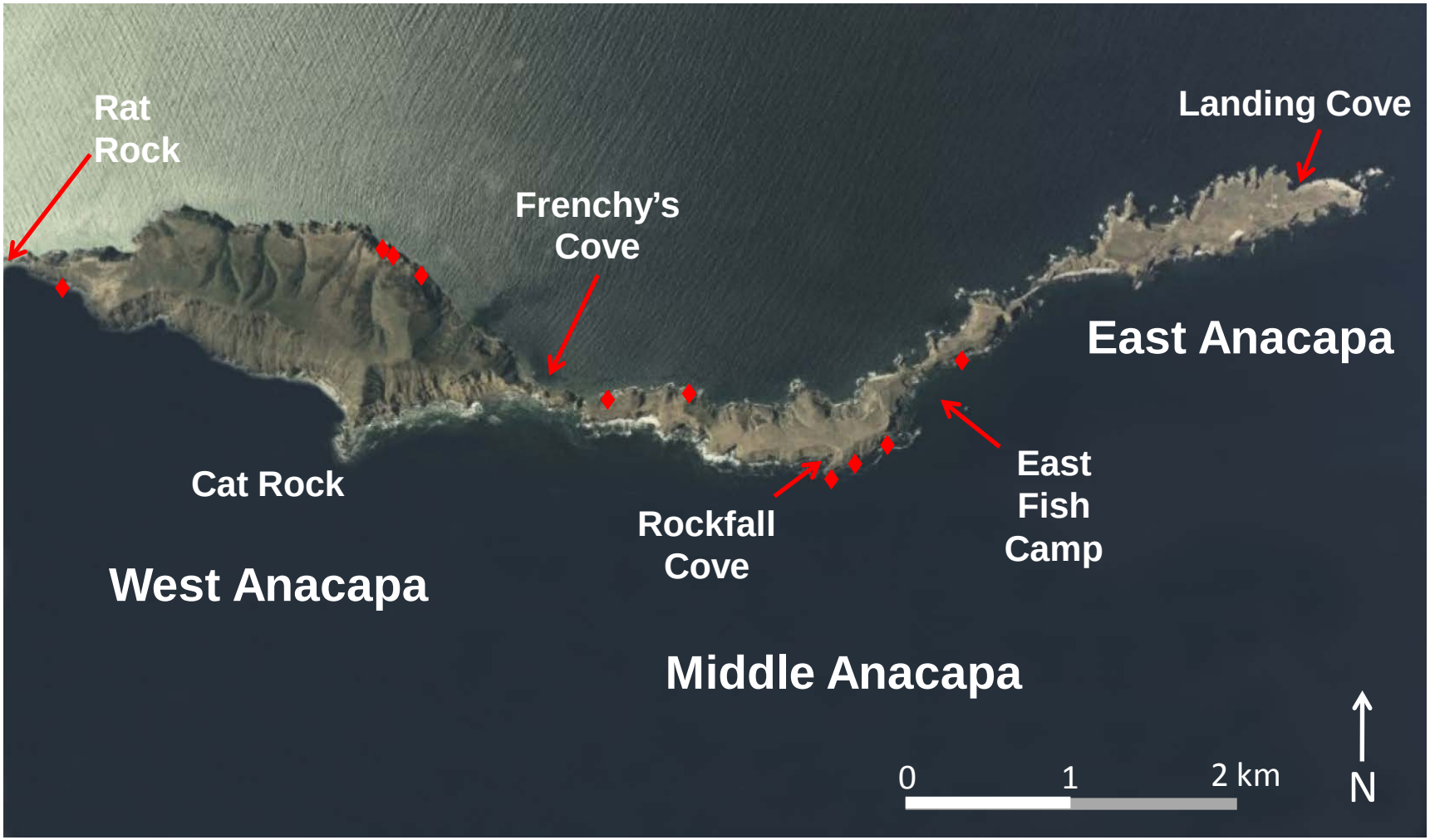


Figure 1. Satellite photograph of Anacapa Island, illustrating the three islets, sea caves (♦) and non-cave plots where Xantus's Murrelet nest monitoring was conducted from 2000-10.

Figure 2. Satellite photograph of West Anacapa Island, illustrating locations of sea caves and non-cave plots where Xantus's Murrelet nest monitoring was conducted from 2000-10.

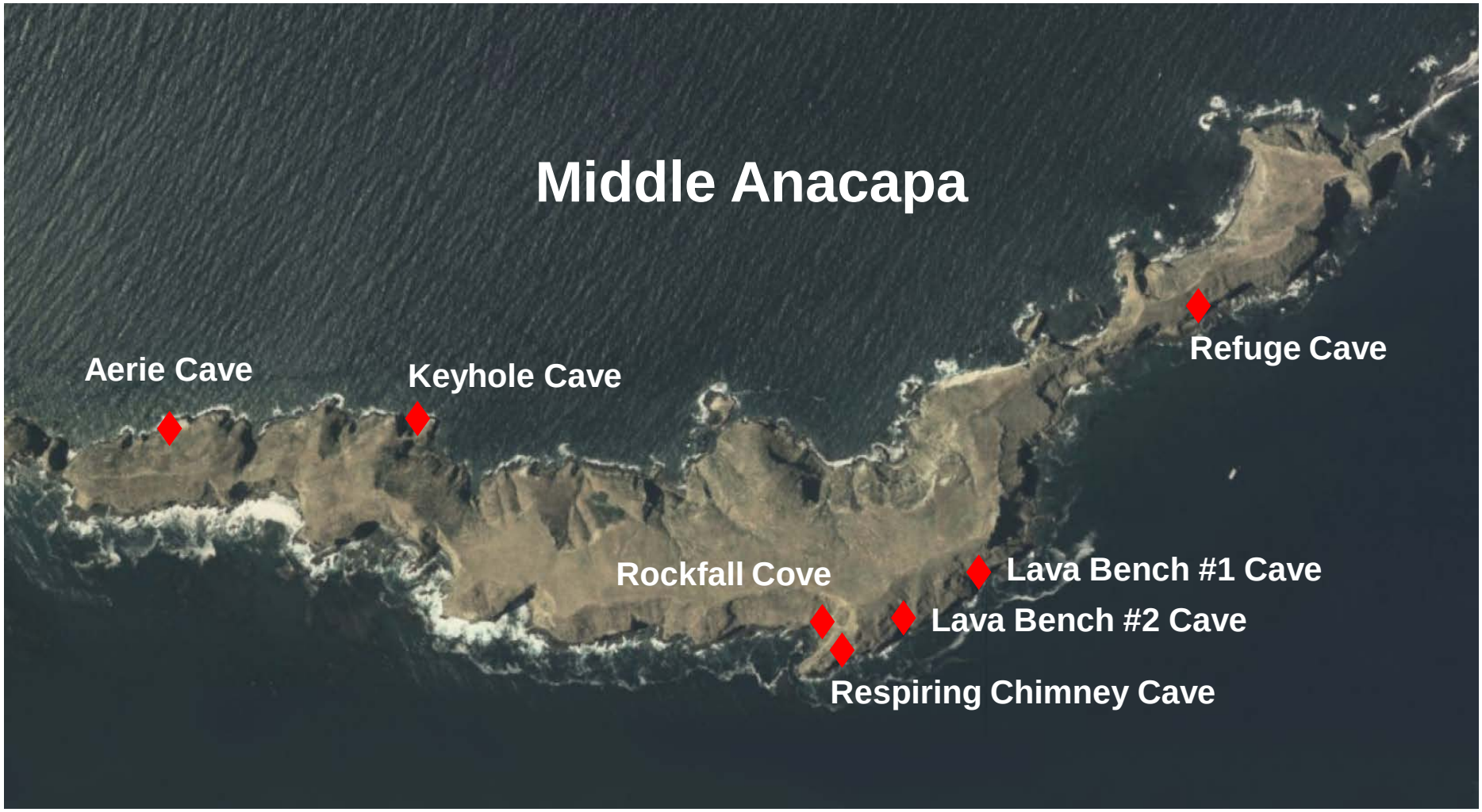


Figure 3. Satellite photograph of Middle Anacapa Island, illustrating locations of sea caves and non-cave plots where Xantus's Murrelet nest monitoring was conducted from 2000-10.

Figure 4. Satellite photograph of East Anacapa Island, illustrating location of Landing Cove where Xantus's Murrelet nest monitoring was conducted from 2000-10.

Figure 5. Hatched eggshells from Pinnacle Cave Nest #4 on 10 April 2009, illustrating characteristic dried membranes which separate from the eggshell. (Photo by D.L. Whitworth).

Figure 6. Mouse depredated eggshell from Nest #3 in Lonely at the Top Cave on 19 April 2010, illustrating small bite marks on the edge of the eggshell. (Photo by D.L. Whitworth).

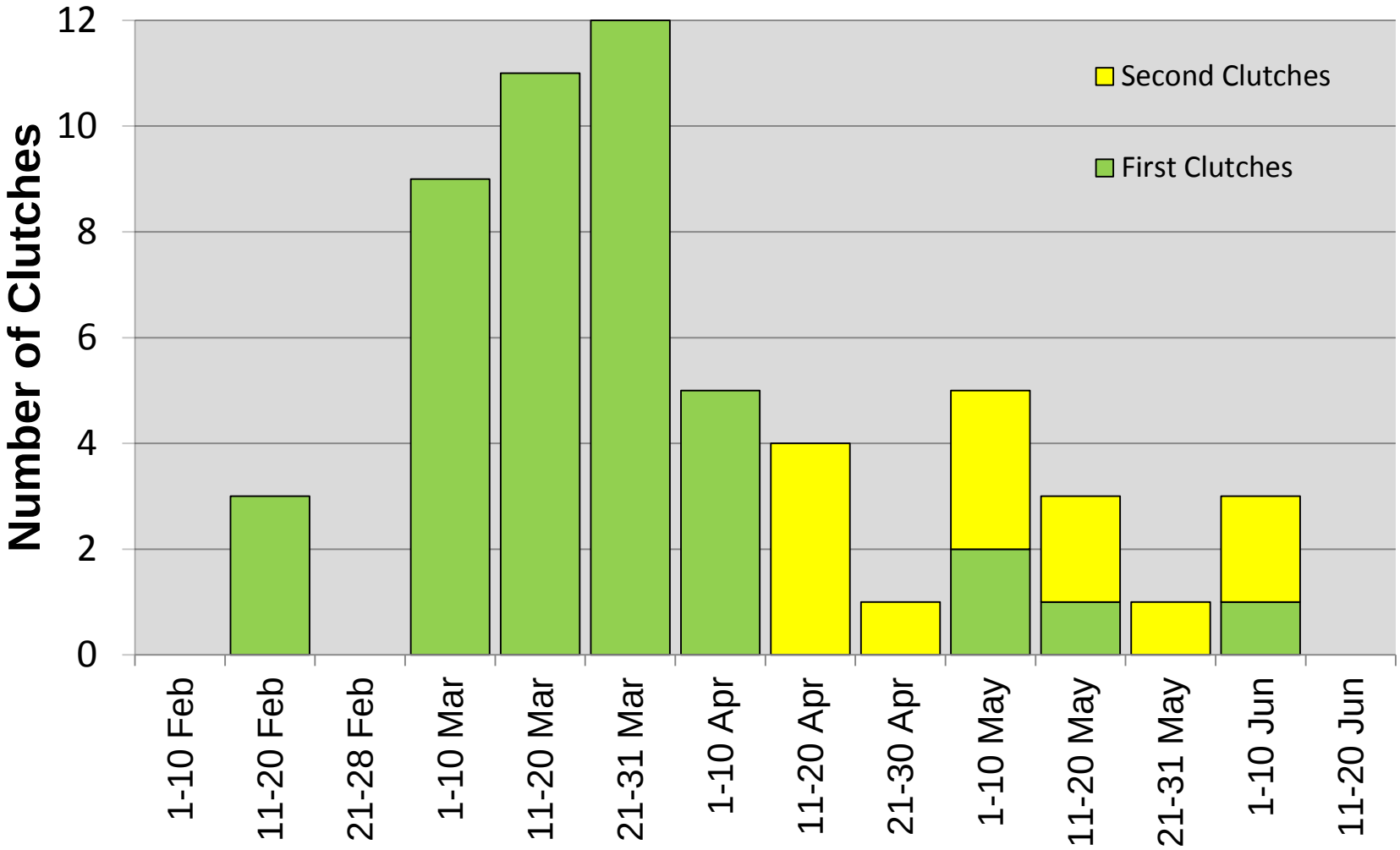


Figure 7. Initiation dates for Xantus's Murrelet clutches at Anacapa Island in 2010.

Figure 8. Pigeon Guillemot chick from an untagged crevice nest in Keyhole Cave, Anacapa Island, 26 June 2010 (Photo by D.L. Whitworth).

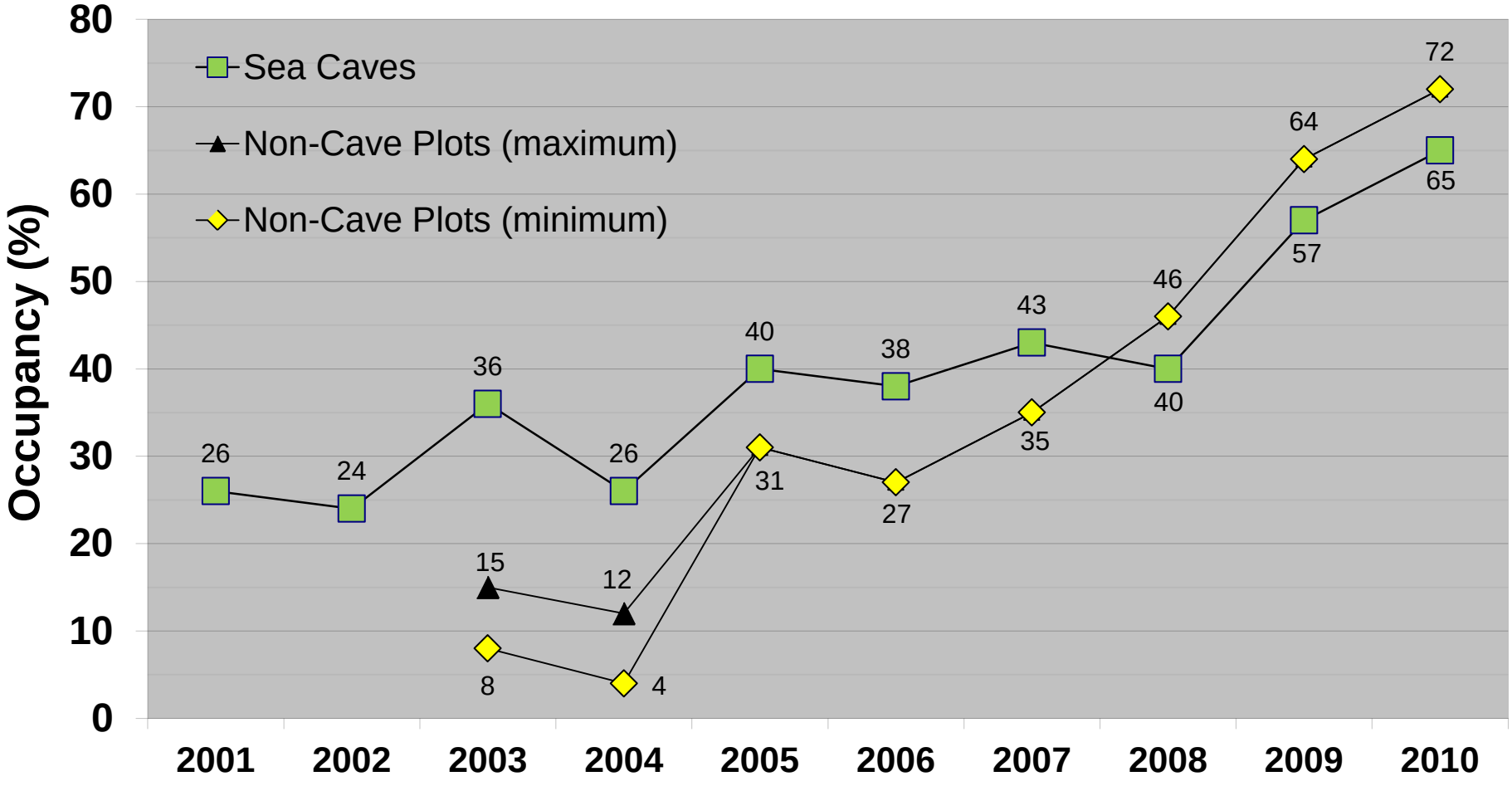


Figure 9. Annual site occupancy for Xantus's Murrelets in sea caves (2001-2010) and non-cave plots (2003-2010) at Anacapa Island, California. Minimum occupancy in non-cave plots assumed no occupied sites in Rockfall Cove plot in 2003-04, while maximum occupancy assumed two occupied nests found in 2005 were occupied in both 2003 and 2004 (*see Methods; Table 3*).

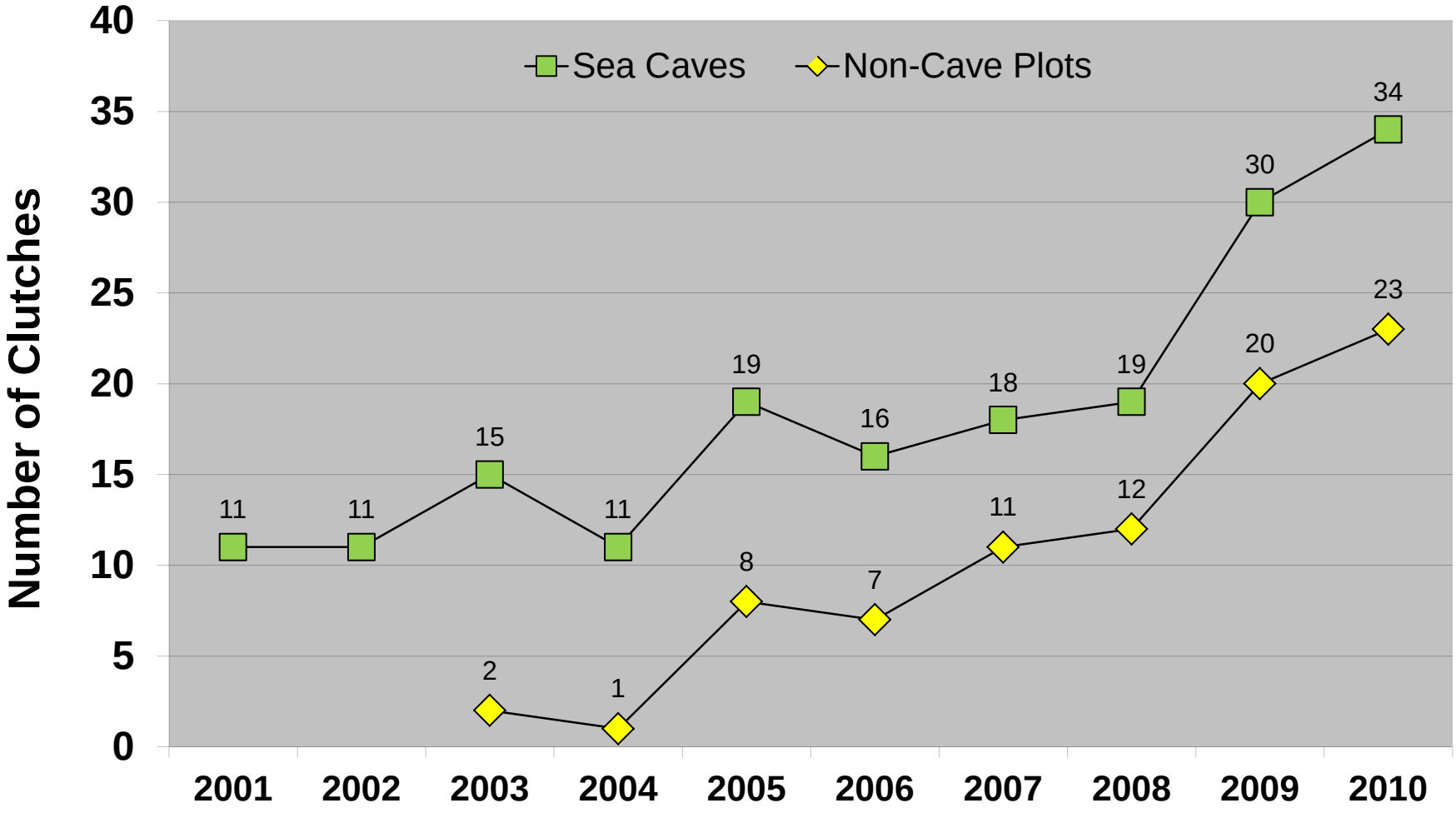


Figure 10. Annual number of clutches for Xantus's Murrelets in sea caves (2001-2010) and non-cave plots (2003-2010) at Anacapa Island, California. No occupied sites were assumed in Rockfall Cove in 2003-04 (*see Methods; Table 3*).

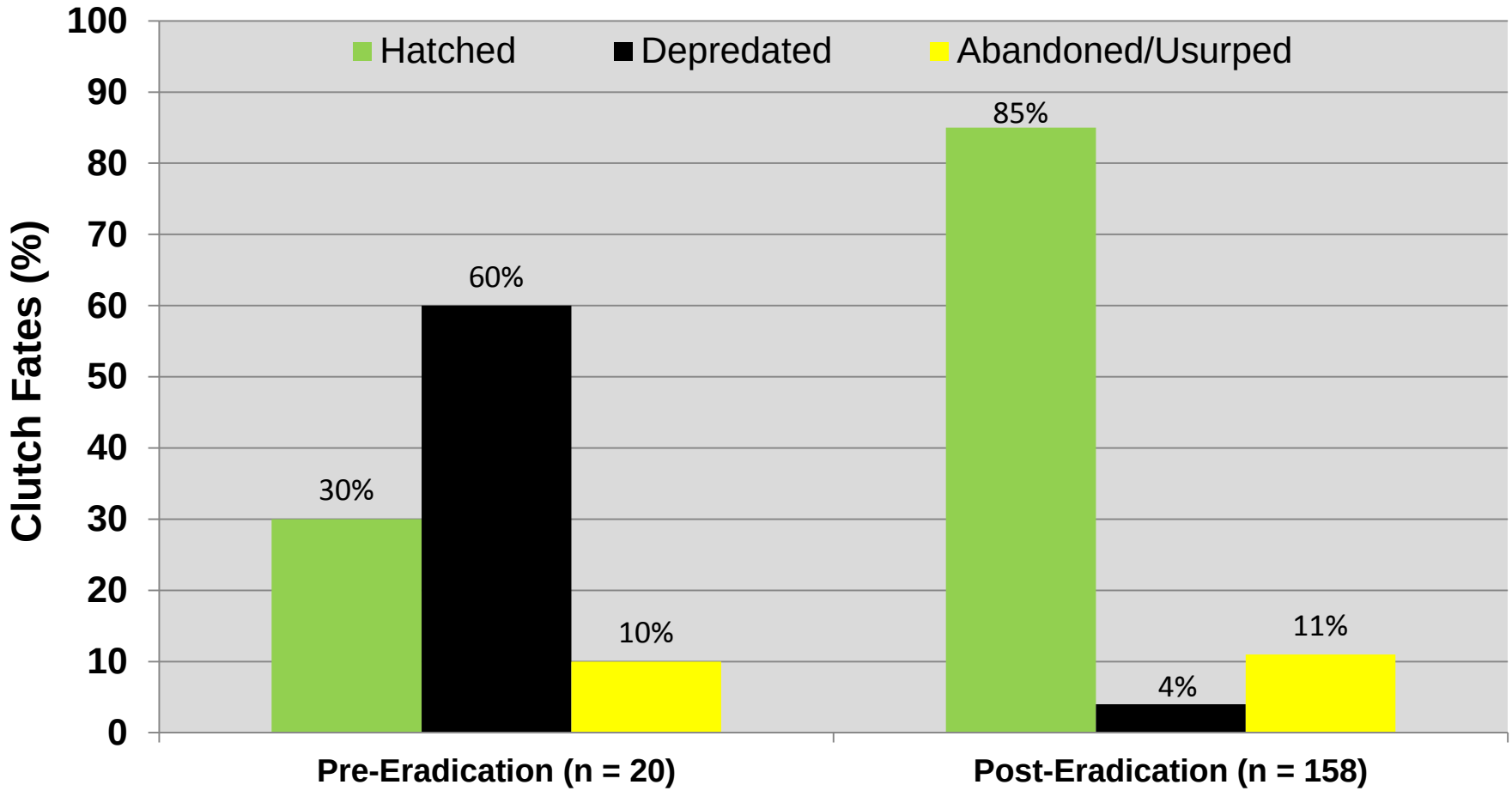


Figure 11. Comparison of Xantus's Murrelet clutch fates in sea caves at Anacapa Island pre-eradication (2001-02) versus post-eradication (2003-10).

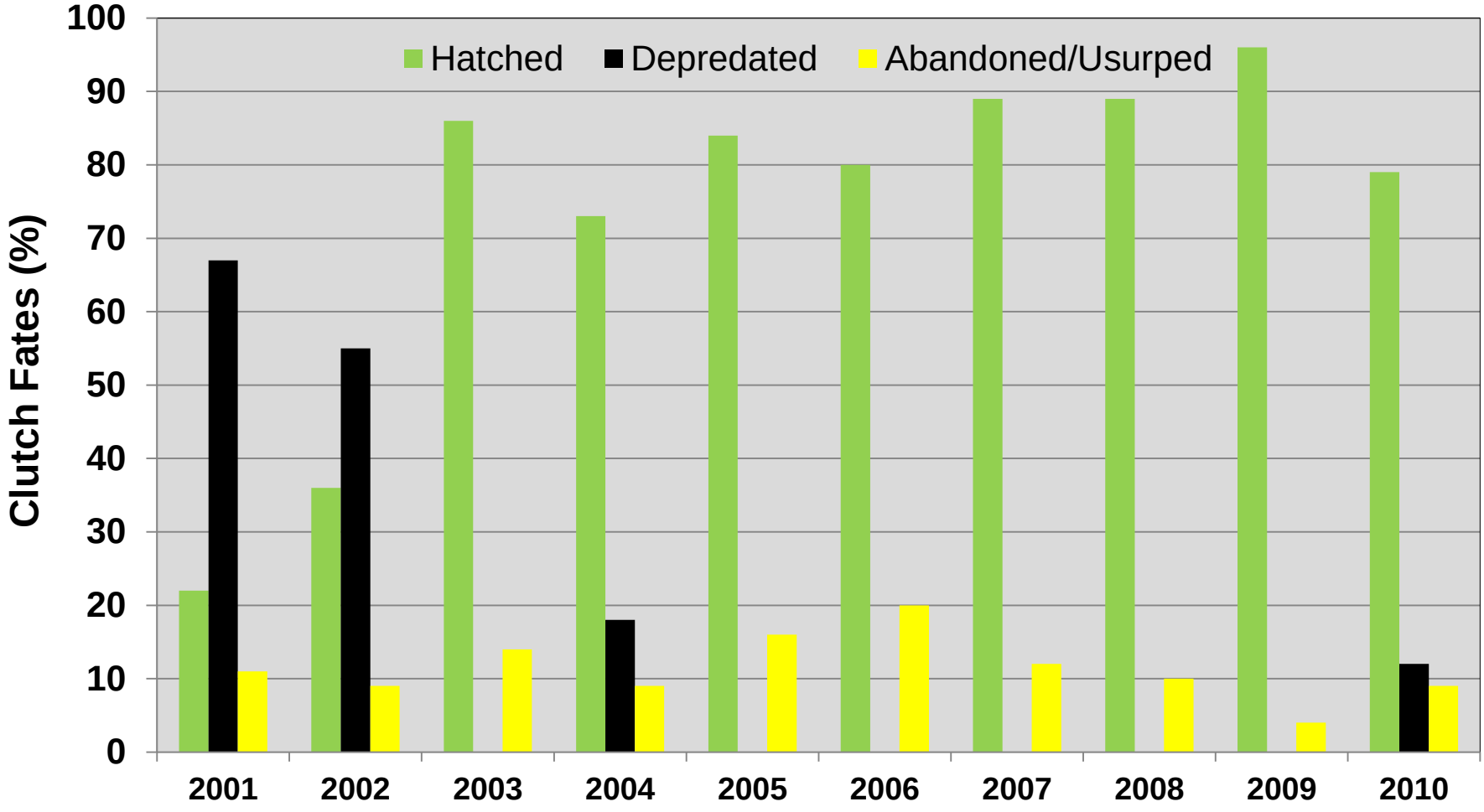


Figure 12. Annual hatching success for Xantus's Murrelets in sea caves at Anacapa Island in 2001-10.

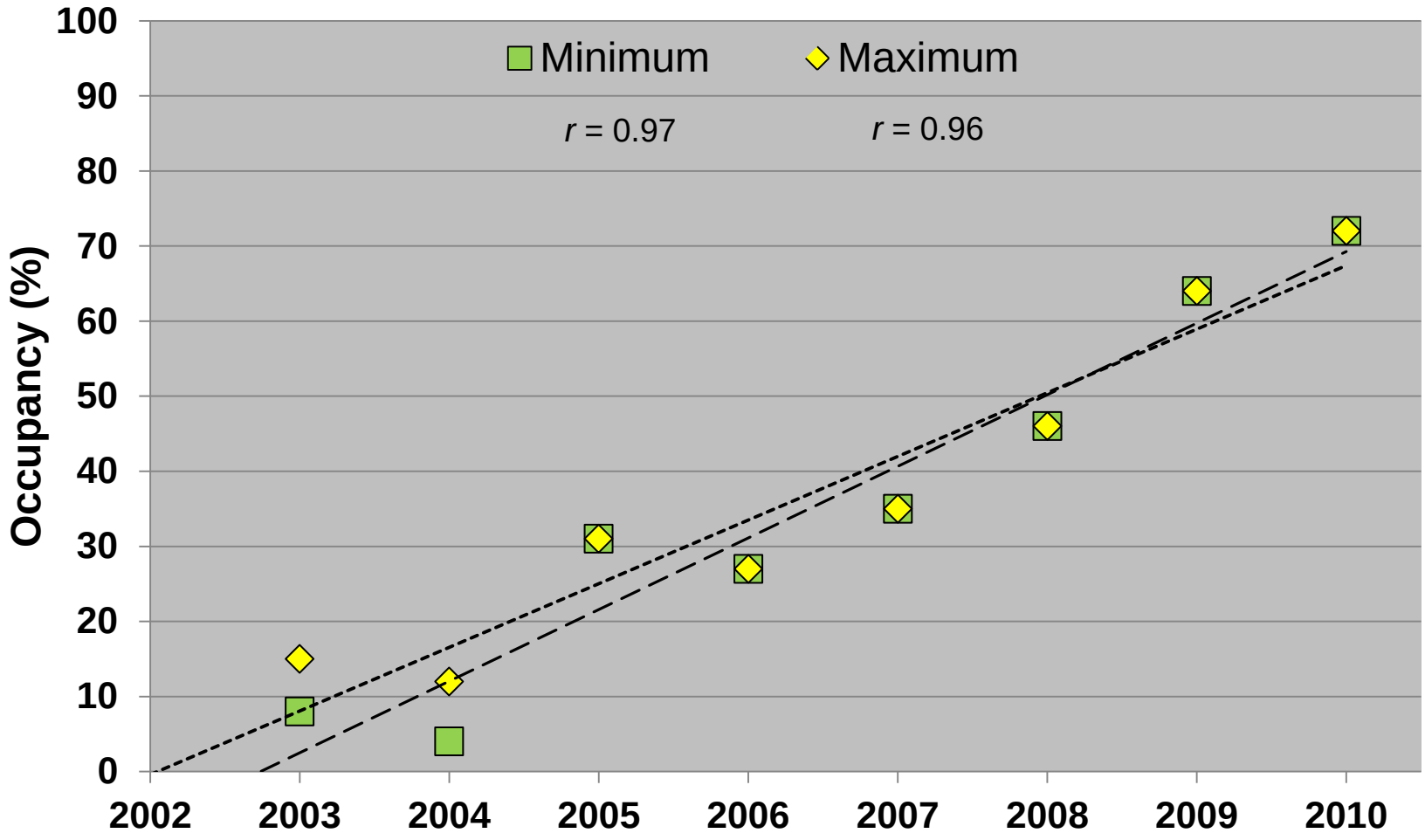


Figure 13. Trends in annual site occupancy for Xantus's Murrelets in non-cave plots at Anacapa Island, California, 2003-10. Trends assume minimum and maximum levels of nesting in Rockfall Cove plot from 2003-2004 (*see Methods; Table 3*).

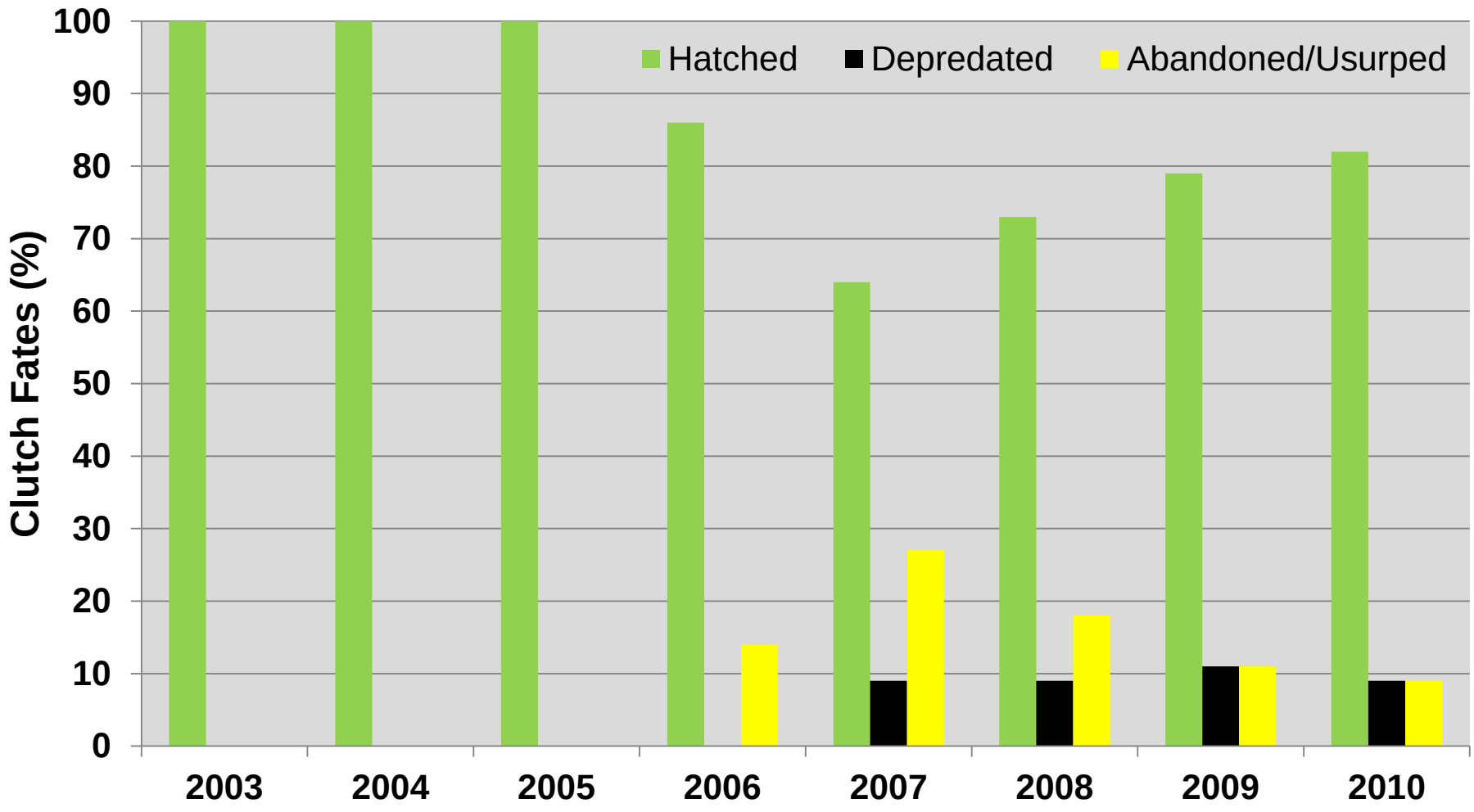


Figure 14. Annual hatching success for Xantus's Murrelets in non-cave plots outside of sea caves at Anacapa Island in 2003-10.

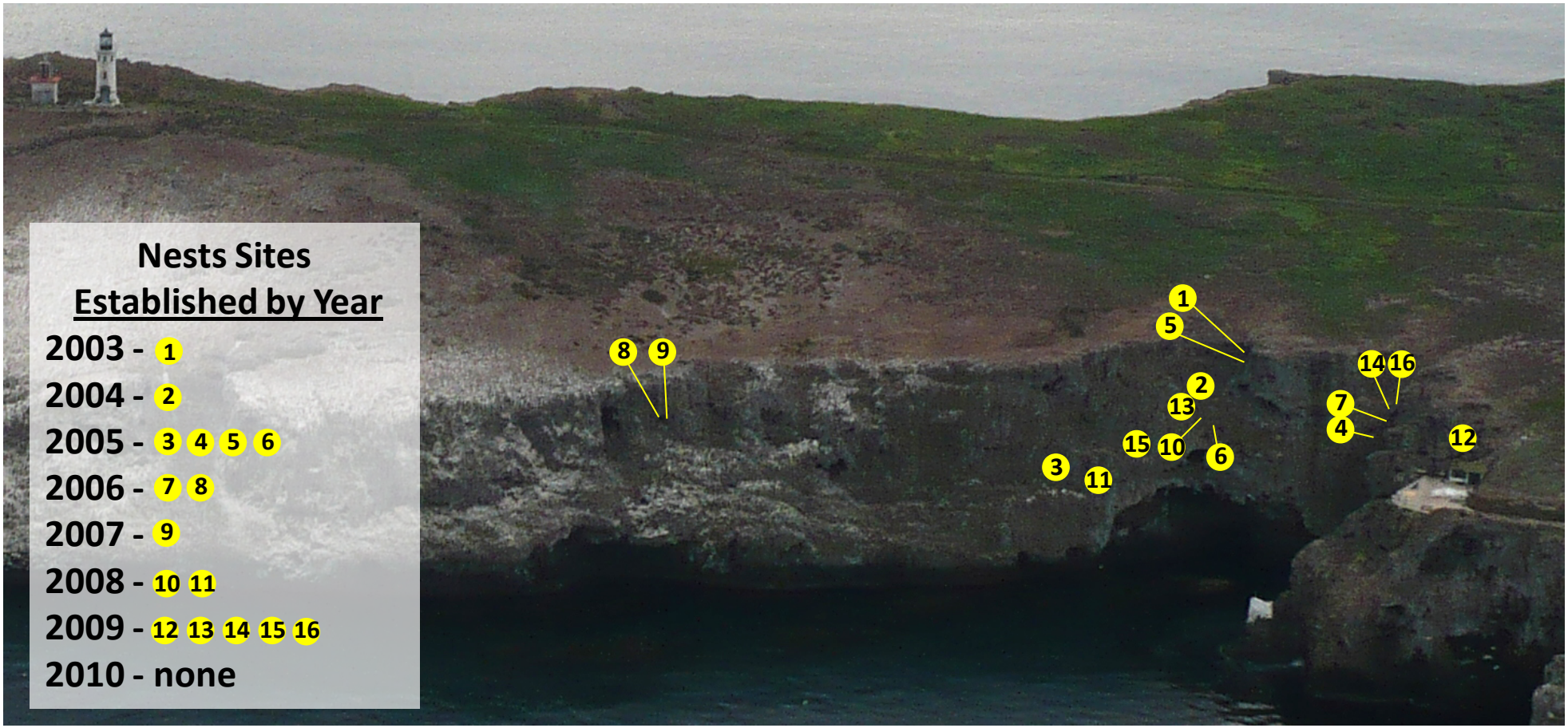
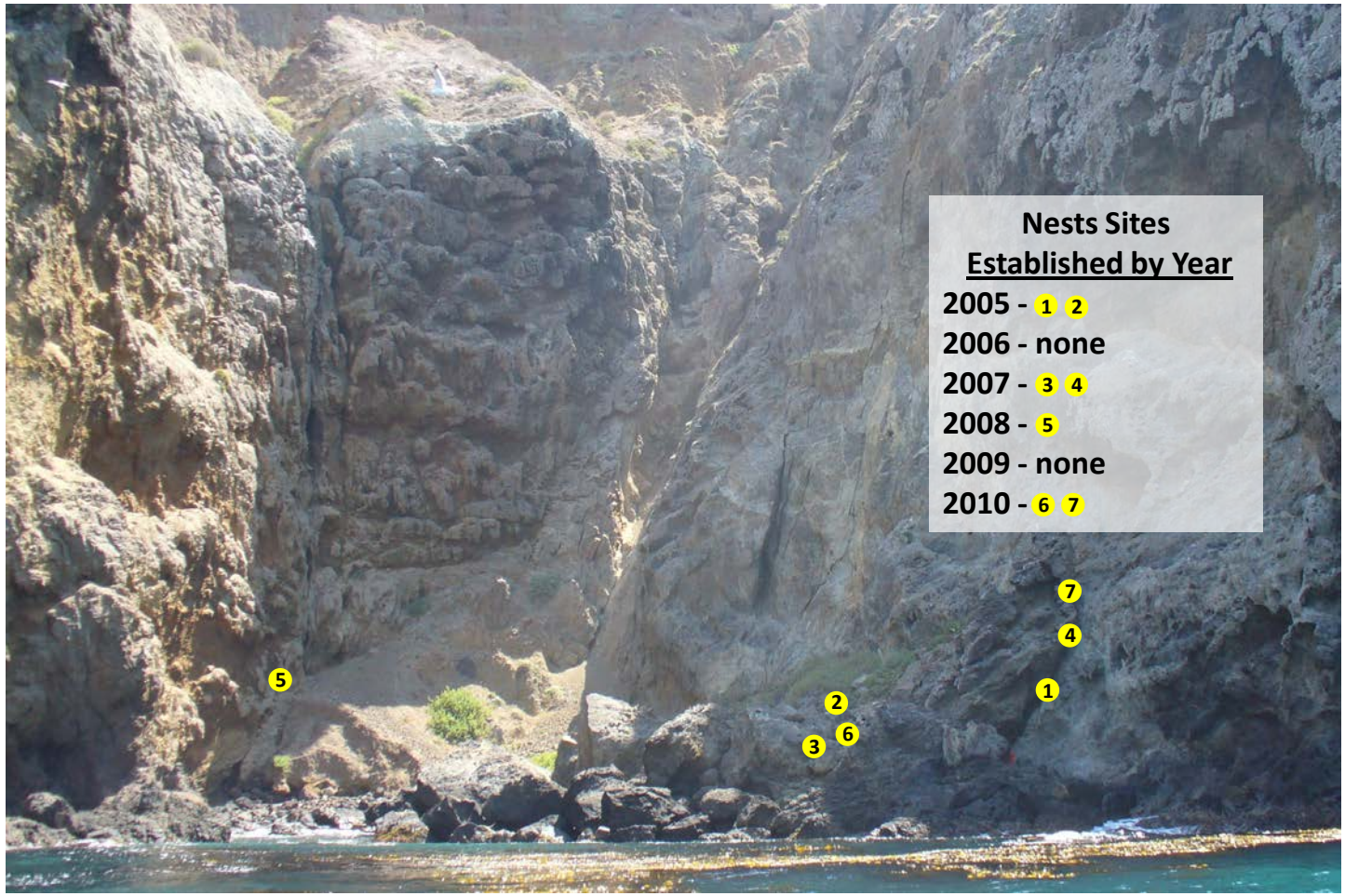
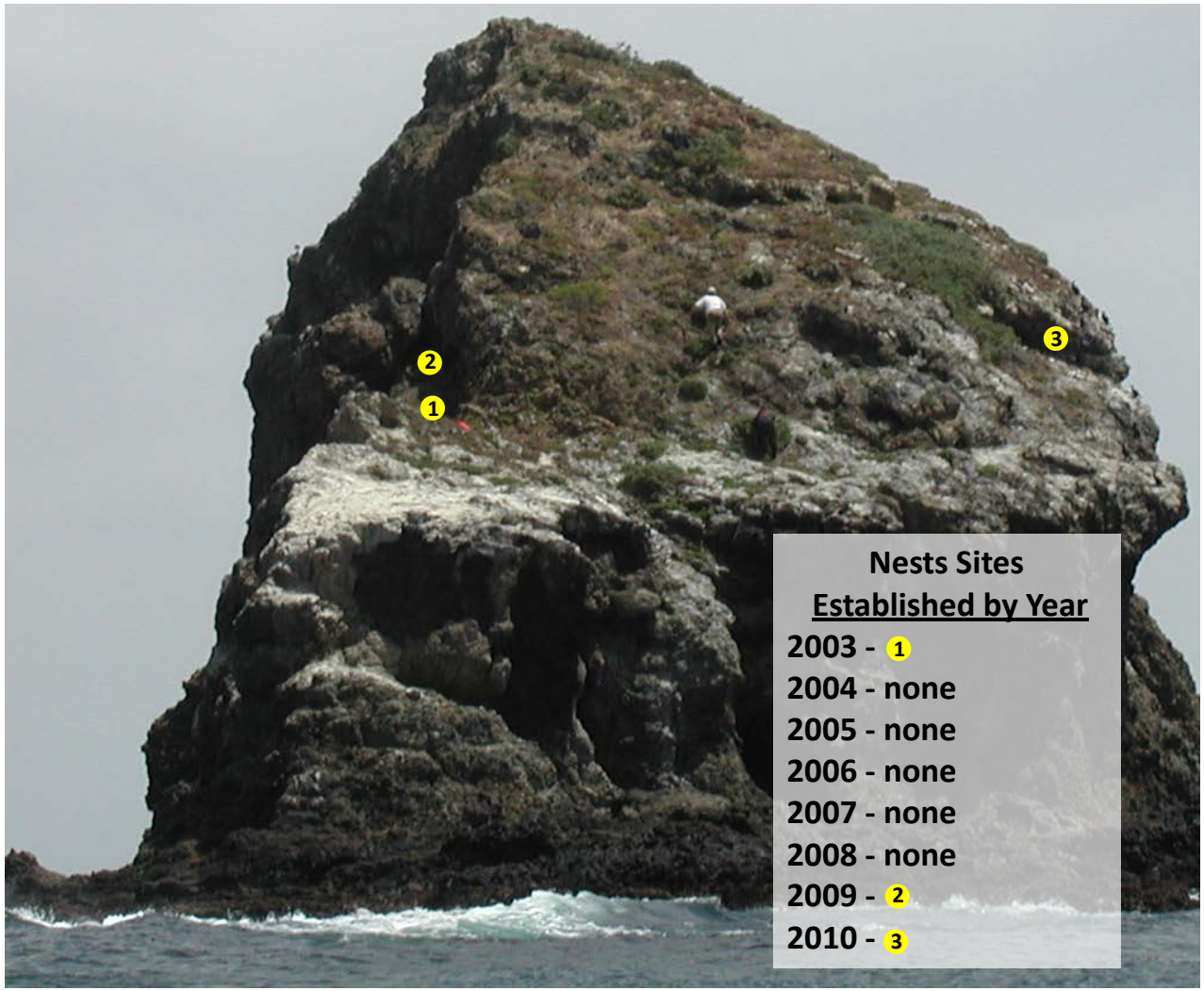


Figure 15. Xantus's Murrelet sites in the Landing Cove cliff plot on East Anacapa Island from 2003 to 2010. Site locations are approximate.



Figures 16. Xantus's Murrelet sites in the Rockfall Cove plot on Middle Anacapa Island from 2005 to 2010. Site locations are approximate.



Figures 17. Xantus's Murrelet sites in the Cat Rock plot off East Anacapa Island from 2003 to 2010. Site locations are approximate.

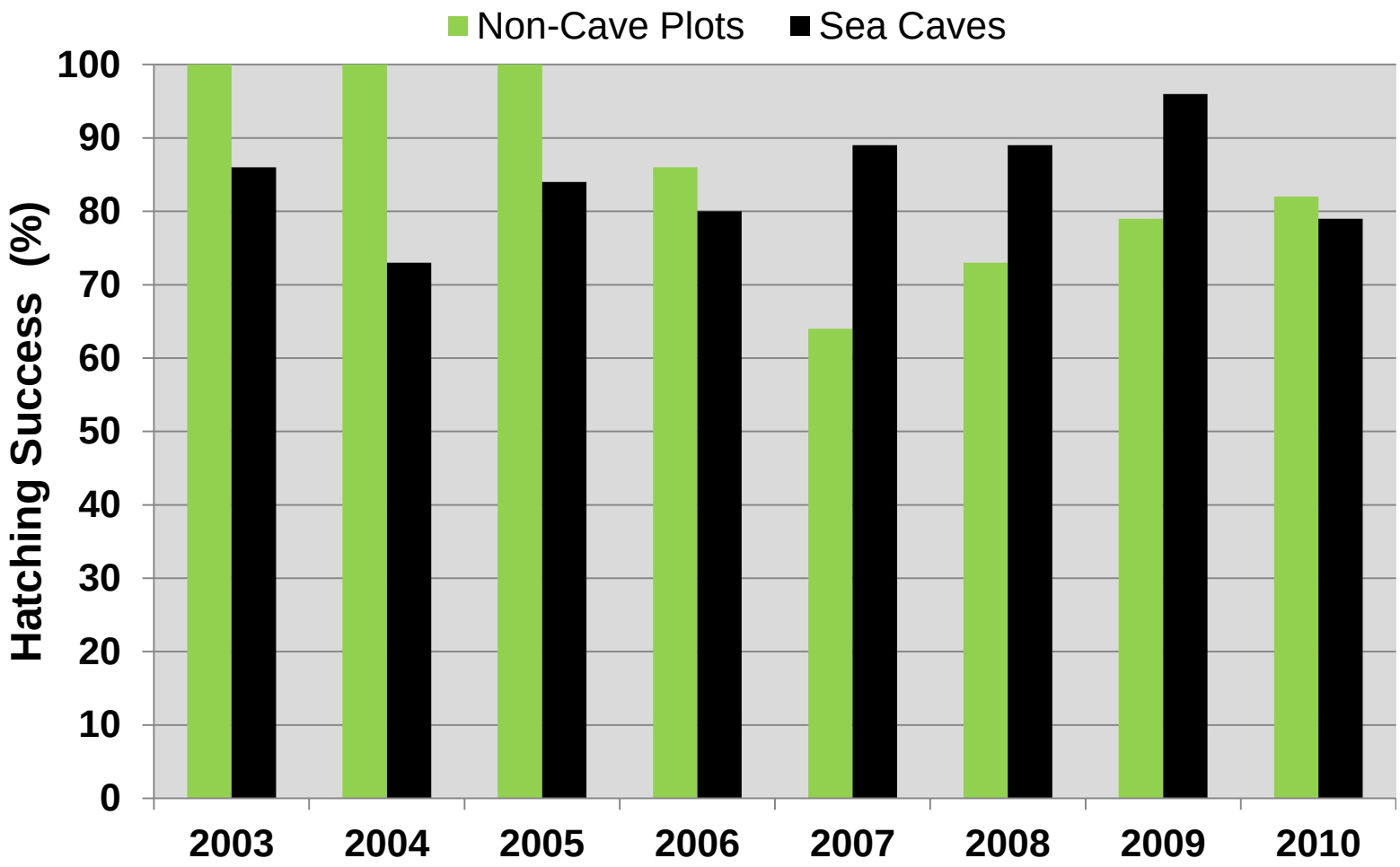


Figure 18. Comparison of annual hatching success for Xantus's Murrelets in non-cave plots and sea caves at Anacapa Island in 2003-10.

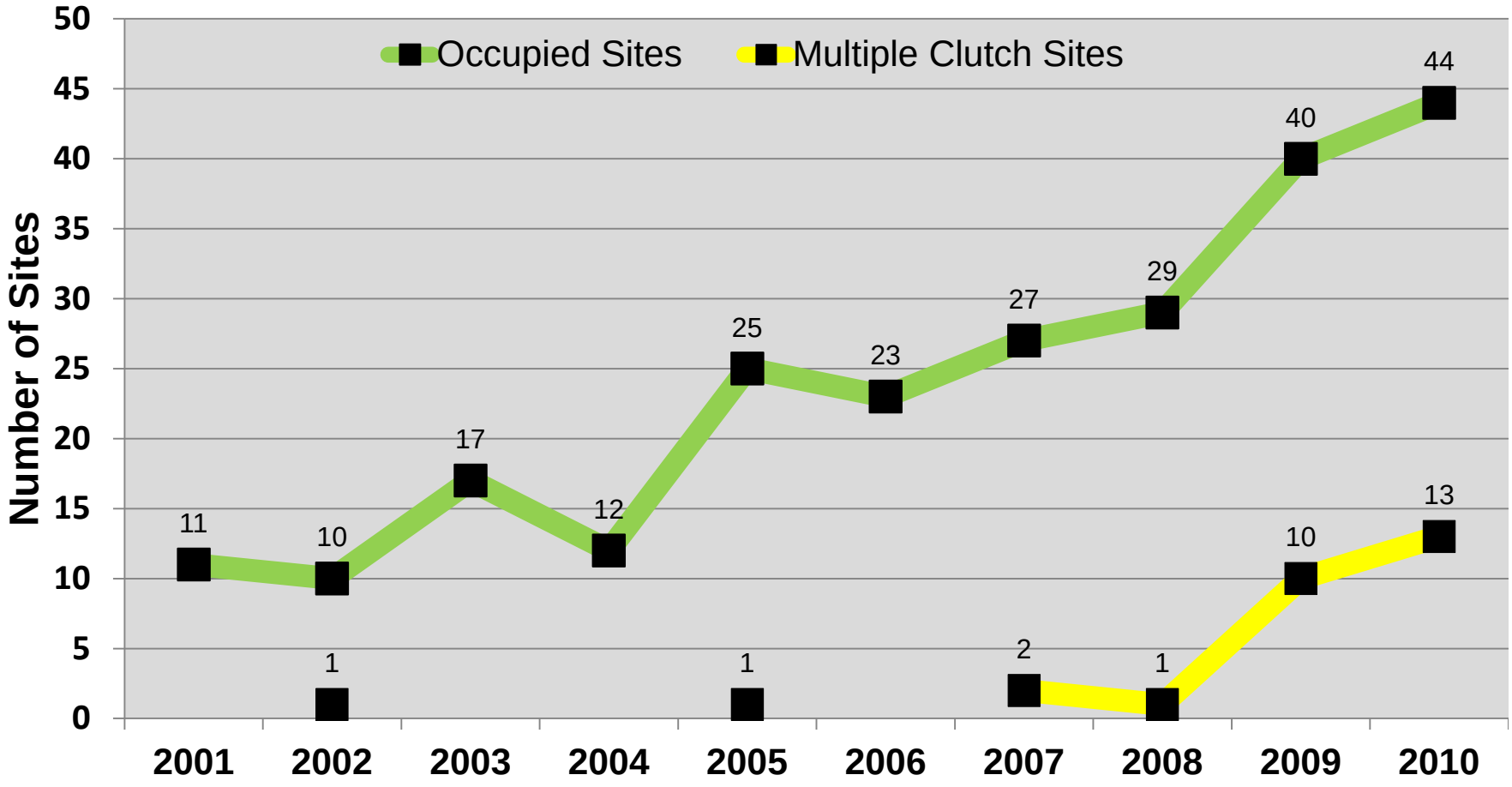


Figure 19. Number of occupied sites and multiple clutch sites (sequential and simultaneous clutches) for Xantus's Murrelets in all areas monitored at Anacapa Island, 2001-10.

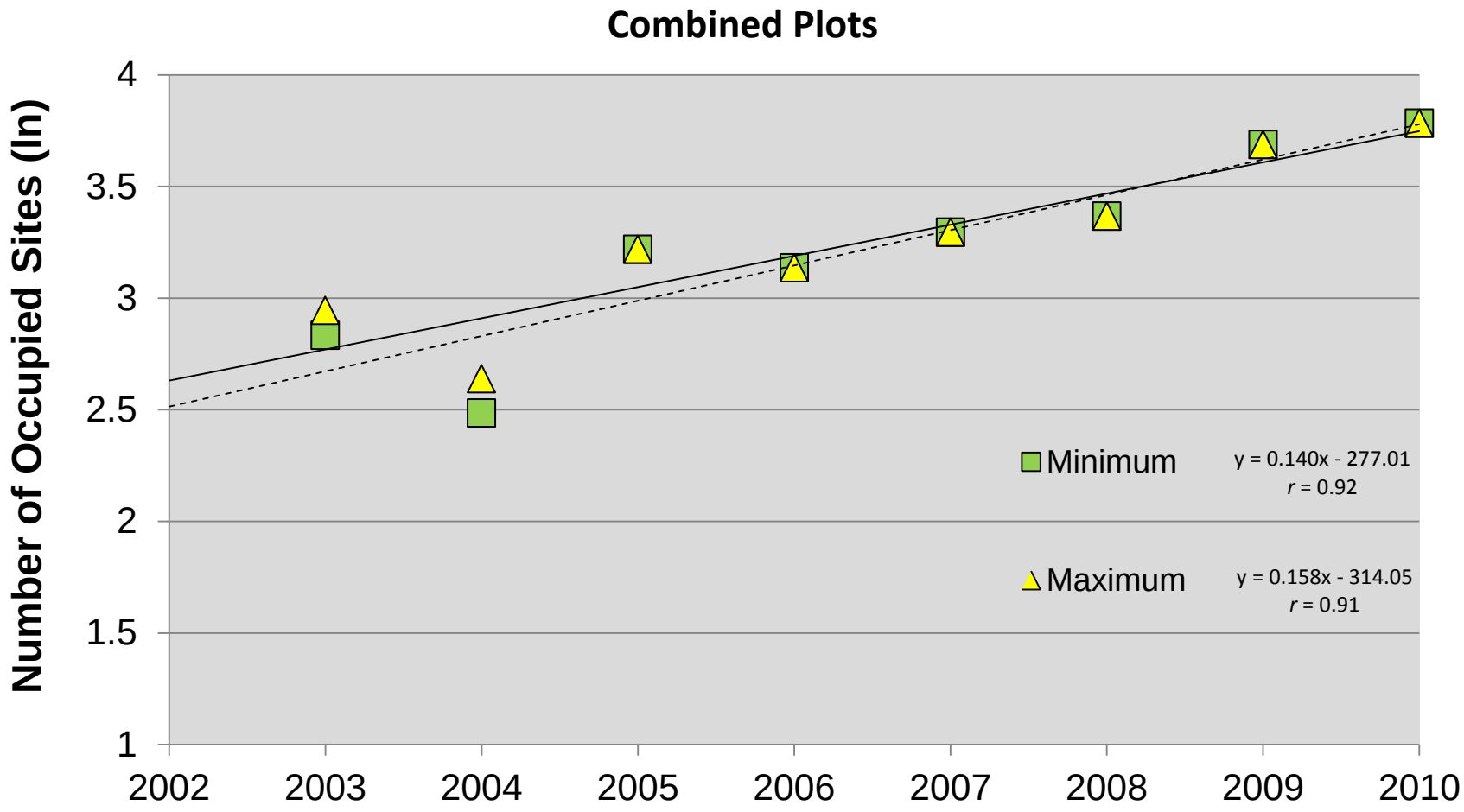


Figure 20. Log-linear regression of the annual number of occupied Xantus's Murrelet nest sites in all monitored areas at Anacapa Island, 2003-10. Trends assume minimum and maximum levels of nesting in the Rockfall Cove plot from 2003-2004 (*see Methods; Table 3*).

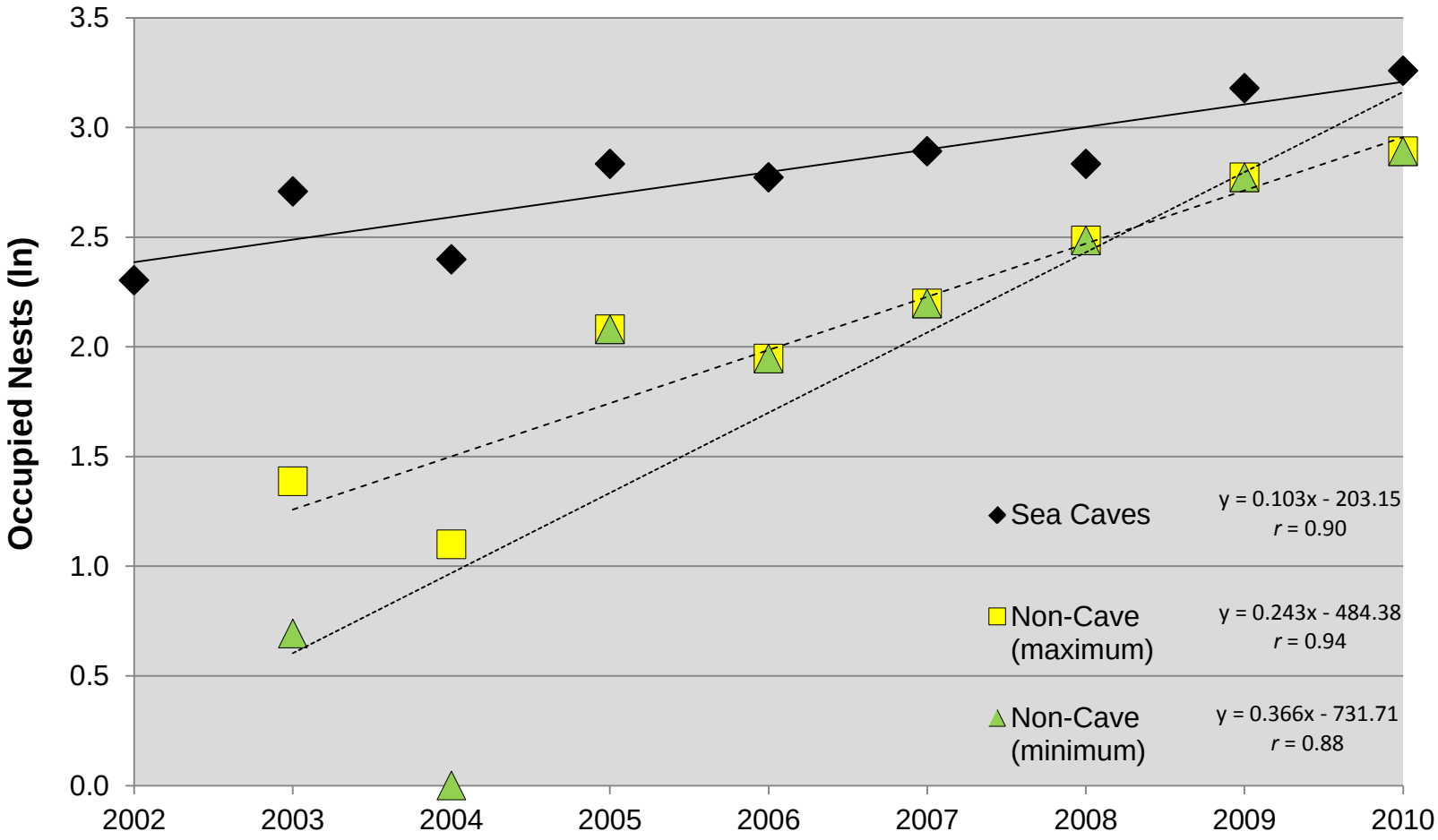


Figure 21. Log-linear regression of the annual number of occupied Xantus's Murrelet nest sites in sea caves (2002-10) and non-cave plots (2003-10) at Anacapa Island. Trends assume minimum and maximum levels of nesting in the Rockfall Cove plot from 2003-2004 (*see Methods; Table 3*).

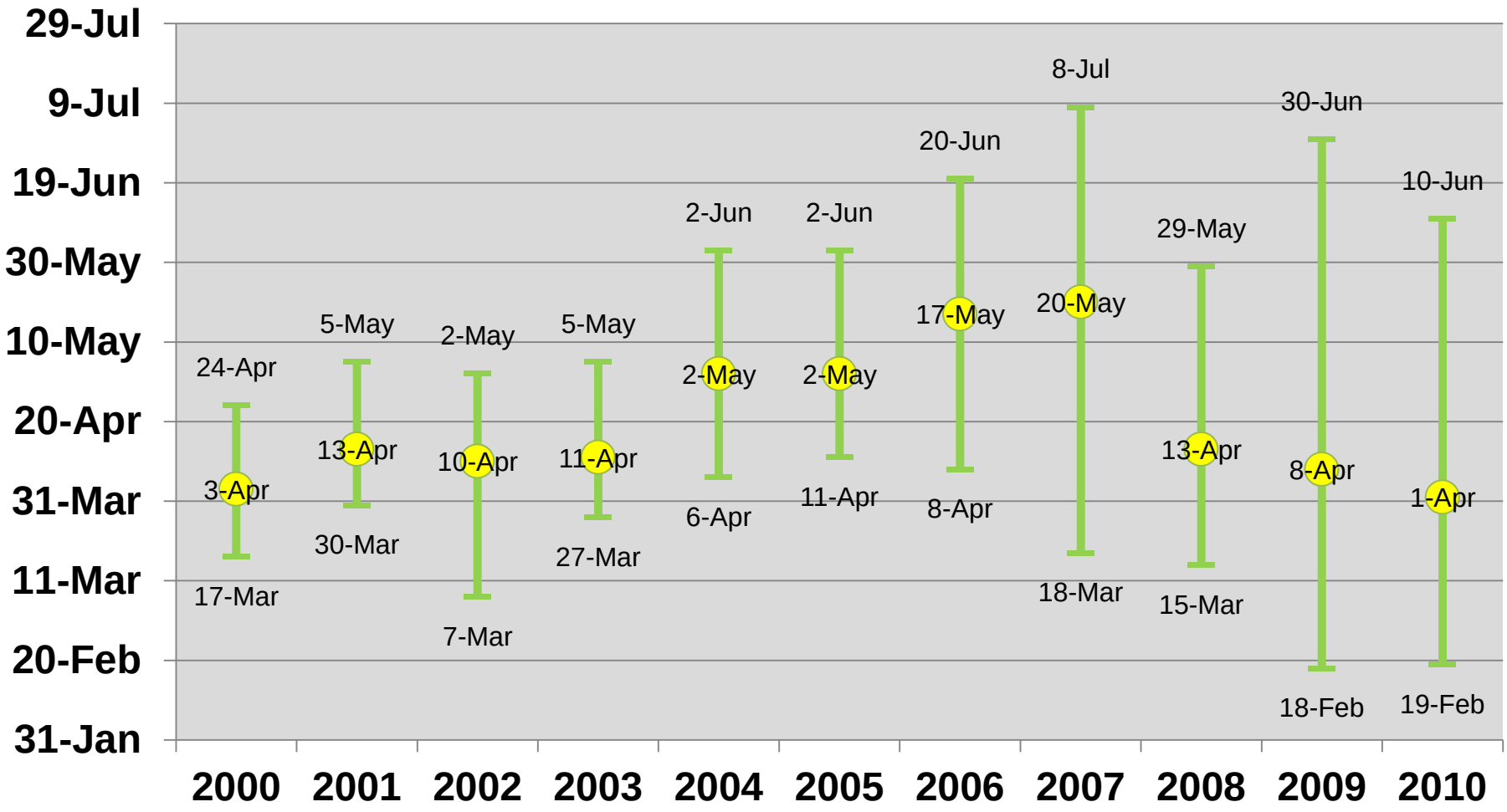


Figure 22. Annual timing of breeding (mean and range of clutch initiation dates) for Xantus's Murrelets in non-cave plots and sea caves at Anacapa Island in 2000-10.

Table 1. Number of monitored sites, clutches and clutch fates for Xantus's Murrelets at Anacapa Island in 2010.

Sea Cave/Plot	Monitored Sites	Occupied Sites	Clutches[a]	Clutch Fates			
				Hatched	Depredated	Abandoned	Unknown
Refuge	5	2	2	2	0	0	0
Lava Bench #1	4	4	4	4	0	0	0
Lava Bench #2	2	2	2	2	0	0	0
Respiring Chimney	3	2	3[a]	3	0	0	0
Lonely at the Top	5	3	5[a]	2	2	1	0
Confusion	0	0	0	0	0	0	0
Pinnacle	10	7	8[a]	6	1	1	0
Moss	4	3	5[a]	4	0	1	0
Aerie	5	3	5[a]	4	1	0	0
Keyhole	2	0	0	0	0	0	0
Sea Cave Total	40	26	34[a]	27	4	3	0
Cat Rock	3	2	3[a]	3	0	0	0
Rockfall Cove	7	5	7[a]	6	0	0	1
Landing Cove	15	11	13[a]	9	2	2	0
Non-cave plots Total	25	18	23[a]	18	2	2	1
Anacapa Total	**65**	**44**	**57[a]**	**45**	**6**	**5**	**1**

[a]More than one clutch laid by the same or different pairs (*see Methods*) occurred in thirteen sites.

Table 2. Nest site use and clutch fates for Xantus's Murrelets in sea caves at Anacapa Island in 2000-10.

	Pre-Eradication				Post-Eradication								
	2000	2001	2002	**2001-02**	2003	2004	2005	2006	2007	2008	2009	2010	**2003-10**
Tagged Sites	13	15	16		24	25	27	28	31	31	37	40	
Potential Sites	42	42	42		42	42	42	42	42	42	42	40[a]	
Occupied Sites (Occupied/Potential)	9	11 26%	10 24%	**25%**	15 36%	11 26%	17 40%	16 38%	18 43%	17 40%	24 57%	26 65%	
Clutches	7(9)[d]	9(11)[d]	11[b]	**20(22)**	14(15)[d]	11	19[b,c]	15(16)[d]	18	19[b,c]	28(30)[b,d]	34[b]	**158(162)**
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%	**135** **85%**
Depredated (Depredated/Clutches)	1	6 67%	6 55%	**12** **60%**	0	2 18%	0	0	0	0	0	4 12%	**6** **4%**
Abandoned (Abandoned/Clutches)	0	1 11%	1 9%	**2** **10 %**	1 7%	1 9%	3 16%	3 20%	1 6%	1 5%	1 4%	3 9%	**14** **9%**
Usurped (Usurped/Nest Clutches)	0	0	0	**0**	1 7%	0	0	0	1 6%	1 5%	0	0	**3** **2%**
Unknown Fate	2	2	0	**2**	1	0	0	1	0	0	2	0	**4**

[a]Two sites destroyed by storm surges in early spring 2010 were excluded from later occupancy analyses.
[b]More than one clutch was laid by the same or different pairs in one site in 2002, one site in 2005, one site in 2008, six sites in 2009 and eight sites in 2010 (*see methods*).
[c]Eggs on cave floor (one in 2005 and one 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 included in occupancy analyses but excluded from calculations of hatching success.

Table 3. Nest site use and clutches of Xantus's Murrelets in non-cave plots at Anacapa Island in 2003-10 (post eradication).

	2003	2004	2005	2006	2007	2008	2009	2010	**2003-10**
Tagged Sites	2	3	9	11	14	17	22	25	
Potential Sites	26[a]	26[a]	26	26	26	26	25[b]	25	
Occupied Sites (Occupied/Potential)	2-4[c] 8-15%	1-3[c] 4-12%	8 31%	7 27%	9 35%	12 46%	16 64%	18 72%	
Clutches	2	1	8	7	11[d]	11(12)[e]	19(20)[d,e]	22(23)[d,e]	**81(84)**
Hatched (Hatched/ Clutches)	2 100%	1 100%	8 100%	6 86%	7 64%	8 73%	15 79%	18 82%	**65** **80%**
Depredated (Depredated/ Clutches)	0	0	0	0	1 9%	1 9%	2 11%	2 9%	**6** **7%**
Abandoned (Abandoned/ Clutches)	0	0	0	1 14%	3 27%	1 9%	2 11%	2 9%	**9** **11%**
Usurped (Usurped/ Clutches)	0	0	0	0	0	1 9%	0	0	**1** **1%**
Unknown Fate	0	0	0	0	0	1	1	1	**3**

[a] Includes seven 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 were excluded from later analyses.
[c] Minimum number assumes no nesting in the Rockfall Cove plot in 2003-2004, maximum number assumes two occupied nests found in the Rockfall Cove plot in 2005 were occupied in 2003-2004.
[d] More than one clutch was laid by the same or different pairs in two sites in 2007, four sites in 2009 and five sites in 2010 (*see Methods*).
[e] Clutches with unknown fates in 2008-10 were included in occupancy analyses but excluded from calculations of hatching success.

Table 4. Use and clutch fates of specific monitored Xantus's Murrelet nest sites in sea caves at Anacapa Island in 2000-10. Codes: hatched - ●; abandoned - ●; depredated or scavenged - ●; usurped/natural disturbance - ●; unknown - ●; site destroyed - x.

Cave	Nest #	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Refuge	1		●				●	●	●	●●	●	●
	2											
	3			●								
	4	●	●									
	5						●	●	●	●	●●	●
Lava Bench 1	1	●		●	●	●	●(●)	●			●	●
	2								●	●	●	●
	3								●		●	●
	4											●
Lava Bench 2	1	●	●	●	●	●	●	●	●	●	●	●
	2										●	●
Respiring Chimney	1	●	●	●●	●	●	●●	●	●	●	●●	●●
	2		●	●	●		●					
	3		●					●	●	●	●●	●
Lonely at the Top	1				●	●						
	2				●	●	●	●	●	●	●●	●●
	3							●	●	(●)	●	●●
	4										●	
	5											●
Pinnacle	1		●							●	●	●
	2				●	●	●	●	●			
	3				●		●					
	4					●	●	●		●	●	●
	5								●	●		
	6										●	●
	7										●	x
	8										●●	●
	9										●	x
	10											●●
	11											●
	12											●
Moss	1	●	●	●	●	●	●		●	●		
	2	●	●	●	●	●	●	●	●	●	●●	●●
	3	●	●	●	●	●	●	●	●	●	●	●
	4				●		●	●	●	●	●	●●
Aerie	1	●	●	●								
	2				●						●	●
	3				●	●	●		●	●	●	●●
	4						●	●				
	5	●		●				●	●	●	●	●●
Keyhole	1				●							
	2						●	●	●	●		

(●) Abandoned egg on cave floor near site was included as a clutch for calculations of hatching success only (*see Methods*).

Table 5. Use and clutch fates of specific monitored Xantus's Murrelet nest sites in shoreline, cliff and offshore rock (non-cave) plots on Anacapa Island in 2003-10. Codes: hatched - ●; abandoned - ●; depredated or scavenged - ●; usurped/natural disturbance - ●; unknown - ●; site destroyed - x. Shaded cells indicate years monitoring was not conducted.

Plot	Nest #	2003	2004	2005	2006	2007	2008	2009	2010
Landing Cove	1	●							●
	2		●	●	●	●●	●	●●	●●
	3			●	●		●	●	●
	4			●		●●	●		●
	5			●			●	●	●
	6			●	●	●			
	7				●	●	●		●
	8				●				
	9					●	●	●	●
	10						●	X	X
	11						●	●●	●●
	12							●●	●
	13							●	●
	14							●	
	15							●●	●
	16							●	
Cat Rock	1	●		●	●	●		●	
	2							●	●
	3								●●
Rockfall Cove	1			●			●	●	
	2			●	●	●	●	●	●●
	3					●			
	4					●	●	●	●●
	5						●	●	●
	6								●
	7								●

Table 6. Timing of breeding for Xantus's Murrelets at Anacapa Island in 2000-10.

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

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

Appendix 1:

Post-Breeding Season Nest Searches for Xantus's Murrelets in Upper Island Habitats at Anacapa Island: October 2009

Nest search crew on upper slopes of West Anacapa Island, 17 October 2009.

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INTRODUCTION

From 15-19 October 2009, the California Institute of Environmental Studies (CIES), in collaboration with staff from Channel Islands National Park (CINP), conducted post-breeding season nest searches for Xantus's Murrelet (*Synthliboramphus hypoleucus*) and other crevice-nesting seabirds in accessible upper island habitats of Anacapa Island. Funded by the American Trader Trustee Council as part of the Anacapa Island Restoration Program, post-breeding season nest searches complemented regular Xantus's Murrelet nest monitoring by assessing upper island habitats and shoreline areas on Anacapa Island which could not be surveyed during the main seabird breeding season because of: 1) potential disturbance to sensitive surface nesting species (i.e., Brown Pelican [*Pelecanus occidentalis*], Brandt's Cormorant [*Phalacrocorax penicillatus*] and Double-crested Cormorant [*P. auritus*]) in or near these habitats; and 2) limited time to conduct nest searches in upper island habitats and other shoreline areas during regular nest monitoring visits. Most upper island areas on Anacapa had not been searched since 1997 (McChesney et al. 2000) and an update was needed to determine if and to what extent crevice-nesting species are using these habitats after completion of Black Rat (*Rattus rattus*) eradication at Anacapa Island in November 2002 (Howald et al. 2005). In this appendix, we present the results of these nest searches, including detailed descriptions and photos of the areas searched at each island for comparison with future efforts.

METHODS

Nest Searches

We employed the same nest search techniques used during regular Xantus's Murrelet nest monitoring conducted at Anacapa Island since 2000 (see *Methods* in main report). However, because these searches were conducted after the main murrelet breeding season (March-July in most years), the only evidence of nesting we expected to find in October was hatched/depredated eggshell fragments, abandoned eggs or dead birds in suitable nest sites. GPS waypoints were recorded for each nest site, but steep terrain above the nest sites often interfered with the GPS satellite signals, resulting in poor location accuracy at most sites. Nest sites were not permanently marked as no follow up monitoring efforts during the breeding season were planned in these areas during the next few years.

We searched representative sample areas in upper island habitats and certain accessible shoreline areas on each of the Anacapa islets, but with limited time we could not replicate the more extensive nest searches conducted at Anacapa Island in April and October-November 1997 (McChesney et al. 2000). We sampled nest search areas based on the following criteria: 1) availability of apparently suitable nesting habitat; 2) accessibility of the habitats to researchers on foot; 3) vicinity to known murrelet nesting areas in sea caves and other plots; and 4) representative samples from upper island habitats on each of the three islets. Upper island slopes above East Fish Camp on the south side of Middle Anacapa were not searched in 1997, but were considered to be one of the priority search areas in 2009 because radar surveys detected considerable numbers of murrelets flying onto these slopes in 2000-03 (Hamer et al. 2003a,b; 2005).

West Anacapa Nest Searches

Sample areas on West Anacapa were searched on 16, 17 and 18 October (Figs. A1-2). Searches were limited to the north side of the island because slopes and cliffs on the south side of West Anacapa were too dangerous to survey without (and perhaps even with) technical climbing gear. Sample nest search areas on West Anacapa Island were named following McChesney et al. (2000; Fig. 2) where possible.

16 October - Nests searches were conducted on the northeast portion of West Anacapa Island from Frenchy's Cove to Frenchy's Cave (Fig. A1), including: 1) the shoreline and accessible slopes on the north and south sides of the rocks in Frenchy's Cove (Fig. A3); 2) the steep upper slopes of Frenchy's Slope (Fig. A4); and the shoreline between Frenchy's Cove and Frenchy's Cave (Fig. A5). This area is inaccessible during the breeding season due to large numbers of nesting Brown Pelicans.

17 October - Nests searches were conducted on the northwest end of West Anacapa Island (Fig. A2) from Rat Rock to the accessible upper slopes of Three Sisters Bluff including: 1) all of Rat Rock; and 2) the accessible cliffs and slopes from the "Grottoes" (Fig. A6) to Three Sisters Bluff (Fig. A7).

18 October - Nests searches were conducted below the steep cliffs and slopes along the northeast portion of West Anacapa Island (Fig. A1) at: 1) Portuguese Point (Fig. A8); 2) West Pinnacle (Fig. A9); and 3) East Pinnacle (Fig. A10).

Middle Anacapa Nest Searches

Sample areas on Middle Anacapa were searched on 15 and 18 October (Figs. A11-12). Caves which bounded the sample nest search areas on Middle Anacapa Island were named following Bunnell (1993).

15 October - Nest searches were conducted on the southeast side of Middle Anacapa Island from Lava Bench Cave #1 to Shipwreck Cave (Fig. A11), including: 1) all accessible slopes (Figs. A13-14); 2) the shoreline and rocky scree at the base of cliffs and slopes (Fig. A15); and 3) the upper island plateau and adjacent slopes accessible from the shoreline (Fig. A16).

18 October - Nest searches were conducted on the north side of Middle Anacapa Island from a shoreline access point just east of Aerie Cave to the Eucalyptus Grove (Fig. A12), including: 1) all accessible cliffs and slopes (Fig. A17-18); and 2) the upper island plateau between Keyhole Cove and the Eucalyptus Grove (Fig. A19).

East Anacapa Nest Searches

19 October – Nest searches were conducted around the periphery of the upper island with most emphasis on the accessible cliff edges above Landing Cove to the east tip of the island, including the rock wall below the Lighthouse.

RESULTS

Nest searches in October 2009 yielded six Xantus's Murrelet nests. However, despite an abundance of apparently suitable nest crevices in upper island habitats (mainly on north side West Anacapa) no nests were found in any of the accessible upper island habitats that were searched. All six murrelet nests were found in relatively low shoreline habitats, two on the south shore of Middle Anacapa Island (Fig. A11) and four on the north shore of West Anacapa Island (A1).

We also found five potential Cassin's Auklet (*Ptychoramphus aleuticus*) nest sites, including one site with a crushed eggshell fragment. All five potential auklet sites were located along the north shore of West Anacapa near Portuguese Rock (Fig. A1). We found no evidence of breeding by other crevice nesting seabirds such as the Ashy Storm-Petrel (*Oceanodroma homochroa*) or Pigeon Guillemot (*Cepphus columba*).

Details of nest search results by island and day are provided below.

West Anacapa Island

<u>16 October</u> -We found evidence of murrelet nesting in four sites which contained hatched or broken eggshell fragments. All four sites were found in rocky crevices just a few meters (< 5 m) above the shoreline (Fig. A20) within a 100 m section below the Brown Pelican nesting area known as the "Amphitheater" (Fig. A1). Limited and patchy potential nesting habitat was found on the rocks in Frenchy's Cove (Fig. A3). An abundance of suitable but apparently unoccupied potential nest sites were found in rocky scree and under dense shrubs and Brown Pelican nest platforms on the accessible slopes of the Frenchy's Slope (Fig. A4). A considerable number of suitable crevice sites were also available in rocky outcrops along the shoreline (Fig. A5).

<u>17 October</u> - No evidence of murrelet nesting was found in any of the areas searched on the west end of West Anacapa Island despite an abundance of suitable nest sites in crevices and under bushes on the accessible slopes and cliffs. "Hundreds" of suitable crevice sites were found in the north facing slopes from the "Grottoes" to Three Sisters Bluff (Fig. A21), but most of these sites were being used as seed caches by the endemic Deer Mouse or contained feces and other evidence of current or former occupation by rodents which may have discouraged use by nesting murrelets. Steep and unstable terrain prevented nest searches on the south side of West Anacapa Island, although there also appears to be abundant potential nesting habitat for murrelets on the south slopes. No nesting habitat was found on the grassy plain on the upper island plateau between the Grottoes and Three Sisters Bluff. Several Cassins's Auklet nests have been found on Rat Rock since 2003 (Whitworth et al. 2004a) and the colony appears to have grown considerably the last few years (*see main report*), but no new evidence of nesting by auklets, murrelets or other crevice nesting seabirds was found in other areas of Rat Rock during these searches.

<u>18 October</u> - Despite a moderate amount of potential nesting habitat in the rocky scree and outcrops along the north shore of West Anacapa Island, we found no evidence of Xantus's Murrelet nesting in any of the areas we searched. However, we did find evidence of a small

Cassin's Auklet colony in the Portuguese Point area (Fig. A8), where five probable nests were discovered including one burrow site (Fig. A22) with small auklet eggshell fragments (Fig. A23).

Middle Anacapa Island

15 October - Despite a considerable number of suitable murrelet nest sites, we found evidence of nesting in only two sites (Fig. A11) an abandoned egg and broken eggshell fragments in a crevice site about 15 m above the shoreline; and 2) hatched eggshell fragments in a crevice site in rocky scree along the shoreline.

18 October - No evidence of murrelet nesting was found in these areas despite a considerable number of suitable nest sites, particularly in the rocky outcrops on the slopes east of Aerie Cave and around Keyhole Cave (Figs. A17-18). However, as observed on West Anacapa Island, many of the most suitable crevices were used as seed caches by Deer Mice (Fig. A24) that may have discouraged use by murrelets. No potential nesting habitat was found on the island plateau between Keyhole Cave and the Eucalyptus Grove (Fig. A19).

East Anacapa Island

19 October - We found no evidence of Xantus's Murrelets or other crevice nesting seabirds in any of the accessible areas we searched on East Anacapa Island. Suitable murrelet nesting habitat was limited to: 1) larger crevices in the rock wall below the Lighthouse (Fig. A25); and 2) patchy crevices on the upper edges of the Landing Cove cliffs (Fig. A26). Very little nesting habitat was found around the rest of the island periphery, most of which is surrounded by steep cliffs and is not accessible without technical climbing gear.

DISCUSSION

Lack of Xantus's Murrelets Breeding in Upper Island Habitats

The lack of colony expansion into apparently suitable murrelet breeding habitats on the accessible upper island slopes and cliffs was a major discouraging result of the post-eradication nest monitoring program. Following several years of strong colony growth in sea caves and localized non-cave plots (mainly along the shoreline), we expected to find some evidence of murrelet breeding during nest searches on the upper island conducted in October 2009. However, the lack of such evidence suggested that recent colony growth and expansion at Anacapa Island has been limited to relatively inaccessible sea caves and localized shoreline plots near areas where small numbers of murrelets apparently had persisted for many decades despite the presence of rats.

Several factors could explain the lack of documented murrelet breeding in upper island habitats in 2009:

1) Although there is an abundance of apparently suitable habitats on the upper parts of the islets, these habitats may never have been used for breeding by murrelets to any

great extent. The only direct evidence of use of upper island habitats is one broken egg found on upper West Anacapa in 1997 and a handful of historical egg/carcass records with mostly vague location descriptions which were likely found in lower island habitats (McChesney et al. 2000). We discuss these historical records in more detail below.

2) While murrelet numbers have increased in long-occupied lower island habitats which served as pre-eradication refugia, post-eradication population increase may not have been sufficient to saturate currently occupied breeding habitats and stimulate more widespread colony expansion. Insufficient time may have passed for occupation of upper island habitats that were once teeming with rats based on abundant rat sign (McChesney et al. 2000). Colony expansion onto the upper island may require many years and begin only after lower island breeding habitats are saturated. Lower island sea caves and shoreline areas may be preferred habitats that provide much easier ocean access to chicks when family groups depart the island.

3) Social stimuli may be important elements of murrelet breeding behavior that are lacking on the upper island. The presence of rats over most of the island for many decades and subsequent extirpation of any murrelets nesting on the upper island likely resulted in the loss of most or all individuals which used these habitats for breeding in the past (if indeed, these habitats were ever used by murrelets to any great extent). If upper island habitats are indeed suitable for breeding, we expect murrelets will eventually reoccupy these areas in large numbers, but the current lack of social stimuli in upper island slopes and cliffs may be a deterrent to rapid recolonization. Given the strong natal philopatry in alcids, natural colonization (or recolonization) may require many years. However, social attraction techniques may help speed colonization in these currently unoccupied habitats. Social attraction has never been used for Xantus's Murrelets, but techniques such as vocal broadcasts and perhaps low intensity point light sources to attract birds merit consideration.

4) Lingering evidence of former occupation by rats (e.g., odor, rat carcasses, feces, food "caches") may discourage murrelets from breeding in these habitats. McChesney et al. (2000) found abundant evidence of rats over most of the upper island that was searched in 1997. Seven years post-eradication, abundant evidence of the former presence of rats still remains in many excellent but unoccupied crevice sites, both on the upper island and in sea caves. Rat "caches" typically contained numerous old bones, sea shells and sea urchin tests. Two of these sites in Refuge Cave were cleaned out in 2010. Should murrelets eventually go on to use these sites in the near future, habitat enhancement should be considered in other sites where evidence of former occupation by rats is present.

Historical and Recent Evidence for Nesting in Upper Island Habitats

Sixteen egg sets and one chick collected at Anacapa Island between 1910 and 1928 were preserved as museum specimens. McChesney et al. (2000) summarized information on 15 egg sets and one chick. One additional record has surfaced since 2000: one egg set (two

eggs) from Cat Rock collected on 11 June 1915 by S.B. Peyton (James R. Slater Museum #14737). No data related to site location was associated with the chick specimen. Museum egg specimens were collected on Cat Rock (n = 8), East Anacapa Island (n = 4), West Anacapa (n = 3) and one unspecified location, with no definite egg records from Middle Anacapa. Location descriptions of the East Anacapa eggs (1912-13) indicate that nests were probably located in the Landing Cove area (i.e., "eggs laid in crevice in small cave near the lighthouse ladder on the northeast end of the east island"; "at the foot of the big cave on the northeast side of the east island"; and "in a hole two feet deep in cliff"). One historical site found on West Anacapa was apparently located on Rat Rock (i.e, "shallow pot hole under rock on north side of the little hill at the extreme west end of the west island"), but the other two site records were less specific (i.e., "northeast end of the main island" and "steep side of the main island, on the south side"). It is unlikely that the egg specimen from the unspecified site was found on the upper island as the location was described as just "10 feet up on a hillside". Thus, most historical nest sites were found in areas where murrelets were likely extirpated over the latter half of the 20th century but have bred post-eradication (i.e, Cat Rock and Landing Cove). Other historical sites may or may not have been located on the upper island, but to date, the only direct evidence to suggest murrelets ever nested in upper island habitats on Anacapa were two rat-depredated eggshells found on the upper slopes of West Anacapa in 1997 (McChesney et al. 2000).

Over the last century, upper island habitats on all three Anacapa islets also have suffered from anthropogenic impacts (in addition to rats) that undoubtedly would have affected any nesting murrelets. Human impacts on upper island habitats have included: 1) sheep farming on all three islets (~ 1869-1960s); 2) introduced cats (at least West Anacapa from ~ 1930-76); 3) rabbits (at least on East Anacapa from ~ 1935 to 1950s); and 4) lighthouse construction on East Anacapa in 1912 (Banks 1966, Anderson et al. 1989, McChesney and Tershy 1998). Furthermore, major changes in plant communities from sheep ranching and introduced rabbits occurred which may have reduced opportunities for breeding under plants. At Santa Barbara Island, murrelet breeding in upper island habitats occurs mainly under plants. Feral cats on West Island would have done considerable damage to any murrelets present on the upper island and may have extirpated breeding murrelets on Cat Rock. Bird remains were not found in a small number of cat fecal samples collected from 1971-75 (Anderson et al. 1989), suggesting that no murrelets were present in upper island habitats at that time. The role of egg collectors in the extirpation of murrelets from these habitats is difficult to assess, but may have been a contributing factor if only small numbers of murrelets nested there.

Apparently little has changed regarding Xantus's Murrelets nesting in upper island habitats on Anacapa since 1997 and probably many decades before. We found no evidence of nesting in the habitats we searched, while McChesney et al. (2000) reported just two rat-depredated murrelet eggshells found below a 60 cm deep crevice near Cherry Canyon, above Pinnacle Cave on the upper northeast slope of West Anacapa (McChesney et al. 2000). The 1997 surveys were conducted over 12 days with upper island nest searches concentrated on the north half of West Anacapa, but no searches of upper island areas on Middle Anacapa. With limited time (5 days, not including one day lost to poor weather which delayed our departure), we could not replicate the earlier survey effort. Thus, we chose not to hike the entire length of West Anacapa to look for the 1997 site, but rather concentrated our efforts on more accessible areas of West and Middle Islands that we considered more promising

potential breeding habitats.

Interestingly, the nest search area at Middle Anacapa on 15 October was immediately adjacent to the anchorage used during 2000-03 radar surveys which detected considerable numbers of murrelets flying to and from the slopes above East Fish Camp (Hamer et al. 2003a,b; 2005). This area is also near four monitored sea caves with breeding murrelets and a moderately large at-sea congregation (Whitworth et al. 2003c, 2004a). Despite proximity to many active nests and suspected murrelet activity on the upper island slopes, little or no nesting is apparently occurring in accessible habitats above East Fish Camp, although inaccessible habitat on the steeper cliffs below the plateau and above the accessible slopes were not searched (Fig. A11).

Nest searches of shoreline areas in October 2009 were not considered a priority, but were conducted in conjunction with searches of the adjacent upper island slopes because they were deemed important for documenting the persistence of eggshell fragments in nest sites. The six murrelet nests found in shoreline areas on Middle (n = 2) and West Anacapa (n = 4) indicated that widespread nesting in lower island areas may be occurring, as suggested by regular monitoring. Searches along the East Fish Camp shoreline in 2004-05 documented one nest in this former monitored plot. This site was destroyed by a large rockfall overwinter and monitoring was discontinued after 2005 when searches failed to detect any new sites in the plot. To our knowledge, nest searches along the shoreline of West Anacapa below the Frenchy's Slope and Amphitheater Brown Pelican colony have never been conducted. Therefore, we cannot determine whether these sites represent long established sites that persisted in shoreline refugia during the pre-eradication period, or newly established sites resulting from colony expansion post-eradication.

Nests searches in upper island habitats at Anacapa conducted seven years after the successful eradication of rats failed to detect Xantus's Murrelets breeding in these habitats. Therefore, frequent nest searches and surveys of upper island habitats are not warranted at this time. However, the murrelet population is apparently growing rapidly, especially in plots outside the sea caves (> 24% per annum; *see main report*). Furthermore, there is circumstantial evidence that breeding sites may be increasingly limited in some sea caves, which will pressure the growing murrelet population to prospect for breeding sites in unoccupied habitats outside sea caves. Therefore, we recommend searches of upper island habitats be conducted again in 2016 (i.e., at seven year intervals), at which time the situation can be re-evaluated with the new information in hand.

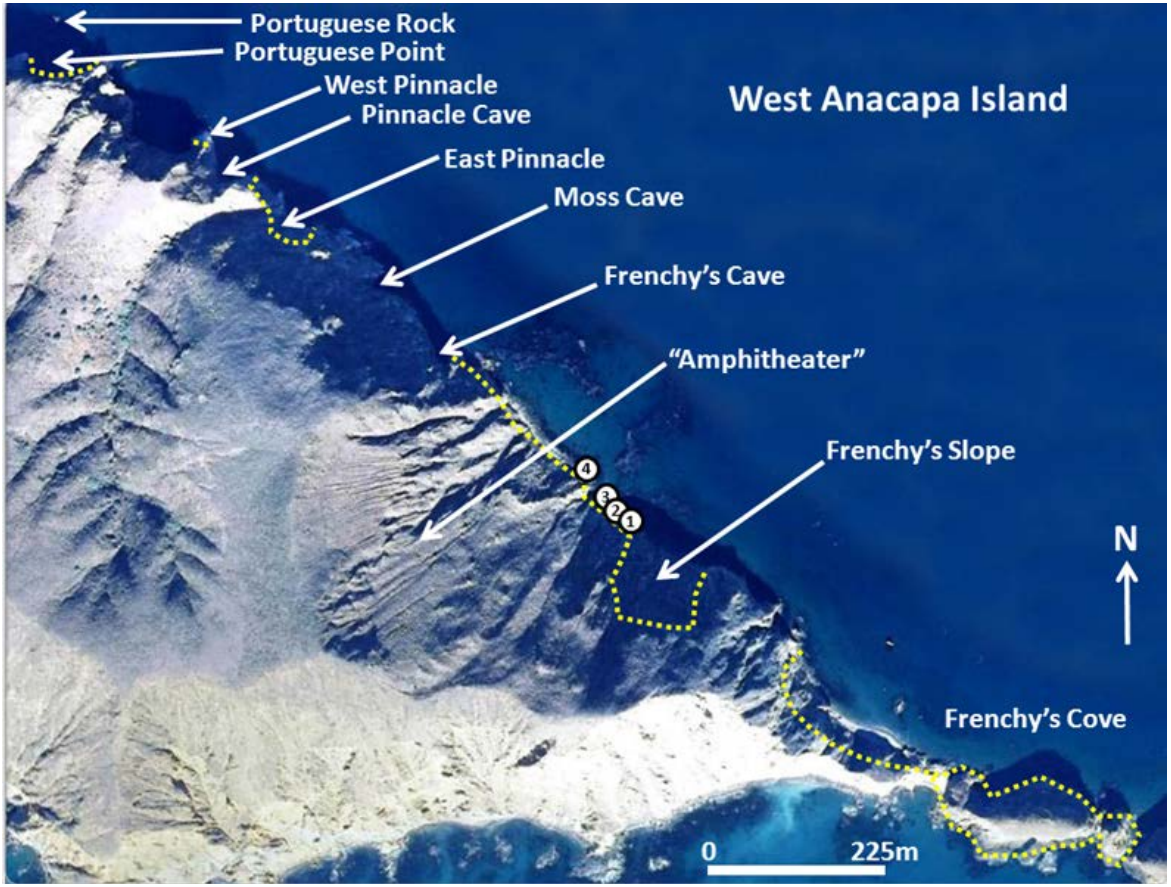

Figure A1. The northeast shore of West Anacapa Island where Xantus's Murrelet nest searches were conducted on 16 and 18 October 2009. Numbered circles indicate the approximate location of murrelet nest sites found in 2009.

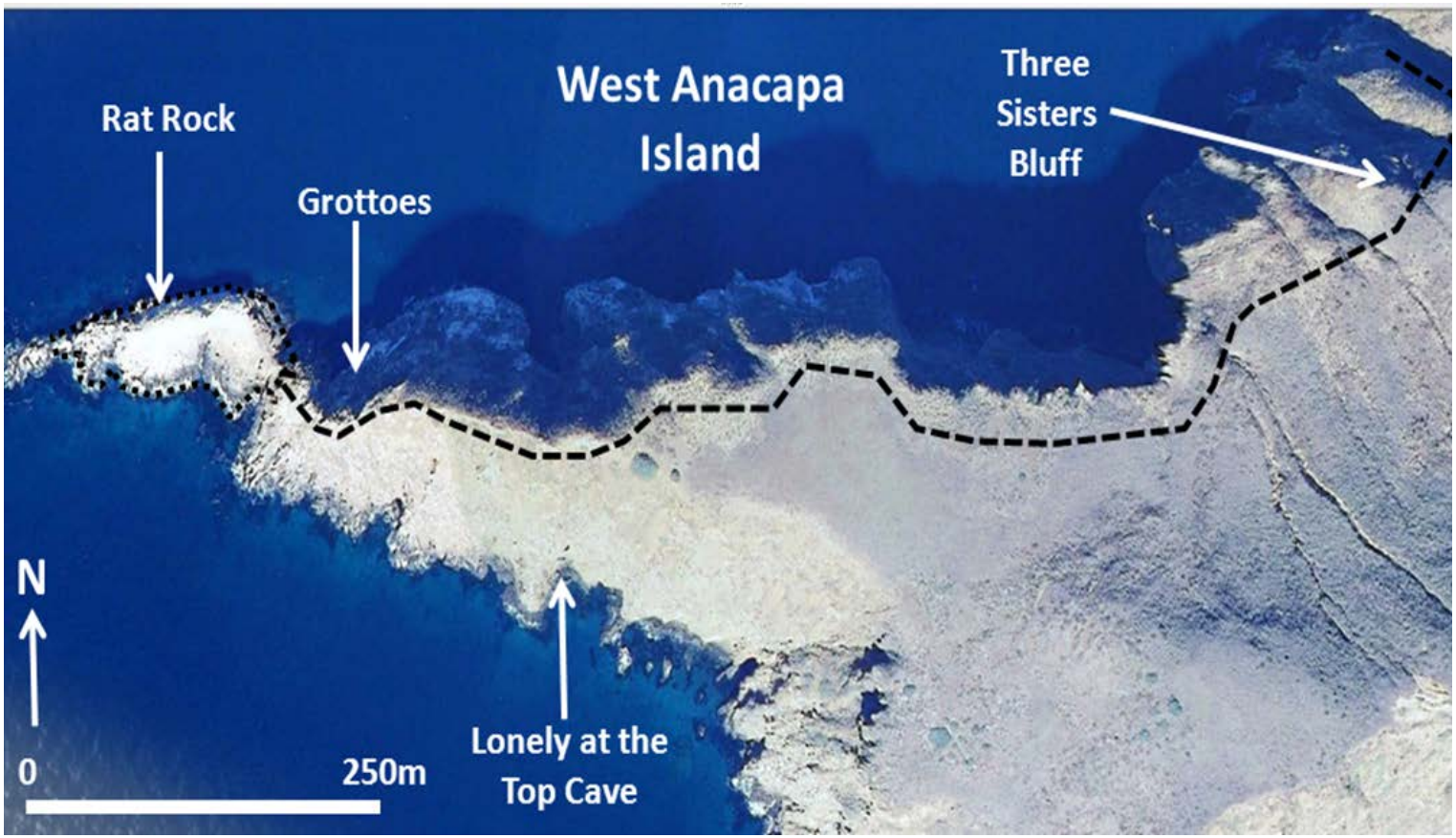

Figure A2. The west end of West Anacapa Island where Xantus's Murrelet nest searches were conducted on 17 October 2009.

Figure A3. Nest searches along the shoreline and accessible slopes on the north and south sides of the rocks in Frenchy's Cove at West Anacapa Island on 16 October 2009.

Figure A4. The steep upper slopes of Frenchy's Slope on West Anacapa Island where Xantus's Murrlet nest searches were conducted on 16 October 2009.

Figure A5. The northeast shoreline of West Anacapa Island between Frenchy's Cove and Frenchy's Cave where Xantus's Murrlet nest searches were conducted on 16 October 2009.

Figure A6. The steep slopes in the "Grottoes" on West Anacapa Island where Xantus's Murrlet nest searches were conducted on 17 October 2009.

Figure A7. The steep upper slopes below Three Sisters Bluff on West Anacapa Island where Xantus's Murrlet nest searches were conducted on 17 October 2009.

Figure A8. Rocky scree below steep cliffs in the Portuguese Point area where Xantus's Murrlet nest searches were conducted at West Anacapa Island on 18 October 2009.

Figure A9. Rocky outcrop below steep cliffs in the West Pinnacle area near Pinnacle Cave where Xantus's Murrlet nest searches were conducted at West Anacapa Island on 18 October 2009.

Figure A10. Rocky outcrop below steep slopes in the East Pinnacle area near Pinnacle Cave where Xantus's Murrlet nest searches were conducted at West Anacapa Island on 18 October 2009.

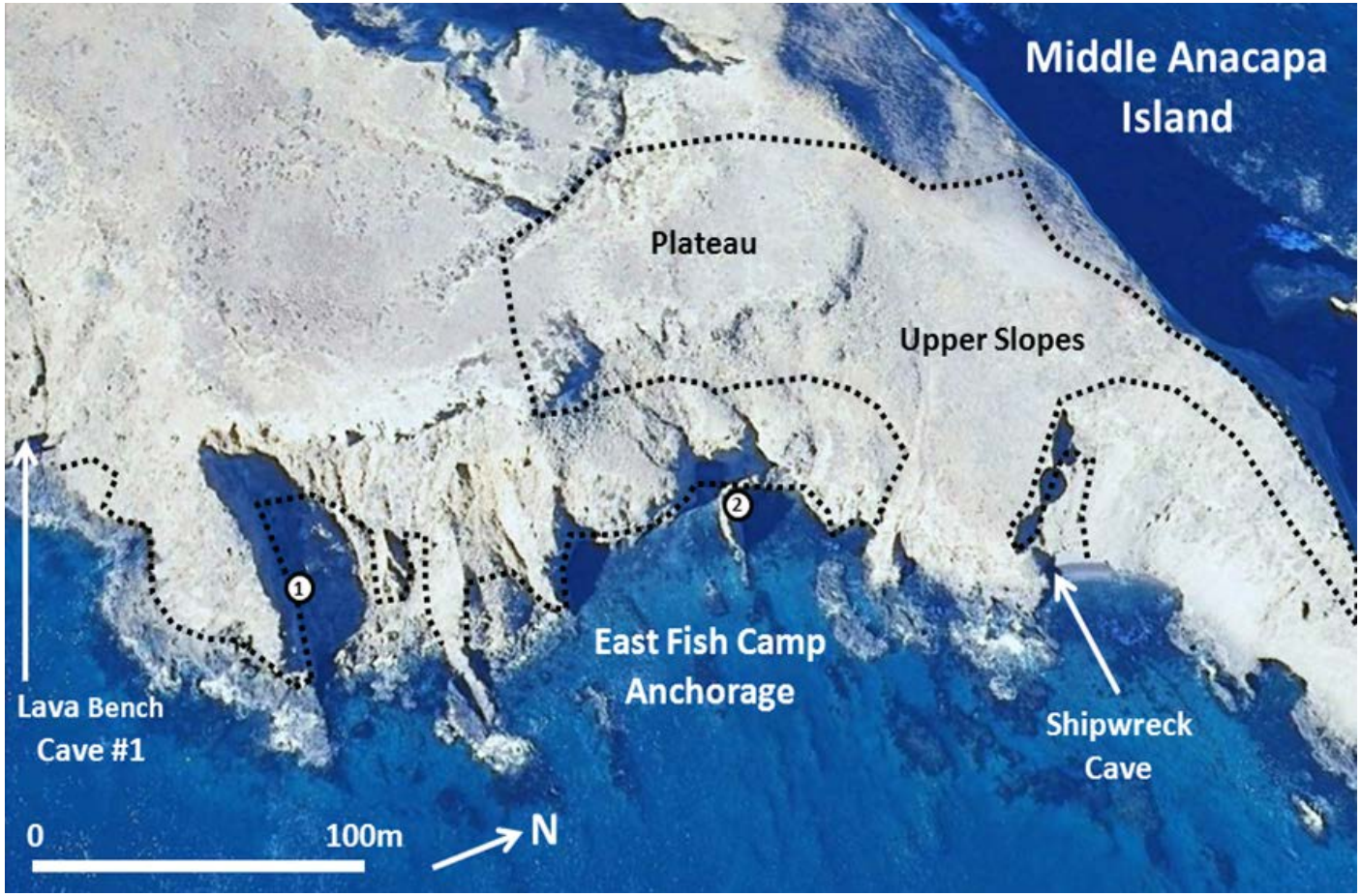

Figure A11. Middle Anacapa Island near the East Fish Camp Anchorage where Xantus's Murrelet nest searches were conducted on 15 October2009. Numbered circles indicate the location of murrelet nest sites found in 2009.

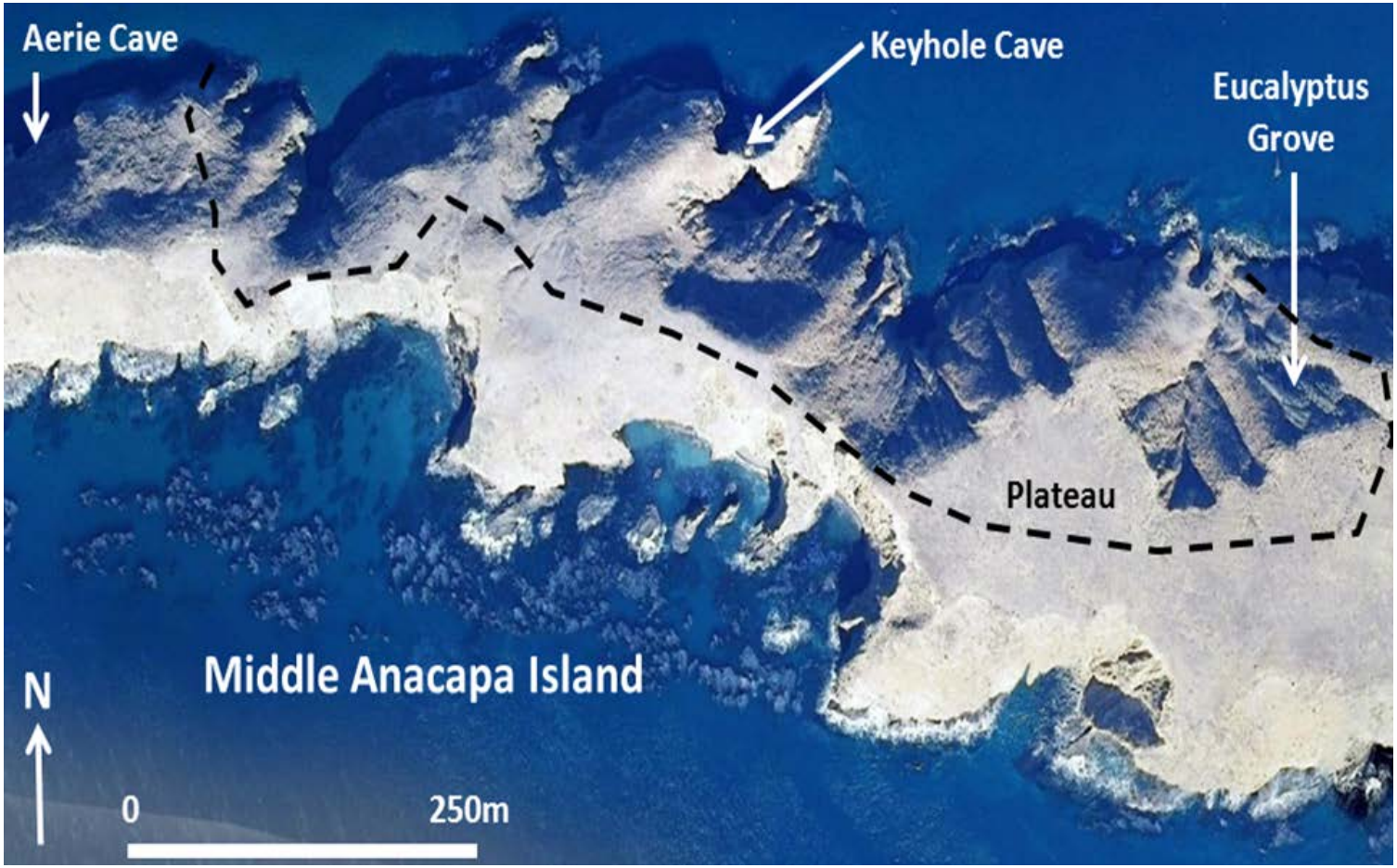

Figure A12. West half of Middle Anacapa Island between Aerie Cave and the Eucalyptus Grove where Xantus's Murrelet nest searches were conducted on 18 October 2009.

Figure A13. Rocky slopes and scree on the south shore of Middle Anacapa Island near the East Fish Camp Anchorage, 15 October 2009.

Figure A14. Steep slopes on the south shore of Middle Anacapa Island near the East Fish Camp Anchorage, 15 October 2009.

Figure A15. Rocky scree on the south shore of Middle Anacapa Island near the East Fish Camp Anchorage, 15 October 2009.

Figure A16. The upper island plateau and adjacent slopes above the East Fish Camp Anchorage of Middle Anacapa Island, 15 October 2009.

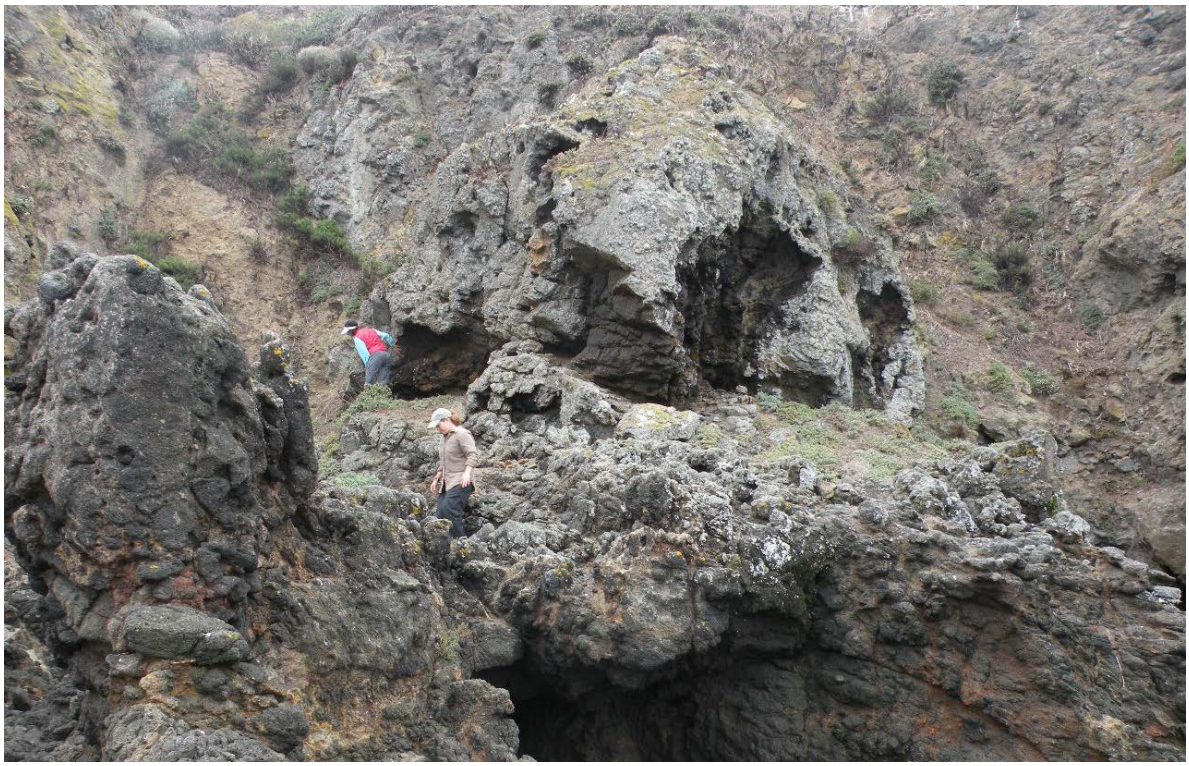

Figure A17. Rocky outcrop on the north shore of Middle Anacapa Island east of Aerie Cave, 18 October 2009.

Figure A18. Rocky outcrop on the north shore of Middle Anacapa Island near Keyhole Cave, 18 October 2009.

Figure A19. The upper island plateau between Keyhole Cave and the Eucalyptus Grove on Middle Anacapa Island, 18 October 2009.

Figure A20. Location of Xantus's Murrelet nest site in shoreline habitat on the northeast shore of West Anacapa Island, 16 October 2009.

Figure A21. Close up of the abundant crevices found on the steep slopes in the "Grottoes" on West Anacapa Island, 17 October 2009.

Figure A22 (left) and A23 (right). Cassin's Auklet nest burrow (left) and eggshell fragment (right) found on Portuguese Point on West Anacapa Island, 18 October 2009.

Figure A24. Seed cache in potential Xantus's Murrelet nest crevice near Keyhole Cave on the north shore of Middle Anacapa Island, 18 October 2009.

Figure A25. Nest searches in the rock wall below the Lighthouse on East Anacapa Island, 19 October 2009.

Figure A26. Cliff edge habitat below the Lighthouse near Landing Cove on East Anacapa Island, 19 October 2009.