Nest Monitoring of Xantus's Murrelets at Anacapa Island, California: 2009 annual report

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Xantus's Murrelet chick in Landing Cove Nest #11 at East Anacapa Island, 27 June 2009

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EXECUTIVE SUMMARY

- In 2009, California Institute of Environmental Studies conducted the tenth year of Xantus's Murrelet (*Synthliboramphus hypoleucus*) nest monitoring at Anacapa Island, California. With funds from the American Trader Trustee Council, a monitoring program was initiated in 2000 to provide four years of baseline data on murrelet reproductive success and population size after eradication of black rats (*Rattus rattus*) in 2002. To obtain evidence of post-eradication population recovery in 2004-09, nest monitoring was used to examine the number of clutches, nest occupancy, hatching success, and colony expansion in sea caves and other sample plots.

- Murrelet breeding indices were highest in 2009, with more clutches laid (n = 50 overall, 30 in sea caves, 20 in other plots), higher nest occupancy (68% overall, 65% in sea caves, 73% in other plots) and higher hatching success (89% overall, 96% in sea caves and 79% in other plots) than in any year since 2000.

- The 2009 breeding season was most notable for the degree of increase in murrelet breeding indices compared to the preceding year, including: 1) 61% increase in the number of clutches laid; 2) 68% increase in the number of hatched clutches; and 3) 20% increase in nest site occupancy.

- Twelve new nest sites (six in sea caves and six in other plots) were established at Anacapa in 2009, by far the largest annual increase since 2000.

- The mean clutch initiation date was 8 April (± 32 d), with the widest range of initiation dates (18 February-30 June; 132 days) since 2000.

- Two clutches were laid in ten murrelet nest sites in 2009. In nine sites, clutches were laid sequentially, but without marked birds it was impossible to determine if these clutches were laid by the same pair (i.e., replacement or second clutches) or different pairs. In most cases (89%), second clutches were laid after the first clutches had hatched. No evidence of pre-departure chick mortality was found in these sites.

- Significant positive trends in number of clutches and site occupancy provided strong evidence of murrelet population growth in Anacapa sea caves post-eradication. Several more years of monitoring data are desirable for more rigorous measurement of murrelet population trends in sea caves using regression analysis. Additional work is needed to determine if trends in sea caves reflect island-wide population trends.

- Increased hatching success likely has been a key factor in post-eradication population growth in sea caves. Post-eradication (2003-09) hatching success has been 84% (range = 69-89%) compared to just 44% (range = 22-86%) pre-eradication (2000-02).

- Mammalian depredation has been essentially eliminated as a cause of nest failure at Anacapa since the removal of rats. Nearly half (48%) of all pre-eradication clutches were depredated by rats, but only 3% of clutches were depredated or scavenged post-eradication by endemic deer mice (*Peromyscus maniculatus anacapae*). Depredated clutches have not been documented in the sea caves since 2004.

- Eradication of rats appears to have been the main factor leading to increased hatching success and colony growth. However, population growth may stall in some years (e.g., 2004) because of periodic low prey availability that can reduce murrelet nesting effort and hatching success.

- Funding from the American Trader Trustee Council for annual nest monitoring at Anacapa is currently scheduled to end 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. In addition, population size monitoring using spotlight surveys and radar monitoring also should be conducted in the future to better assess island-wide changes in population size.

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 litigation settlement in 1998, the American Trader Trustee Council (ATTC), in collaboration with Channel Islands National Park (CINP), developed a restoration program to enhance seabird breeding habitat on Anacapa Island, California, by eradicating non-native Black Rats (*Rattus rattus*) (ATTC 2001, Howald et al. 2005). The Xantus's Murrelet (*Synthliboramphus hypoleucus*) was identified as the species expected to benefit most from rat eradication because 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). The ATTC determined that rat eradication would assist murrelet population recovery and prevent possible loss of this important colony. In December 2004, Xantus's Murrelet was listed as threatened by the California Fish and Game Commission and 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). Xantus's Murrelet currently is listed as a candidate species under the federal Endangered Species Act.

Island Conservation and CINP successfully eradicated rats from Anacapa Island in two phases: a) East Anacapa in December 2001; and b) Middle and West Anacapa in November 2002 (Howald et al. 2005). While non-native introduced predators had 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 prior to 2000 to document the benefits of predator eradication for murrelets or other seabirds. In 2000, the ATTC sponsored Humboldt State University and Hamer Environmental (with collaboration by Channel Islands National Marine Sanctuary [CINMS] and California Institute of Environmental Studies [CIES]) to design and implement a Xantus's Murrelet Monitoring Program for Anacapa Island. The primary goals of this monitoring program were to: a) determine baseline levels of population size indices and reproductive success prior to eradication; and b) measure expected increases in murrelet population size and reproductive success 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 for measuring changes over time (Whitworth et al. 2002a,b; 2003a,b,c; 2004a; 2005a; Hamer et al. 2005).

In 2004, the ATTC decided that baseline data collection was completed for the Xantus's Murrelet population monitoring program but annual long-term monitoring was still needed to provide information on key demographic parameters and the general progress of expected population increases. CIES was funded by ATTC to continue nest searches and monitoring in sea caves and other nesting habitats at Anacapa Island. In 2004-09, this work has provided standardized data for: a) measuring number of clutches, site occupancy, hatching success, and nest depredation rates; and b) detecting expansion of the colony into habitats previously occupied by rats (Whitworth et al. 2004b, 2005b, 2006, 2008b,c). Monitoring efforts in 2009 marked the tenth consecutive year of Xantus's Murrelet nest monitoring at Anacapa Island and the seventh year of monitoring since rat eradication. In this report, we present the results of 2009 nest monitoring with comparison to previous years.

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 steep, rocky cliffs punctuated with over 100 sea caves (Bunnell 1993). West Anacapa is the largest (1.7 km^2) and highest (284 m) of the three islets (Fig. 2), followed by Middle Anacapa (0.6 km^2, 99 m; Fig 3), and East Anacapa (0.5 km^2, 73 m; Fig. 4). Anacapa Island is managed by CINP which maintains quarters for staff and facilities for campers on East Anacapa, but the rest of the island is 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).

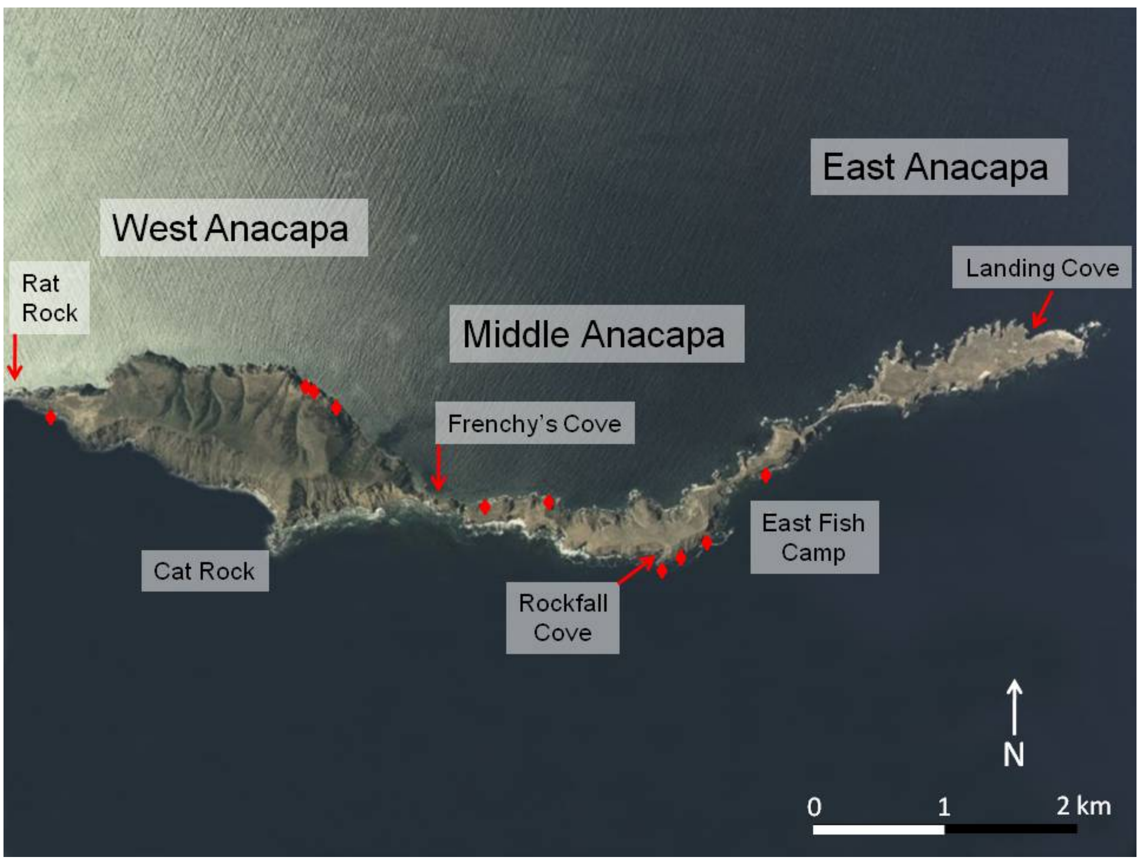
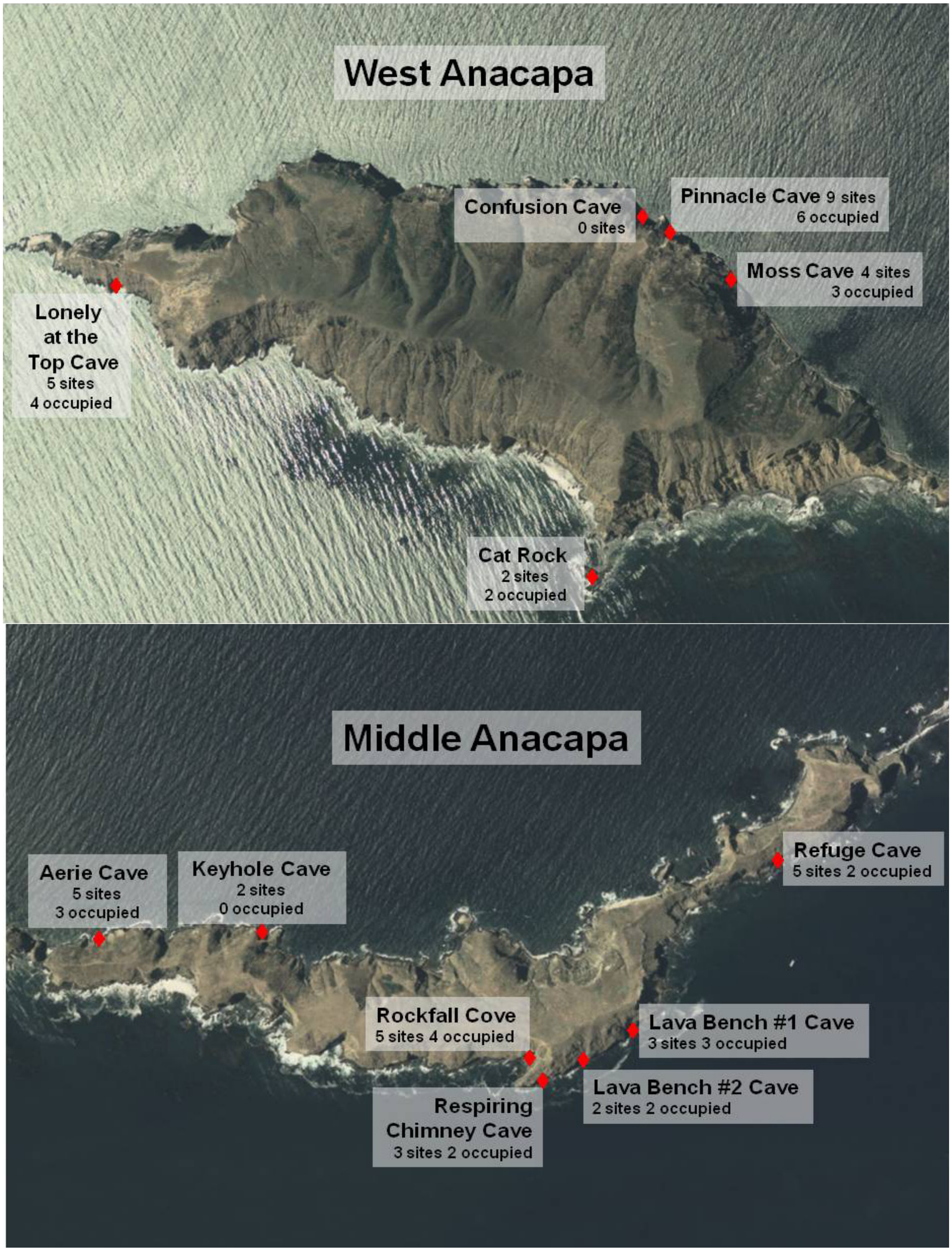


Figure 1. Satellite photograph of Anacapa Island, illustrating the three islets, sea caves (♦) and other areas where Xantus's Murrelet nest monitoring was conducted from 2000-09.



Figures 2-3. Satellite photographs of West (upper) and Middle (lower) Anacapa Island, illustrating locations of sea caves and other areas where Xantus's Murrelet nest monitoring was conducted from 2000-09.

Figure 4. Satellite photograph of East Anacapa Island, illustrating locations of Xantus's Murrelet nest sites found in the Landing Cove cliffs from 2003-09. Nest sites occupied in 2009 are denoted by red diamonds (♦) and empty sites by black diamonds (♦).

Nest Monitoring

In March-July 2009, we conducted nest searches and monitoring in 10 sea caves previously monitored in 2000-08 (Figs. 2-4). Caves were named by Bunnell (1993). All potential nesting habitat in sea caves was searched using hand-held flashlights during each visit. Sea caves were checked every 10-12 days during the peak of the breeding season from 29 March to 1 June, but less frequently later in the breeding season on 27 June and 14 July.

With reduced funds and extended nesting beyond June in 2004-09, nest monitoring was changed from the weekly schedule used in 2001-04 to a less frequent schedule in 2005-08 (biweekly) and 2009 (every 10-12 days). We now consider the 10-14 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 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 2000, the first year of monitoring, nest checks were conducted only infrequently (on 11-13 April, 27 April, 5 May, 17 May and 21 July) and not all caves were checked after April; thus, monitoring data were less reliable compared to data from subsequent years.

Systematic efforts to survey potential murrelet nesting areas in cliff, shoreline and offshore rock habitats began in 2003 and were continued and expanded in 2004-09. Using methods similar to sea cave nest monitoring, areas were thoroughly searched as follows: 1) cliffs in Landing Cove on East Anacapa (2003-09; Fig. 4); 2) Cat Rock off West Anacapa (2003-09; Fig. 2); and 3) Rockfall Cove on the south side of Middle Anacapa (2005-09; Fig. 3). Previously tagged sites in these plots were checked every 10-12 days as for sea cave sites. More extensive nest searches of sample areas 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. In 2007-09, limited time prevented nest searches along shoreline areas on the south side of Middle Anacapa near East Fish Camp (Fig. 2) that were searched in 2004-06, although no monitored sites were located in this area in 2005-06.

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. During visits to sea caves, 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.

<u>Hatching Success</u> – As in past years, hatching success was determined as the percent of 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. 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 potential clutch fate in 2008 after considerable numbers of murrelet eggs were broken or ejected from sites by Pigeon Guillemots (*Cepphus columba*) in 2007-08. Clutches with unknown nest fates were excluded from calculations of hatching success and rates of depredation and abandonment.

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 a nest on the slope above Landing Cove at Santa Barbara Island on 28 April 2009, illustrating small bite marks on the edge of the eggshell. (Photo by D.L. Whitworth).

Occupancy - In 2009, nest occupancy in sea caves was calculated for each year as the percentage of total monitored nest sites found in 2000-09 (regardless of when the site was first tagged) in which egg laying was detected at least once. Potential nest sites were not tagged until some evidence of egg laying was observed, but because all habitats in sea caves were thoroughly searched each year, we believe that untagged sites in caves could reliably be considered unoccupied in the years prior to tagging. This technique increases comparability of occupancy rates among years. Using this method, calculated occupancy rates in sea caves for a particular year will decrease as the murrelet population increases and new monitored sites are added, but occupancy rates will more reliably reflect growth of the murrelet population. Estimates of nest occupancy over the entire island were calculated as for sea caves. However, systematic nest searches in cliff, shoreline, and offshore rock plots began in different years (*see above*) and the total number of monitored sites used to calculate occupancy differed among years.

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 10-14 days in 2005-09, slightly greater error was involved in this process than with weekly nest checks in 2001-04.

Clutch Intervals – To help assess whether sequential clutches in the same site represented replacement clutches (i.e, a clutch laid by a pair after failure of their first clutch), "true" second clutches (i.e, a clutch laid by a pair after they successfully raised the first clutch brood to independence) or clutches laid by different pairs, we calculated the interval between first clutch nest departure or failure and second clutch egg laying for all sites (2000-09) where sequential clutches were laid within a breeding season. Throughout the text, the latter of two sequential clutches will be referred to as a second clutch, as opposed to a "true" second clutch (*see above*). Maximum clutch intervals were calculated by subtracting the earliest possible first clutch departure or failure date from the latest possible second clutch lay date. Minimum clutch intervals were calculated by subtracting the latest possible first clutch failure or departure date from the earliest possible second clutch lay date. First clutch nest failure or departure dates were calculated directly from the monitoring data as follows: 1) early 1^{st} clutch failure = last observation of whole eggs or a incubating adult in a site; 2) early 1^{st} clutch departure = last observation of an incubating or brooding adult + 2 days; and 3) late 1^{st} clutch failure and departure = first observation of broken, depredated, scavenged, abandoned or hatched eggshells in or near a site. Early second clutch lay dates were calculated as the check date before the first observation of second clutch eggs or incubating adults. Late second clutch lay dates were calculated as follows: 1) one egg = the check date; 2) two eggs = the check date - 8 days; and 3) incubating adult = the check date - 10 days.

Data Analysis

We used nonparametric Spearman Rank Correlation (R) to examine trends in numbers of clutches, nest occupancy and hatching success in the sea caves since the eradication of rats (2002-09). A Yates corrected Chi-square analyses for a 2 x 2 contingency table (χ^2) was used to examine differences in the frequencies of hatched and failed clutches between: 1) pre-eradication versus post-eradication periods; and 2) sea caves versus other plots in the post-eradication period.

RESULTS

Nest Monitoring in 2009

Nesting Effort and Occupancy - In 2009, we monitored a total of 59 nest sites, including 37 sites in 10 sea caves and 22 sites in other plots (Table 1). A total of 50 clutches (30 in sea caves and 20 in other plots) were recorded in 40 sites (24 sites in sea caves and 16 in other plots). Clutches were laid in eight of ten sea caves (all except Confusion and Keyhole Caves) and in all three plots (Landing Cove cliffs, Rockfall Cove and Cat Rock; Table 1).

A total of 12 new murrelet nest sites were established in 2009 (Table 2). Six new sites were established in sea caves (Table 3), including five in Pinnacle Cave and one in Lava Bench Cave #2. Six new sites were also established in the other plots (Table 4), including five on the Landing Cove cliffs and one on Cat Rock. One nest site on the Landing Cove cliffs (Nest #10) was lost due to a small rockslide over the winter and excluded from occupancy analyses. Occupancy of monitored sites was 68% over the entire island (n = 59; Table 2), with 65% (n = 37) in sea caves (Table 3) and 73% (n = 22) in other plots (Table 4).

Sequential clutches were recorded in nine nest sites (Tables 1, 5), five in sea caves and four in other plots. In six cases, second clutches may have been initiated more than one month after first clutch chicks departed the nest (maximum 35-52 days; Table 5), although the minimum clutch intervals were shorter (9-25 days). In two cases a maximum of only 19 days elapsed between chick departure and second clutch initiation. Evidence of simultaneous clutches (i.e, three eggs in a site probably from two different pairs) was found in Respiring Chimney Cave Nest #1 on 11 May and 23 May (Fig. 7). Only one incubating adult was ever observed in the site and only two hatched eggshells were recovered. For calculations of number of clutches and hatching success, we considered these three eggs to be separate clutches laid by two different pairs. Although two hatched eggs were found in the site on 27 June, there was no evidence to determine the fate of the third egg. Therefore, we assumed the second murrelet pair abandoned their egg and it was ejected from the site by the other pair.

Timing of Breeding - Murrelet clutches (including first and second clutches) were initiated over 132 days between 18 February and 30 June, with a mean initiation date of 8 April (± 32 d, n = 48). Poor information was available for two clutches and their initiation dates could not be estimated. Peak egg laying occurred from mid-March to early April, although small numbers of first clutches and relatively high numbers of second clutches were initiated from late April through June (Fig. 8). Mean initiation date was 28 March (± 21 d, n = 39) for first clutches and 26 May (± 21 d, n = 9) for second clutches.

Figure 7. Three Xantus's Murrelet eggs found on 11 May 2009 in Respiring Chimney Cave Nest # 1 at Anacapa Island. (Photo by D.L. Whitworth).

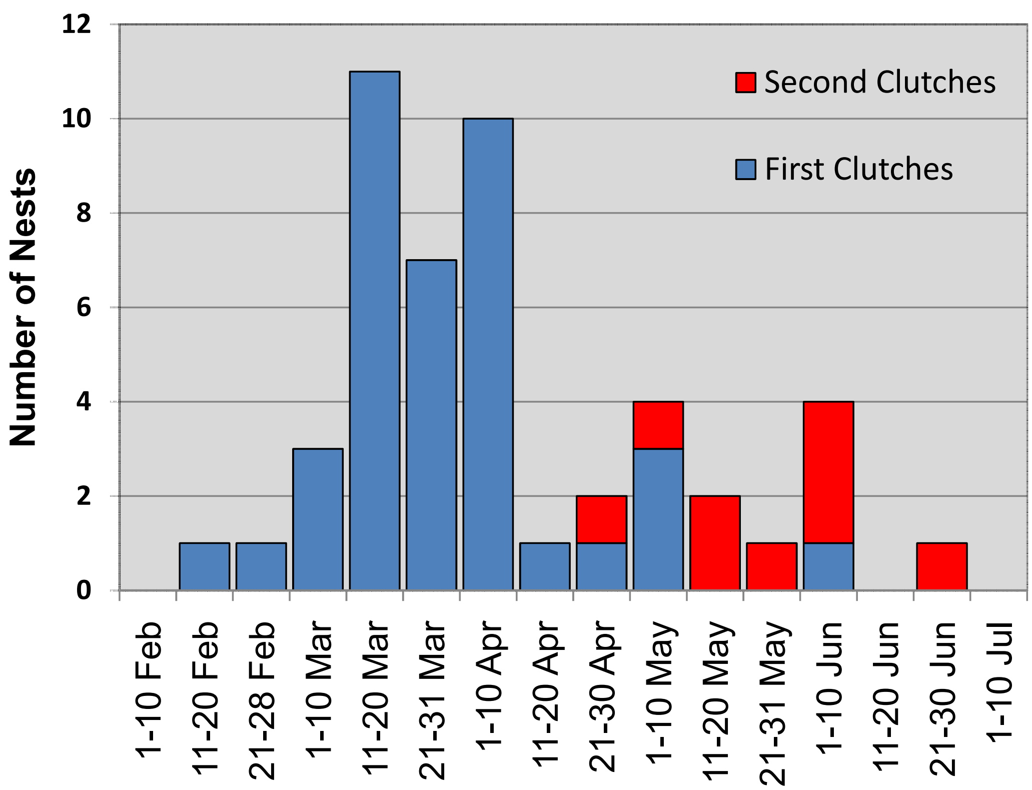


Figure 8. Initiation dates for Xantus's Murrelet clutches at Anacapa Island in 2009.

Hatching Success - We documented 42 hatched clutches at Anacapa in 2009 (Table 1), with 27 in sea caves and 15 in other plots. Excluding three clutches with unknown fates, overall hatching success was 89% (n = 47; Table 2), with 96% hatching success in sea caves (n = 28; Table 3) and 79% in other plots (n = 19; Table 4). Hatched eggshell fragments were found in or near the nest site for all 42 hatched clutches in 2009, although six clutches hatched only one egg, as evidenced by single intact eggs left in the site. Three of these intact eggs were opened and showed no evidence of embryo development. Adults brooding chicks were observed in four sites. Dead chicks were not observed in or near any nest sites and all chicks were assumed to have successfully departed from the nest.

In the nine sites with sequential clutches in 2009, eight (89%) first clutches and seven (100%) second clutches with known fates hatched. One first clutch in Landing Cove was apparently abandoned and later scavenged; while two second clutches had unknown fates (*see below*).

Only five failed clutches (11%; n = 47) were recorded at Anacapa in 2009, four clutches in the Landing Cove cliffs and one in the sea caves (Table 1). Three clutches (6%) failed due to abandonment, including one of two simultaneous clutches laid in Respiring Chimney Cave Nest #1. Two failed clutches (4%) with broken eggshells were assumed to have been depredated or scavenged by endemic deer mice (*Peromyscus maniculatus anacapae*).

Three murrelet clutches were assigned unknown fates in 2009 (Table 1). The second clutch in Pinnacle Cave Nest #8 was still being incubated during the last check on 14 July. The second clutch in Landing Cove Nest #12 was active from 1 May to 1 June (i.e., for most of the incubation period), but hatched eggshells were not found. Hatched eggshells may have been pushed back out of view in this relatively deep crevice, but we also considered that an abandoned egg from the first clutch disappeared from this site earlier in the season, possibly moved by mice. An incubating adult was seen in a new site at the entrance to Lonely at the Top Cave (Nest #4) but no evidence of eggshells was found on later visits. Although murrelets are not known to attend sites during the day without incubating eggs or brooding chicks, we could not confirm that eggs had been laid.

Cassin's Auklet – One Cassin's Auklet (*Ptychoramphus aleuticus*) nest found in Landing Cove in 2008 was active again in 2009. This deep crevice site was difficult to monitor, although observations of birds in the site from late March through late May suggested successful nesting and possibly a second clutch. Auklets also may have nested in two other Landing Cove sites (Nest #6 and an untagged site) where auklet guano and odor were detected at the crevice entrances, but sites were too deep to observe an adult, egg or chick.

Three auklet nests were found on Rat Rock in 2009, including two tagged crevice sites (Nests #1 and #2) that were present in 2003-05, but were not checked in 2006-08 due to nesting Brandt's Cormorants (*Phalacrocorax penicillatus*) above the sites. Observation of a fully-feathered chick in Nest #1 on 20 April and an incubating adult on 11 May indicated that two clutches were laid in this site. Auklets were seen in Nest #2 from late March (unknown age) through late May (adult), suggesting successful nesting and possibly a second clutch in this site as well. A third site was found when a previously unidentified burrow containing a downy chick (Fig. 9) was discovered when the burrow collapsed while monitoring at a nearby site. The damaged burrow was repaired before replacing the chick in the site, but the chick was not visible in the repaired burrow and fledging success could not be determined.

Figure 9. Cassin's Auklet downy chick from an untagged burrow on Rat Rock, Anacapa Island, 29 March 2009 (Photo by D.L. Whitworth).

Pigeon Guillemot - Four guillemot nest sites were found in 2009, including three sites in Keyhole Cave and one in Aerie Cave. 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. We did not determine hatching or fledging success, but large guillemot chicks were observed in two sites in Keyhole Cave (Nest #2 and an untagged site) on June 27. Dead downy chicks were found near Aerie Cave Nest # 1 and at a second untagged site in Keyhole Cave.

Ashy Storm-Petrel – We found no evidence of storm-petrels breeding in any sea cave or monitored plot at Anacapa Island in 2009.

Inter-Annual Trends in Sea Caves (2002-09)

Annual Number of Clutches and Nest Occupancy – Since 2002 (the last year rats were present on Anacapa), significant increases over time were noted both in the annual number of clutches ($R = 0.86$, $p < 0.007$) and nest site occupancy ($R = 0.90$, $p < 0.003$) in the sea caves (Fig. 10). Since rat eradication, the number of monitored sites in sea caves has increased from 16 sites in 2002 to 37 sites in 2009 (Table 3). The number of clutches and nest occupancy in sea caves was highest in 2009 with 30 clutches and 65% nest occupancy (Table 3, Fig. 10), far exceeding the annual maximums recorded in previous years (19 total clutches in 2005 and 2008 and 49% occupancy in 2007).

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 reliable than in subsequent years. Furthermore, our analysis of 2000 data excluded six rat depredated eggs of unknown origin found in sea caves. Since at least some of these depredated eggs likely came from monitored sites, we probably underestimated the number of clutches (n = 9) and nest occupancy (24%), and overestimated hatching success (86% - considerably higher than other pre-eradication years) in 2000.

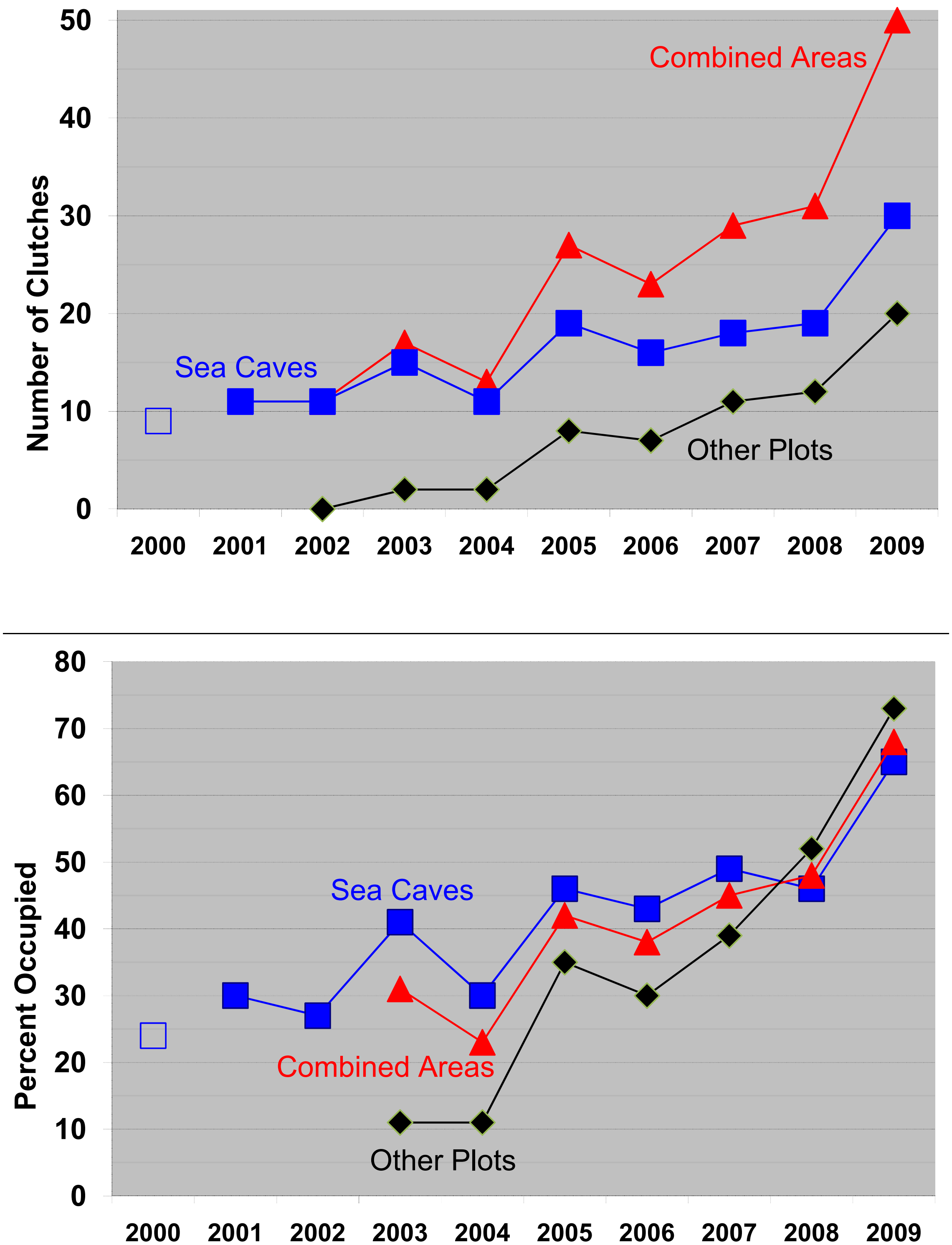


Figure 10. Annual number of clutches (upper graph) and nest occupancy (lower graph) for Xantus's Murrelets in sea caves, other plots, and combined areas at Anacapa Island in 2000-09. Data from 2000 (indicated by □) are not comparable with subsequent years (see methods).

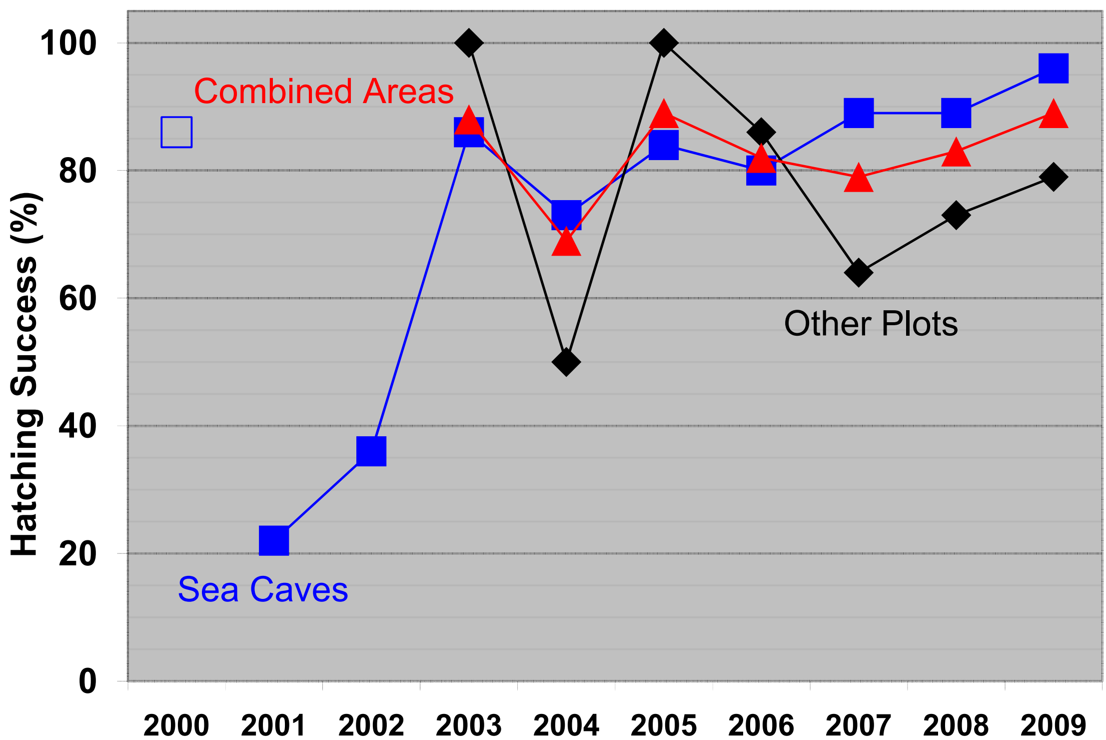


Figure 11. Annual hatching success for Xantus's Murrelets in sea caves, other plots, and combined areas at Anacapa Island in 2000-09. Data from 2000 (indicated by □) are not comparable with subsequent years (see methods).

Hatching Success – Significant increases were noted in hatching success (R = 0.83, $p < 0.02$) since 2002, although hatching success has been consistently high (range 73-96%) after the eradication of rats (Table 3; Fig. 11). Numbers of hatched clutches (n = 27) and hatching success (96%) in sea caves were much higher in 2009 compared to the previous annual maximums, 17 hatched clutches in 2008 and 89% hatching success in 2007 and 2008.

Excluding clutches with unknown fates, hatching success in sea caves post eradication (87%, n = 124) was nearly twice that observed pre-eradication (44%; n = 27 clutches), while the relative frequency of hatched versus failed clutches was significantly higher ($\chi^2 = 22.18$, $p < 0.0001$) post-eradication. In fact, nearly as many failed clutches (n = 15) were found in sea caves during three pre-eradication years as during seven post-eradication years (n = 16).

Post-eradication clutch failures in the sea caves have been attributed primarily to abandonment (69%), with smaller numbers of usurped/disturbed (19%) and depredated or scavenged (13%) clutches. In contrast, clutch failures pre-eradication were due primarily to depredation by rats or mice (87%), with only two (13%) failed clutches due to abandonment (Table 3). Abandoned clutches in sea caves have occurred consistently since 2001 (range = 4-20%), with 1-3 abandoned clutches each year, but depredated clutches have not been documented in the sea caves since 2004.

Colony Expansion (2003-09)

A total of 62 clutches were found in 22 monitored sites (excluding sites destroyed by winter landslides in 2005-06 and 2008-09) in plots outside of sea caves (Table 4), where no evidence of breeding was found during sporadic nest searches from 1991-2003. The number of monitored sites in these plots increased from two in 2003 to 22 in 2009, while the number of clutches laid increased from two in 2003 to 20 in 2009 (Table 4; Fig. 10). Occupancy in sites outside sea caves increased steadily from 11% to 73% over this period (Table 4; Fig. 10).

Colony expansion has been most evident in the Landing Cove plot, where the number of monitored sites increased from one to 15 (not including one site destroyed over winter in 2008-09) and the number of clutches increased from one to 14 since 2003. In contrast, only one site has been added on the Cat Rock plot over the same period. The Rockfall Cove plot has shown moderate growth from two to five monitored sites since 2005.

Overall hatching success (excluding two clutches with unknown fates) in these plots has been 78%, with only 22% failed (n = 60 clutches) in 2003-09. Hatching success has been higher at Cat Rock (100%; n = 6 clutches) and Rockfall Cove (93%; n = 14 clutches), compared to Landing Cove (72%; n = 39 clutches), although small samples of clutches in the Cat Rock and Rockfall Cove plots allowed for only rough comparisons. Relatively high variability in hatching success outside the sea caves from 2003 to 2006 (50-100%; Table 4; Fig. 11) was largely an artifact of small annual samples (n = 2-8 clutches/year). Hatching success has ranged more narrowly (64-79%) since 2007 when larger samples (> 10 clutches/year) became available in these plots.

Clutch failures in plots outside sea caves (n = 13 failed nests) have been due primarily to abandonment (n = 8; 62%), with only four depredated or scavenged clutches (31%) and one nest site usurped by Pigeon Guillemots (8%).

Comparisons of Hatching Success between Sea Caves and Other Plots

No significant differences were found in the frequencies of hatched clutches ($\chi^2 = 1.73$, $p > 0.18$) between the sea caves and other plots since 2003. However, hatching success has been consistently higher (+ 16-25%) in sea caves in 2007-09 (Fig. 11; Tables 3-4) when larger samples of clutches (> 10/year) became available in the plots. Comparisons of data from 2007-09 does indicate relatively higher frequencies ($\chi^2 = 5.77$, $p < 0.02$) of hatched clutches in sea caves since 2007-09.

Timing of Breeding (2000-09)

Annual mean clutch initiation (all clutches) dates ranged from 3 April (± 11 d) in 2000 to 20 May (± 29 d) in 2007 (Table 6), although phenology data in 2000 was affected by infrequent monitoring that year. The earliest clutch initiation date occurred in 2009 (18 February), while the latest clutch initiation date (which incidentally was not a second clutch) occurred in 2007 (8 July). The widest range of clutch initiation dates within a single year occurred in 2009 (132 days), while the narrowest range occurred in 2001 (36 days).

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 7-8). Excluding new sites found in 2009, 15 sites have been occupied each year since breeding was first documented, including four sea cave sites active in each of the last 10 years. In contrast, four sites have not been used since at least 2003, although intervals of up to 6-7 years have passed between nesting in other sites. Two of 3 new sites established in 2008 were again used in 2009, but the third was destroyed by a small landslide in the interceding winter.

Sequential clutches have occurred on 14 occasions, with nine in 2009, two in 2007, and one each in 2002, 2005 and 2008 (Tables 5,7,8). In 11 (79%) instances, second clutches were laid after the first clutch had hatched. Eleven (92%) of 12 second clutches with known fates hatched and one was abandoned. Two second clutches had unknown fates (both in 2009).

DISCUSSION

Xantus's Murrelet Recovery at Anacapa Island

In 2009, Xantus's Murrelet nest monitoring provided unequivocal evidence demonstrating increased breeding on Anacapa Island following the eradication of Black Rats in 2001-02 (Howald et al. 2005; Whitworth et al. 2005a), as part of the Anacapa Island Restoration Program (ATTC 2001). Number of clutches, nest site occupancy, and hatching success were higher in 2009, than in any year previous year (2000-08). The 2009 breeding season was perhaps most notable for the large increase in number of clutches (61%) over 2008, the largest year-to-year increase noted in this index since monitoring began in 2000.

Significant positive trends in numbers of clutches and nest site occupancy in sea caves from 2002 to 2009 (Fig. 10) provided the best evidence of murrelet population growth post-eradication, although only preliminary non-parametric trend analyses are possible with eight years of data. Comparisons of pre- and post-eradication hatching success in sea caves indicated that increased hatching success probably was the most significant factor in post-eradication colony growth. Hatching success in sea caves doubled from 44% pre-eradication (2000-02) to 88% post-eradication (2003-09), while egg depredation by mammalian predators has been essentially eliminated as a cause of nest failure. There is no available data to suggest that other factors (either at the colony or at-sea) affecting adult survival or chick recruitment have changed to any significant degree since 2003 to account for the population growth observed at Anacapa Island following seven years of sustained high hatching success. On the contrary, monitoring data at nearby Santa Barbara Island reported declines in the number of breeding pairs in monitored plots over the last several years (Whitworth et al. 2009; CINP, unpubl. data). This is a noteworthy difference considering the overlap in foraging, chick-rearing and over wintering areas between murrelets from these two colonies (Whitworth et al. 2000, Hamilton 2005), and suggests that factors at the colony are primarily responsible for declines at Santa Barbara Island.

Colony expansion in other plots has demonstrated that murrelets also are responding to the greater availability of suitable breeding habitat in coastal areas outside the sea caves. The number of murrelet clutches has increased markedly in these plots, particularly on the Landing Cove cliffs and to a lesser extent on Cat Rock (with limited breeding habitat) and in Rockfall Cove. Unfortunately, low sample sizes (7 years in Landing Cove and Cat Rock, 5 years in Rockfall Cove) make trend analyses using regression less dependable at this point. Significant positive trends ($R = 0.97$, $p < 0.0001$) are evident if we assume that murrelets did not breed in these plots prior to rat eradication. This assumption is reasonable based on limited searches within these plots in 1991-2002 which found no evidence of murrelet breeding (Carter et al. 1992, unpubl. data; McChesney et al. 2000; Whitworth et al. 2003a).

Recent colony growth at Anacapa Island appears to be limited to relatively inaccessible sea caves and localized shoreline plots where small numbers of murrelets persisted despite the presence of rats, suggesting strong natal philopatry or other social components are important elements of murrelet breeding behavior. Suitable nest sites appear to be abundant in upper island areas, but extensive surveys in October 2009 found no evidence of recent occupation by murrelets or other crevice nesting seabirds in these areas (D. Whitworth, unpubl. data). The presence of rats over most of the island for many decades likely has resulted in the loss of most or all individuals which used upper island habitats for breeding in the past (if indeed, these habitats were ever used by murrelets to any great extent). We expect that murrelets will reoccupy these areas but pioneering individuals must first discover these areas before large numbers will breed in these areas. Many years may be necessary for the colony to expand widely over the island.

The post-eradication period of high hatching success at Anacapa may be a temporary phase as the island slowly returns to a natural equilibrium following the eradication of rats. Clutch failure rates may increase as the natural relationships are established between murrelets, the deer mouse population, and alternate food sources for mice. By 2009, mice were noticeably more abundant on the East Anacapa Landing Cove cliffs than in other monitored areas along the shoreline of West and Middle Anacapa. In fact, most of the depredated eggs found post-eradication, and all depredated eggs found since 2004, were found in nests on the Landing Cove cliffs. Since 2007, lower hatching success in other plots compared to sea caves was primarily a result of the relatively large number of failed clutches (abandoned and depredated/scavenged) in the Landing Cove plot. Several factors, including human activity (dock, ranger/staff quarters, picnic area and visitor center), may cause higher mouse densities around Landing Cove. Very little evidence of mice (e.g., feces, seed caches, foot prints) has been noted in the sea caves in recent years, but a study comparing mouse densities in sea caves to other shoreline and upper island habitats around the island would be useful to determine if mice occupy sea caves to any great extent during the murrelet breeding season.

Protected sea caves and offshore rocks may constitute optimal breeding habitat where hatching success is enhanced by reduced avian and mammalian depredation (Whitworth et al. 2008a). The almost total lack of documented nesting outside sea caves prior to rat eradication, suggests that Anacapa sea caves likely served as refugia that permitted the survival of the murrelet colony during the period when rats occupied most of the island (McChesney et al. 2000). Sea caves and offshore rocks likely served as refugia following the introduction of cats (*Felis catus*) on several other murrelet breeding colonies in Baja and Southern California (e.g., Guadalupe Island and Santa Barbara Island; McChesney and Tershy 1998; Keitt 2005; H. Carter and D. Whitworth, unpubl. data). Considering their importance to murrelets in the past and perhaps future, these habitats deserve special consideration during development of murrelet management and conservation plans.

Sequential and Simultaneous Clutches in Nest Sites

We found sequential or simultaneous clutches in one quarter of the occupied Xantus's Murrelet nest sites at Anacapa Island in 2009. Similar cases are known from Santa Barbara Island (Murray et al. 1983) and the Coronado Islands (Carter et al. 2006; Whitworth et al. 2007, 2008a), where in some years second clutches have comprised a large proportion of the total clutches laid in a breeding season (e.g., ~16% of all clutches laid at the Coronado Islands in 2007; Whitworth et al. 2008a). Sequential clutches are much more common, although infrequent instances of simultaneous clutches have been documented at Santa Barbara Island (Murray et al. 1983), Coronado Islands (Carter et al. 2006) and in 2009 at Anacapa Island (Fig. 7). Simultaneous clutches have been assumed to reflect two clutches by different pairs (Drost and Lewis 1995, Gaston and Jones 1998, Carter et al. 2006, Whitworth et al. 2008a). However, studies have not been conducted to definitively determine if two or more pairs laid eggs in nests with three or more eggs. Often (but not always; see Fig. 7), simultaneous clutches have visibly different base colors or markings, likely indicating production by different females. In most cases, none of the eggs in simultaneous clutches hatch, probably a result of site abandonment by both pairs, although two of the three eggs from the simultaneous clutches laid at Anacapa in 2009 did hatch.

Without marked birds, it is difficult to determine if sequential clutches in a site were laid by the same pair, different pairs, or perhaps on rare occasions one member of the original pair with a different partner. Sequential clutches by the same pair could occur after the first clutch failed to hatch or the chick(s) perished at-sea prior to independence (i.e., replacement clutch) or after first brood chicks were independent of the parents (i.e., a "true" second clutch). Interestingly, most instances of sequential clutches at Anacapa in 2009 occurred after first clutches had hatched (89%), raising three possibilities: 1) replacement clutches were laid after a considerable number of broods perished at-sea prior to independence from the adults; 2) prolonged favorable prey conditions allowed murrelets to attempt to lay "true" second clutches after first broods achieved independence from adults; or 3) favorable prey conditions persisted late in the breeding season to allow sequential use of individual nest sites by different pairs.

<u>Replacement Clutches</u> - Survival of murrelet chicks after nest departure has not been studied, but considering the numerous perils chicks doubtless encounter during nest departure and first days at sea, many may perish long before they gain independence from adults. Only one documented replacement clutch involving marked birds has ever been reported for Xantus's Murrelets. One pair marked with spots of paint during breeding biology studies at Santa Barbara Island in the 1970's (Murray et al. 1983) laid a replacement clutch after the first clutch failed to hatch and was abandoned. Replacement clutches have been suspected in numerous other sites with unmarked murrelets at Santa Barbara Island (Murray et al. 1983) and the Coronado Islands (Carter et al. 2006; Whitworth et al. 2007, 2008a), but their tendency to abandon clutches when captured and handled from nest sites severely limits opportunities to study nest site use by different pairs, site fidelity and the frequency of replacement clutches.

Replacement clutches are rather common in other Alcidae (Harris and Birkhead 1985, Ainley and Boekelheide 1990a) and remain the most likely interpretation for second clutches when first clutches fail. However, replacement clutches have not been documented in the closely related (and better studied) Ancient Murrelet (*S. antiquus*; Sealy 1976, Gaston 1992). Ancient Murrelets breed in burrows at higher latitudes with shorter breeding seasons, providing less time for laying and less opportunity for documentation of replacement eggs.

<u>"True" Second Clutches</u> - Laying a "true" second clutch after successfully raising chicks at sea has never been documented for Xantus's Murrelets, and is unknown in other Alcidae except for Cassin's Auklets in the southern part of their breeding range (where they are sympatric with Xantus's Murrelets), and then only in certain years (Manuwal 1979, Ainley et al. 1990b). Historical accounts of true second clutches by murrelets at the Coronado Islands (Howell 1910: 184) were clearly speculative, apparently based on what was considered a prolonged but discontinuous breeding season and the rather curious observation that "no ornithologist has ever taken eggs of this species in May". Without marked birds but possibly with marked nest sites, Howell stated further that "from my observations, it seems to be beyond doubt that these birds nest twice during the year", from which Bent (1919: 150) concluded that murrelets are "credited with raising two broods in a season". We interpret this historical literature to reflect sequential laying of more than one clutch in certain nest sites.

One difficulty with investigating the possibility of "true" second clutches is the total lack of information concerning the length of parental care of chicks at-sea. Xantus's Murrelet family groups move quickly away from the colony and far out to sea 2-3 nights after chicks hatch, but virtually nothing is known concerning the extent and duration of parental care for precocial murrelet chicks in the wild. Based on at-sea observations of Ancient Murrelet family groups, *Synthliboramphus* murrelet adults attend and feed the chicks until they become independent (Sealy and Campbell 1979, Litvinenko and Shibaev 1987, Duncan and Gaston 1990, Sealy et al., in review). However, the reported 42-49 day period of parental care in Ancient Murrelets is mostly speculative, while data for semi-precocial chicks of other small Alcidae has shown that chicks can reach independence much sooner. Minimum nestling periods of 25-33 days have been reported as follow: Kittlitz's Murrelet (*Brachyramphus brevirostris*) - 25 days (Naslund et al. 1994); Dovekies (*Alle alle*) - 27 or 28 days (Evans 1981, Harris and Birkhead 1985); Least Auklets (*Aethia pusilla*) - 29 days (Roby and Brink 1986, Piatt et al. 1990); and Crested Auklets (*Aethia cristatella*) - 33 days (Piatt et al. 1990). While precocial *Synthliboramphus* murrelet chicks are proficient divers and swimmers from the moment they leave the nest (Howell in Bent 1919, Sealy 1976, Gaston 1992) and may be capable of foraging at a young age (D. Forsell in Gaston 1992), parents undoubtedly still feed chicks while the family group remains intact. The duration of parental care may vary considerably within and between years, depending on prey availability, weather conditions and other factors, such that independence may be reached at ages prior to 42 days, and perhaps as early as 25 days.

<u>Sequential Use of Individual Nest Sites by Different Pairs</u> - Infrequent occurrences of simultaneous clutches by different pairs in a site have been reasonably demonstrated (Murray et al. 1983, Carter et al. 2006, Whitworth et al. 2008a), thus instances of sequential site use by different pairs might also be expected, but have never been confirmed. Use of individual sites by different pairs may indicate that nest sites (especially high quality nest sites) may be in short supply in some portions of breeding colonies or throughout a colony, especially

under high-density conditions (Carter et al. 2006). As available nesting habitat in sea caves and other suitable shoreline habitats becomes saturated during periods of colony growth, intense competition for nest sites in these areas may lead to more frequent sequential or simultaneous use of limited crevice sites by different pairs.

The wide range of inter-clutch intervals we documented (Table 5) suggests that second clutches could have resulted from any of the above possibilities. Assuming that time to independence is similar for Xantus's and Ancient Murrelet chicks (42-49 days; Litvinenko and Shibaev 1987, Gaston 1992), it is clear from the maximum intervals between clutches in Table 5 that only a few of the 14 second clutches documented at Anacapa Island could have been "true" second clutches, perhaps only the four sites that had maximum inter-clutch intervals ≥ 41 days. In fact, even for these nests, copulation and egg development for second clutches would have occurred during the latter stages of parental care at sea to account for eggs laid a few days after first broods became independent. Shorter inter-clutch intervals are more consistent with replacement clutches or different pairs.

Sequential clutches could also occur through other less plausible or unusual circumstances such as: 1) death of one member of a pair during incubation or at-sea chick rearing, or 2) abandonment of the family group by one member of the pair after first brood chicks are sufficiently grown to be cared for by one parent. Little is known concerning murrelet courtship or mating, but at-sea care of a single chick by one parent is known for Common Murres (*Uria aalge*), Thick-billed Murres (*Uria lomvia*) and Razorbills (*Alca torda*), with chicks leaving the nest about 20 days after hatching and raised at-sea solely by the male (Gaston 1985, Harris and Birkhead 1985). Observations by D. Roberson of single older murrelet chicks (identified by obvious natal down on the head and neck) accompanied by a single adult (http://creagrus.home.montereybay.com/MTYlistXAMU-PB.html) in Monterey Bay in August 2005, led him to speculate that one murrelet parent may abandon the family group at some point during at-sea chick rearing. This behavior would allow females to attempt a second clutch (in the same or a different site) with another mate when conditions are favorable. While monogamy is believed to be the universal breeding strategy for all Alcidae, extra pair copulations are not uncommon in many species (Gaston and Jones 1998) and taken to an extreme could lead to infrequent instances of serial polyandry.

Pilot studies are needed to investigate the degree and extent of replacement clutches, the possibility of "true" second clutches, and sequential nest site use by different pairs of Xantus's Murrelets. Genetic analysis of eggshell membranes would be the least intrusive and reliable method for determining whether sequential clutches were produced by the same breeding pair (V. Friesen, pers. comm.). Eggshell collections for genetic studies could be easily incorporated into the Anacapa monitoring program with no added expense, although eggshell storage and funding for laboratory analyses also are required. Due to the relative infrequency of sequential clutches at Anacapa Island, it would require several years of data to evaluate a large enough sample to: 1) reliably estimate the proportions of sequential clutches resulting from replacement clutches, "true" second clutches and different pairs; and 2) experience different environmental conditions for better interpretation of factors affecting sequential clutches. If pilot studies warrant further investigation, collection of eggshell fragments could easily be incorporated in the monitoring program at Santa Barbara Island to hasten collection of adequate samples of sequential clutches for genetic analysis.

Other Seabird Species

Small numbers of Cassin's Auklet nests found on the Landing Cove cliffs and Rat Rock (west end of West Anacapa Island- not a detached rock) provided additional evidence of recovery of this species in the absence of rats. During post-breeding season nest searches conducted in October 2009 outside the currently monitored sea caves and plots, we also found evidence (i.e., recently occupied burrows and eggshell fragments) of a small Cassin's Auklet colony in rocky scree on the north side of West Anacapa (D. Whitworth, unpubl. data). However, no evidence of recent breeding by Ashy Storm Petrels was found in the areas searched. Definitive evidence of breeding by storm-petrels has never been found at Anacapa, although small numbers of Ashy 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 have continued to occur in habitats that were inaccessible to rats (Carter et al. 2008). Greater research and monitoring effort (involving spotlight surveys, radar surveys, mist-net captures, and expanded nest searches) are needed to document breeding by murrelets, auklets, storm-petrels and other crevice nesting species in areas that are not currently monitored.

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. 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. The process of recovery of seabird colonies after removal of rats has never been well studied. With a decade of baseline data on murrelet hatching success and colony growth, it is clear that Anacapa Island provides the best opportunity to carefully study recovery of Xantus's Murrelets, Cassin's Auklets and other seabirds after removal of black rats. Studies have not been conducted at other murrelet breeding islands in Baja California or southern California where introduced predators (mainly cats) have been removed to examine: a) baseline population conditions prior to eradication; and b) the process of recovery of murrelet and other seabird populations.

Identifying funding for continuing the Xantus's Murrelet monitoring program at Anacapa Island is critical. Although, the Xantus's Murrelet is a California state threatened species, Anacapa and Santa Barbara Islands are currently the only southern California colonies with ongoing murrelet monitoring programs. Two Santa Barbara Island nest plots (Cat Canyon and Nature Trail) have been monitored since 1975 and have provided most long-term knowledge of breeding biology of this species (Murray et al. 1983, Drost and Lewis 1995, Schwemm and Martin 2005). However, numbers of occupied nests in these plots have been declining and the Nature Trail plot has not been accessible for monitoring since 2004 when Brown Pelicans (*Pelecanus occidentalis*) began nesting at this location. We suggest that long-term murrelet monitoring at Anacapa should be continued to: 1) conduct a more rigorous measurement of population trends with regression analysis to further document recovery of seabird populations after rat eradication; 2) compare hatching success, timing of breeding, and population trends among and between study areas at Santa Barbara Island and Anacapa Island; 3) maintain long-term knowledge on breeding biology of the species if the colony at Santa Barbara Island becomes unsuitable for monitoring; and 4) expand our knowledge of factors affecting breeding in this species at several breeding colonies.

A more extensive survey of accessible upper island, cliff and shoreline habitats of East, Middle and West Anacapa was conducted in October 2009 but results will be presented in a separate report. Most upper island areas have not been searched since 1997 (McChesney et al. 2000) and an update was needed on the extent to which crevice-nesting species (e.g., Xantus's Murrelets, Cassin's Auklets, and Ashy Storm-Petrels) are now using these previously unoccupied habitats. To prevent disturbance to surface-nesting Brown Pelicans, Double-crested Cormorants (*Phalacrocorax auritus*), and Brandt's Cormorants, surveys of upper habitats at Middle and West Anacapa was conducted in fall 2009 as done in 1997 (McChesney et al. 2000). These surveys primarily involved extensive searches for eggshell fragments in accessible habitats.

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Table 1. Number of monitored sites, clutches and clutch fates for Xantus's Murrelets at Anacapa Island in 2009.

Sea Cave/Plot	Monitored Sites	Occupied Sites	Clutches[a]	Clutch Fates			
				Hatched	Depredated	Abandoned	Unknown
Refuge	5	2	3[a]	3	0	0	0
Lava Bench #1	3	3	3	3	0	0	0
Lava Bench #2	2	2	2	2	0	0	0
Respiring Chimney	3	2	4[a]	3	0	1	0
Lonely at the Top	4	3	4[a]	3	0	0	1
Confusion	0	0	0	0	0	0	0
Pinnacle	9	6	7[a]	6	0	0	1
Moss	4	3	4[a]	4	0	0	0
Aerie	5	3	3	3	0	0	0
Keyhole	2	0	0	0	0	0	0
Sea Cave Total	37	24	30[a]	27	0	1	2
Cat Rock	2	2	2	2	0	0	0
Rockfall Cove	5	4	4	4	0	0	0
Landing Cove	15	10	14[a]	9	2	2	1
Plot Total	22	16	20[a]	15	2	2	1
Anacapa Total	59	40	50[a]	42	2	3	3

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

Table 2. Nest site use and clutch fates for Xantus's Murrelets in all monitored areas at Anacapa Island in 2000-09.

	Pre-Eradication				Post-Eradication							
	2000	2001	2002	**2000-02**	2003	2004	2005[a]	2006	2007	2008	2009[a]	**2003-09**
Tagged Sites	13	15	16		26	29	36	39	45	48	59	
Potential Sites	37	37	37		55	56	60	60	60	60	59	
Occupied Sites (Occupied/Potential)	9 24%	11 30%	10 27%	**27%**	17 31%	13 23%	25 42%	23 38%	27 45%	29 48%	40 68%	**42%**
Clutches	7(9)[c]	9(11)[c]	11[b]	**27(31)**[c]	16(17)[c]	13	27[b,d]	22(23)[b]	29[d]	30(31)[b,c,d]	47(50)[b,c]	**184(190)**[c]
Hatched (Hatched/Clutches)	6 86%	2 22%	4 36%	**12 44%**	14 88%	9 69%	24 89%	18 82%	23 79%	25 83%	42 89 %	**155 84%**
Depredated (Depredated/Clutches)	1 14%	6 67%	6 55%	**13 48%**	0	2 15%	0	0	1 3%	1 3%	2 4%	**6 3%**
Abandoned (Abandoned/Clutches)	0	1 11%	1 9%	**2 7 %**	1 6%	2 15%	3 11%	4 18%	4 14%	2 7%	3 6%	**19 10%**
Usurped (Usurped/Clutches)	0	0	0	**0**	1 6%	0	0	0	1 3%	2 7%	0	**4 2%**
Unknown Fate	2	2	0	**4**	1	0	0	1	0	1	3	**6**

[a] Sites destroyed by landslides overwinter in 2004-05 and 2008-09 were excluded from later analyses.
[b]More than one clutch was laid by the same or different pairs in one site in 2002, one site in 2005, two sites in 2007, one site in 2008 and ten sites in 2009 (*see methods*).
[c]Clutches with unknowns fate were included in occupancy analyses but excluded from calculations of hatching success.
[d]Eggs on cave floor (one in 2005 and one in 2008) in marginal nest sites were considered to be clutches for calculations of hatching success but sites were not tagged and were excluded from occupancy analyses (*see methods*).

Table 3. Nest site use and clutch fates for Xantus's Murrelets in sea caves at Anacapa Island in 2000-09.

	Pre-Eradication				**Post-Eradication**							
	2000	2001	2002	**2000-02**	2003	2004	2005	2006	2007	2008	2009	**2003-08**
Tagged Sites	13	15	16		24	25	27	28	31	31	37	
Potential Sites	37	37	37		37	37	37	37	37	37	37	
Occupied Sites (Occupied/Potential)	9 24%	11 30%	10 27%	**27%**	15 41%	11 30%	17 46%	16 43%	18 49%	17 46%	24 65%	**52%**
Clutches	7(9)[c]	9(11)[c]	11[a]	**27(31)**[c]	14(15)[c]	11	19[a,b]	15(16)[c]	18	19[a,b]	28(30)[a,c]	**124(128)**[c]
Hatched (Hatched/Clutches)	6 86%	2 22%	4 36%	**12 44%**	12 86%	8 73%	16 84%	12 80%	16 89%	17 89%	27 96%	**108 87%**
Depredated (Depredated/Clutches)	1 14%	6 67%	6 55%	**13 48%**	0	2 18%	0	0	0	0	0	**2 2%**
Abandoned (Abandoned/Clutches)	0	1 11%	1 9%	**2 7 %**	1 7%	1 9%	3 16%	3 20%	1 6%	1 5%	1 4%	**11 9%**
Usurped (Usurped/Nest Clutches)	0	0	0	**0**	1 7%	0	0	0	1 6%	1 5%	0	**3 2%**
Unknown Fate	2	2	0	**4**	1	0	0	1	0	0	2	**4**

[a]More than one clutch was laid by the same or different pairs in one site in 2002, one site in 2005, one site in 2008 and six sites in 2009 (*see methods*).
[b]Eggs on cave floor (one in 2005 and one in 2008) were considered to be clutches for calculations of hatching success but sites were not tagged and were excluded from occupancy analyses (*see methods*).
[c]Clutches with unknown fates were included in occupancy analyses but excluded from calculations of hatching success.

Table 4. Nest site use and clutches of Xantus's Murrelets in plots outside sea caves at Anacapa Island in 2003-09 (post eradication).

	2003	2004	2005[a]	2006	2007	2008	2009[a]	**2003-09**
Tagged Sites	2	4	9	11	14	17	22	
Potential Sites	18	19	23	23	23	23	22	
Occupied Sites (Occupied/Potential)	2 11%	2 11%	8 35%	7 30%	9 39%	12 52%	16 73%	**37%**
Clutches	2	2	8	7	11[b]	11(12)[c]	19(20)[b,c]	**60(62)**[c]
Hatched (Hatched/ Clutches)	2 100%	1 50%	8 100%	6 86%	7 64%	8 73%	15 79%	**47** **78%**
Depredated (Depredated/ Clutches)	0	0	0	0	1 9%	1 9%	2 11%	**4** **7%**
Abandoned (Abandoned/ Clutches)	0	1 50%	0	1 14%	3 27%	1 9%	2 11%	**8** **13%**
Usurped (Usurped/ Clutches)	0	0	0	0	0	1 9%	0	**1** **2%**
Unknown Fate	0	0	0	0	0	1	1	**2**

[a] Sites destroyed by landslides overwinter in 2004-05 and 2008-09 were excluded from later analyses.
[b]More than one clutch was laid by the same or different pairs in two sites in 2007 and four sites in 2009 (*see methods*).
[c]Clutches with unknown fates in 2008 and 2009 were included in occupancy analyses but excluded from calculations of hatching success.

Table 5: Xantus's Murrelet nest monitoring data from 14 nest sites with sequential clutches in 2002-09.

Year	Nest (1st Clutch Fate)	1st Clutch Departure or Fail Date Early Late	2nd Clutch Lay Date Late Early	Clutch Interval Maximum Minimum
2002	Respiring Chimney #1 (Fail)	8 April 22 April	29 April 29 April	21 days 7 days
2005	Respiring Chimney #1 (Hatch)	15 May 25 May	8 June 1 June	24 days 7 days
2007	Landing Cove #2 (Hatch)	23 May 20 June	20 June 20 June	28 days 0 days
	Landing Cove #4 (Fail)	25 April *	10 June 21 May	46 days *
2008	Refuge #1 (Hatch)	12 May 14 May	2 June 29 May	21 days 15 days
2009	Refuge #5 (Hatch)	13 May 23 May	1 June 24 May	19 days 1 day
	Respiring Chimney #3 (Hatch)	13 May 23 May	17 June 1 June	35 days 9 days
	Lonely at the Top #2 (Hatch)	1 May 11 May	17 June 1 June	47 days 21 days
	Pinnacle #8 (Hatch)	13 May 23 May	4 July *	52 days *
	Moss #2 (Hatch)	4 May 11 May	17 June 1 June	44 days 21 days
	Landing Cove #2 (Hatch)	12 April 20 April	1 May 1 May	19 days 11 days
	Landing Cove #11 (Hatch)	12 April 20 April	23 May 15 May	41 days 25 days
	Landing Cove #12 (Fail)	29 March 10 April	1 May 22 April	31 days 12 days
	Landing Cove #15 (Hatch)	* 1 May	13 May 11 May	* 10 days

*Insufficient data to determine date

Table 6. Timing of breeding for Xantus's Murrelets at Anacapa Island in 2000-09.

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

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

Table 7: Use and clutch fates of specific monitored Xantus's Murrelet nest sites in sea caves at Anacapa Island in 2000-09. Codes: hatched - ⚫; abandoned - 🔴; depredated or scavenged - 🔵; usurped - 🟢; unknown - ⚪.

Cave	Nest #	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Refuge	1		🔵				⚫	⚫	⚫	⚫⚫	⚫
	2										
	3			🔴							
	4	🔵	🔵								
	5						⚫	⚫	⚫	⚫	⚫⚫
Lava Bench 1	1	⚪		🔵	⚫	⚫	⚫(🔴[1])	⚪			⚫
	2								⚫	⚫	⚫
	3								🔴		⚫
Lava Bench 2	1	⚫	🔵	🔵	⚫	🔵	⚫	⚫	⚫	⚫	⚫
	2										⚫
Respiring Chimney	1	⚫	⚫	🔵⚫	⚫	⚫	⚫⚫	⚫	⚫	⚫	⚫🔴
	2		🔴	🔵	⚫		🔴				
	3		🔵					⚫	⚫	⚫	⚫⚫
Lonely at the Top	1				⚫	🔵					
	2				⚫	⚫	⚫	⚫	⚫	⚫	⚫⚫
	3							⚫	⚫	(🔴[1])	⚫
	4										⚪
Pinnacle	1		⚫							⚫	⚫
	2				⚫	🔴	⚫	⚫	⚫		
	3				⚫		🔴				
	4					⚫	⚫	🔴		⚫	⚫
	5								⚫	⚫	
	6										⚫
	7										⚫
	8										⚫⚪
	9										⚫
Moss	1	⚫	⚪	⚫	⚫	⚫	⚫		⚫	⚫	
	2	⚫	🔵	⚫	🔴	⚫	⚫	⚫	⚫	⚫	⚫⚫
	3	⚪	⚪	⚫	⚫	⚫	⚫	⚫	⚫	⚫	⚫
	4				⚫		⚫	⚫	⚫	⚫	⚫
Aerie	1	⚫	🔵	🔵							
	2				⚪						⚫
	3				⚫	⚫	⚫		⚫	⚫	⚫
	4						⚫	🔴			
	5	⚫		🔵				🔴	⚫	⚫	⚫
Keyhole	1				🟢						
	2						⚫	⚫	🟢	🟢	

[1]Abandoned egg on cave floor near site was included as a clutch for calculations of hatching success only (*see methods*).

Table 8: Use and clutch fates of specific monitored Xantus's Murrelet nest sites in shoreline, cliff and offshore rock plots on Anacapa Island in 2003-09. Codes: hatched - ● (black); abandoned - ● (red); depredated or scavenged - ● (blue); usurped - ● (green); unknown - ● (grey). Shaded cells indicate years monitoring was not conducted.

Plot	Nest #	2003	2004	2005	2006	2007	2008	2009
Landing Cove	1	●						
	2		●	●	●	● ● (red)	●	●●
	3			●	●		●	●
	4			●		● (blue) ●	● (blue)	
	5			●			● (red)	● (blue)
	6			●	●	●		
	7				●	●	● (green)	
	8				● (red)			
	9					● (red)	●	● (blue)
	10						● (grey)	[shaded] a
	11						●	●●
	12							● (red) ● (grey)
	13							● (red)
	14							●
	15							●●
	16							●
Cat Rock	1	●		●	●	●		●
	2							●
East Fish Camp	1	[shaded]	● (red)	[shaded]	[shaded]	[shaded] a	[shaded]	[shaded]
Rockfall Cove	1	[shaded]	[shaded]	●			●	●
	2	[shaded]	[shaded]	●	●	●	●	●
	3	[shaded]	[shaded]			● (red)		
	4	[shaded]	[shaded]			●	●	●
	5	[shaded]	[shaded]				●	●

[a]site destroyed