Nest Monitoring of Xantus's Murrelets at Anacapa Island, California: 2007 annual report

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EXECUTIVE SUMMARY

- In 2007, the eighth year of Xantus's Murrelet (*Synthliboramphus hypoleucus*) nest monitoring and the fifth year of post-eradication monitoring was conducted at Anacapa Island, California. With support from the American Trader Trustee Council, Channel Islands National Park, and Channel Islands National Marine Sanctuary, a monitoring program was initiated in 2000 to provide baseline data on reproductive success and population size prior to the eradication of Black Rats (*Rattus rattus*) from Anacapa Island in 2000-02. In 2003-07, nest monitoring was used to examine reproductive success and numbers of breeding murrelets in sample areas post-eradication.

- An increase in nesting effort occurred in 2007 compared to 2006: a) 18 nests were recorded in sea caves and 11 nests in other plots, compared to 16 and 7 nests, respectively, in 2006; b) nest occupancy was 58% in sea caves and 64% in other plots, compared to 52% and 50%, respectively, in 2006; and c) 6 new nests were discovered over the entire island in 2007, compared to 3 new nests in 2006.

- Murrelets continued to expand their nesting distribution into habitats previously occupied by rats; three new nests (2 in Rockfall Cove and 1 in Landing Cove) were established in cliff, shoreline and offshore rock habitats in 2007, where none were known prior to 2003.

- Despite extremely late nesting in 2007, hatching success in sea caves (89%) was higher than in any other post-eradication year; although hatching success in the other plots (64%) was lower than in every post-eradication year except 2004.

- Nest abandonment accounted for 4 of 6 (66%) failed nests at Anacapa in 2007; broken or missing eggs assumed to have been depredated or scavenged by endemic Deer Mice (*Peromyscus maniculatus anacapae*) were noted in two other failed nests.

- The mean nest initiation date in 2007 (20 May) was 3-51 days later than observed in 2000-06 (range 30 March – 17 May), while the range of laying dates in 2007 (112 d) was wider than in any previous year (range 29-73 d).

- The number of monitored sites in sea caves has increased 94% since eradication, while the mean annual number of active nests has increased 53%.

- Hatching success in sea caves has nearly doubled post-eradication, with 82% hatching success in 2003-07 compared to 42% in 2000-02.

- Over half (52%) of all pre-eradication nests failed due to rat depredation, but no rat-depredated nests have been recorded post eradication. The small numbers (5%) of depredated or scavenged nests found post-eradication have been attributed to Deer Mice.

- Eradication of rats has led to improved hatching success and colony growth. While rat depredation was likely the primary factor impacting the murrelet colony over the last century, population recovery may occur slowly for many years post-eradication because of the naturally low reproductive rates of *Synthliboramphus* murrelets, and anthropogenic and natural factors that can reduce nesting effort or hatching success in some years (e.g., 2004).

- Annual nest monitoring in sea caves and other plots is needed to best document continued recovery of Xantus's Murrelet at Anacapa Island. Additional efforts are needed to: a) examine recovery of murrelet nesting in other habitats at Anacapa Island; and b) to document trends in population size through comparison to baseline spotlight survey data and radar monitoring data gathered in 2000-03.

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 the Anacapa Island Restoration Program as the 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, murrelets were 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). The 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 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 has been made to document the benefits of predator eradication for murrelets or other seabirds. To measure the improvement in reproductive success and the expected growth for the murrelet population at Anacapa Island, ATTC sponsored Humboldt State University and Hamer Environmental (with collaboration by Channel Islands National Marine Sanctuary and the California Institute of Environmental Studies) to design and implement a Xantus's Murrelet Monitoring Program. The primary goals of the monitoring program were: a) to determine baseline levels of population size indices and reproductive success prior to eradication; and b) to measure expected increases in murrelet population size and reproductive success post eradication. From 2000-03, the team developed innovative population monitoring techniques (including nest monitoring in sea caves, nocturnal spotlight surveys of at-sea congregations, and radar monitoring) which have provided reliable indices of murrelet population size and reproductive success for measuring changes over time (Whitworth et al. 2003a,b,c; 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 lower-cost annual long-term monitoring was still needed. The California Institute of Environmental Studies (CIES; with collaboration by Humboldt State University and Channel Islands National Marine Sanctuary) was funded to continue nest searches and monitoring in sea caves and other nesting habitats at Anacapa Island. In 2004-07, continued nest searches and monitoring provided standardized data to: a) measure nesting effort, hatching success, and nest depredation rates; and b) detect expansion of the colony into habitats previously occupied by rats. While this reduced monitoring program allowed for continued annual information for measuring the progress of recovery, additional efforts (i.e., spotlight surveys, radar surveys, and broad-scale nest searches) will be necessary in the future to better measure changes in overall population size and breeding distribution in island habitats over time.

In 2007, with joint funding from ATTC and CINP, CIES continued murrelet nest searches and monitoring in sea caves and cliff, shoreline and offshore rock plots around Anacapa Island. Our efforts in 2007 marked the eighth consecutive year of Xantus's Murrelet nest monitoring and the fifth year of monitoring since eradication. In this report, we present the results of 2007 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 (Fig. 1). It is comprised of three small islets (West, Middle, and East; Figs. 2 and 3) separated by narrow channels that are sometimes exposed at low tide. The island chain is approximately 7.5 km long and is surrounded by 17.5 km of steep, rocky cliffs punctuated with over 100 sea caves (Bunnell 1993; Figs. 2 and 3). 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. 3). Anacapa Island is managed by CINP which maintains quarters for staff and facilities for campers on East Anacapa, but the rest of the island chain is uninhabited. Surrounding waters out to 9.7 km (6 miles) are managed by CINMS, out to 4.8 km (3 miles) by California Department of Fish and Game, and out to 1.6 km (1 mile) by CINP.

Field Logistics

In 2007, we used the CINMS research vessel *Shearwater* (Santa Barbara, CA), the private charter vessel *Miss Devin* (Santa Barbara, CA) and the private recreational vessel *Retriever* (Ventura, CA) for transportation to Anacapa Island and accommodations while at the island. All field work was conducted by CIES staff (DLW, JSK), CIES subcontractor (HRC [Carter Biological Consulting [CBC], Victoria, BC), and volunteers from CBC, CINMS, and the Channel Islands Naturalist Corps. Access to sea caves and other sample areas was performed in a 3.8 m Zodiac® inflatable craft powered by 15-25 hp outboard engines. Boats and personnel were supplied with all required safety equipment.

Nest Monitoring

In April-August 2007, we conducted nest searches and monitoring in 10 sea caves previously monitored in 2000-06 (Whitworth et al. 2002a,b; 2003a,b,c; 2004a,b; 2005a,b; 2006; Figs. 2 and 3). Caves were named by Bunnell (1993). All potential nesting habitats in sea caves were searched using hand-held flashlights during each visit. Sea caves were checked every two weeks from 25 April to 17 July, although extreme winds limited nest checks during the 6-7 June trip. Only sites which were active on 17 July were checked during the last visit on 13 August.

With reduced funds and extended nesting beyond June in 2004-07, we changed from the weekly nest monitoring schedule used in 2001-04 to biweekly monitoring in 2005-07. In 2000, nest checks were conducted every 2-3 weeks due to limited funding. We considered biweekly checks to be the most efficient long-term monitoring schedule for obtaining adequate data with available time, funds, and boat support. While biweekly checks result in less exact data for estimating breeding phenology, they do not affect accuracy of hatching success (usually determined by presence of 1-2 hatched eggshell fragments after evidence of full-term incubation), but may affect determination of cause of failure at some nests.

Systematic efforts to examine potential murrelet nesting areas in cliff, shoreline and offshore rock habitats began in 2003 and were continued and expanded in 2004-07 (Figs. 2 and 3). We used methods similar to sea cave nest monitoring to thoroughly search: 1) cliffs in Landing Cove on East Anacapa (2003-07); 2) Cat Rock off West Anacapa (2003-07); and 3) Rockfall Cove on the south side of Middle Anacapa (2005-07). Previously tagged sites in these plots were checked biweekly as for sea cave sites, but due to larger areas searched, more extensive nest searches of sample areas were conducted 1-2 times during the breeding season after egg laying had commenced in most sea caves. By initiating limited monitoring outside of sea caves, we aimed to detect when murrelets begin colonizing nesting areas that previously were not used, apparently due to presence of rats. In 2007, limited time for nest searches in the expanded survey area outside of the sea caves prevented nest searches along shoreline areas on the south side of Middle Anacapa near East Fish Camp that were searched in 2004-0006, although no monitored sites are currently located in this area.

Monitored nest sites were identified as suitable crevices or sheltered sites, containing an incubating or brooding adult or other evidence of past or present murrelet breeding (i.e, whole unattended eggs, broken or hatched eggshell fragments, or eggshell membranes). During the first visit of the year, we carefully inspected each cave and collected any remaining eggshell fragments from the past breeding season to avoid confusion with previous nesting efforts. During subsequent biweekly visits to sea caves, we recorded contents for each tagged nest (e.g., empty nest, one or two unattended eggs, incubating or brooding adult, abandoned eggs, broken or hatched eggshell fragments) and we searched for other new nest sites that had not been present in previous years. Incubating adults were observed briefly with a small flashlight but were not handled or prodded to reduce the possibility of nest abandonment due to researcher disturbance.

<u>Hatching Success</u> – As in past years, hatching success was determined as the percent of nesting attempts (i.e., each clutch of 1-2 eggs laid) 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) at the nest site. However, we also assumed successful hatching had occurred in certain sites where hatched eggshell fragments were not found, when: 1) incubating adults

were observed for periods that were considered sufficient to assume successful hatching (i.e., > 35 days after the estimated nest initiation date); and 2) no evidence of depredated eggs was noted in or near the nest site. We used Chi-square analyses for a 2 x 2 contingency tables (χ^2) to examine differences in the frequency of hatched nests between pre-eradication and post-eradication periods.

Failed nesting attempts were classified as either depredated or abandoned. Depredated nests were usually identified by the presence of broken eggshells in or near the site, but we included a few attempts where eggs disappeared (presumably removed by rats or mice pre-eradication and mice post-eradication) before the earliest possible hatch date. Broken eggs were examined for signs of depredation 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). While we noted depredation from mice, we could not determine if this was the reason for nest failure or whether eggs (whole, cracked, or broken) had been scavenged after abandonment. Nesting attempts 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. Nests with unknown nest fates were excluded from calculations of hatching success and rates of nest depredation and abandonment.

<u>Nest Occupancy</u> - In 2007, we calculated nest occupancy in sea caves for each year as the percentage of total monitored nest sites found in 2000-07 (regardless of when the site was first tagged) in which at least one egg was laid in that year (i.e., the nest site was "active"). Potential nest sites were not tagged until some evidence of potential nesting 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 prior to tagging. This technique increases the comparability of occupancy rates between 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.

A single egg found in 2005 in a very open site in Lava Bench #1 Cave was treated as a nesting attempt for calculations of hatching success that year, but we did not consider it a potential nest site and it was not included in analyses of nest occupancy in 2005 or later. Inspection of the general area where the egg was found indicated that the site was completely exposed to light and predators, the substrate was unsuitable for a potential nest site, and the egg could not possibly have rolled or been moved from a nearby hidden nest. We considered that the egg was probably abandoned immediately after laying. Given that similar instances of eggs laid outside of potential nest sites have not been previously described in Xantus's Murrelets, we suspect that unusual circumstances (e.g., site competition, first-time breeding, predation, attempted predation, injury, or mortality) led to this occurrence.

<u>Timing of Breeding</u> - A range of possible clutch initiation dates (i.e., laying date of the first egg of the clutch) was estimated for each nest by subtracting an estimated period of time from the date of 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) “chicks in nest” (i.e., between 0-3 days since hatching); 3) “fresh hatched eggshell fragments” (i.e., 3-7 days since hatching); or 4) the first date in a series of repeated checks with incubating birds (i.e., 1-14 days since laying). 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 nest 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 biweekly nest checks in 2005-07, slightly greater error was involved in this process than with weekly nest checks in 2001-04.

RESULTS

Nest Monitoring in 2007

Nesting Effort and Occupancy - In 2007, we monitored a total of 45 nest sites, including 31 sites in 10 sea caves and 14 sites in other habitats (Table 1). We found a total of 27 occupied murrelet nests, including 18 in sea caves and 9 in other habitats. Nesting was observed in: a) 9 of 10 (90%) monitored sea caves; b) five nests in the cliffs at Landing Cove; c) three nests in the rocky scree in Rockfall Cove; and d) a single nest on Cat Rock (Table 1).

A total of six new nests were found in 2007 (Table 2), including three in sea caves (two in Lava Bench Cave #1 and one in Pinnacle Cave) and three in other habitats (one in Landing Cove and two in Rockfall Cove). Occupancy of monitored sites was 60% over the entire island (27 occupied/45 monitored; Table 2), with 58% (18 occupied/31 monitored) in sea caves (Table 3) and 64% (9 occupied/14 monitored) in other plots (Table 4).

Monitoring evidence suggested that second clutches laid in two sites in Landing Cove were nesting attempts by different pairs. The second clutch in one site was laid soon after hatching of the first clutch, presumably while the first pair was raising chick(s) at sea. The first clutch in the other site was considered a failed attempt when the single egg disappeared soon after being laid. The second clutch was not discovered until two months later and was considered a separate nesting attempt for monitoring purposes, although it is possible the same pair was responsible for both clutches. Definite replacement clutches have yet to be documented during monitoring at Anacapa.

Nesting Success - Hatching success was 79% over the entire island (23 hatched/29 active; Table 2), with 89% (16 hatched/18 active; Table 3) in sea caves and 64% (7 hatched/11 active; Table 3) in other plots. Three nests were assumed to have hatched even though hatched eggshell fragments were not found in or near the sites as all three sites contained incubating murrelets for periods that were considered sufficient to assume successful hatching. One late nest in Pinnacle Cave contained an incubating adult 36 days after the estimated initiation date and was assumed to have hatched soon after the last 2007 nest check on 13 August. The other two sites (one each in Landing Cove and Aerie Cave) contained incubating murrelets 40 days after estimated nest initiation dates, but were located in deep crevices where hatched eggshells would not be seen (either moved out of the site or farther back into the site) after the family group apparently departed from the nest.

Only six failed nests (21%) were recorded at Anacapa in 2007 (Tables 1 and 2). Four nests (14%) failed due to abandonment, while two nests (7%) were either depredated or scavenged by endemic Deer Mice (*Peromyscus maniculatus anacapae*). One abandoned nest and one depredated nest were found in sea caves (Table 3), compared to three abandoned nests and one depredated nest in the other plots (Table 4).

Timing of Breeding - Murrelet nests were initiated over 112 days between 18 March and 8 July, with a mean nest initiation date of 20 May (± 29 d; Table 5, Fig. 4). Peak egg laying occurred in mid to late May, although relatively high numbers of nests were initiated from early May through late June. Despite this relatively late timing of breeding, a minor peak in nest initiations was also observed in mid to early March.

Inter-Annual Comparisons in Sea Caves (2000-07)

Nesting Effort and Occupancy – With three new nest sites discovered in sea caves in 2007, the total number of monitored sites increased from 13 sites in 2000 to 31 sites in 2007. We have recorded general increases of 1-3 sites in sea caves per year, except for 2003 (the first murrelet breeding season after eradication) when an increase of 8 sites occurred over 2002 (Table 3). Overall, the number of monitored sites in sea caves has increased 94% post-eradication from 16 sites in 2002 to 31 sites in 2006 (Table 3).

Despite very late breeding in 2007, we recorded the highest number of occupied sites (18), highest nest occupancy (58%), and the second highest number of nesting attempts (18) in sea caves since monitoring began in 2000 (Table 3). The mean annual number of nesting attempts has increased 53% between pre-eradication years (2000-02; mean 10.33 nests/year) and post-eradication years (2003-07; mean 15.80 nests/year). Nest occupancy was consistently low pre-eradication (range 29-35%), but has increased markedly post-eradication (range 35-58%; Table 3).

Nesting Success - Hatching success (89%) improved and nest failure (12%) declined in sea caves in 2007, compared to previous post-eradication years, although hatching success has been consistently high (range 73-84%) and nest failure rates consistently low (range 16-27%; Table 3) since 2002. Overall hatching success (excluding nests with unknown fates) in sea caves post-eradication (82%; 64 hatched/78 nests) has been much higher ($\chi^2 = 17.21$, $P < 0.0001$) than pre-eradication (42%; 13 hatched/31 nests). Correspondingly, the overall nest failure rate has been much lower post-eradication (18%; 14 failed/78 nests) compared to pre-eradication (58%; 18 failed/31 nests; Table 3).

We recorded a lower rate of nest abandonment in sea caves in 2007 (6%) than in any previous post-eradication year 2003-06 (range 9-20%; Table 3). Nest failure post-eradication has been due primarily to abandonment (71%; 10 abandoned/14 failed), with only small numbers of depredated or scavenged nests (29%; 4 depredated or scavenged/14 failed). Missing eggs in 2 sites in 2003 and single depredated nests in 2004 and 2007 were attributed to depredation or scavenging by Deer Mice, but depredated nests were not found in 2005 or 2006. In contrast, nest failures pre-eradication were due primarily to depredation by rats (89%; 16 depredated/18 failed), with highest rates (73% and 55%) in 2001 and 2002, respectively (Table 3).

Colony Expansion (2003-07)

Post eradication (2003-07), a total of 30 nesting attempts in 15 monitored sites (including one site destroyed by a landslide in winter 2004-05) were discovered during nest searches in non-seacave areas, where none were known prior to 2003 (Table 4). Single nests were first found in Landing Cove cliffs and Cat Rock in 2003. Two more nests were discovered in 2004, 1 in Landing Cove and 1 along the shoreline of East Fish Camp; the latter nest site was destroyed by a landslide after the 2004 breeding season. Six new nests were found in 2005 (4 in Landing Cove and 2 in Rockfall Cove). Just 2 nest sites were discovered in 2006 (both in Landing Cove), but 3 new sites were located in 2007 (1 in Landing Cove and 2 in Rockfall Cove).

Nest occupancy in monitored nest sites outside sea caves was low in 2003 and 2004 (20% and 18%, respectively) but increased markedly in 2005 (57%), 2006 (50%), and 2007 (64%; Table 3). Overall hatching success in these plots has been 80% (24 hatched/ 30 nests), with only 20% failed nests (6 failed/ 30 nests). Nest failures in plots outside sea caves have been due primarily to abandonment (83%; 5 abandoned/ 6 failed) with only 1 depredated or scavenged nest (17%; 1 depredated or scavenged/ 6 failed). However, most nest failures in these plots occurred in 2007 (66%; 4 of 6 failed nests).

Timing of Breeding (2000-07)

Mean nest initiation dates ranged from 30 March (± 11 d) in 2000 to 20 May (± 29 d) in 2007 (Table 5; Figure 9), with the earliest individual lay date occurring in 2002 (7 March) and the latest in 2007 (8 July). The widest range of lay dates within a single year occurred in 2007 (112 days), while the narrowest range of lay dates occurred in 2000 (29 days).

Nesting in Individual Sites

Since 2000, nesting has been noted at least once in all but one of the monitored sites, a nest marked in Refuge Cave in 1994. However, four other sites originally marked during the pre-eradication period have been inactive since at least 2002. In contrast, four sites in sea caves have had nest attempts every year from 2000 to 2007, while 1 site was active 7 years and another 6 years (Table 6). These six sites (3 in Moss Cave and 1 each in Lava Bench 1, Lava Bench 2 and Respiring Chimney Caves) together accounted for 19% of all monitored sites in sea caves, but 43% of all active nests and 47% of all hatched nests documented in sea caves from 2000 to 2007.

Excluding six new sites found in 2007, 13 sites have been active every year after nesting was first documented in those sites (Table 6), including sites active each of the last 8 years (4 sites), 5 years (2 sites), 4 years (1 site), 3 years (4 sites) and 2 years (2 sites). An additional eight sites had active nests in all but one year once nesting had commenced in the site.

Nesting has been less consistent in nine sites where gaps of up to 4 years have been documented between active nests. In these sites, nesting was noted in 6 years (1 site), 4 years (3 sites), 3 years (2 sites) and 2 years (3 sites). The other eight sites had only one year of nesting activity. One site along the shoreline of East Fish Camp was destroyed by a landslide the winter after the nest was first discovered.

Available data suggest similar high site fidelity in other plots, but few years of monitoring data from sites in other plots are available to compare site use to sea caves. Only one site found outside of the sea caves has been active every year since monitoring began in that plot, a nest in Rockfall Cove active in 2005-07. However, single sites in Landing Cove and on Cat Rock have been active for 4 of 5 years between 2003 and 2007.

DISCUSSION

Xantus's Murrelet Recovery at Anacapa Island

Despite extremely late nesting again in 2007, strong evidence of continued improvement in reproductive success and colony growth were obtained at Anacapa Island five years after eradication of Black Rats in December 2002. In 2007, nest monitoring in sea caves documented higher nest occupancy (58%), higher numbers of occupied sites (18 nests), and higher hatching success (89%) than observed in any previous year post-eradication. Pre-eradication and post-eradication comparisons in sea caves continued to provide convincing evidence of beneficial effects of rat eradication for Anacapa murrelets. The number of nest attempts has increased over 50% and hatching success has nearly doubled post-eradication (2003-07), while egg depredation has been almost entirely eliminated as a cause of nest failure.

Continued colony expansion outside sea caves further demonstrated that murrelets were gradually responding to improvement in breeding conditions. Outside sea caves, murrelets seldom attempted to breed prior to eradication. The steady increase in the number of nests found in Landing Cove from 2003-07 (9 sites) and Rockfall Cove from 2005-07 (4 sites) best illustrates this colony expansion in accessible monitoring areas. We suspect that similar colony expansion and increase in numbers of nesting birds are occurring widely in suitable cliff, shoreline and upper-island habitats on East, Middle and West Anacapa but special nest searches are needed to document this expansion in currently non-monitored locations and spotlight surveys are needed to confirm growth in the population over the entire island.

This post-eradication period of extremely high hatching success at Anacapa may be a temporary phase as the island returns to a natural equilibrium following the removal of rats. Nest failure rates may increase as the natural relationships are re-established between murrelets, the re-introduced Deer Mouse population (eradicated concurrently with rats in 2001-02), plant communities (alternate food sources for mice) and avian predators. Although overall hatching success at Anacapa was high in 2007, we did note some disparity in hatching success between murrelets nesting in sea caves (89%) and the other Anacapa plots (64%); the first time such a strong disparity was evident since adequate samples of nests were available outside the sea caves. Hatching success in the non-sea cave habitats has declined from 100% in 2005 (8 nests) to 86% in 2006 (7 nests) and 64% in 2007 (11 nests). These data suggest that breeding conditions outside of the Anacapa sea caves may already be returning to the more natural levels observed at other colonies (*see below*), but undoubtedly are still much better than when rats occupied the island. Over time, highest levels of hatching success recently observed at Anacapa Island may be limited to sea caves after the island ecosystem returns to a more natural state.

Whether these disparate trends in sea caves and other habitats continue is uncertain, but there is evidence from other islands to suggest that under natural conditions (i.e., in the absence of introduced terrestrial predators) murrelets nesting in protected sea caves experience higher hatching success than in more open habitats. During monitoring at the Coronado Islands from 2005-07, we recorded 100% hatching success for a small number of nest sites in Violin Cave on Middle Coronado Rock (Carter et al. 2006; Whitworth et al. 2007, in prep.), a sea cave with nesting habitat very similar to the caves at Anacapa Island, while hatching success was only 41% for a larger sample size on the rest of the island (2005 only; Carter et al. 2006). Protected sea caves (which currently comprise over half of the nesting sample at Anacapa) may constitute optimal breeding habitat by greatly reducing avian and mammalian depredation. In fact, Anacapa sea caves may have served as refugia that permitted the survival of the murrelet colony during the period when rats occupied the island (McChesney et al. 2000).

Comparisons with Other Colonies

Xantus's Murrelet reproductive success data are available from three other colonies: Santa Barbara Island (1983-2005), the Coronado Islands (2005-07), and the San Benito Islands (2003-04). Differences in monitoring methods (e.g., 5-day to 2-week nest check intervals) and calculations of hatching success among years and colonies make for difficult comparisons between years at each colony or among colonies. At Santa Barbara Island from 1993-2002 (Schwemm and Martin 2005), hatching success (calculated as the percentage hatched of all eggs laid) may have yielded slightly lower values than at Anacapa Island because some two-egg clutches may hatch only one egg. However, for some clutches at Santa Barbara Island where it was not clear if a second egg was laid or not, a second egg was still assumed to have been laid because most clutches (at least 75%) contain two eggs (Murray et al. 1983; P. Martin, pers. comm.). At the Coronado Islands from 2005-07 (Carter et al. 2006; Whitworth et al. 2007, in prep.), hatching success (calculated as the percentage of breeding pairs hatching at least one egg) would yield slightly higher values than at Anacapa Island because failed first clutches are excluded when replacement clutches are laid. However, replacement eggs have not yet been documented (especially with high hatching success post-eradication) and use of certain nest sites by more than one pair has been rarely noted. Thus, hatching success at Anacapa Island in 2000-07 is directly comparable to the Coronado Islands in 2005-07.

At Santa Barbara Island, replacement eggs and use of sites by more than one pair have been well documented (Murray et al. 1983) but it is unclear how these events were treated during analyses of hatching success per egg (1993-2002) or per nest (1983-92) (Drost and Lewis 1995, Schwemm and Martin 2005). At the San Benito Islands, it is unclear if replacement eggs or use of sites by more than one breeding pair were recorded in 2003-04 (Wolf et al. 2005) but, given high abandonment during these years, they may not have occurred. Although replacement clutches may occur frequently in certain years (e.g., Santa Barbara Island), site use by more than one pair occurs only rarely. In the future, greater reporting on and standardization of data handling is needed to account for these issues and allow better comparisons between colonies.

Hatching success reported for Santa Barbara Island ranged from 27-75% (mean 57% of nests hatched) from 1983 to 1992 (Drost and Lewis 1995) and 26-71 % (mean 48% of eggs hatched) from 1993 to 2002 (Schwemm and Martin 2005). Hatching success (% of nests hatched) at the San Benito Islands was 35% in 2003 and 52% in 2004 (Wolf et al. 2005), while hatching success (% of breeding pairs that hatched at least one egg) at South Coronado

Island was 68% in 2005, 47% in 2006 and 49% in 2007 (Carter et al. 2006; Whitworth et al. 2007, in prep.). Thus, although high hatching success has been observed at Santa Barbara Island and South Coronado Island in some years, overall hatching success at these colonies has been much lower over time compared to the post-eradication period at Anacapa Island (mean 81%; range 69-89%). Variation in data handling likely accounted for only a relatively small amount of this degree of difference.

As for Anacapa Island, nest abandonment has been the primary cause of reported nest failure at the San Benito Islands (Wolf et al. 2005) and Coronado Islands (Carter et al. 2006; Whitworth et al. 2007, in prep.). Abandonment accounted for 55% of all failed eggs at the San Benito Islands in 2003-04 and 50% of all failed nests at South Coronado Island in 2005-07. In contrast, egg depredation by native Deer Mice accounted for most nest failures at Santa Barbara Island (Drost and Lewis 1995), with up to 69% of all eggs laid depredated by mice in some years (Schwemm and Martin 2005). Mouse predation on unattended first eggs prior to clutch completion is well recognized at Santa Barbara Island (Murray et al. 1983, Drost and Lewis 1995, Schwemm and Martin 2005), but subsequent egg predation during incubation has not been clearly separated from scavenging on abandoned eggs. Additional studies of the reasons behind nest abandonment and the eating of eggs by mice at different colonies are clearly needed before effective interpretation and comparison of reproductive success can occur. Given that abandonment can result from various factors which are not easily detectable at the colony (e.g., low prey availability, pollutants, predators, etc.), it is likely that abandonment will usually be the primary reported reason for nest failure regardless of the cause, in the absence of extensive egg depredation.

Nest Failure at Anacapa Island during the Pre- and Post-Eradication Period

Post eradication (since 2003), only 20 failed nests have been recorded at Anacapa Island, with most nest fates (75%) classified as abandoned. In fact, the only negative trend observed in recent years at the Anacapa Island colony has been a slight increase in the number of abandoned nests. Increased post-eradication abandonment could have resulted from: 1) natural or human disturbances; 2) poor foraging conditions possibly correlated with late breeding; 3) predation on breeding adults; 4) reduced depredation or scavenging by mice; and 5) a greater proportion of nesting attempts by first-time breeders.

We doubt that disturbance from our monitoring activities has had any significant effect on breeding success. Adult murrelets were never observed in 11 (65%) of 17 abandoned nests found in 2000-07 and we have yet to cause any incubating adults to flush or move off eggs during monitoring. However, direct evidence from nest monitoring indicates that natural disturbances have had some negative impacts on breeding murrelets. Pigeon Guillemots (*Cepphus columba*) disturbed an active murrelet nest in Keyhole Cave in 2003 (Whitworth et al. 2004a) and eventually usurped the site for several years. Guillemots also nest in Aerie Cave and in 2003 usurped a murrelet nest that had been active in this cave from 2000-02. Cassin's Auklets (*Ptychoramphus aleuticus*) are another potential nest site competitor currently breeding in small numbers at Anacapa Island (McChesney et al. 2000; Whitworth et al. 2004a,b), although evidence of only one auklet egg has been found in sea caves and there is little evidence of much overlap in breeding habitats between auklets and murrelets.

Indirect evidence suggests that poor prey availability could have played some role in nest abandonment, as suspected at Santa Barbara Island in some years (Roth et al. 2005). Delayed murrelet breeding, indicative of poor foraging conditions, was recorded in 2006-07, along with higher numbers of abandoned nests. Abandonment prior to incubation, an indication of poor prey availability in the congeneric Ancient Murrelet (*S. antiquus*; Gaston 1992), may have occurred in 11 of the 17 abandoned nests where incubating adults were never observed during nest checks (although a complete lack of incubation could not be confirmed with biweekly checks). Several years of delayed breeding and increasing abandonment rates may signal an extended period of poor prey availability which could slow or stop colony growth.

Wolf et al. (2005) surmised that avian predation of adults had led to high nest abandonment at the San Benito Islands in 2003-04, but adult predation on murrelets at Anacapa has been documented at only one site, a failed nest in Lonely at the Top Cave where the carcass of an adult murrelet and depredated eggs were found near the site in 2004 (Whitworth et al. 2004b). This site has not been used since this incident. Nine other monitored nests (excluding sites usurped by Pigeon Guillemots) have remained empty every year following a failed nesting attempt, and another three sites remained empty for 3-4 years following nest failure. While definitive evidence is lacking, nest failure and subsequent site vacancy may be caused by adult mortalities. In the five years since rat eradication, avian predators such as the Peregrine Falcon (*Falco peregrinus*), Barn Owl (*Tyto alba*), and Western Gull (*Larus occidentalis*) have been the primary predation threats to adult murrelets. Avian predators likely prey upon breeding adults away from nest sites, although Barn Owls might occasionally take an adult murrelet near a nest site (as suspected at Lonely at the Top Cave in 2004; Whitworth et al. 2004). If a breeding adult from a monitored site was preyed upon away from the site, eggs would be abandoned by the mate and we would record nest fate as "abandoned". Thus, we may have overestimated the proportion of failed nests that were truly abandoned, but reliable determination of nest fates for failed nests in such cases would be impossible even with continuous nest surveillance.

Increased abandonment in the post-eradication period may be an artifact of reduced depredation or scavenging by rodents. During the pre-eradication period, any abandoned nests were probably scavenged soon after incubation ceased and mistakenly classified as depredated when we found broken or missing eggs. In such cases, more frequent monitoring might lead to better determination of fates for failed nests, although measures of hatching success probably would not be affected. A future study is needed to compare daily, 5-day, weekly and biweekly nest checks to examine any possible differences in nest fates that may arise. In the post-eradication period, with the absence of rats and mouse populations still reaching an equilibrium, intact abandoned eggs may persist longer in nest sites, increasing our chances of finding them before scavenging occurs.

Assessing the effects of recent high hatching success and colony growth on demographic parameters of the Anacapa population requires individually marked birds. Thus, we have no evidence to suggest breeding by cohorts of inexperienced birds has resulted in increased abandonment.

Nest Site Fidelity

Without marked individuals, it is difficult to prove whether extended use of certain sites reflects strong nest site fidelity, mate fidelity, high nest-site quality, or some combination. In other alcids, high site and mate fidelity occurs (Gaston and Jones 1998) and we suspect that regular site use at Anacapa Island by Xantus's Murrelets reflects similar behavior. Although murrelets apparently exhibit rather high site fidelity between years, nest failures may stimulate movement to new sites nearby. Several new sites were established within 1-2 m of sites which failed in the previous year (e.g., 3c in Pinnacle Cave, N1 in Lava Bench Cave #1, and 1110a in Landing Cove; Table 6). Nest site disturbance also may provide impetus for establishment of new sites. New sites were quickly established in Aerie and Keyhole caves, after previously occupied murrelet nests were usurped by Pigeon Guillemots.

Future Murrelet Monitoring at Anacapa

In fall 2007, the ATTC and CINP decided to continue funding for Xantus's Murrelet nest monitoring by CIES for at least three more years in 2008-10. Continuation of the current nest monitoring program in sea caves and selected shoreline plots is desirable for most effective documentation of improvement in breeding conditions at Anacapa Island during the early period of colony restoration. Monitoring requires compete searches of all accessible habitats in each sea cave or plot to detect any new sites as the colony grows, but also to detect possible movements between sites.

A more extensive survey of accessible upper island, cliff and shoreline habitats of East, Middle and West Anacapa is also being considered for 2009. Many upper island areas have not been searched since 1997 (McChesney et al. 2000) and it is advisable to determine the extent to which murrelets and other burrow-nesting (Cassin's Auklet) or crevice-nesting (e.g., Ashy Storm-Petrel *Oceanodroma homochroa*) seabirds are using previously unoccupied habitats. To prevent disturbance to surface-nesting Brown Pelicans (*Pelecanus occidentalis*), Double-crested Cormorants (*Phalacrocorax auritus*), and Brandt's Cormorants (*P. penicillatus)*, surveys of upper habitats at Middle and West Anacapa must be conducted in the fall (McChesney et al. 2000). These surveys will involve searches for murrelet and auklet eggshell fragments and may involve limited mist-netting for storm-petrels to provide minimal baseline data for assessing future changes.

With expansion of the murrelet colony into the shoreline and cliff habitats occurring shortly after rat eradication, detectable increases in overall population size of Xantus's Murrelets at Anacapa Island probably have occurred sooner than originally anticipated. If substantial use of upper island habitats is detected in 2009 surveys, spotlight and radar surveys (Whitworth et al. 2003c; Hamer et al. 2005) should be conducted in 2010 at minimum and possibly in 2010-2012 for best comparison to baseline data gathered in 2001-03 for determining the degree of change in the overall murrelet population.

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Table 1: Number of monitored nests and nest fates for Xantus's Murrelets at Anacapa Island in 2007.

Sea Cave/ Shoreline Plot	Monitored Sites	Occupied Sites	Nesting Attempts	Hatched Nests	Depredated Nests	Abandoned Nests	Unknown Fate
Refuge	5	2	2	2	0	0	0
Lava Bench #1	3	2	2	1	0	1	0
Lava Bench #2	1	1	1	1	0	0	0
Respiring Chimney	3	2	2	2	0	0	0
Lonely at the Top	3	2	2	2	0	0	0
Confusion	0	0	0	0	0	0	0
Pinnacle	5	2	2	2	0	0	0
Moss	4	4	4	4	0	0	0
Aerie	5	2	2	2	0	0	0
Keyhole	2	1	1	0	1	0	0
Sea Cave Total	31	18	18	16	1	1	0
Cat Rock	1	1	1	1	0	0	0
Rockfall Cove	4	3	3	2	0	1	0
Landing Cove	9	5	7[1]	4	1	2	0
Shoreline Total	14	9	11	7	1	3	0
Anacapa Total	45	27	29	23	2	4	0

[1]Nesting efforts by different pairs occurred in two sites in Landing Cove.

Table 2: Breeding indices for Xantus's Murrelets in all nests sites found on Anacapa Island prior to and after the eradication of Black Rats.

	Pre-Eradication				**Post-Eradication**					
Nest Site Summary	2000	2001	2002	**2000-02**	2003	2004	2005	2006	2007	**2003-07**
Tagged & Monitored	13	15	16	**16**	26	29[a]	36	39	45	**45**
Potential	31	31	31	**31**	41	42	45	45	45	**45**
Nest attempts	9	11	11	**31**	17	13	27	23(22)[b]	29	**109(108)**[b]
Occupied	9	11	10[d]	**--**	17	13	25[c,d]	23	27[d]	**--**
(Occupied/Potential)	29%	35%	32%	**32%**	41%	31%	56%	51%	60%	**48%**
Hatched	7	2	4	**13**	14	9	24	18	23	**88**
(Hatched/Nest attempts)	78%	18%	36%	**42%**	82%	69%	89%	82%	79%	**81%**
Depredated	2	8	6	**16**	1	2	0	0	2	**5**
(Depredated/Nest attempts)	22%	73%	55%	**52%**	6%	15%			7%	**5%**
Abandoned	0	1	1	**2**	2	2	3	4	4	**15**
(Abandoned/Nest attempts)		9%	9%	**6%**	12%	15%	11%	18%	14%	**14%**
Unknown Fate	0	0	0	**0**	0	0	0	1	0	**1**

[a]Includes one tagged site found in 2004, but destroyed by a landslide in winter 2004-05 and excluded from later analyses.

[b]One nest with an unknown fate was included in occupancy analyses but excluded from calculations of hatching success and rates of nest depredation and abandonment.

[c] A single egg on cave floor in 2005 was considered a nesting attempt for calculations of hatching success but was not tagged and was excluded from occupancy analyses in 2005 and later (*see methods*).

[d]Two nesting attempts by different pairs of adults occurred in some sites (*see methods*).

Table 3: Breeding indices for Xantus's Murrelets in sea caves at Anacapa Island prior to and after the eradication of Black Rats (2000-07).

	Pre-Eradication				**Post-Eradication**					
Nest Site Summary	2000	2001	2002	**2000-02**	2003	2004	2005	2006	2007	**2003-07**
Tagged & Monitored	13	15	16	**16**	24	25	27	28	31	**31**
Potential	31	31	31	**31**	31	31	31	31	31	**31**
Nest attempts	9	11	11	**31**	15	11	19	16(15)[a]	18	**79(78)**[b]
Occupied	9	11	10[d]	**--**	15	11	17[b,c]	16	18	**--**
(Occupied/Potential)	29%	35%	32%	**32%**	48%	35%	55%	52%	58%	**50%**
Hatched	7	2	4	**13**	12	8	16	12	16	**64**
(Hatched/Nest attempts)	78%	18%	36%	**42%**	80%	73%	84%	80%	89%	**82%**
Depredated	2	8	6	**16**	1	2	0	0	1	**4**
(Depredated/Nest attempts)	22%	73%	55%	**52%**	7%	18%			6%	**5%**
Abandoned	0	1	1	**2**	2	1	3	3	1	**10**
(Abandoned/Nest attempts)		9%	9%	**6%**	13%	9%	16%	20%	6%	**13%**
Unknown Fate	0	0	0	**0**	0	0	0	1	0	**1**

[a]One nest with an unknown fate was included in occupancy analyses but excluded from calculations of hatching success and rates of nest depredation and abandonment.
[b] A single egg on cave floor in 2005 was considered a nesting attempt for calculations of hatching success but was not tagged and was excluded from occupancy analyses in 2005 and later (*see methods*).
[c]Two nesting attempts by different pairs of adults occurred in some sites (*see methods*).

Table 4: Breeding indices for Xantus's Murrelets in cliff, shoreline and offshore rock plots at Anacapa Island (2003-07).

Nest Site Summary	2003	2004	2005	2006	2007
Tagged & Monitored	2	4[a]	9	11	14
Potential	10	11	14	14	14
Nest attempts	2	2	8	7	11[b]
Occupied	2	2	8	7	9
(Occupied/Potential)	20%	18%	57%	50%	64%
Hatched	2	1	8	6	7
(Hatched/Nest attempts)	100%	50%	100%	86%	64%
Depredated	0	0	0	0	1
(Depredated/Nest attempts)					9%
Abandoned	0	1	0	1	3
(Abandoned/Nest attempts)		50%		14%	27%

[a]Includes one tagged site found in 2004, but destroyed by a landslide in winter 2004-05 and excluded from later analyses.

[b]Two nesting attempts by different pairs of adults occurred in two sites (*see methods*).

Table 5: Initiation dates for Xantus's Murrelet nests at Anacapa Island in 2000-07.

Year	Mean Initiation Date	Standard Deviation	Range (Dates)	Range (Days)	No. of Nests
2000	30 Mar	11	16 Mar - 14 Apr	29	9
2001	13 Apr	15	25 Mar - 5 May	41	12
2002[a]	10 Apr	16	7 Mar - 3 May	57	11
2003	9 Apr	11	26 Mar - 5 May	40	23
2004	1 May	20	6 Apr - 3 Jun	58	12
2005[a]	2 May	14	11 Apr - 2 Jun	52	26
2006	17 May	24	8 Apr – 20 Jun	73	22
2007 [a]	20 May	29	18 Mar – 8 July	112	29

[a]Includes initiation dates for multiple nesting attempts in the same site.

Table 6: Use of specific monitored Xantus's Murrelet nest sites at Anacapa Island in 2000-07. Hatched nests are indicated by ●; failed nests by ○; and unknown fate by ● (grey). Shaded cells indicate years before monitoring was initiated in those plots.

Cave or Plot	Nest #	2000	2001	2002	2003	2004	2005	2006	2007	Years Active
Refuge	1		○				●	●	●	4
	3			○						1
	4	○	○							2
	5						●	●	●	3
Lava Bench 1	1	●		○	●	●	●(○[1])	● (grey)		6
	N1								●	1
	N2								○	1
Lava Bench 2	1	●	○	○	●	○	●	●	●	8
Respiring Chimney	1	●	●	○●	●	●	●●	●	●	8
	2		○	○	●		○			4
	3		○					●	●	3
Lonely at the Top	1				●	○				2
	2				●	●	●	●	●	5
	1111							●	●	2
Pinnacle	1		●							1
	2				●	○	●	●	●	5
	3a				●		○			2
	3b					●	●	○		3
	3c								●	1
Moss	1	●	○	●	●	●	●		●	7
	2	●	○	●	○	●	●	●	●	8
	3	○	○	●	●	●	●	●	●	8
	4				●		●	●	●	4
Aerie	1	●	○	○						3
	2				○					1
	3				●	●	●		●	4
	1101a						●	○		2
	1101b	●		○				○	●	4
Keyhole	1				○					1
	1103						●	●	○	3
Landing Cove	1				●					1
	2					●	●	●	●○	4
	1102						●	●		2
	1104						●		○●	2
	1105						●			1
	1106						●	●	●	3
	1109							●	●	2
	1110a							○		1
	1110b								○	1
Rockfall Cove	1107						●			1
	1108						●	●	●	3
	N1								○	1
	N2								●	1
East Fish Camp	1					○	Site Destroyed			1
Cat Rock	1				●		●	●	●	4

[1]Abandoned egg on cave floor near Nest 1was included in calculations of hatching success only (*see methods*).

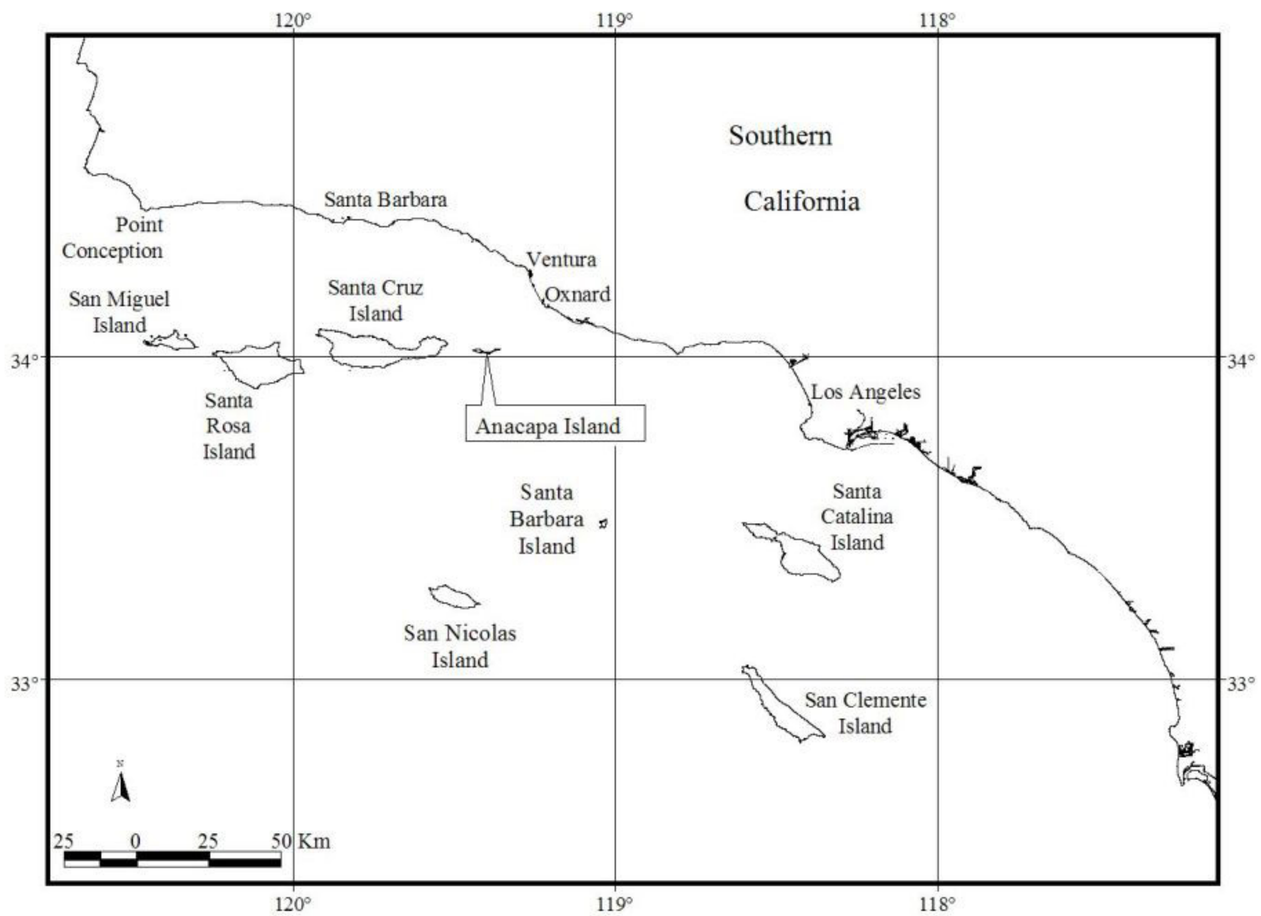

Figure 1. Location of Anacapa Island within the Southern California Bight.

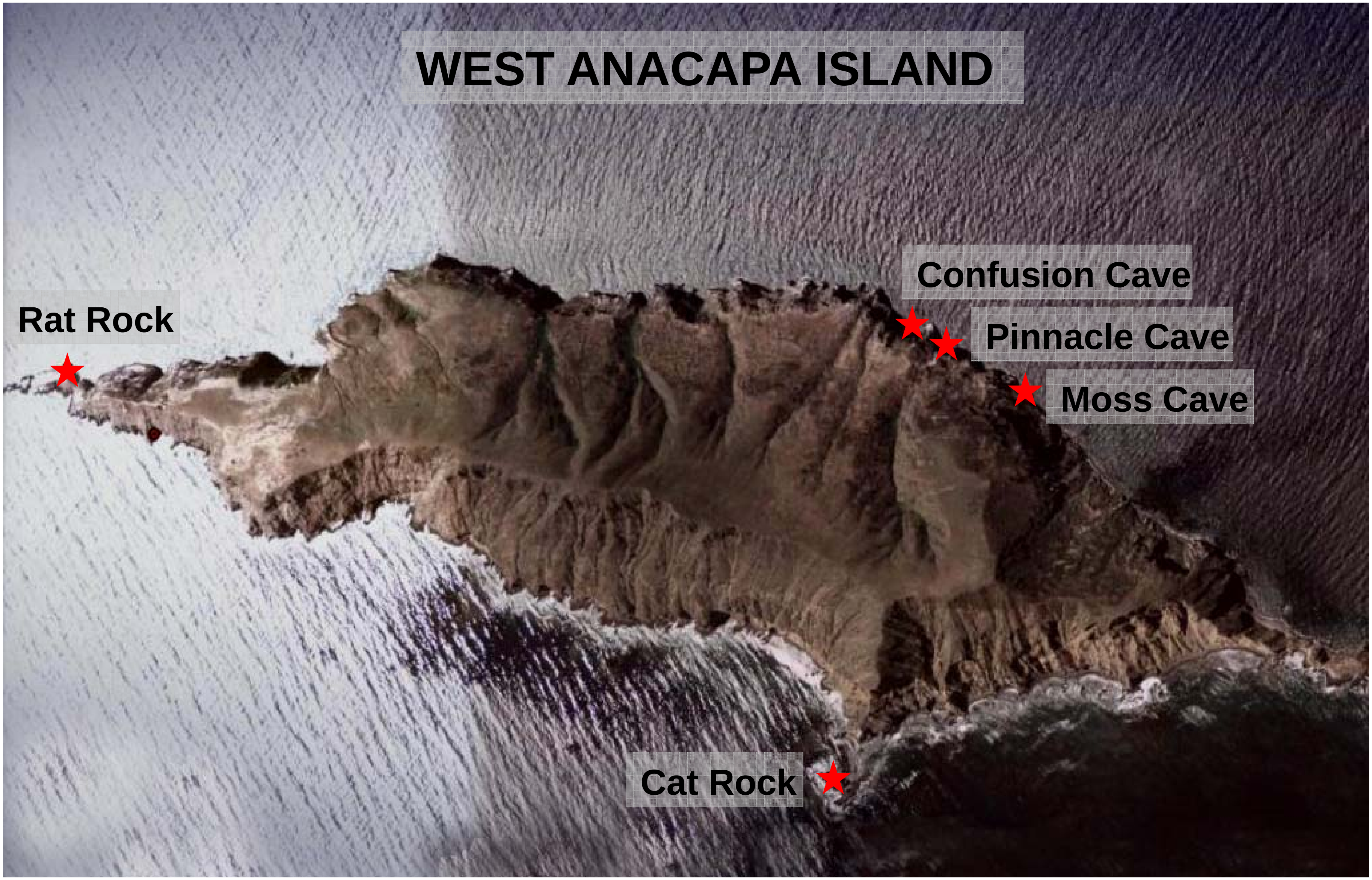

Figure 2. Satellite photograph of West Anacapa Island illustrating the location of sea caves and other areas where Xantus's Murrelet monitoring has been conducted from 2000-07.

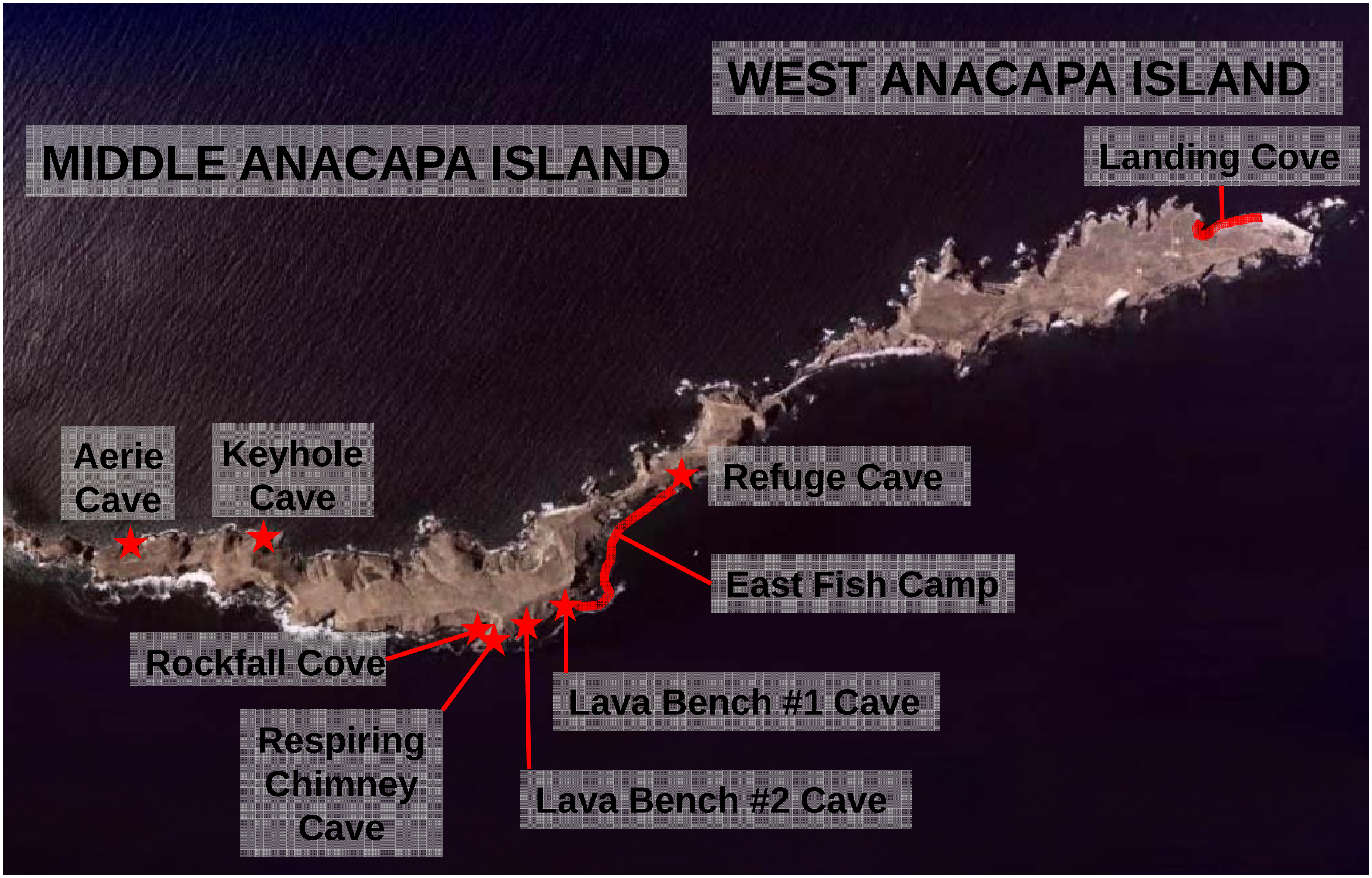

Figure 3. Satellite photograph of East and Middle Anacapa Islands illustrating the location of sea caves and other areas where Xantus's Murrelet monitoring has been conducted from 2000-07.

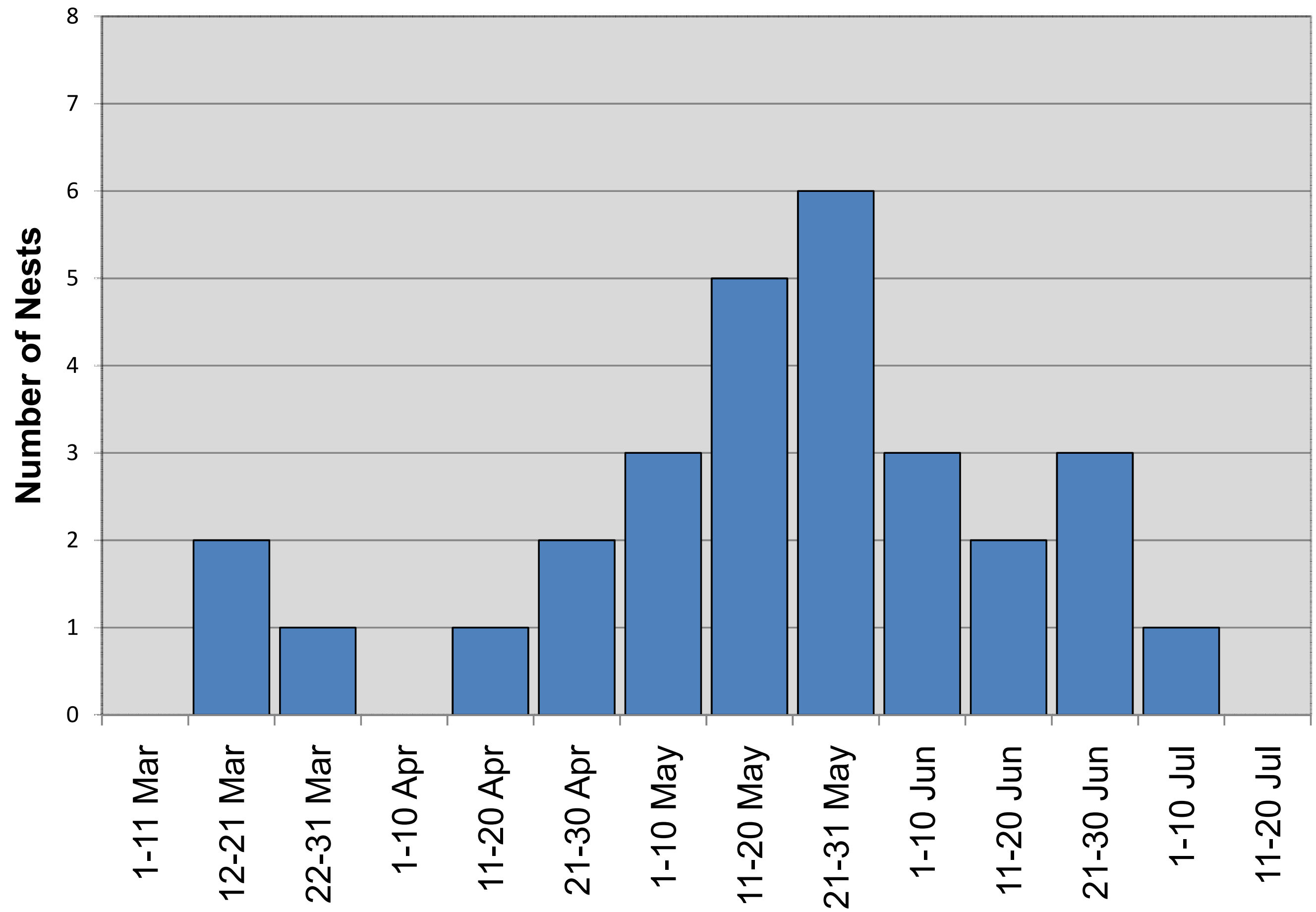

Figure 4. Distribution of nest initiation dates for Xantus's Murrelets at Anacapa Island in 2007.

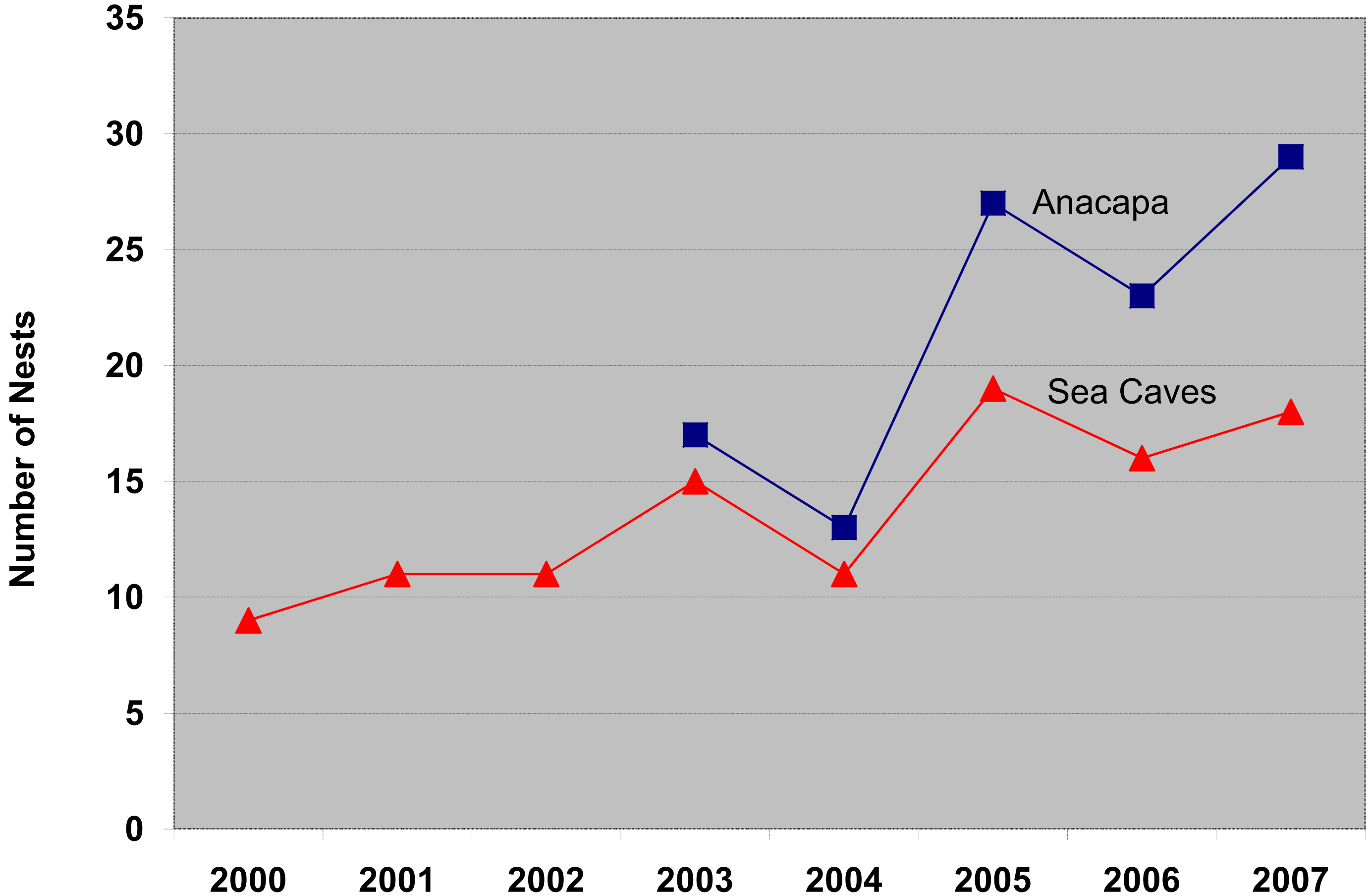

Figure 5. Numbers of Xantus's Murrelet nests initiated in sea cave sites (2000-07) and all monitored sites (2003-07) at Anacapa Island.

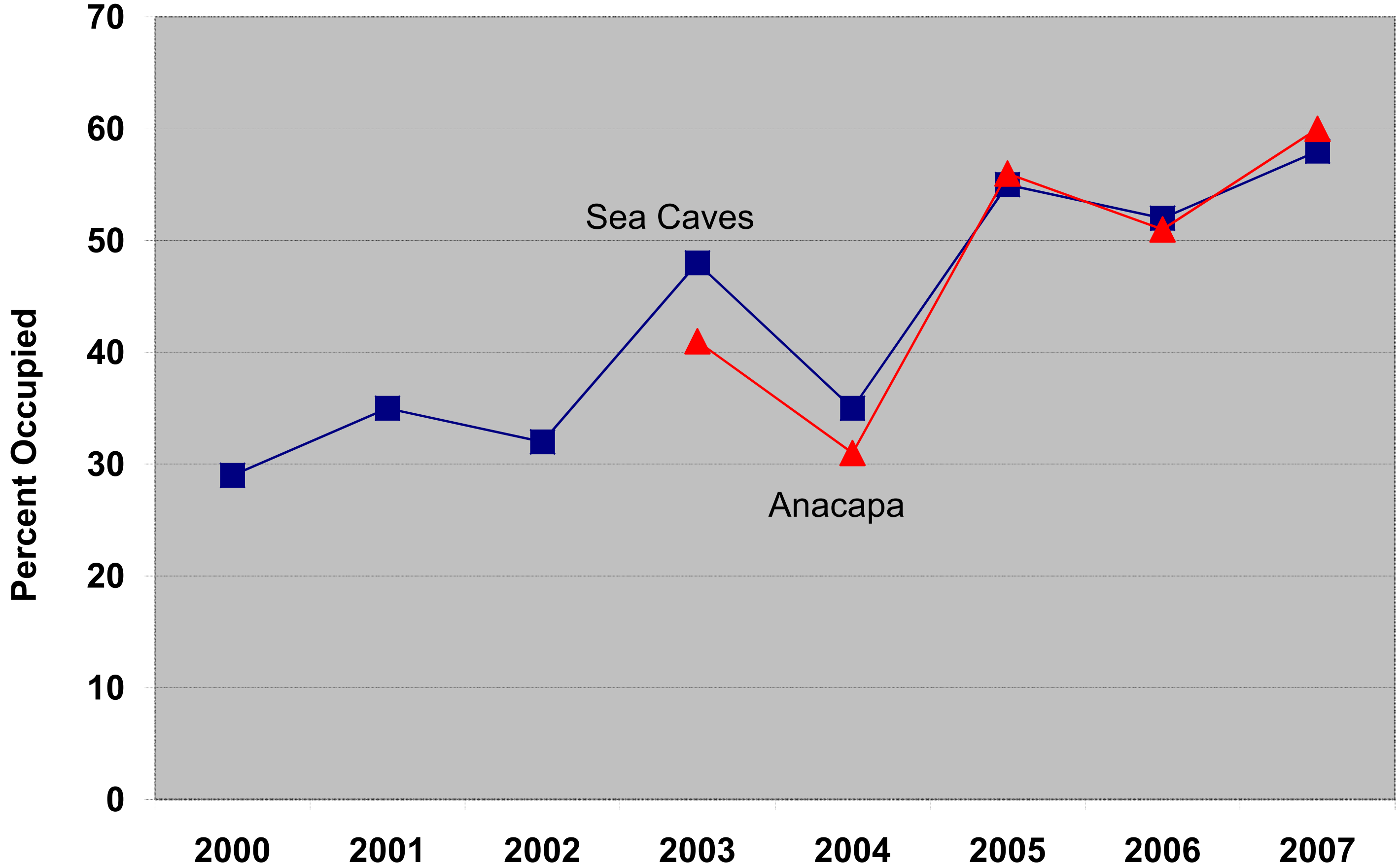

Figure 6. Xantus's Murrelet nest occupancy in sea caves sites (2000-07) and all monitored sites (2003-07) at Anacapa Island.

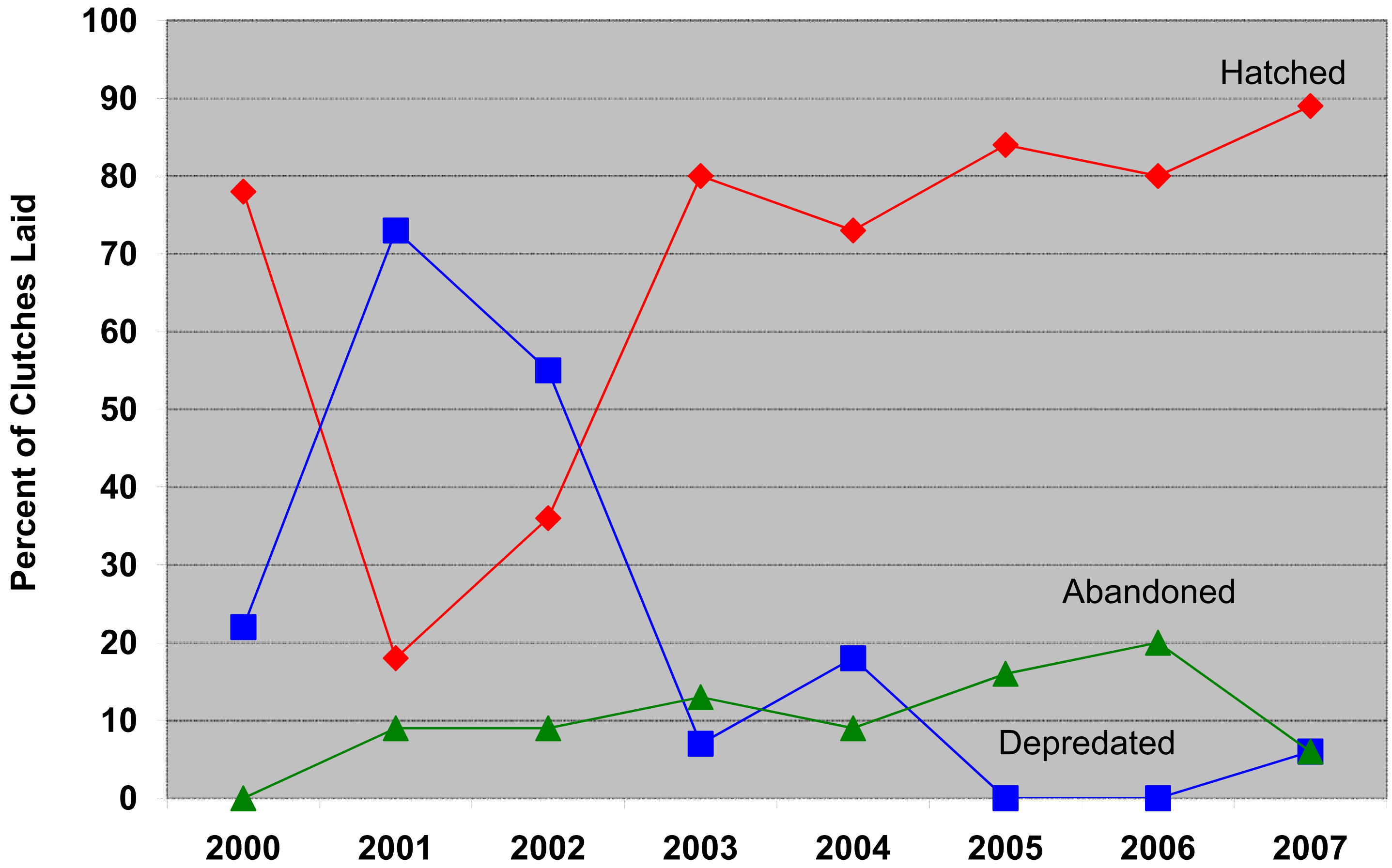

Figure 7. Hatching success and rates of nest depredation and abandonment for Xantus's Murrelets in sea caves at Anacapa Island in 2000-07.

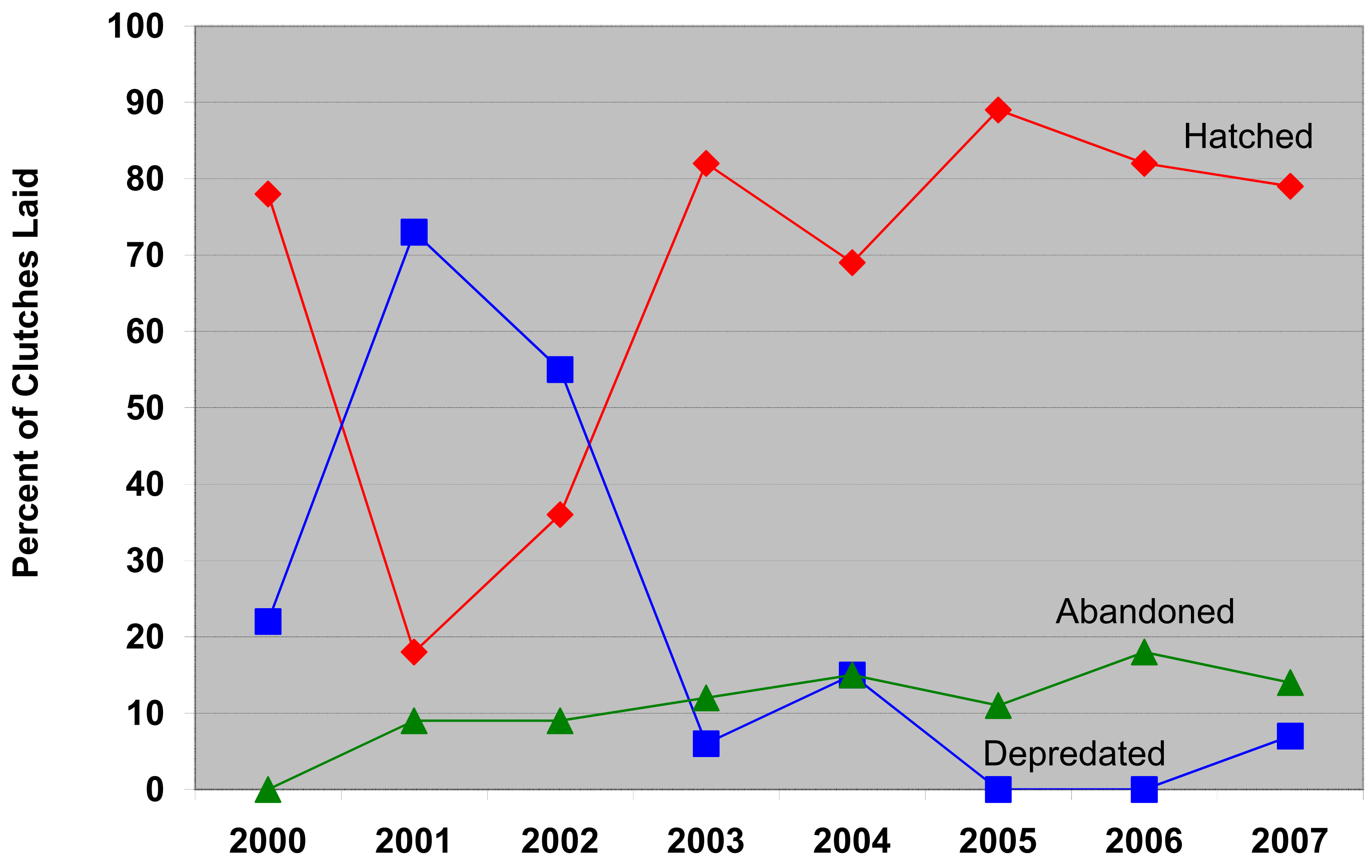

Figure 8. Hatching success and rates of nest depredation and abandonment in all monitored nest sites at Anacapa Island from 2000-07.

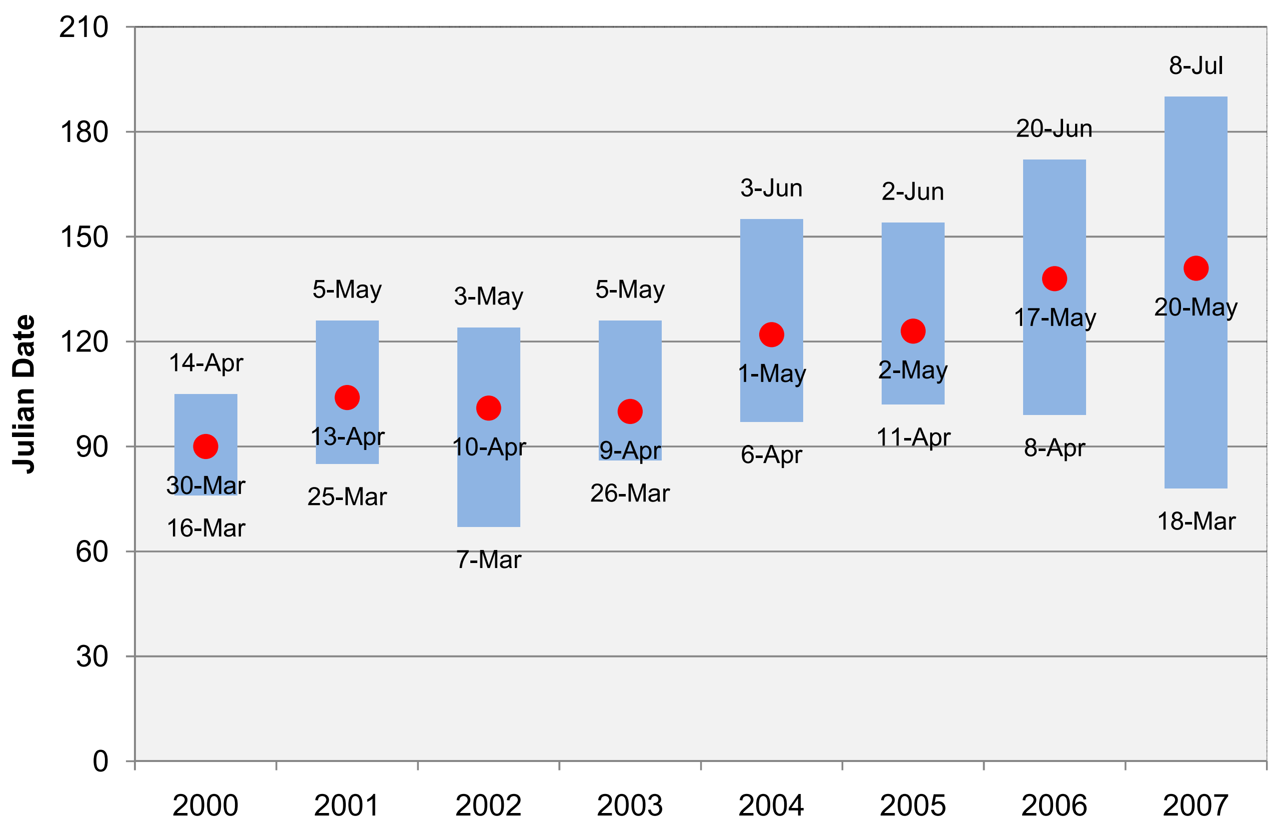

Figure 9. Annual mean and range of initiation dates for Xantus's Murrelet nests at Anacapa Island from 2000-07.