

Nest Monitoring of Xantus's Murrelets at Anacapa Island, California: 2010 Annual Report

Darrell L. Whitworth¹, Harry R. Carter^{1,2} and Franklin Gress¹



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

²Carter Biological Consulting
1015 Hampshire Road, Victoria, British Columbia V8S4S8 Canada

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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 spotlight surveys, nest monitoring 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 ("island plots") where murrelets were not known to nest before 2003.
- 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 island plots) than in any year since monitoring began. Mean egg-laying (1 April \pm 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. Overall hatching success was 79% in sea caves (n = 34 clutches) and 82% in the island plots (n = 22 clutches). This was the first year that hatching success in island plots exceeded that in sea caves since adequate samples (> 10 clutches) became available in the island plots in 2007.
- Significant positive trends in site occupancy in sea caves and island plots provided strong evidence of improved breeding conditions that permitted murrelet population growth at Anacapa Island post-eradication.
- Evident signs of growth in the murrelet breeding population were first observed in 2003 and 2005, the first and third years after rat eradication. However, the intervening and subsequent years saw weak growth (2007 and 2008) or reduction in the number of occupied sites (2004 and 2006), followed by strong to moderate increases in the number of occupied sites in 2009 and 2010, respectively. Clearly, the eradication of rats has created conditions that allowed for population growth, but murrelets still required favorable environmental conditions for 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), island 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 monitored areas. Growth was 10.3% in sea caves and 24.3% to 36.6% in island 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 over time in the dynamics of the breeding population as larger post-eradication cohorts reached maturity.
- 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 island 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.
- Post-breeding season 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) habitats are not suitable for widespread breeding and have never been used by murrelets to any great extent; 2) insufficient time may have passed for occupation of upper island habitats; 3) long-term presence of rats and the subsequent extirpation of murrelets has resulted in an absence of social stimuli necessary to rapidly recolonize upper island habitats; and 4) lingering evidence of former occupation by rats that may discourage murrelets from breeding in these 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 these 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 population now breeds in at least four separate locations on Anacapa Island, providing additional evidence of the benefits of the rat eradication program for island seabirds.
- 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 in December 2001; and 2) Middle and West 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 km²) and highest (284 m) of the three islets (Fig. 2), followed by Middle Anacapa (0.6 km², 99 m; Fig. 3), and East Anacapa (0.5 km², 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 ("island 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 island plots was searched using hand-held flashlights during each visit. Sea caves and island 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 island plots began in 2003 and were expanded in 2005. Using methods similar to sea cave nest monitoring, island 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 island 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) could not be determined 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 indicated by observations of chicks or freshly hatched eggshell fragments (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 (*Cephus 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 - Site occupancy was calculated for each year 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 island 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 island plots were calculated as for sea caves. However, systematic nest searches in island 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 other plots. The 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 in the site 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 referred to as a second clutch (not to be confused with “true” second clutches described above) because we could not determine the parentage of sequential clutches, although we suspect at least some 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) 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 island 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 island 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), island 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 generated from the time series for annual number of occupied sites. Regression analyses of occupancy trends and population growth in sea 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 island plots. Regression analysis of island 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 island plots (Table 1). A total of 57 clutches (34 in sea caves and 23 in island plots) were recorded in 44 sites (26 in sea caves and 18 in island plots). Clutches were laid in eight of ten sea caves (all except Confusion Cave and Keyhole Cave) and in all three island 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), with 65% ($n = 40$) in sea caves (Table 2) and 72% ($n = 25$) in island plots (Table 3). Sequential clutches were recorded in thirteen sites (Table 1), eight in sea caves and five in the island plots. We found no evidence of simultaneous clutches (i.e, three or more eggs found at the same time in a site probably from two different pairs) in 2010.

A total of eight new murrelet sites were established in 2010. Five new 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 new sites were also established in the island 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% (45 hatched of 56 clutches with known clutch fates; Table 1); 79% (34 of 43 clutches) for first clutches and 85% (11 of 13 clutches) for second clutches. Overall hatching success was 79% in sea caves (27 of 34 clutches; Table 2) and 82% in the island plots (18 of 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 island 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 evidenced by 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 the thirteen 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 first and second clutches failed.

Only eleven failed clutches (20%; $n = 56$) were recorded at Anacapa in 2010, with seven failed clutches in the sea caves and four in the island plots (Table 1). Six clutches (55% of failed clutches) failed to due to possible depredation, 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 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 at the site entrances, 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 in 2001, 2002 and 2004 to 34 clutches in 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%, $n = 158$) 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 2002 (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 failed clutches), with smaller numbers of depredated or scavenged ($n = 6$; 26%) and usurped or disturbed ($n = 3$; 13%) clutches (Table 2). In contrast, pre-eradication (2001-02) clutch failures ($n = 14$) were attributed 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 the pre- and post-eradication 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 Island Plots

In 2003-10, a total of 84 clutches were found in 26 monitored sites (including one site destroyed by a rockfall during the 2008 breeding season) in island plots outside of the sea caves (Table 3). No evidence of breeding had been found during infrequent nest searches in these areas from 1991 to 2002. The number of monitored sites in island 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 assumptions regarding the level of nesting in the Rockfall Cove plot from 2003-2004 (Table 3) had little effect on trends in site occupancy. Strong increases in occupancy from 2003-2010 were noted in island 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 island plots has been 80% ($n = 81$ clutches), with only 20% failed in 2003-10 (Table 3). Extremely high hatching success in the island plots from 2003 to 2006 (86-100%; Table 3, Fig. 14) was affected by small annual samples ($n = 2-8$ clutches/year). Hatching success has decreased somewhat (64-82%) since 2007 when larger samples (> 10 clutches/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 island 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 which has the greatest amount of unoccupied breeding habitat (Fig. 15). 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 Island 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 island 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 the island plots, but this difference was not observed in 2010 when hatching success in island 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 island 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 ($\chi^2_c = 0.98, p > 0.05$) 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 to independence was unclear), 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 simultaneous clutches at Anacapa Island during this study 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 colony growth (number of occupied sites in combined plots) from 2003-10 whether minimum ($r = 0.91, p < 0.002$) or

maximum ($r = 0.92$, $p < 0.002$) levels of nesting were assumed in Rockfall Cove from 2003-04 (Fig. 20). Results of the log-linear regression analyses (slope of the regression line; Fig. 20) indicated that assumptions of minimum or maximum levels of nesting (Table 3) had little effect on estimates of the overall annual growth rate, with 14.0% growth in the number of occupied sites assuming maximum occupancy and 15.8% growth assuming minimum occupancy.

Significant increases in the number of occupied sites in sea caves ($r = 0.90$, $p < 0.001$) resulted in 10.3% annual growth from 2002-10. However, much greater growth occurred in the island plots from 2003-10 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 from 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 egg-laying 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 (nearly three times that pre-eradication) noted immediately after eradication and every year since, while egg depredation by mammalian predators was nearly eliminated as a cause of post-eradication nest failure. High hatching success was not limited to sea caves and also has occurred in island plots outside sea caves since 2003. Significant positive trends in nest occupancy indicated considerable growth in the murrelet breeding population post-eradication. Colony expansion in the island plots also indicated that murrelets have responded to the greater availability of suitable breeding habitat in coastal areas outside the sea caves where murrelets had not been documented breeding for several decades due to the presence of rats. To our knowledge, this is one of the first studies documenting the continuous short- to medium-term response of an alcid to eradication of an introduced predator from an entire breeding island.

Annual Variability in Murrelet Breeding

While post-eradication nest monitoring has documented improved breeding conditions and impressive overall population growth, increases in the annual number of occupied nest sites (the most reliable index of breeding population size) have not been consistent. Evident signs

of growth in the murrelet breeding population were first observed 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 created conditions on Anacapa that allowed for population growth given favorable conditions, but environmental factors other than reduced nest depredation (e.g., adequate prey availability and abundance and acceptable rates of adult survival and chick recruitment) clearly had major effects on the dynamics of the murrelet breeding population during the recovery period.

We have yet to examine direct relationships between murrelet breeding indices and factors such as local foraging and oceanographic conditions, but timing of breeding is considered a reliable indirect indicator of prey conditions for alcids in the California Current System (Ainley and Boekelheide 1990). Late breeding by Xantus's Murrelets has been associated with reduced nesting and poor reproductive success related to reduced prey abundance or availability (Hunt and Butler 1980, Roth et al. 2005). Late egg-laying from 2004-2007 (Fig. 6) apparently reflected poor foraging conditions that coincided with weak population growth or decline (with the notable exception of 2005). 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 during pre-eradication years, suggesting favorable conditions may have existed to encourage murrelet breeding had rats not been present on Anacapa.

The poorest post-eradication breeding season, based on year to year change in the number of occupied nests, occurred in 2004, when late egg-laying coincided with a 29% decrease in occupied nests and the lowest hatching success in sea caves since eradication. The 8% decrease in occupied sites in 2006 was less severe even though mean egg-laying was later than 2004. Data from individual nests suggests poor foraging conditions in 2004 and 2006 caused many experienced adult murrelets to refrain from breeding in those years, but had little evident impact on adult survival as breeding resumed in most of the vacant nests the subsequent years. Poor foraging conditions are known to cause experienced adults to refrain from breeding, particularly in long-lived birds with low annual reproductive output (Erikstad et al. 1998). This propensity to refrain from breeding in some years has been demonstrated in a number of alcids (Ashcroft 1979, Hudson 1985, Ainley and Boekelheide 1990).

Direct relationships between nesting phenology and murrelet breeding indices were not always evident. Contrary to what might be expected, the years with the latest (2007) and earliest (2010) mean egg-laying dates showed similar modest increases in occupied nests, while the two breeding seasons that experienced the highest year to year decrease (2004) and increase (2005) in occupied nests shared very similar (and relatively late) mean egg-laying dates. Clearly, murrelet breeding indices were dependent on rather complex interactions between prey, oceanography and colony-based factors that require more study.

Recruitment and Population Growth

The small numbers of murrelets nesting in sea caves and isolated cliff refugiums while rats were present on Anacapa provided an important source of recruits to maintain the remnant pre-eradication population and could have contributed to colony growth and expansion in the

early post-eradication years. However, nest monitoring provided limited data to assess whether murrelet population increases at Anacapa resulted from local recruitment or other factors such as immigration or an increased propensity for breeding. Age at first breeding has not been studied for Xantus's Murrelet, but deferred sexual maturity is a trait shared among most seabirds and probably all Alcidae (Lack 1968, Hudson 1985). Age at first breeding for *Synthliboramphus* murrelets is probably similar to Ancient Murrelets which begin breeding at 3-4 years (Gaston 1990, 1992). Given that the separate phases of rat eradication were conducted on East Anacapa in 2001 and West-Middle Anacapa in 2002, deferred maturity precluded population increases through local recruitment of post-eradication cohorts until 2005 at the earliest.

The increase in occupied nests from 2002 to 2003 could have resulted from a larger proportion of adult murrelets attempting to breed in the absence of rats. For many decades, rats heavily utilized crevice sites required for nesting by murrelets (Jones et al. 2005). Over time their mere presence in murrelet breeding habitats could have reduced the ratio of breeding to non-breeding adults in the population. A similar decline due to the presence of introduced rats was speculated for burrow-nesting Ancient Murrelets at Langara Island, British Columbia (Regehr et al. 2007). Species which breed in habitats where nest sites are limited are more likely to have relatively high proportions of non-breeding adults in the population (Manuwal 1974). Crevice nesting sites for Xantus's Murrelets may be limited even at predator free islands, but introduced rats would only exacerbate the scarcity of nest sites on infested islands. At-sea capture studies have certainly demonstrated a large pool of non-breeding birds, comprised of subadults and perhaps non-breeding adults (including birds at least 14 years old that displayed no evidence of brood patches), attending at-sea congregations at Anacapa (Whitworth et al. 1997, unpubl. data), but we have no other data to support this hypothesis.

It is also possible that the number of occupied sites remained relatively stable from 2001-04, but we simply underestimated nesting in sea caves in 2001-2002 by failing to detect some undocumented clutches that were depredated by rats 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 (Whitworth et al. 2002a,b) that were moved from nest sites by rats or mice. This 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.

Part of the large increase in occupied nests in 2005 resulted from comparison with extremely poor breeding the previous year when many adults refrained from nesting. However, the increase from 2003 to 2005 was also substantial (+47%), with seven new nest sites established in areas monitored continuously since at least 2003, and four of these in the Landing Cove cliffs on East Anacapa Island. There is evidence to suggest that the first post-eradication cohort may have contributed to this growth, particularly in Landing Cove, as maturity and possible recruitment of the first post-eradication cohort hatched from East Anacapa in 2002 coincided with the establishment of new nest sites in the Landing Cove plot in 2005. Natal philopatry (Lack 1968, Greenwood and Harvey 1982) has not been studied in Xantus's Murrelets, but is a trait shared among most seabirds and a variety of alcids (e.g., Harris et al. 1996, Pyle 2001, Breton et al. 2006, Lavers et al. 2007; but see Coulson and Coulson 2008). Strong natal philopatry has been demonstrated for Cassin's Auklets at

Southeast Farallon Island, California, which commonly recruited within a few meters of their natal burrow (Pyle 2001), and Razorbills (*Alca torda*) in the Gannet Islands, Labrador, which almost always recruited on their natal island, mostly within a few hundred meters of the natal colony (Lavers et al 2007). Strong philopatry in murrelets would support the premise that most, if not all of the new nests in Landing Cove in 2005 were established by local recruits. Unfortunately, documenting recruitment of locally produced young may not be feasible for Xantus's Murrelets given the difficulties in capturing and banding large samples of chicks and their sensitivity to capture and handling from nests.

Recruitment of locally produced chicks surely became an increasingly important factor in dynamics of the breeding population beginning in 2006 when larger post-eradication cohorts reached maturity. Larger cohorts may have limited population decreases and even permitted weak growth in years when poor foraging conditions apparently impacted murrelet breeding (e.g., 2006-2008). When favorable foraging conditions prevailed, post-eradication cohorts undoubtedly contributed to impressive increases in the breeding population (e.g., 2009).

It is difficult to assess the possible role of immigration in the murrelet population increase at Anacapa. Relatively high gene flow among all *S. scrippsi* colonies suggests some form of immigration occurs among islands (Birt *et al.*, in press), although even infrequent immigration events are enough to maintain population structure. Banding studies suggest that breeding dispersal (i.e., immigration of established breeders from another breeding locale) does not occur in Xantus's Murrelets. Many hundreds of murrelets 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). Murrelets do not appear to visit other islands once they begin attending at-sea congregations at a particular island, probably two years after hatch (Gaston 1992), but more studies are needed.

In the absence of significant breeding dispersal, gene flow among murrelet breeding islands may be mediated through natal dispersal (i.e., immigration of immature birds away from the natal hatching colony). Natal philopatry is assumed to be strong in Alcidae, but banding studies have demonstrated natal dispersal in a variety of species (Harris 1983, Hudson 1985, Halley and Harris 1993, Gaston and Jones 1998, Lavers et al. 2007) and considerable inter-colony movements for immature Ancient Murrelets (Gaston 1992). Given the current distribution and size of Xantus's Murrelet colonies in southern California (Whitworth and Carter, in prep.), if significant immigration has occurred at Anacapa, Santa Barbara Island (the largest murrelet colony but the smallest island) is probably the only colony capable of providing substantial numbers of immigrants to promote population growth. As for recruitment, documenting natal dispersal through banding studies is difficult in this species.

Population Growth Rates

With eight monitoring years since the final eradication of rats in fall 2002, we conducted a preliminary analysis of the murrelet population growth rate using the annual number of occupied nest sites as an index of murrelet breeding population size. 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. Such strong growth

is not unreasonable if rats were a major impediment limiting population growth at Anacapa. In fact, the occupied nest site time series data fit well with an exponential growth model, particularly since 2006 (Fig. 20). Other studies have surmised that the low reproductive potential of most alcids 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 larger clutch size (2 eggs) of *Synthliboramphus* murrelets increases their reproductive potential compared to most other alcids, making relatively large population increases more feasible.

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, over the entire island proportionally much more breeding habitat is available in shoreline and cliff habitats. The actual rate of overall population growth at Anacapa may be closer to that observed in the island plots (24-36%).

Furthermore, estimates based on the number of occupied nests may have been somewhat conservative if some sequential clutches were laid by different pairs. In this case, growth rates would be better represented by the overall number of clutches. The extent of nest site competition at Anacapa and whether it leads to delayed nesting for some pairs and sequential clutches has yet to be confirmed, but high hatching success of first clutches (73%) and increased numbers of sequential clutches coinciding with increased nest occupancy over time is at least suggestive that some second clutches were laid by second pairs. Evidence for nest site competition is strong at Santa Barbara Island where pairs have been observed scuffling in a nest site in which simultaneous clutches were laid (L. Harvey, unpubl. data). Simultaneous clutches in a nest on Anacapa suggests some competition for nest sites probably occurs there as well. Sequential clutches in a nest where one of the first clutch adults was killed by an avian predator provided further evidence for nesting by different pairs in a site within a breeding season. The parentage of sequential clutches merits much further study (*see below*).

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 colony 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 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. Breeding conditions eventually improved, with increased burrow occupancy and a doubling of the

overall population between 1999 and 2004 (Regehr 2007). The rapid population growth at Langara Island was attributed primarily to increased adult survival, reduced emigration and behavioral changes such as increased propensity to breed and burrow philopatry, but recruitment was not believed to have increased markedly. Annual growth rates have not been reported at this colony for comparison with Anacapa.

Colony Expansion

Colony expansion at Anacapa post-eradication was made possible by the sudden increase in availability of suitable nesting habitat. The higher population growth rate observed in the island plots (Fig. 21) likely resulted from the extremely low baseline level of nesting in these plots compared to sea caves. Baseline murrelet population levels measured in 2000-02 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 island plots were adjacent to long-occupied but limited habitats in sea caves, as well as at-sea congregations where relatively large numbers of birds served as a source of adults to explore and use these habitats.

Murrelet nesting in the Cat Rock and Landing Cove plots since 2003 represents reoccupation of these cliff and offshore rock habitats after many decades of absence. Reoccupation of these plots occurred within one year of rat eradication, with single nests found in each plot in 2003. Infrequent searches in Cat Rock and Landing Cove plots from 1991-2002 found no evidence of breeding murrelets (Carter et al. 1992, unpubl. data; McChesney et al. 2000; Whitworth et al. 2003a) and the small number of nests found in 2003 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 1900s, though the extent of breeding in these areas could not be determined. Egg records specified Cat Rock as the location of eight collected clutches, while location descriptions (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”) clearly identify Landing Cove as the site of four collected clutches, even though it was not specifically stated. 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. As far as we know, nest searches have never been conducted in the Rockfall Cove plot prior to this study.

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 has suddenly been freed from the heavy impacts of an introduced terrestrial predator (Black Rats) and can expand into unoccupied breeding habitats with few constraints. This period of population growth is undoubtedly a temporary phase as suitable breeding habitats reach capacity and the island slowly returns to a natural equilibrium. It is uncertain how long this period of strong colony growth at Anacapa Island will continue, although the duration will likely depend on continued high hatching success and high survival, as well as the degree and rate at which the murrelet colony expands into currently unoccupied upper island habitats. We expect annual increases in the number of occupied sites 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 island plots (Fig. 19), although further study is needed (*see below*). Clutch failure rates in the monitored sea caves and island plots also may increase as new predator-prey relationships are established among murrelets, the deer mouse population and avian predators of both murrelets and mice. Nest monitoring data suggested that avian predators are already 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 in four separate locations at Anacapa Island in 2010 provided additional evidence of recovery of this species in the absence of rats. Prior to 2003, the only evidence of auklets ever breeding on Anacapa was an eggshell fragment found in the open on the floor of Pinnacle Cave in 1997 (McChesney et al. 2000), two auklets captured in mist nets on Rat Rock and auklets heard vocalizing in Landing Cove in 1994 (H. Carter, unpubl. data). 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 and perhaps Pigeon Guillemots as well.

Unfortunately, no evidence of breeding by Ashy Storm-Petrels was found in any of the areas searched during the course of this study. Definitive evidence of breeding by storm-petrels has never been found at Anacapa, although small numbers of storm-petrels captured in mist nets on East and West Anacapa in 1994 (H. Carter, unpubl. data) and radar observations of storm-petrels circling upper cliff areas at Middle Anacapa in 2000-02 (T. Hamer, unpubl. data) suggest that breeding may occur in habitats that were inaccessible to rats (Carter et al. 2008). Further studies examining the current status of Ashy Storm-Petrels, possibly including social attraction techniques to encourage breeding in accessible habitats, will begin at Anacapa Island in 2011 (L. Harvey, pers. comm.).

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 been obtained, although CINP plan to conduct nest monitoring at Anacapa Island in 2011. Continuation of monitoring after 2010 is desirable for best documentation of the rate and pattern of recovery of this colony until it has neared its carrying capacity in the absence of rats. In previous reports we identified and discussed a number of pertinent issues for Xantus's Murrelets at Anacapa Island that merit further investigation:

Sequential clutches - Further studies examining the origin of sequential and simultaneous clutches are needed to determine whether annual number of clutches or occupied sites provide the best estimates of breeding 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

represent true second clutches, replacement clutches or clutches laid by different pairs of birds 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 has provided evidence of population growth since 2002, benefits to the overall murrelet population at Anacapa cannot be quantified using only nest monitoring in localized sea caves and island plots. Therefore, population monitoring with spotlight surveys should also be conducted in the future to better assess island-wide population trends. Comparisons of future spotlight survey data with baseline data collected in 2001-04 (Whitworth et al. 2003c, 2004a) will allow for better assessments of overall population trends and should confirm large population gains.

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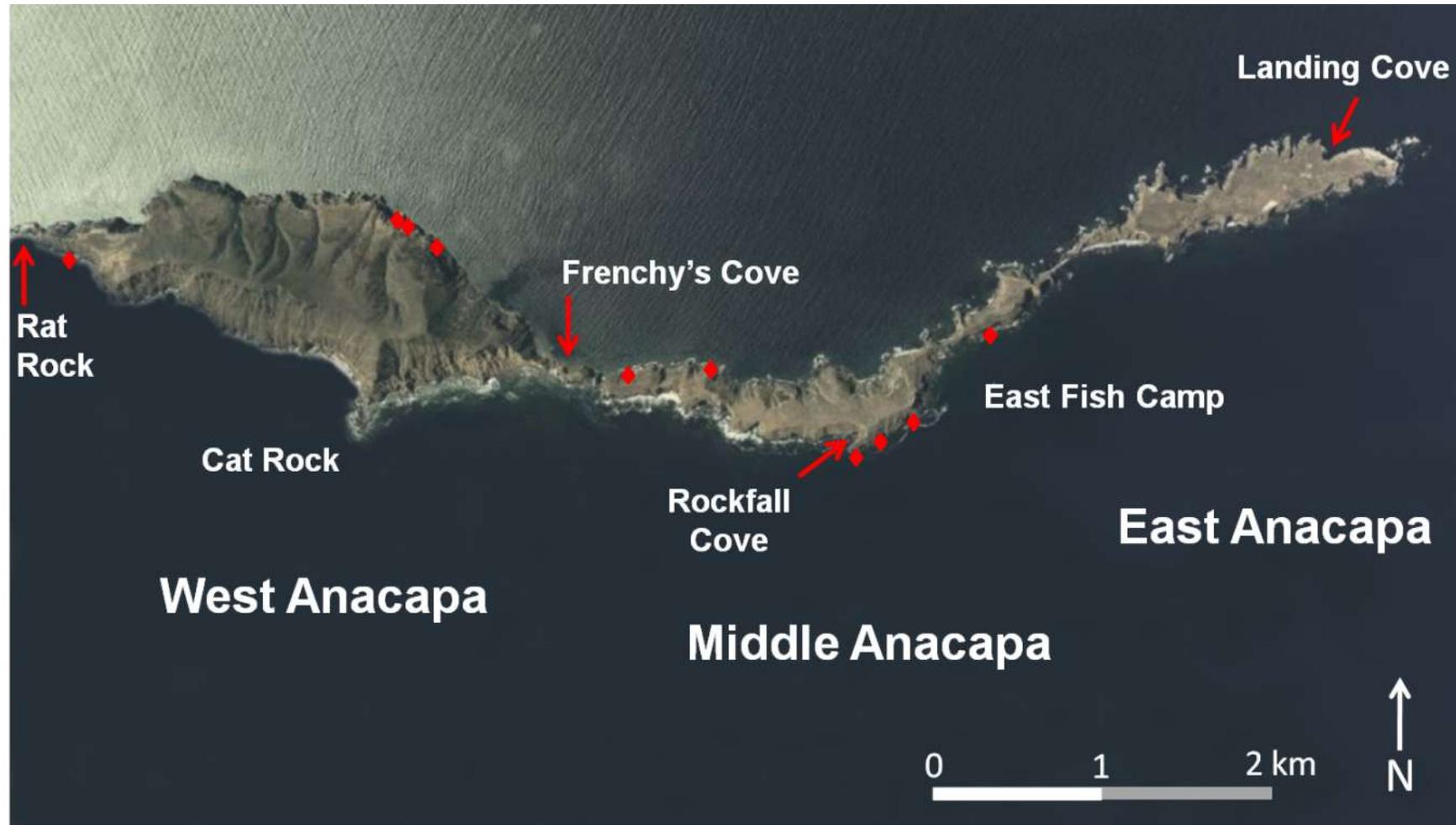


Figure 1. Satellite photograph of Anacapa Island, illustrating the three islets, sea caves (♦) and island plots where Xantus's Murrelet nest monitoring was conducted from 2000-10.

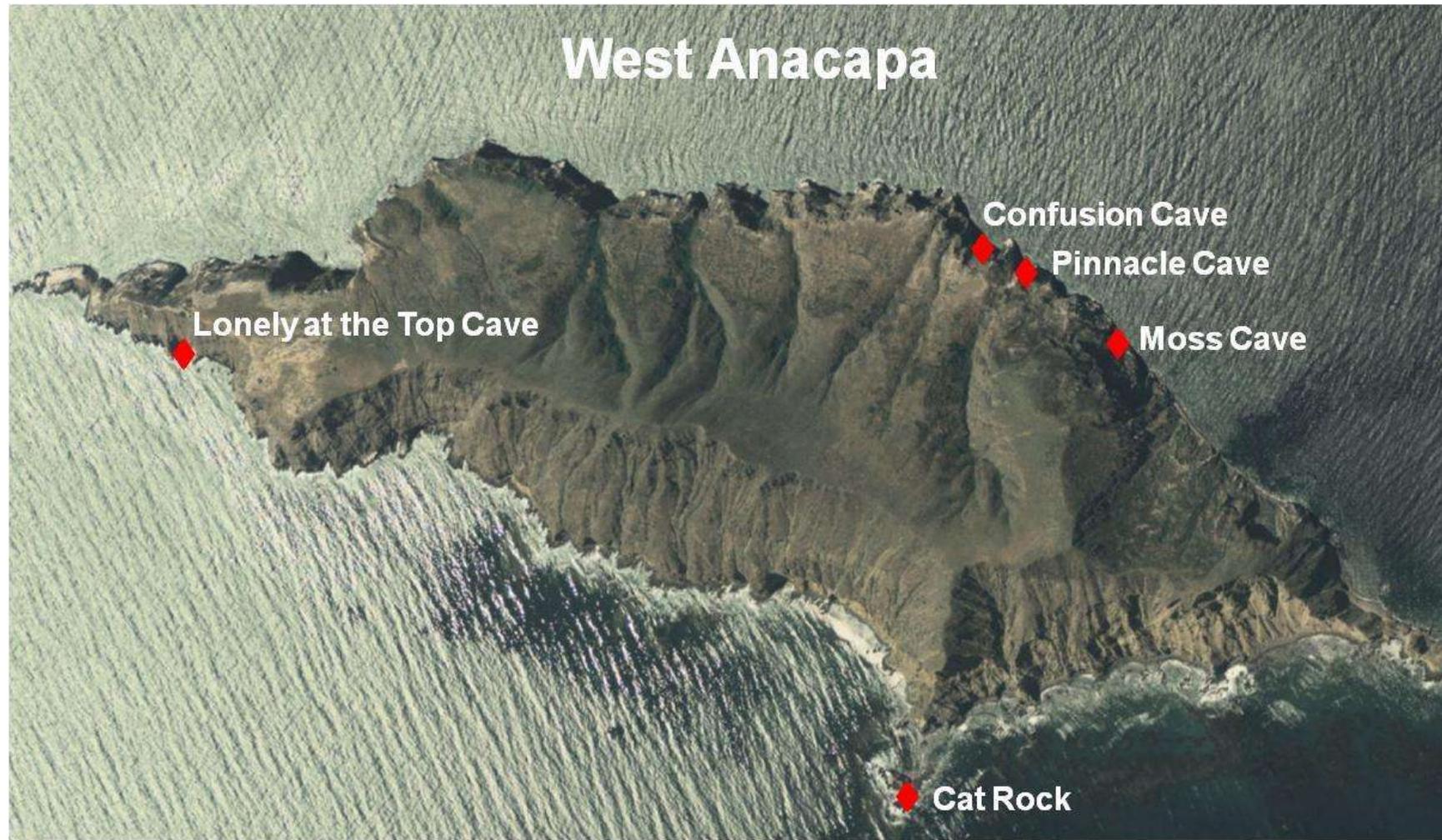


Figure 2. Satellite photograph of West Anacapa Island, illustrating locations of sea caves and island plots where Xantus's Murrelet nest monitoring was conducted from 2000-10.

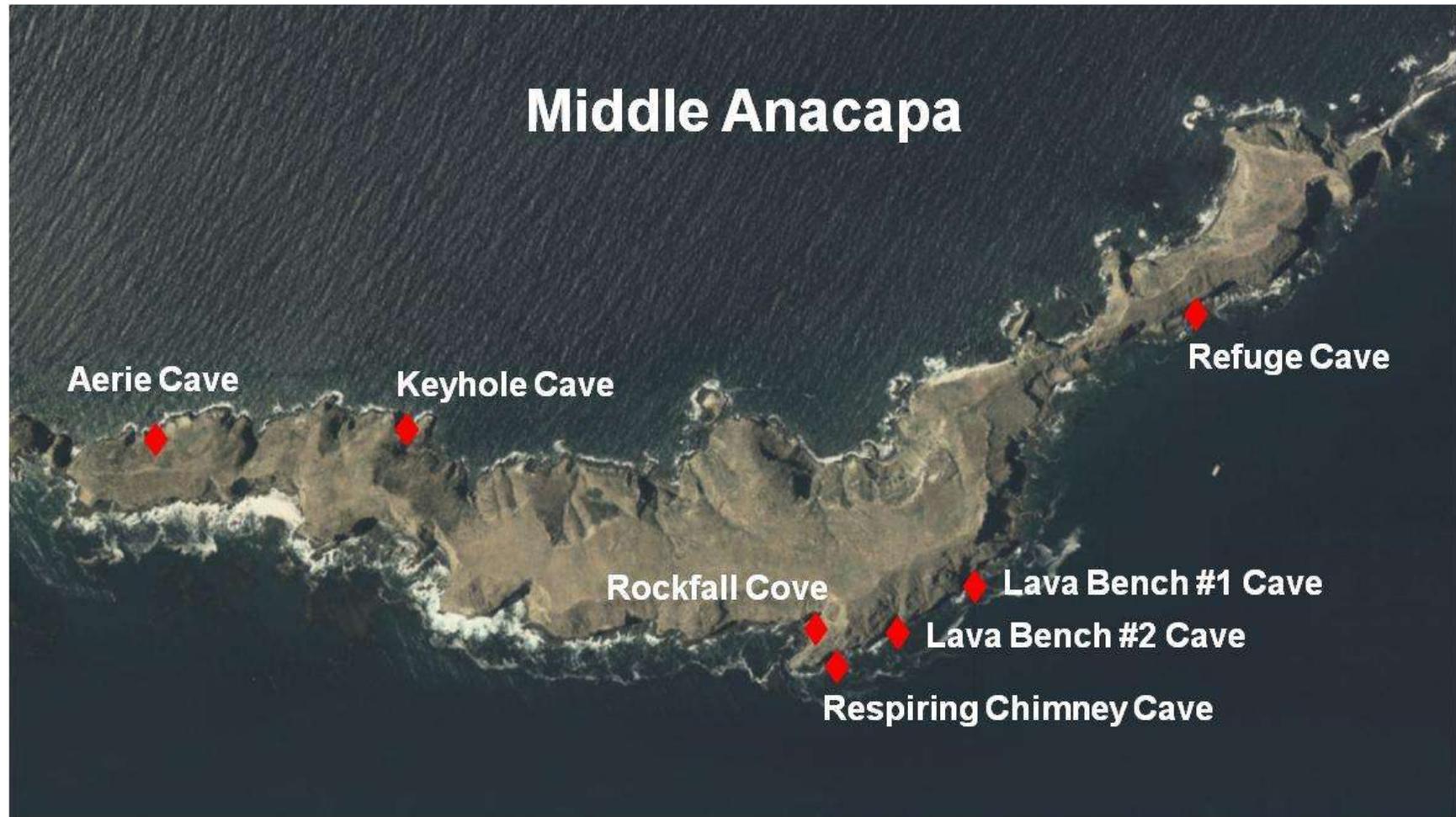


Figure 3. Satellite photograph of Middle Anacapa Island, illustrating locations of sea caves and island plots where Xantus's Murrelet nest monitoring was conducted from 2000-10.



Figure 4. Satellite photograph of East Anacapa Island, illustrating locations of sea caves and other areas 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).

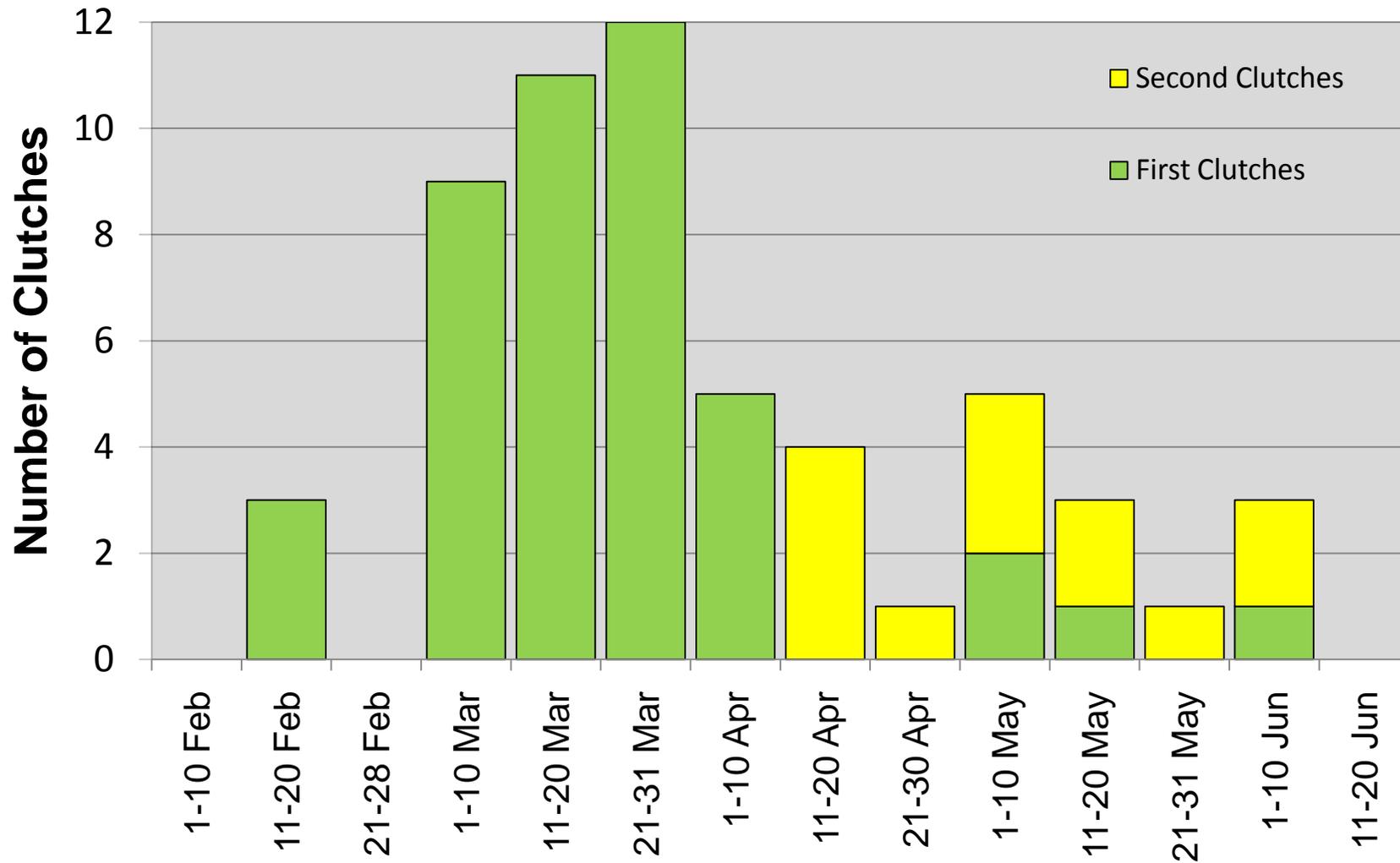


Figure 7. Initiation dates for Xantus's Murrelet clutches at Anacapa Island in 2010.



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

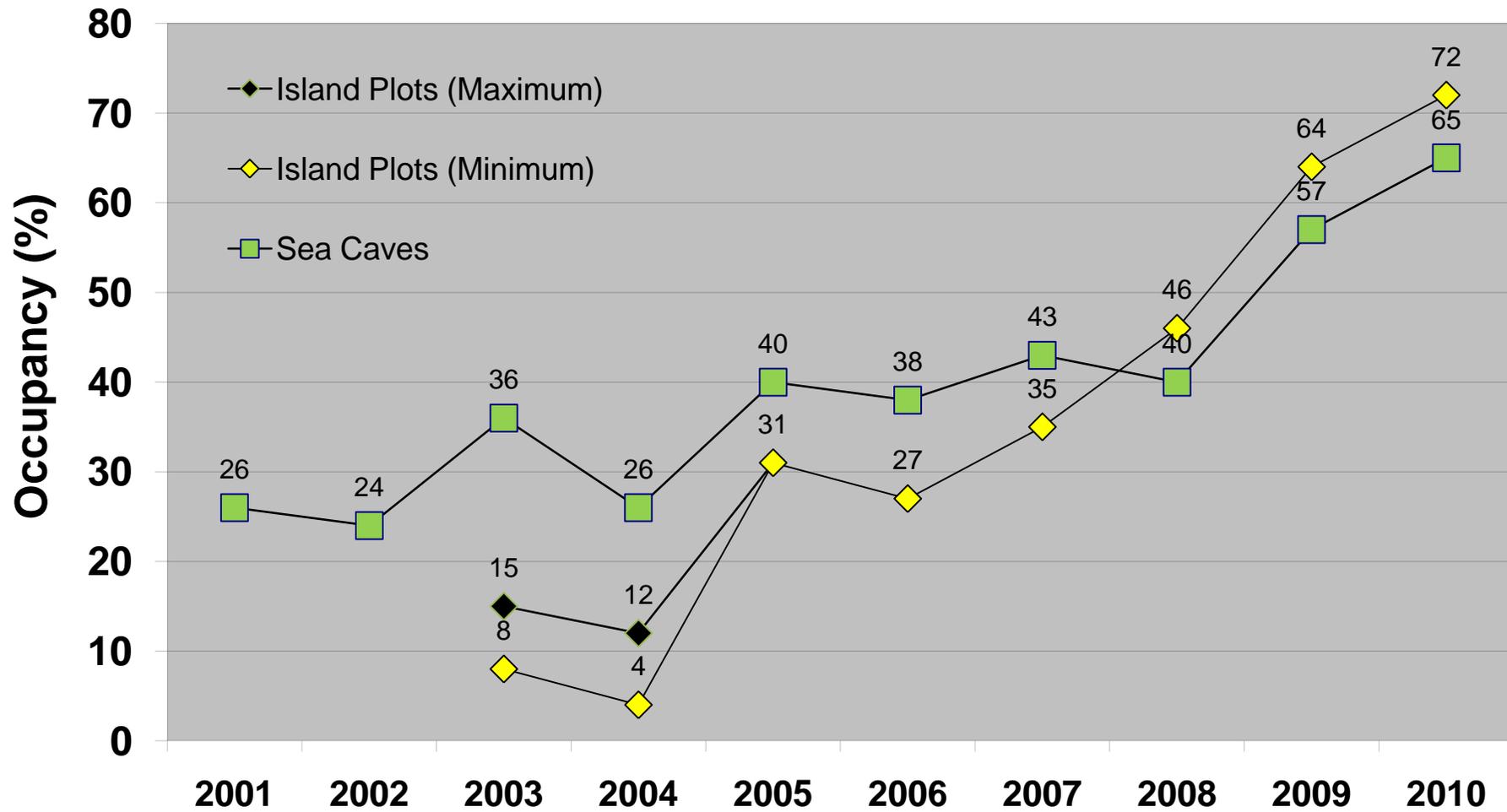


Figure 9. Annual site occupancy for Xantus's Murrelets in sea caves (2001-2010) and island plots (2003-2010) at Anacapa Island, California. Minimum occupancy in island plots assumed no occupied sites in Rockfall Cove plot in 2003-04, while maximum occupancy assumed two occupied nests found in 2005 were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

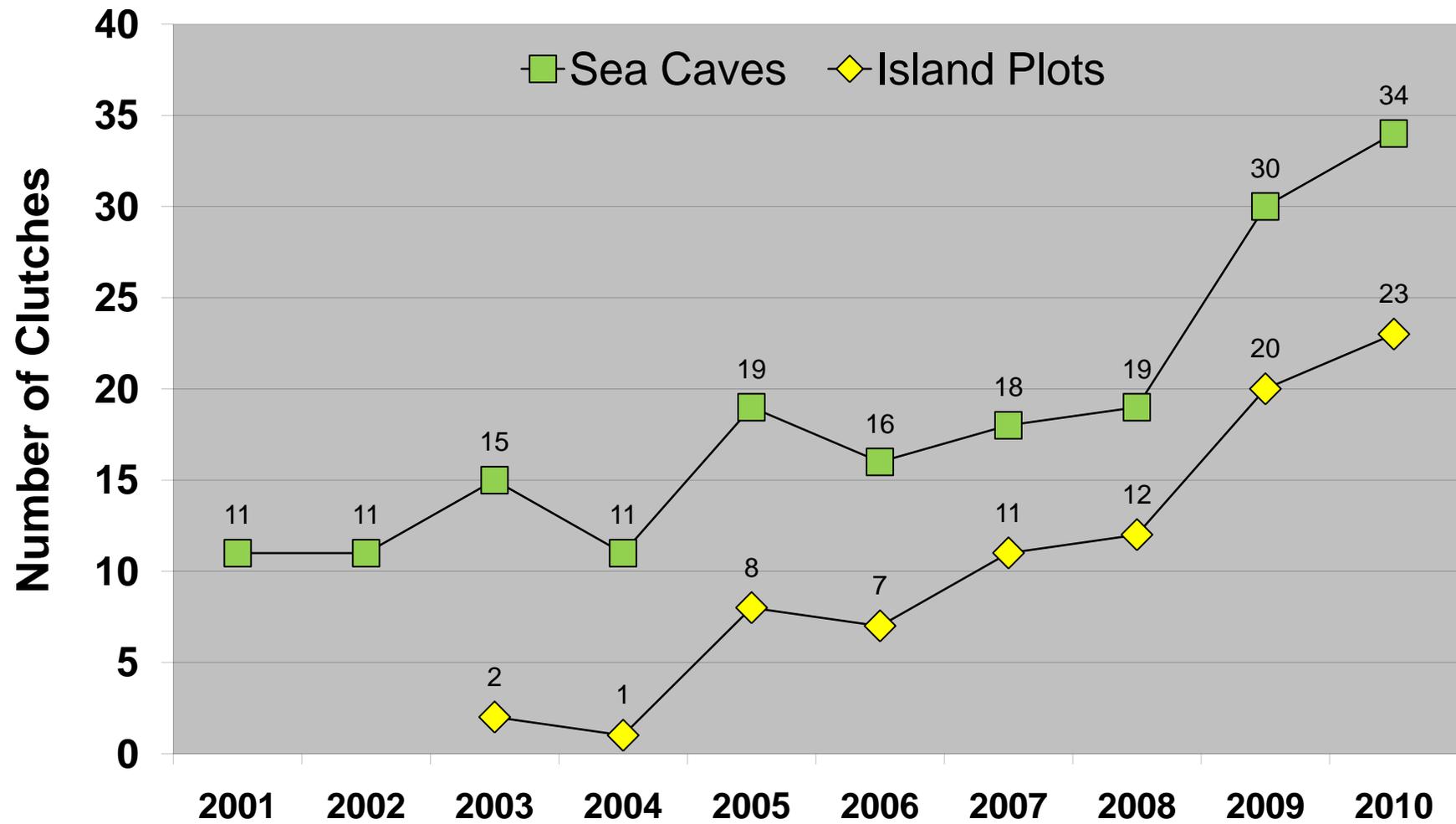


Figure 10. Annual number of clutches for Xantus’s Murrelets in sea caves (2001-2010) and island plots (2003-2010) at Anacapa Island, California. No occupied sites were assumed in Rockfall Cove in 2003-04 (see *Methods; Table 3*)

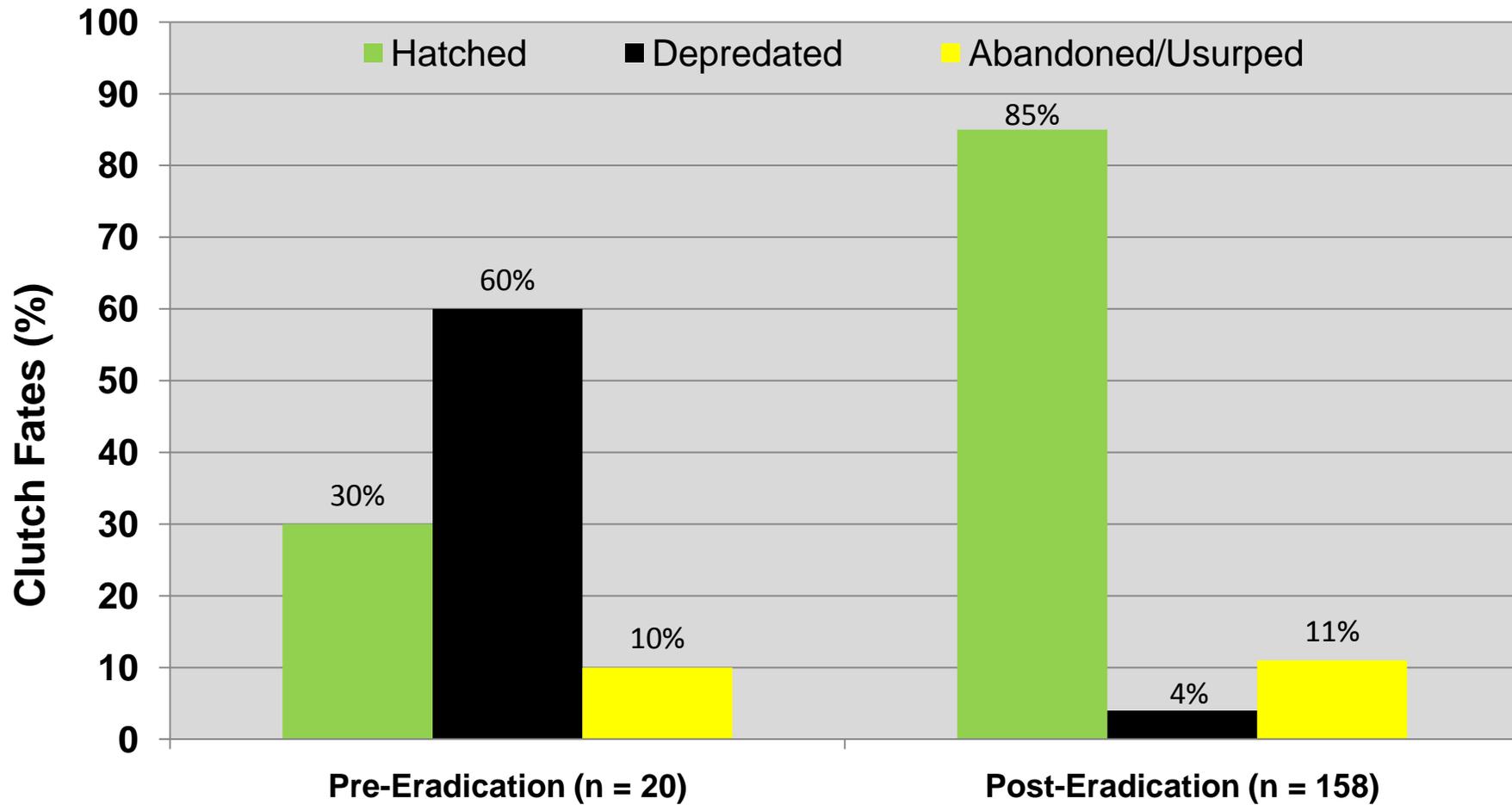


Figure 11. Comparison of Xantus's Murrelet clutch fates in sea caves at Anacapa Island pre-eradication (2001-02) versus post-eradication (2003-10).

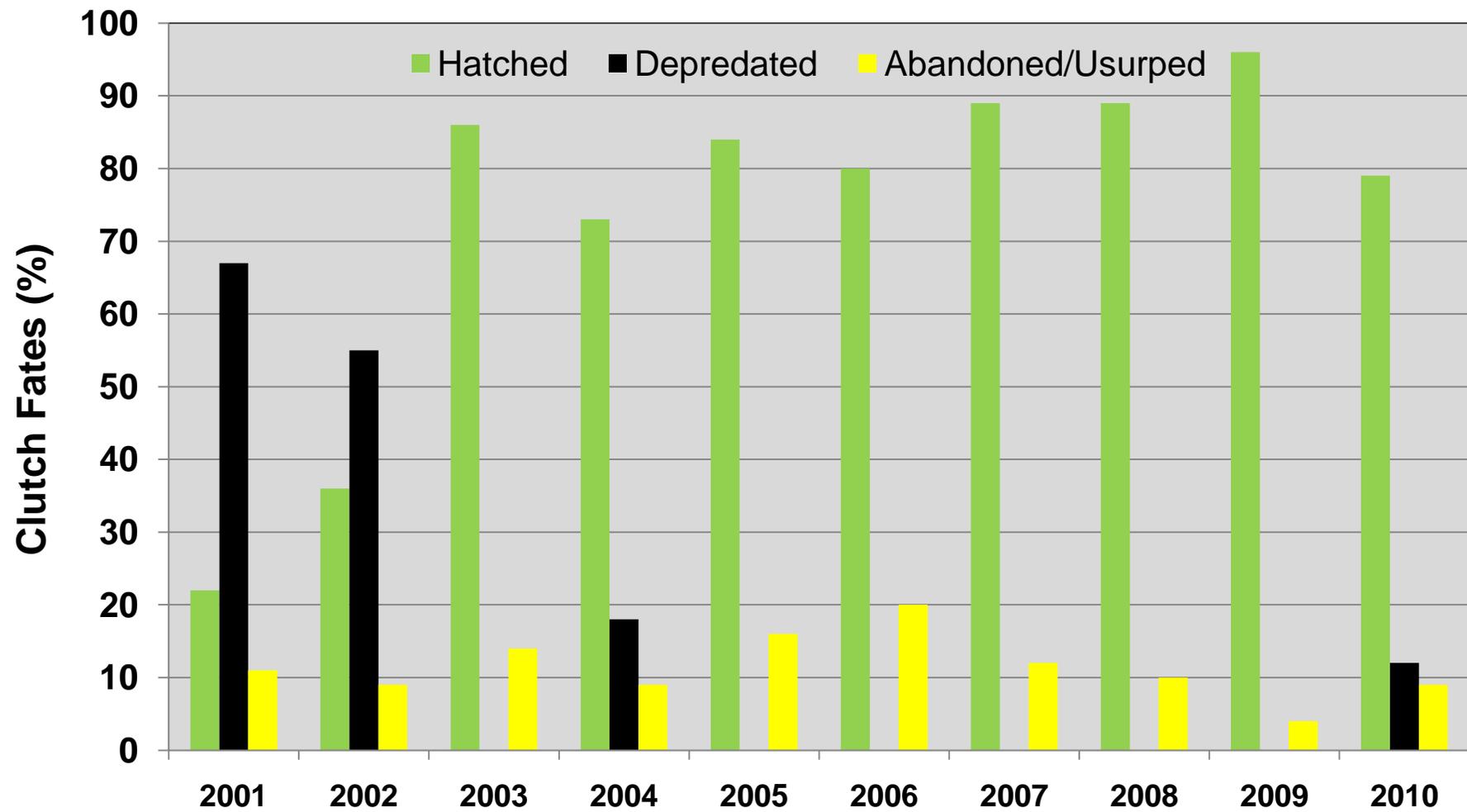


Figure 12. Annual hatching success for Xantus's Murrelets in sea caves at Anacapa Island in 2001-10.

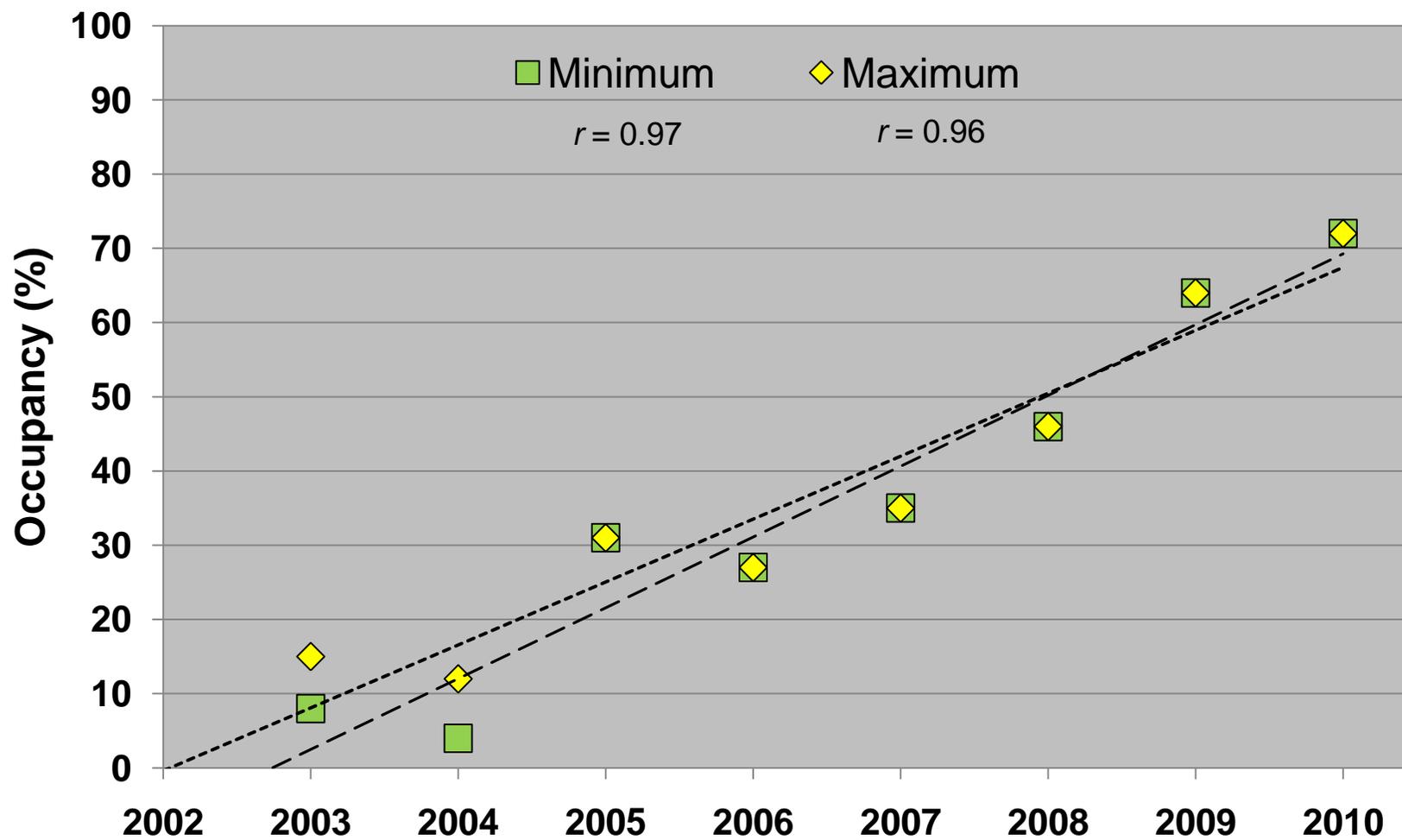


Figure 13. Trends in annual site occupancy for Xantus's Murrelets in island plots at Anacapa Island, California, 2003-10. Trends assume minimum and maximum levels of nesting in Rockfall Cove plot from 2003-2004 (see *Methods*; *Table 3*).

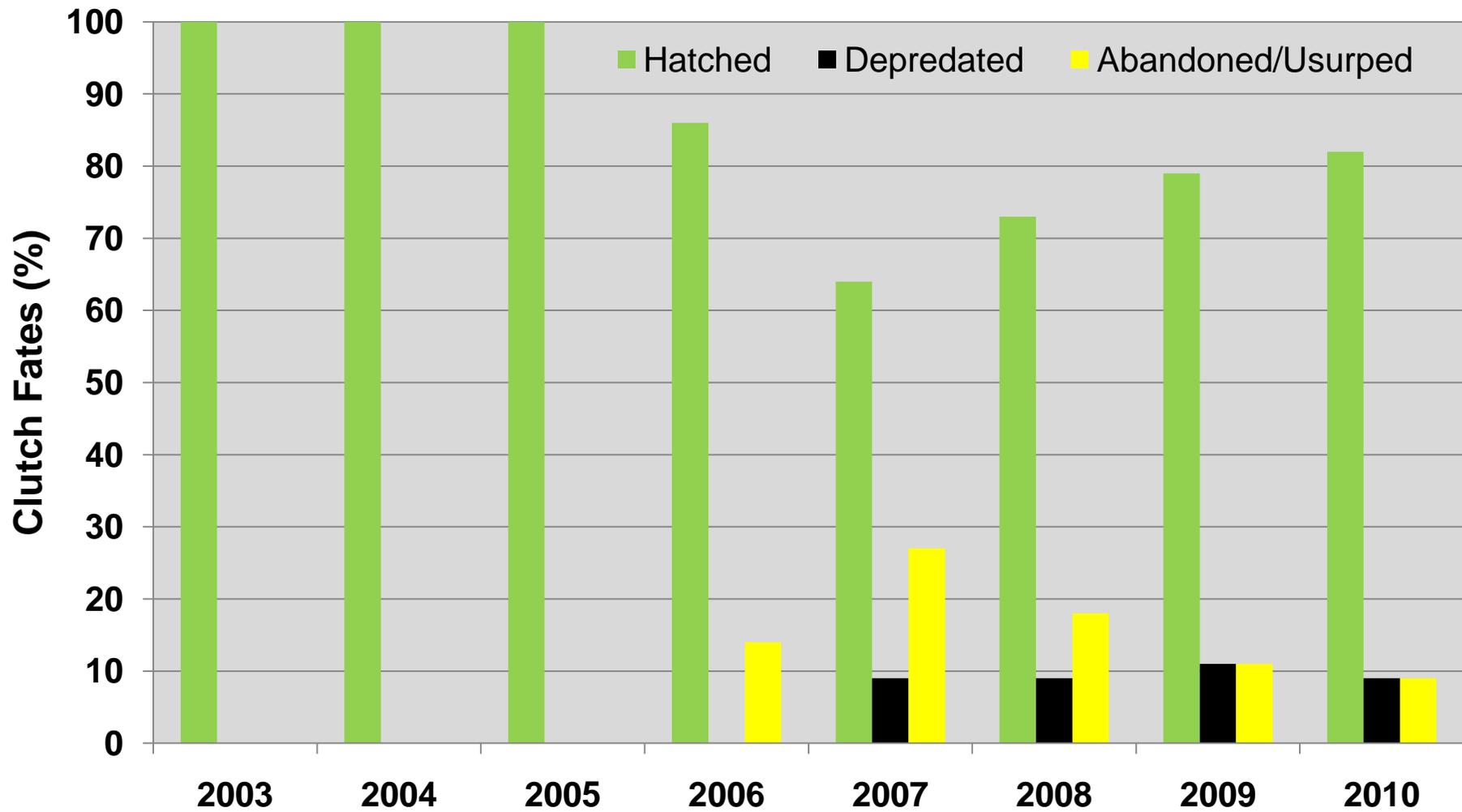


Figure 14. Annual hatching success for Xantus's Murrelets in island plots outside of sea caves at Anacapa Island in 2003-10.

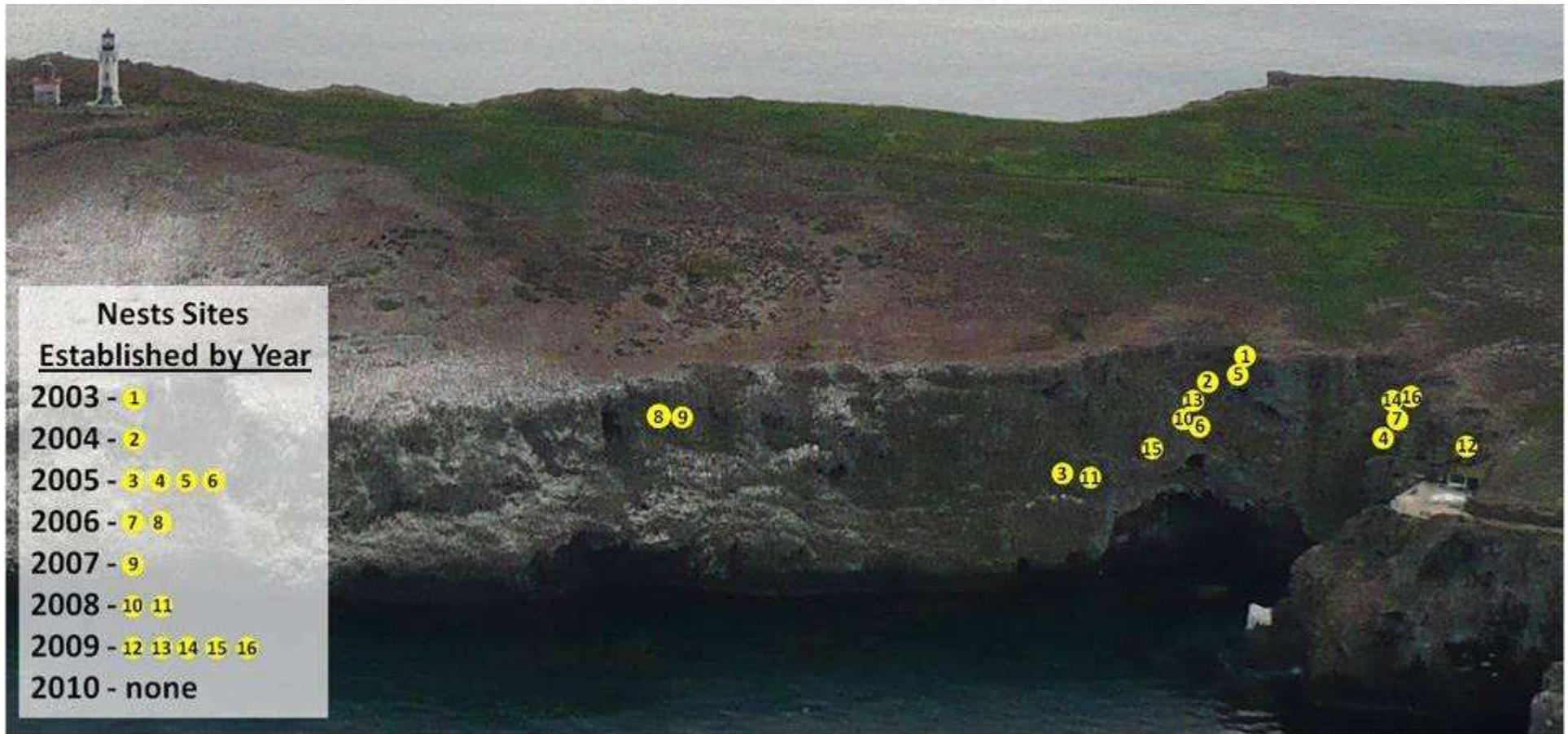
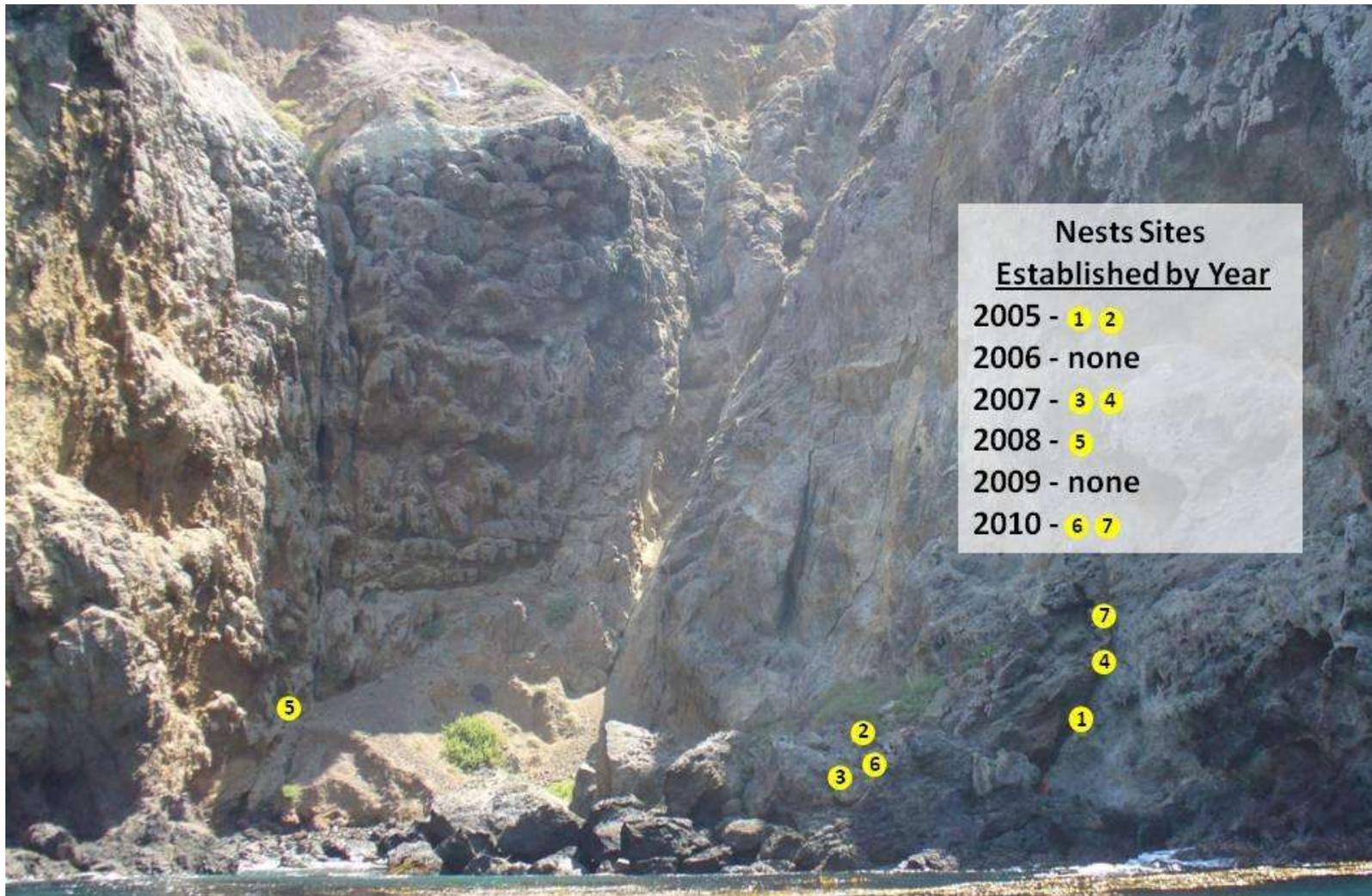
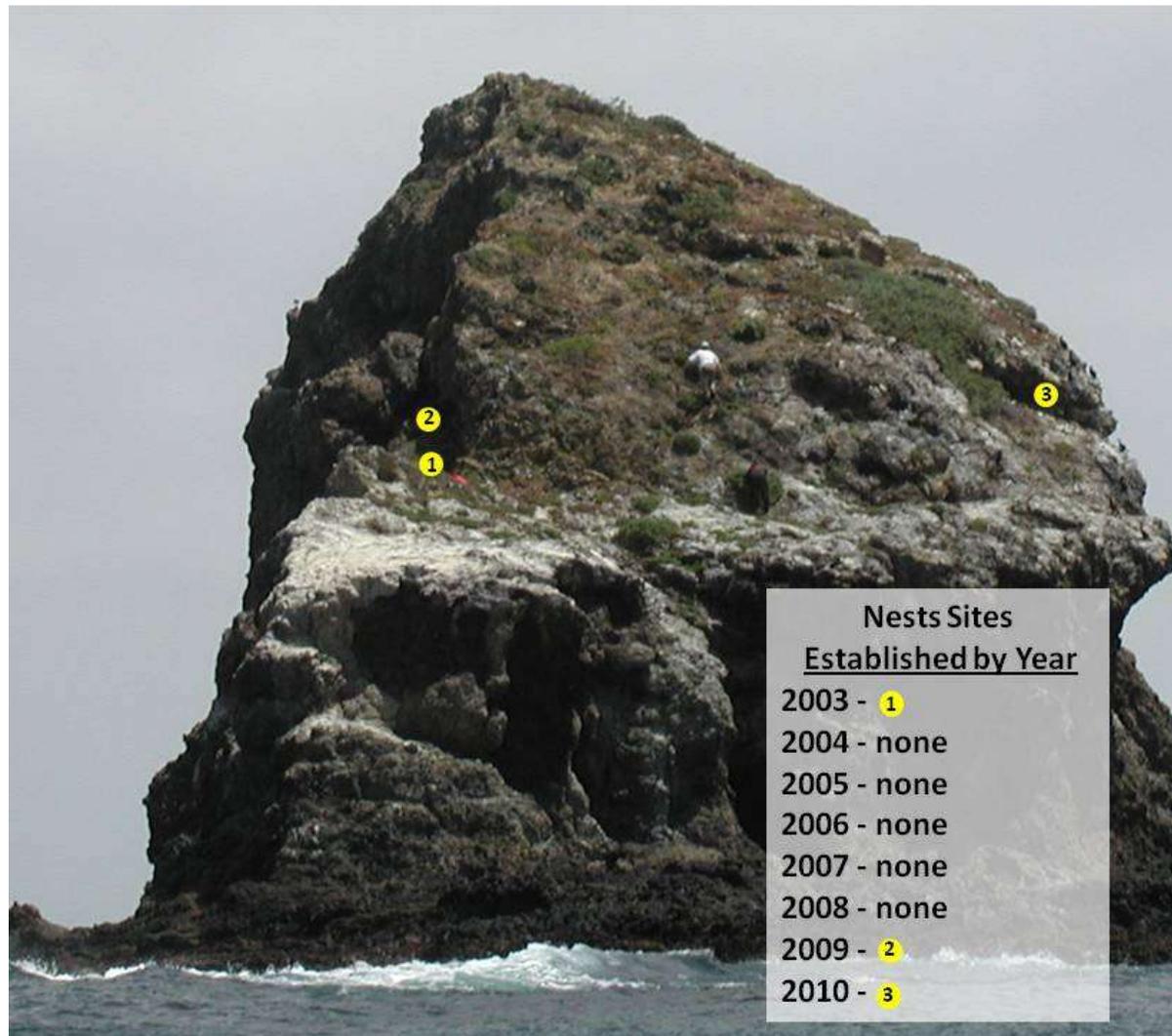


Figure 15. Xantus's Murrelet sites in the Landing Cove cliff plot on East Anacapa Island from 2003 to 2010. Site locations are approximate.



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.

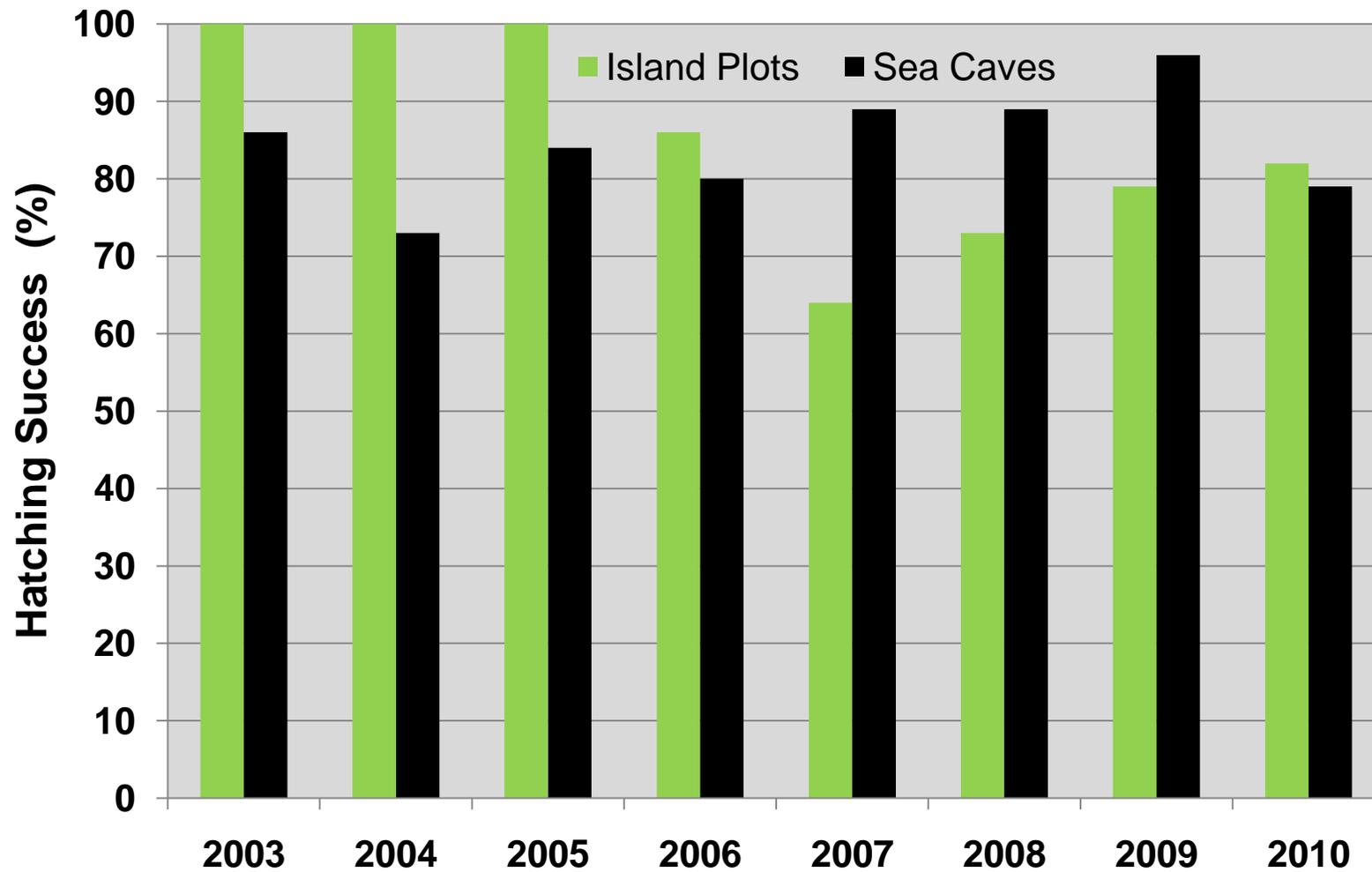


Figure 18. Comparison of annual hatching success for Xantus's Murrelets in island plots and sea caves at Anacapa Island in 2003-10.

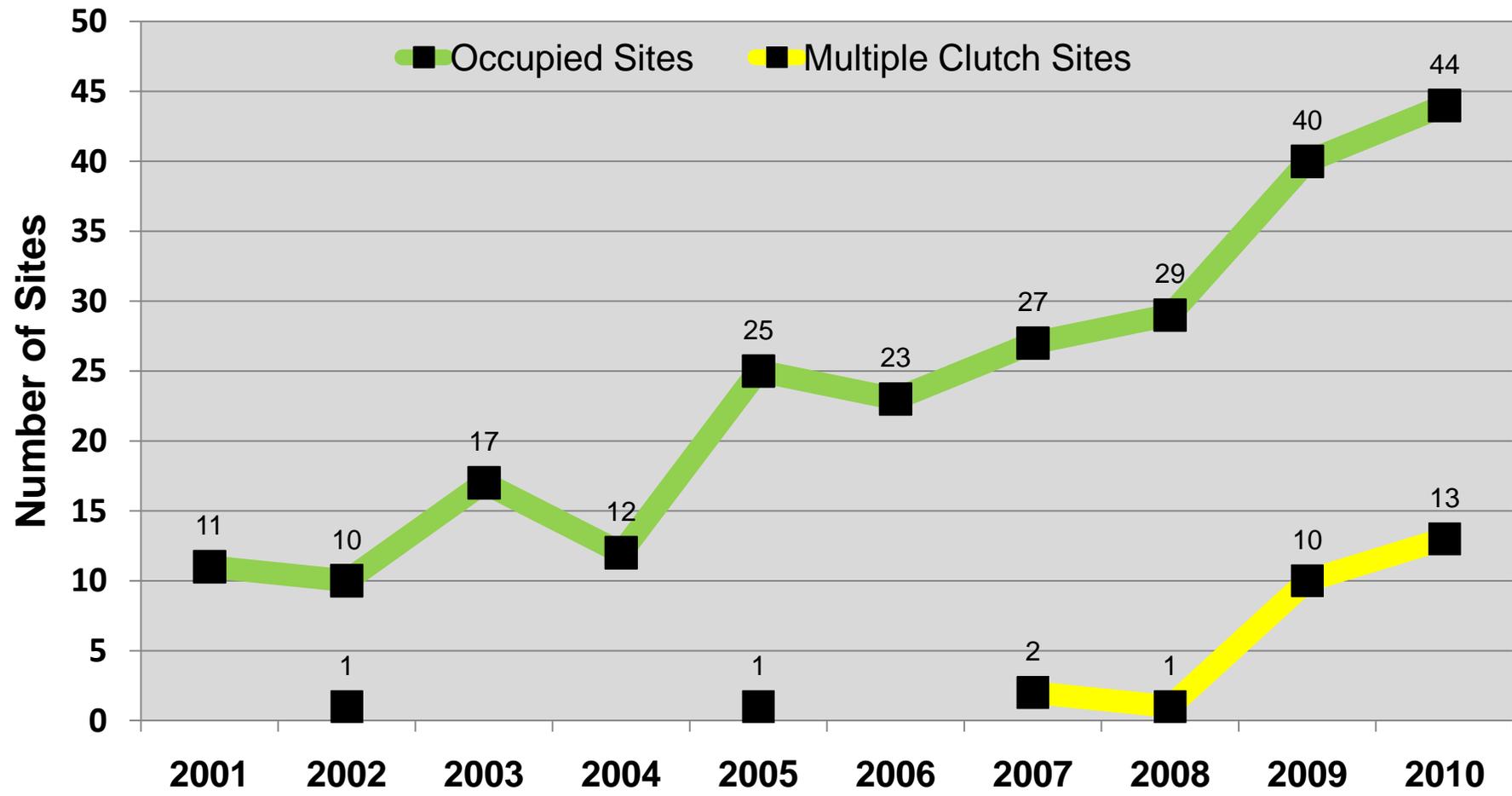


Figure 19. Number of occupied sites and multiple clutch sites (sequential and simultaneous clutches) for Xantus’s Murrelets in all areas monitored at Anacapa Island, 2001-10.

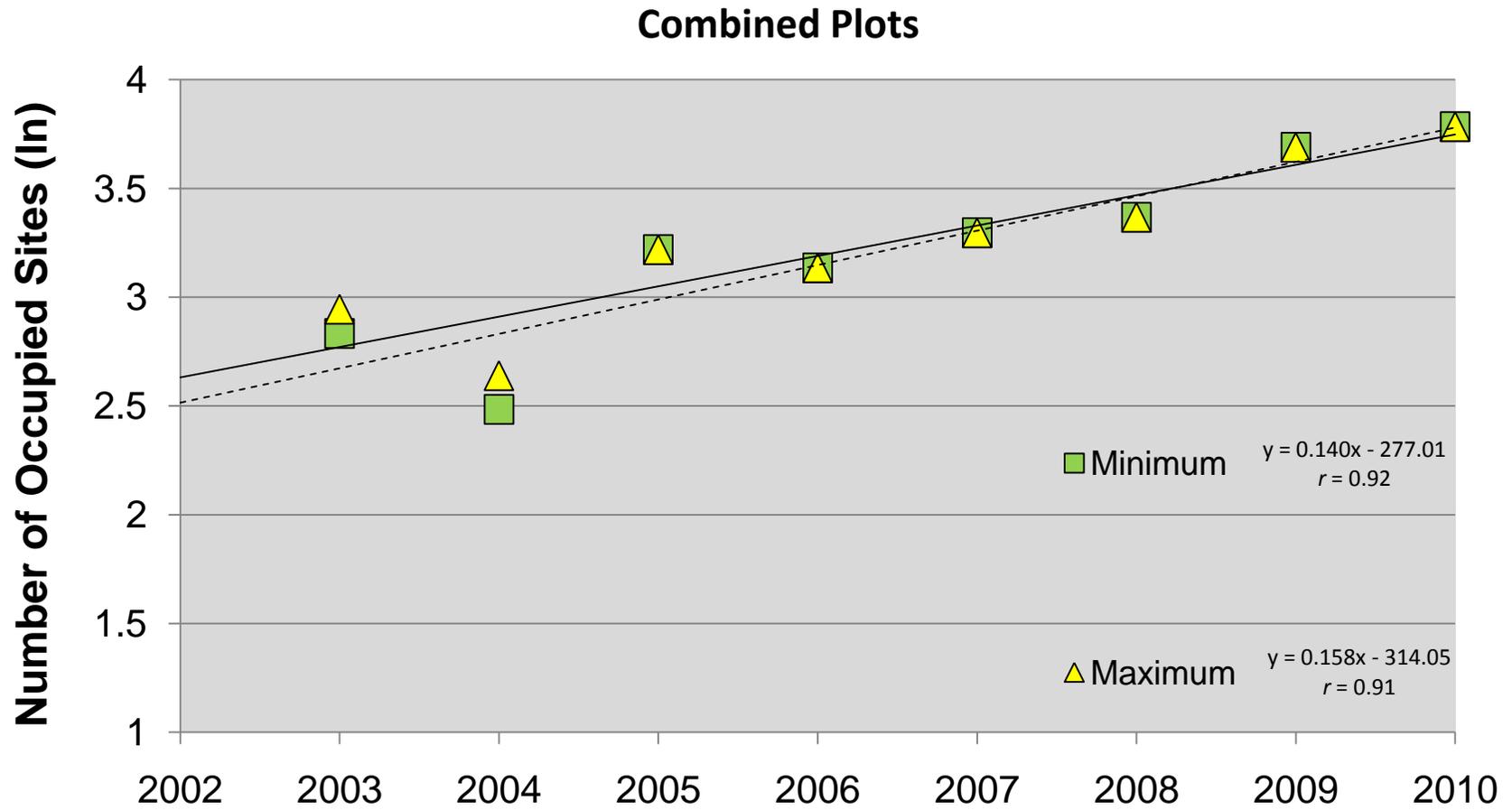


Figure 20. Log-linear regression of the annual number of occupied Xantus’s Murrelet nest sites in all monitored areas at Anacapa Island, 2003-10. Trends assume minimum and maximum levels of nesting in the Rockfall Cove plot from 2003-2004 (see *Methods*; Table 3).

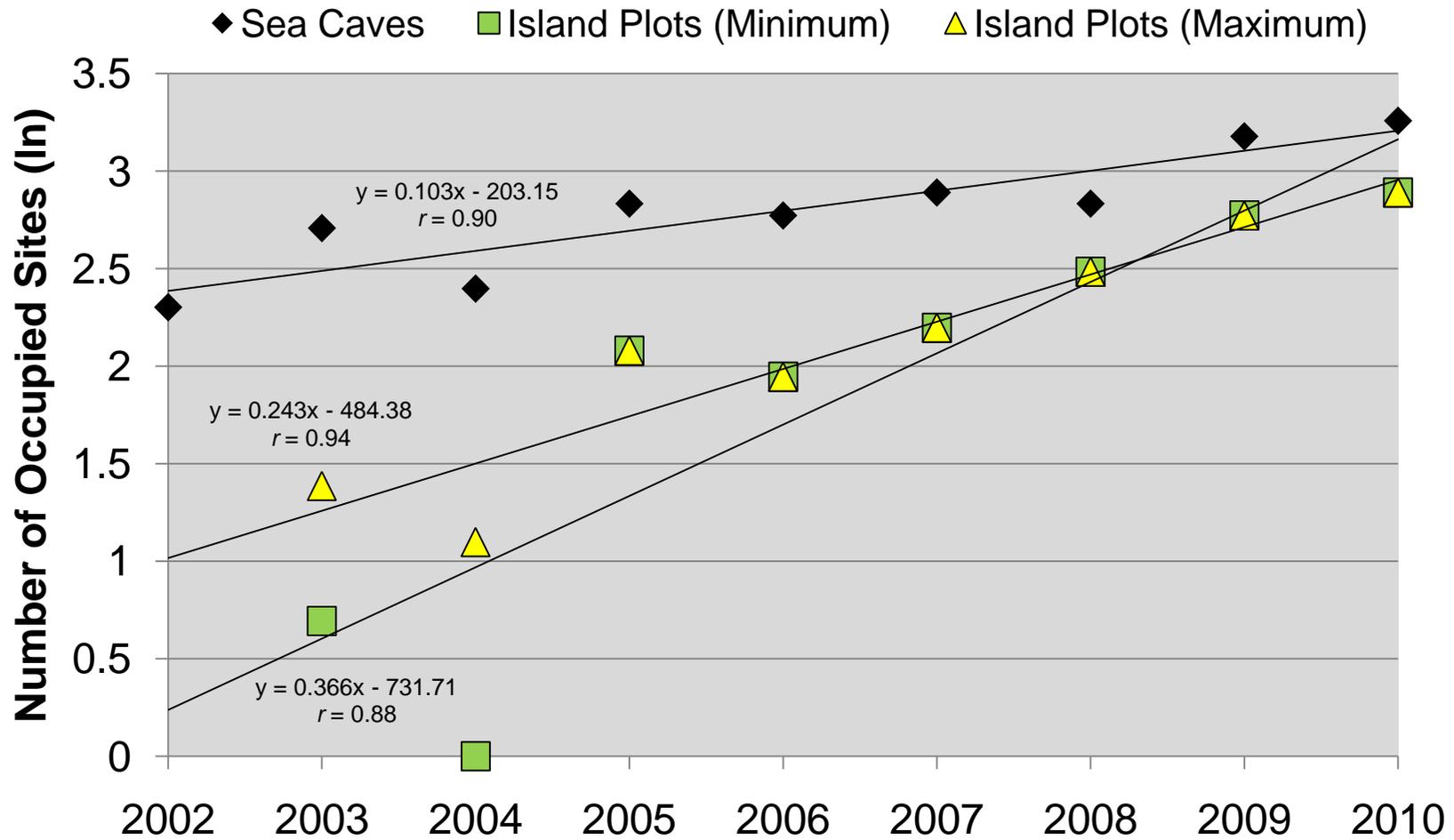


Figure 21. Log-linear regression of the annual number of occupied Xantus’s Murrelet nest sites in sea caves (2002-10) and island plots (2003-10) at Anacapa Island. Trends assume minimum and maximum levels of nesting in the Rockfall Cove plot from 2003-2004 (see *Methods; Table 3*).

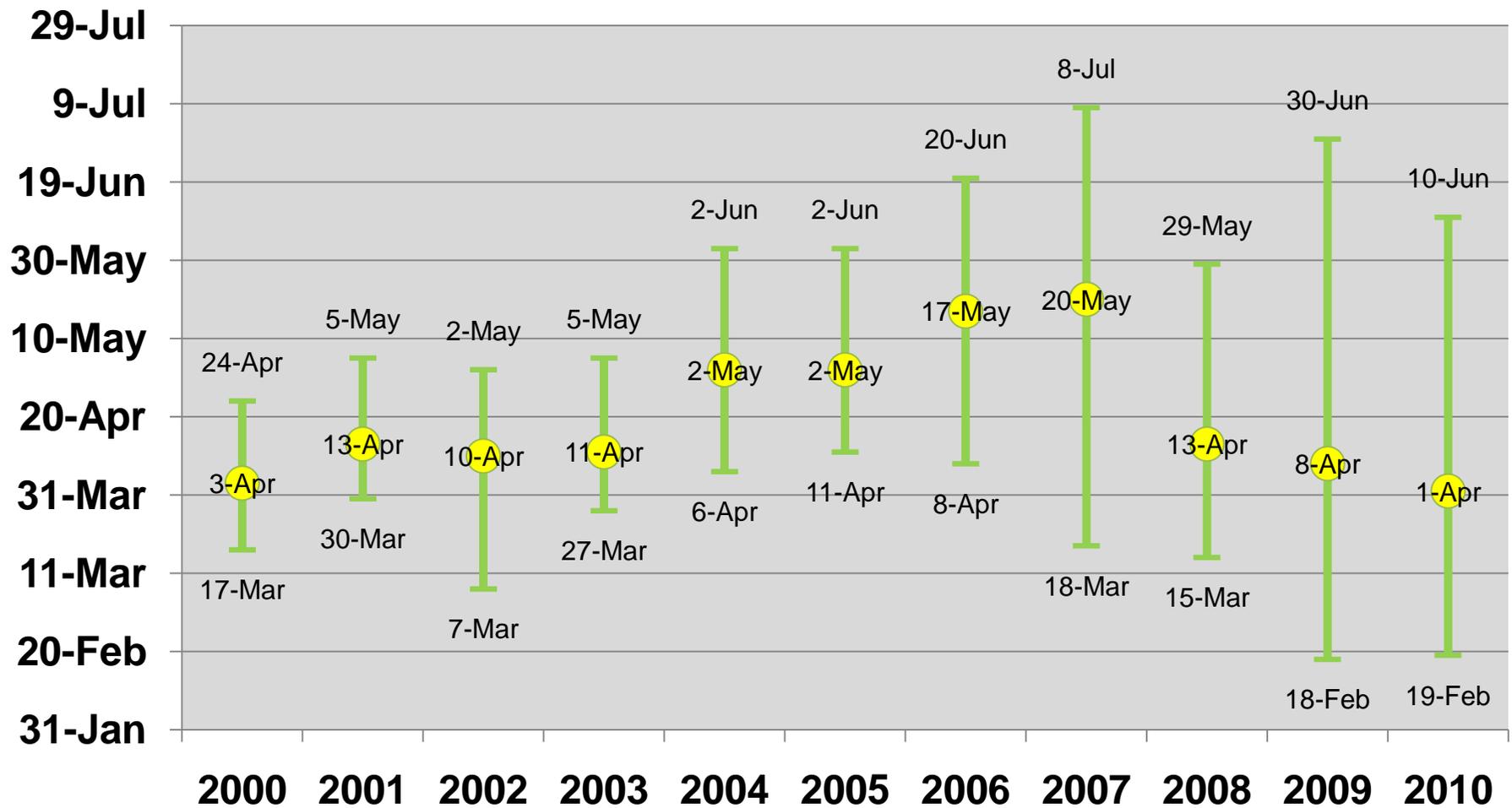


Figure 22. Annual timing of breeding (mean and range of clutch initiation dates) for Xantus's Murrelets in island plots and sea caves at Anacapa Island in 2000-10.

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
Island Plots Total	25	18	23^a	18	2	2	1
Anacapa Total	65	44	57^a	45	6	5	1

^aMore 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

^aTwo sites destroyed by storm surges in early spring 2010 were excluded from later occupancy analyses.

^bMore 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*).

^cEggs 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*).

^dClutches 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 island plots outside sea caves 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 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 (\pm sd)	Range of Dates	Range (d)	Clutches
2000	3 April \pm 11 d	17 March - 24 April	38	9
2001	13 April \pm 13 d	30 March - 5 May	36	11
2002 ^a	10 April \pm 16 d	7 March - 2 May	56	11
2003	11 April \pm 12 d	27 March - 5 May	39	17
2004	2 May \pm 21 d	6 April - 2 June	58	11
2005 ^a	2 May \pm 14 d	11 April - 2 June	52	26
2006	17 May \pm 24 d	8 April - 20 June	73	22
2007 ^a	20 May \pm 29 d	18 March - 8 July	112	29
2008 ^a	13 April \pm 20 d	15 March - 29 May	75	30
2009 ^a	8 April \pm 32 d	18 February - 30 June	132	48
2010 ^a	1 April \pm 29 d	19 February - 10 June	111	57

^aIncludes initiation dates for sequential and simultaneous clutches.

Appendix 1:

**Post-Breeding Season Nest Searches for Crevice-Nesting Seabirds
in Upper Island Habitats at Anacapa Island: October 2009**

Darrell L. Whitworth¹, Josh Koepke¹, Sarah K. Thomsen¹, April Allard
and A. Laurie Harvey²



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

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

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

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 eradication of Black Rats (*Rattus rattus*) from Anacapa Island in fall 2002. 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 (Fig. 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 West Anacapa Island) 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 Island 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 (*Cephus columba*).

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

West Anacapa Island

16 October - 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).

17 October - 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 Cassin'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.

18 October - 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. Little 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 island 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, 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.

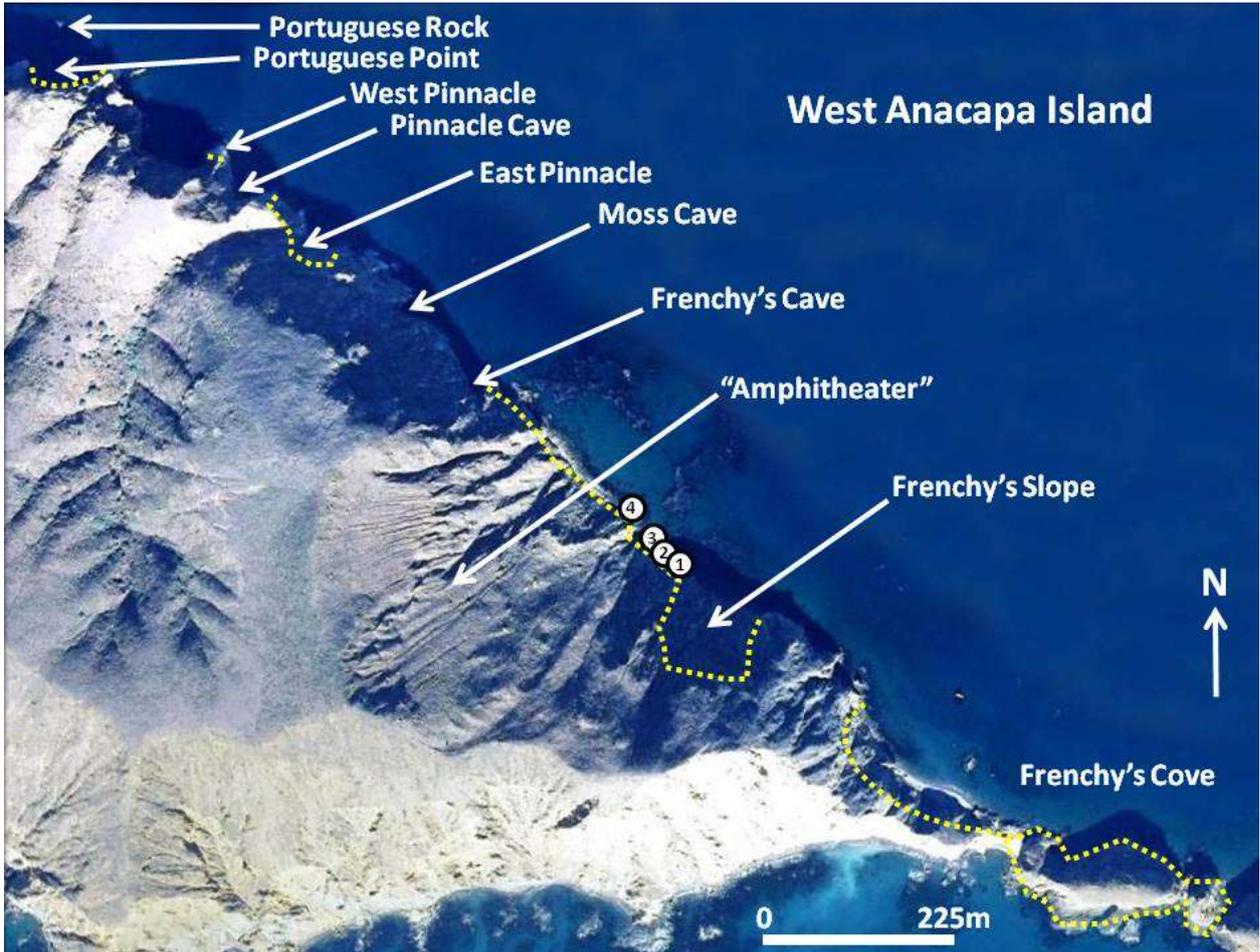


Figure A1. The northeast shore of West Anacapa Island where Xantus's Murrelet nest searches were conducted on 16 and 18 October 2009. Numbered circles indicate the approximate location of murrelet nest sites found in 2009.

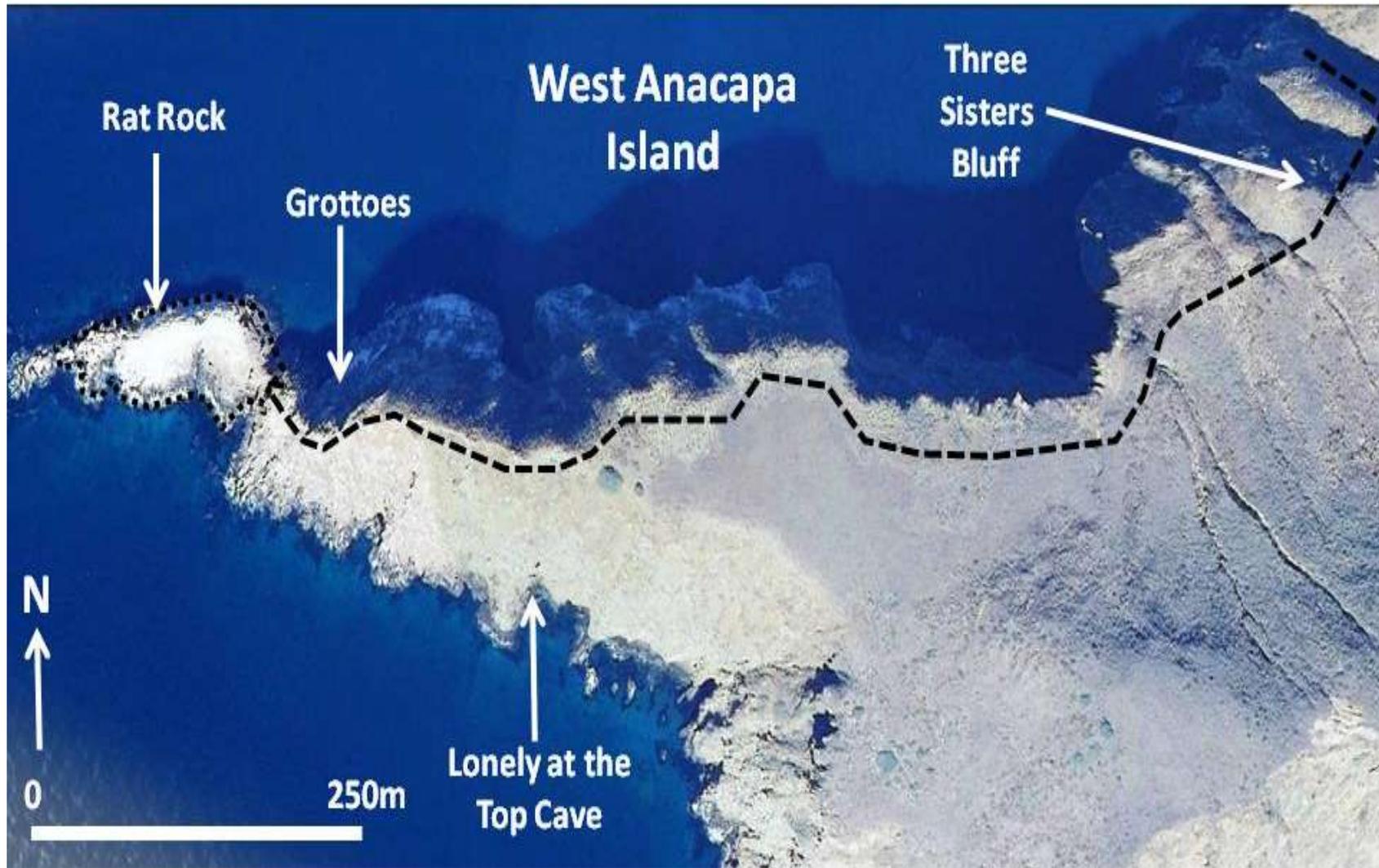


Figure A2. The west end of West Anacapa Island where Xantus's Murrelet nest searches were conducted on 17 October 2009.



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 Murrelet 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 Murrelet nest searches were conducted on 16 October 2009.



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



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

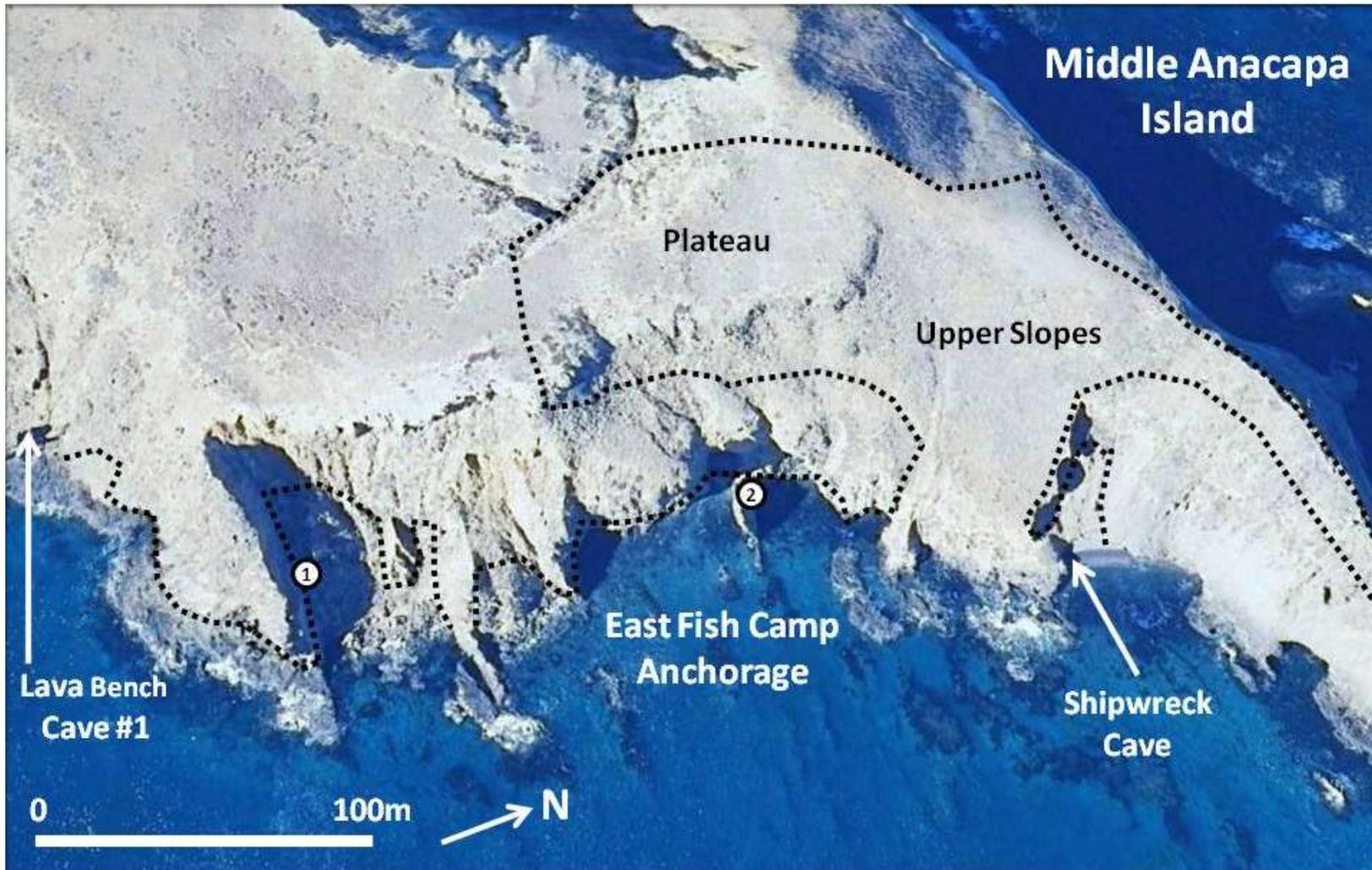


Figure A11. Middle Anacapa Island near the East Fish Camp Anchorage where Xantus's Murrelet nest searches were conducted on 15 October 2009. Numbered circles indicate the location of murrelet nest sites found in 2009.



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.

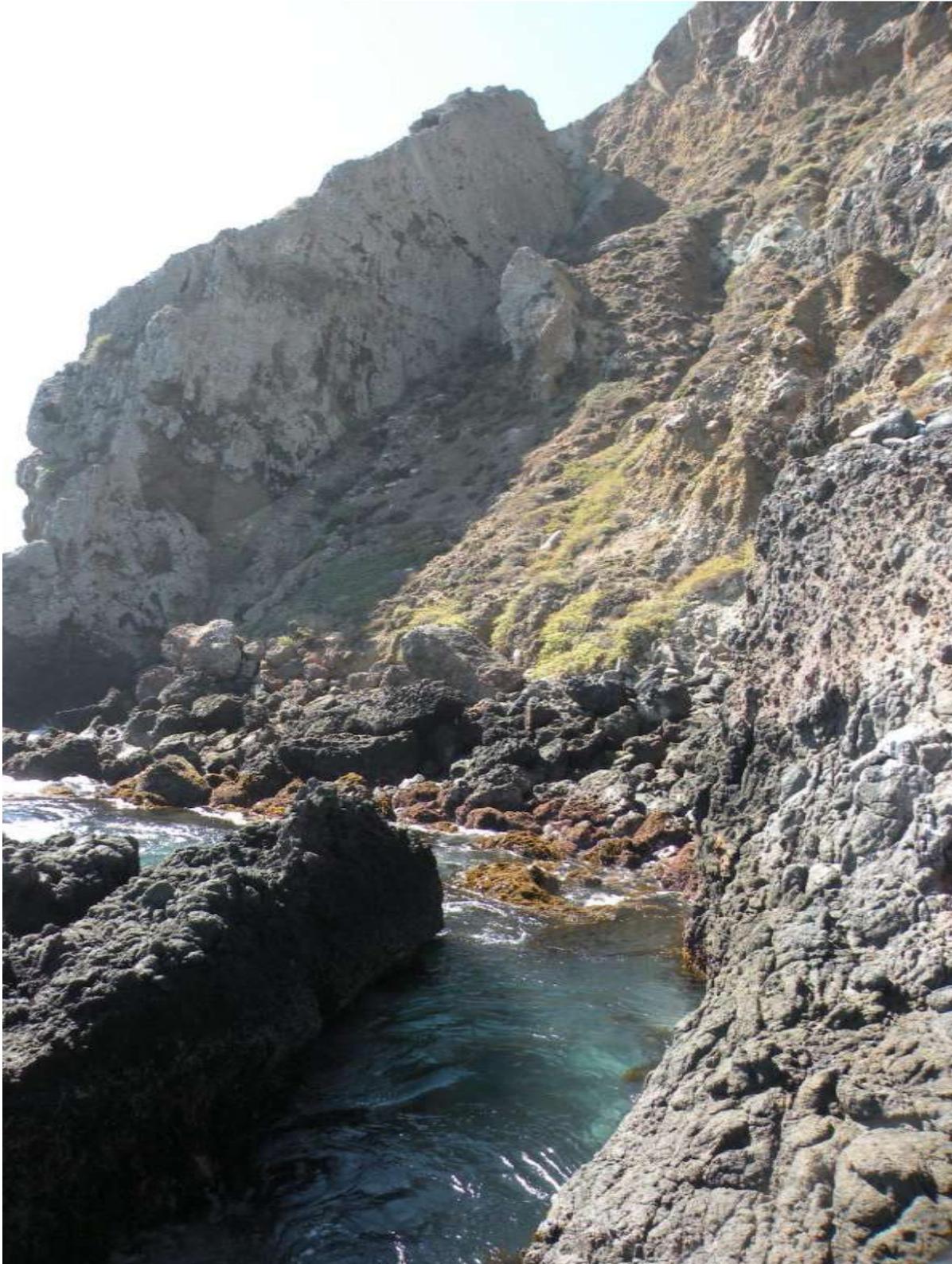


Figure A13. Rocky slopes and scree on the south shore of Middle Anacapa Island near the East Fish Camp Anchorage, 15 October 2009.



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 in area EFC3 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.