Nest Monitoring of Xantus's Murrelets at Anacapa Island, California: 2006 annual report

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EXECUTIVE SUMMARY

- In 2006, the California Institute of Environmental Studies conducted the seventh year (2000-06) of Xantus's Murrelet (*Synthliboramphus hypoleucus*) nest monitoring in sea caves and other selected plots in cliff-shoreline-offshore rock habitats at Anacapa Island, California. With support from the American Trader Trustee Council and Channel Islands National Park, monitoring was initiated in 2000 to provide data prior to eradication of Black Rats (*Rattus rattus*) from the island in 2001-02. In 2003-06, we have monitored the response of murrelets to the absence of rat predation for four years post-eradication.

- A slight decrease in murrelet nesting effort occurred in 2006 compared to the previous year: a) 16 active nests were recorded in sea caves and 7 nests in other island habitats, compared to 19 and 8 nests, respectively, in 2005; b) occupancy was 57% in sea caves and 64% in other plots, compared to 61% and 73%, respectively, in 2005; and 3) 3 new nests were discovered in 2006, compared to 8 new nests discovered in 2005.

- Murrelets continued to expand their nesting distribution into island habitats previously occupied by rats, with 2 new nests (both in Landing Cove) established in cliff-shoreline-offshore rock habitats in 2006, where none were known prior to 2003.

- Despite extremely late nesting in 2006, hatching success in sea caves (80%) and other sample areas (86%) was comparable to other post-eradication years (2003-05).

- We found no evidence of nest depredation by rats or endemic Deer Mice (*Peromyscus maniculatus anacapae*) in monitored murrelet nests or elsewhere at Anacapa in 2006.

- The mean nest initiation date in 2006 (17 May) was 15-48 days later than observed in 2000-05 (30 March – 2 May), while the range of laying dates in 2006 (73 d) was wider than in any previous year of monitoring (29-58 d). Timing of breeding from 2001-06 was negatively correlated with mean seasonal upwelling indices and positively correlated with mean seasonal sea surface temperatures in April-June.

- The number of monitored sites in sea caves has increased 75% since eradication, while the number of active nests has increased 48%. Hatching success in sea caves has nearly doubled post-eradication (80% in 2003-06 vs. 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. No mouse depredated nests were found pre-eradication and only 3 (5%) have been recorded post eradication.

- Eradication of rats from Anacapa has led to improved hatching success and colony growth that should eventually result in the development of a much larger colony in the future. While rat depredation was likely the primary factor detrimentally impacting the murrelet colony over the last century, anthropogenic and natural factors unrelated to rat depredation may reduce adult survival, nesting effort or hatching success in some years (e.g., 2004) and slow population recovery.

- Ongoing and expanded monitoring is needed to document continued recovery of Xantus's Murrelet at Anacapa Island.

INTRODUCTION

With funds from the *American Trader* oil spill settlement, the American Trader Trustee Council (ATTC), in league with Channel Islands National Park (CINP) sponsored a restoration program to enhance seabird breeding habitat on Anacapa Island, California, by eradicating non-native Black Rats (*Rattus rattus*) in 2001-02 (ATTC 2001, Howald et al. 2005). The Xantus's Murrelet (*Synthliboramphus hypoleucus*) was identified as the seabird species expected to benefit most from the Anacapa Island Restoration Program. The murrelet colony at Anacapa is thought to have 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 eventual loss of this important colony. In 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 species' probability of maintaining viable populations in California (Burkett et al. 2003).

Island Conservation and CINP successfully eliminated 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 Tershey 1998), little effort has been made to document the benefits of predator eradication for murrelets or other seabirds. To measure the effectiveness of rat eradication for the murrelet population at Anacapa Island, ATTC sponsored an experienced team of biologists from Humboldt State University, California Institute of Environmental Studies (CIES), Channel Islands National Marine Sanctuary (CINMS), and Hamer Environmental 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 breeding success prior to eradication; and b) to measure expected increases in murrelet population size and breeding success post eradication. From 2000-03, the team developed innovative population monitoring techniques which have provided reliable indices of murrelet population size and breeding success for measuring changes over time (Whitworth et al. 2003a, 2005; Hamer et al. 2005).

In 2004-05, budgetary constraints compelled ATTC to reduce funding for the Xantus's Murrelet population monitoring program. CIES was funded to continue nest searches and monitoring in sea caves and other cliff-shoreline-offshore rock habitats at Anacapa. Nest searches and monitoring in sample areas provide 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 distribution over time.

In 2006, 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 2006 marked the seventh consecutive year of Xantus's Murrelet nest monitoring and the fourth year of monitoring since eradication. In this report, we present the results of 2006 nest monitoring with comparison to previous years of monitoring.

METHODS

Study Area

Anacapa Island is the easternmost and smallest of the northern four California Channel Islands and sits just off the California mainland, 15 km southwest of Ventura (Fig. 1). It is comprised of three small islets (West, Middle, and East; Fig. 2) separated by narrow channels which are sometimes exposed at low tide. The narrow 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). West Anacapa is the largest (1.7 km^2) and highest (284 m) of the three islets, followed by Middle Anacapa (0.6 km^2, 99 m), and East Anacapa (0.5 km^2, 73 m). Anacapa Island is managed by CINP which maintains quarters for staff and facilities for campers, but the island is otherwise 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

We used the CINMS research vessel *Shearwater* for transportation to Anacapa Island and accommodations while at the island. All field work was conducted by DLW, JSK, HRC and volunteers from 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 provided by ATTC through CINP and CINMS. We used the Island Packer Inc. vessel *Vanguard* for transportation to Anacapa during single-day trips to check late nests on 30 July and 26 August, while the private charter boat *Miss Devin* assisted the final nest check on 23 September. Boats and personnel were supplied with all required safety equipment.

Nest Monitoring

In March-September 2006, we conducted nest searches and monitoring in 10 sea caves monitored in 2000-05 (Whitworth et al. 2002a,b; 2003a,b,c; 2004a,b; 2005a,b; Fig. 2). 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 26 March to 26 June. Only sites which were active on 26 June were further checked on 30 July, 26 August, or 23 September.

With limited funds and to account for extended nesting beyond June, we changed from the weekly survey schedule used in 2001-04 to biweekly checks in 2005-06. In 2000, nest checks also were conducted every 2-3 weeks. We considered biweekly checks to be the most efficient survey 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.

Systematic efforts to examine potential murrelet nesting areas in cliff, shoreline and offshore rock habitats began in 2003 and were continued and expanded in 2004-06 (Fig. 2). We used methods similar to sea cave nest monitoring to thoroughly search: 1) cliffs in Landing Cove on East Anacapa (2003-06); 2) Cat Rock off West Anacapa (2003-06); 3) shoreline areas on the south side of Middle Anacapa near East Fish Camp (2004-06); and 4) Rockfall Cove on the south side of Middle Anacapa (2005-06). 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 due to presence of rats.

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.

Hatching Success - Hatching success was determined as the percent of monitored nest sites where a “nesting attempt” occurred (i.e., a clutch of 1-2 eggs was laid) that successfully hatched at least one egg. Successful hatching was indicated by observations of chicks or freshly hatched eggshell fragments (identified by the dried or bloody membrane which separates from the shell) at the nest site. We used Chi-square analyses with Yates correction for 2 x 2 tables (χ^2_c) 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 possible hatching. 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). Nesting attempts were considered abandoned when whole unattended eggs were observed over two consecutive nest checks. Nests with unknown nest fates were excluded from calculations of hatching success and rates of nest depredation and abandonment.

Nest Occupancy - In 2006, we determined annual nest occupancy in sea caves as the percentage of the total monitored nest sites found in 2000-06 (regardless of when the site was first tagged) in which at least one egg was laid that year. This technique increases the comparability of occupancy rates between years. Potential nest sites were not tagged until some evidence of potential nesting was observed, although all habitat in sea caves was thoroughly searched each year. We believe that untagged sites in caves could reliably be presumed to have been unoccupied prior to tagging. 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 tentatively considered an active nest, but this "site" was excluded from analyses in 2006. We reconsidered our original evaluation of this "site" and now consider the egg to have been an abandoned "dump" egg laid by a murrelet pair with no intention of further incubation. An inspection of the general area where the egg was found indicated that the "site" was completely exposed and entirely unsuitable as a potential nest and the egg could not possibly have rolled or been moved from a nearby hidden nest.

Timing of Breeding - 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 2005-06, greater error was involved in this process than with weekly nest checks in 2001-04.

We used a one-way Analysis of Variance (ANOVA F) and LSD *post-hoc* comparisons to examine differences in timing of breeding among years in 2001-06. Data from 2000 was excluded from inter-annual comparisons of nesting phenology because a standardized monitoring schedule had not been implemented and accuracy of the data obtained during the sporadic nest checks was uncertain.

We used Spearman rank correlation (R) to examine relationships between timing of breeding and oceanographic conditions, characterized by sea surface temperature (SST) and coastal upwelling (Bakun Upwelling Index; BUI) for each year from 2001-06. We used hourly SST (C°) and daily BUI (m^3 s^{-1} 100 m coastline^{-2}) readings in February-June each year to calculate average SST and BUI values for combinations of consecutive months. First, we examined if relationships existed between oceanographic conditions and timing of breeding. Second, we examined which combination of months yielded strongest correlations. SST and BUI data were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Center (NDBC; www.nbdb.noaa.gov) and NOAA Pacific Fisheries Environmental Laboratory (www.pfeg.noaa.gov), respectively. SST data were obtained from NBDC buoy 46025 located in the Santa Monica Basin at 33°44'42" N and 119°05'02" W about 40 km southeast of Anacapa Island (Fig. 1). BUI data were obtained from the nearest standardized study area located at 33° N 119° W about 116 km south-southeast of Anacapa.

RESULTS

Nest Monitoring in 2006

Nesting Effort and Occupancy - In 2006, we monitored a total of 39 nest sites, including 28 sites in 10 sea caves and 11 sites in other habitats (Table 1). We found a total of 23 active murrelet nests, including 16 in sea caves and 7 in other habitats. Nesting was observed in: a) 9 of 10 (90%) monitored sea caves; b) all but one of other plots; c) 5 nests in the cliffs at Landing Cove on East Anacapa; and d) single nests on Cat Rock off West Anacapa and in Rockfall Cove along the shoreline of Middle Anacapa (Table 1).

A total of 3 new nests were found in 2006 (Table 2), including 1 at Lonely at the Top Cave and 2 in Landing Cove. Total occupancy was 59% (23 occupied sites/39 monitored sites; Table 2) for all monitored areas, 57% (16 occupied/28 monitored sites) in sea caves (Table 3) and 64% (7 occupied/11 monitored sites) in other plots (Table 3).

Nesting Success - Overall hatching success per nest (excluding nests with unknown fates) was 82% (18 hatched/22 nests; Table 2). Hatching success per nest was 80% (12 hatched/15 nests; Table 3) in sea caves and 86% (6 hatched/7 nests; Table 3) in other plots. One site with an unknown nest fate was the last murrelet nest initiated in 2006 (on about 20 June). We found a single egg in the site on 26 June, but we were not able to inspect the site again until 23 September, when only small eggshell fragments were present.

Only four failed nests (18%) were recorded at Anacapa in 2006, all due to abandonment (Tables 1, 2). We did not document depredated eggs in any monitored sites or elsewhere at Anacapa in 2006. Nest failure (and abandonment) rates were 20% in sea caves and 14% in other sample areas (Table 3).

Timing of Breeding - Murrelet nests were initiated over 73 days between 8 April and 20 June, with a mean nest initiation date of 17 May (± 24 d; Table 4, Fig. 3). Nesting occurred in two distinct periods, April and mid-May through mid-June. Peak egg laying occurred in early June when nearly half (45%) of all nests were initiated, with a much weaker early season peak in mid-April.

Inter-Annual Comparisons in Sea Caves (2000-06)

Nesting Effort and Occupancy - We discovered 1 new nest site in sea caves in 2006, which is consistent with most previous years. The total number of monitored sites has increased from 13 sites in 2000 to 28 sites in 2006, with general increases of 1-2 sites per year, except for 2003 (the first murrelet breeding season after eradication) when an increase of 8 sites occurred over 2002 (Tables 2, 3). Overall, the number of monitored sites in sea caves has increased 75% post-eradication, from 16 sites in 2002 to 28 sites in 2006 (Table 5).

Despite very late breeding in 2006 and slightly lower nesting effort compared to 2005 (-3 nests), we recorded the second highest nesting effort (16 nests) and occupancy (57%) in sea caves since monitoring began in 2000 (Tables 2, 3; Fig. 4). Numbers of active nests increased 48% between pre-eradication years of 2000-02 (0 = 10.33 nests/year) and post-eradication years of 2003-06 (0 = 15.25 nests/year). Nest occupancy was consistently low pre-eradication (0 = 36%), but has increased markedly post-eradication (0 = 53%; Table 5).

Nesting Success - Hatching success (80%) and nest failure rates (20%) in sea caves in 2006 were comparable to previous post-eradication years in 2003-05 when hatching success was consistently high (range 73-84%) and nest failure low (range 16-27%; Table 3; Fig. 4). Overall hatching success (excluding nests with unknown fates) in sea caves post-eradication in 2003-06 (80%; 48 hatched/60 nests) has been much higher (P^2_c = 11.73, $P < 0.005$) than pre-eradication (42%; 13 hatched/31 nests). Correspondingly, the overall nest failure rate has been much lower post-eradication (20%; 12 failed nests) compared to pre-eradication (58%; 18 failed nests; Table 5).

We recorded higher rates of nest abandonment in 2006 (20%) than in any previous year from 2000-05 (0-16%; Table 3). Nest failure post-eradication in 2003-06 has been primarily due to abandonment (75%; 9 abandoned/12 failed nests), with only small numbers of depredated nests (25%; 3 depredated/12 failed nests). No depredated nests were noted in 2005 or 2006. A missing egg in 2003 and two depredated nests in 2004 were attributed to depredation by endemic Deer Mice (*Peromyscus maniculatus anacapae*) but also may reflect scavenging by mice after abandonment. With weekly or biweekly checks, we may not detect abandonment until after eggs have been scavenged by mice. In contrast, nest failures pre-eradication were primarily due to depredation by rats (89%; 16 depredated/18 failed nests), with highest depredation rates (73% and 55%) in 2001 and 2002, respectively (Table 3). We assume that rats have a greater ability than mice to actively take eggs or kill adults during active incubation and that rat depredation rates reflect true depredation and not scavenging, although they may have scavenged a few abandoned eggs.

Colony Expansion (2003-06)

Post eradication (2003-06), a total of 19 nesting attempts in 12 monitored nest sites were discovered during nest searches in non-seacave areas, where none were known prior to 2003 (Table 3). 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.

Nest occupancy in monitored nest sites outside sea caves was low in 2003 and 2004 (22% and 20%, respectively) but increased markedly in 2005 (73%) and 2006 (64%; Table 3). Nearly all (89%) nesting attempts in these plots hatched, and none were depredated. The only failed nesting attempts in non-sea cave habitats were both abandoned; one in East Fish Camp in 2004 and another in Landing Cove in 2006.

Timing of Breeding (2000-06)

Mean nest initiation dates ranged from 30 March (± 11 d) in 2000 to 17 May (± 24 d) in 2006 (Table 4), with the earliest individual lay date occurring in 2002 (7 March) and the latest in 2006 (20 June). The widest range of lay dates occurred in 2006 (73 days), while the narrowest occurred in 2000 (29 days).

Excluding data from 2000 (*see methods*), timing of breeding differed significantly among years (ANOVA $F_{5,100} = 15.86$; $P < 0.0001$), with murrelet nests initiated later in 2006 than in any previous year from 2001-05 (LSD test; all $P < 0.01$; Table 4). Timing of breeding was similar between 2004 and 2005 and among years in 2001-03 (all $P > 0.43$). Breeding was later in 2004-05 compared to 2001-03 (all $P < 0.01$).

Timing of breeding in 2001-06 was most strongly correlated with mean April-June BUI (Spearman $R = -0.99$, $P < 0.0005$) and SST (Spearman $R = 0.90$, $P < 0.02$) each year (Fig. 5).

Nesting in Individual Sites

Four of 39 monitored sites in sea caves had active nests in each year from 2000 to 2006 and 2 other sites had active nests in 6 of 7 years of nest monitoring (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 about half (46%) of all active nests and about half (51%) of all hatched nests documented in sea caves in 2000-06.

In contrast, five nests were active in only one year (Table 6). Four of these sites were inactive over the last 3-5 years, but 1 site was new in 2006 (Table 6). An additional 7 nests were active only 2 years, although 3 were new sites in 2005 and were active in 2006. Only one site, a nest marked in Refuge Cave in 1994 was not active in any year from 2000-06.

Nine sites had active nests in 3-4 of 7 monitoring years (Table 6). Three of these sites were new nests in 2003 or 2004 and have been mostly active since first noted. Nesting in 2 sites in Aerie Cave occurred over consecutive 3-year spans in 2000-02 (nest #1) and 2003-05 (nest #3). We cannot discount the possibility that individuals moved from nest #1 to nest #3 in 2003 after the former site was usurped by Pigeon Guillemots (*Cepphus columba*). Nesting was sporadic in the remaining 4 sites with gaps as long as 3 years between some nesting efforts.

Few years of monitoring data from other plots are available to examine nesting activity in individual sites. Only one site has been active every year since monitoring began in that plot, a nest in Rockfall Cove active in 2005 and 2006. However, single sites in Landing Cove and on Cat Rock have been active for 3 of 4 years between 2003 and 2006.

DISCUSSION

Xantus's Murrelet Recovery at Anacapa Island

Despite extremely late nesting in 2006, strong evidence of continued improvement in reproductive success and colony growth were obtained at Anacapa Island in 2006, 4 years after eradication of Black Rats in December 2002. All indices of murrelet nesting effort and breeding success in sea caves in 2006 were better than or equal to other post-eradication years, with high numbers of active nests (18 nests), high nest occupancy (57%), high hatching success (80%) and few depredated nests (0%). Pre-eradication and post-eradication comparisons in sea caves continued to provide convincing evidence of beneficial effects of rat eradication for Anacapa murrelets. Post-eradication (2003-06), murrelet nesting effort has increased 48%, hatching success has nearly doubled, and nest 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 continued increase in nesting documented in Landing Cove from 2003-06 best illustrates this colony expansion in accessible monitoring areas. We suspect that similar recolonization and increase in numbers of nesting birds are occurring widely in cliff, shoreline and upper-island habitats on East, Middle and West Anacapa.

Cliffs and cliff tops in Landing Cove were virtually devoid of nesting murrelets prior to eradication, with evidence of just one depredated egg found in 1997 (Carter et al. 1992, unpubl. data; McChesney et al 2000, Whitworth et al. 2003a). The first active nest in several decades was discovered in Landing Cove in 2003. Only one active nest was found in 2004, but the number of nests increased markedly to 5 in both 2005 and 2006. Nests in Landing Cove have also been remarkably successful, with 11 (92%) hatched nests and only one failed (abandoned) nest.

The only negative trend observed in recent years has been an increase in the number of abandoned nests, although the perceived increase may have resulted from mistakenly classifying some pre-eradication nests as depredated, when in fact the nest was abandoned before eggs were scavenged by predators. Increased post-eradication abandonment could have resulted from: 1) relatively poor foraging conditions (especially in 2004-06; *see below*); 2) a greater proportion of nesting attempts by first-time breeders; or 3) predation on breeding adults. We can rule out disturbance from our monitoring activities because we have yet to cause any incubating adults to flush or move off eggs during monitoring and we reduced visitation frequency in 2005-06. Incubating murrelets were never observed in 8 of 13 abandoned nests found in 2000-06, while Pigeon Guillemots usurped 1 of 5 other nests where an incubating adult was observed prior to abandonment. Abandonment prior to incubation is likely indicative of poor prey availability for adults within foraging distance of the colony early in the breeding season, as also found in the Ancient Murrelet (*S. antiquus*; Gaston 1992).

Considering increased nesting efforts in sea caves and expansion of habitats used in 2003-06, detectable increases in overall population size of Xantus's Murrelets at Anacapa Island may occur sooner than anticipated. We did not expect detectable increases for several years, because *Synthliboramphus* murrelets have relatively low reproductive rates and juvenile survival, strong natal philopatry, and delayed sexual maturity (Murray et al. 1983; Gaston 1992, Drost and Lewis 1995; Gaston and Jones 1998). While high hatching success post-eradication likely has produced strong potential cohorts, particularly in 2003 and 2005, only a small proportion of chicks that depart from the colony are expected to return to breed at the colony 3-4 years later. The first major recruitment of chicks produced post-eradication (i.e., that portion of chicks fledged in 2003 and bred at 3 years of age or younger) likely occurred in 2006. Most increase up to 2006 mainly involved changes in breeding by the pre-eradication population. We expect that greater increases will occur in future years, once greater recruitment occurs from post-eradication chick production. However, we are concerned that increasing abandonment rates for several consecutive years may signal an extended period of poor prey availability which could slow or stop colony growth. On the other hand, if prey availability remains adequate, enhanced breeding conditions should continue to foster colony growth over the foreseeable future.

Murrelet Breeding and the Marine Environment

A reasonable understanding of relationships between murrelet breeding, prey availability, colony factors, and anthropogenic factors is necessary to best interpret monitoring data and murrelet recovery on Anacapa. Murrelets, like many seabirds, inhabit a variable marine environment where the interactions of diverse oceanographic, biologic and anthropogenic factors (e.g., mouse and raptor predation, prey availability, El Nino-Southern Oscillation [ENSO] events, light pollution and potential oil spills) result in significant year-to-year fluctuations in nesting effort and productivity (Harris and Birkhead 1985, Gaston and Jones 1998). Correlations between timing of breeding and oceanographic conditions have demonstrated how factors unrelated to rat depredation will play an important role in recovery of the Anacapa murrelet colony. In 2004 and 2006, years characterized by highest SSTs and lowest BUIs during the 2000-06 period, we noted reduced nesting effort, significantly delayed nesting (Fig. 5), and decreased hatching success (2004 only; Fig. 6) compared to 2003 and 2005. As observed in 2004 and to a lesser extent in 2006, occasional poor reproductive seasons will occur and slow the rate of population recovery, but it is unclear how frequently such years will occur in the future.

Various mechanisms can link seabird breeding parameters with indices of physical oceanography. In general, increased upwelling and flow from the California Current transports cool, nutrient rich waters into the Southern California Bight, resulting in increased primary and secondary productivity and ultimately greater seabird prey abundance (Chelton et al. 1982). We found that murrelets nested significantly earlier during the first four years of monitoring (2000-03) when cooler SSTs and increased upwelling were prevalent in the Southern California Bight. While hatching success was generally low during this period, rat depredation certainly caused or at least contributed to unnaturally low hatching success prior to eradication. In contrast, murrelets nested early and had high hatching success in 2003; the only year marine conditions were favorable for high prey availability post-eradication. In 2004-06, marine conditions were characterized by warmer ocean temperatures and reduced upwelling which led to later breeding and relatively low nesting effort in 2004 and 2006. However, hatching success was not affected and was generally high in the absence of rat depredation in 2004-06.

Using nest monitoring data at Santa Barbara Island, Hunt and Butler (1980) and Roth et al. (2005) also found strong relationships between timing of murrelet breeding and marine conditions. Roth et al. (2005) further found weak relationships between available indices of prey abundance and breeding parameters. This result is not surprising given that prey availability for breeding murrelets at each colony is affected by many factors, in addition to general prey abundance indices. With only 4 years of limited monitoring data without the confounding effects of rat depredation in 2003-06, we have chosen to not examine statistical relationships between marine conditions and breeding parameters (i.e., nesting effort and hatching success) at this time, but intend to conduct such analyses in the future if sufficient suitable data can be obtained.

Protection of Sensitive Breeding Areas

Nest monitoring and searches have identified several critical areas which merit special protection during the murrelet breeding season. Existing protection for Moss Cave (with 4 nests and 23 nesting attempts since 2000) should be sufficient, as this cave lies in the California Brown Pelican closure area on the north side of West Anacapa Island. Pinnacle Cave, on the north side of West Anacapa, also is also located within this protected area. However, 3 adjacent caves (Lava Bench #1, Lava Bench #2 and Respiring Chimney Caves with 29 nesting attempts since 2000) on the south side of Middle Anacapa currently have no measures in place to prevent public access. These 3 caves are very accessible to humans in kayaks or other boats under favorable ocean conditions and harbor several nests in very open sites which offer little or no shelter from unaware visitors (Fig. 7). Four other caves also have hosted nesting murrelets over the past 2-4 years and have no measures in place to prevent public access. We suggest that CINP should develop a plan to greater protection of these caves that involves posting signs inside caves, ranger patrols of cave areas, and education, especially for kayakers, to not land in any of these caves throughout the year. In Respiring Chimney Cave, a dangerous drop-off also exists which may cause bodily injury to an unsuspecting visitor.

Most new sites established in Landing Cove occur in a small area directly across the cove from the loading dock which has heavy human traffic from park visitors and staff. These fragile slopes are currently off-limits, but the upper slopes are readily accessible to most visitors and the lower slopes to moderately skilled climbers. We have observed some evidence of limited human visitation to the Landing Cove cliffs and it is possible that certain people may observe us during monitoring activities on these slopes and wish to do the same. Educational signs informing visitors of the presence of murrelets, human safety concerns, and off-limit areas are desirable.

Future Murrelet Monitoring at Anacapa

The ATTC and CINP intend to provide funds to CIES for at least one more year of the nest monitoring at Anacapa Island in 2007. While existing funds may be exhausted after 2007, continued funding may be derived from other sources. We suggest that nest monitoring should continue annually to continue to provide comparable data to 2000-06 for effective documentation of improvement in breeding conditions at Anacapa Island during the early period of colony restoration. During this period, the colony is still greatly reduced and susceptible to impacts from poor prey availability and anthropogenic factors. Evidence of substantial population increase is desirable prior to stopping annual nest monitoring.

As a first step in gathering such evidence, we suggest that much wider surveys of accessible upper island and shoreline habitats of East, Middle and West Anacapa should be conducted in 2008 or later to determine the extent to which murrelets and other seabirds are using previously unoccupied habitats. To prevent disturbance to other sensitive seabird species, surveys of upper habitats at Middle and West Anacapa will need to be conducted in the fall, after Brown Pelicans (*Pelecanus occidentalis*), Double-crested Cormorants (*Phalacrocorax auritus*) and Brandt's Cormorants (*Phalacrocorax penicillatus*) have finished breeding (McChesney et al. 2000). These surveys should involve searches for murrelet and Cassin's Auklet (*Ptychoramphus aleuticus*) nests (with eggshell fragments) and limited mist-netting for storm-petrels (*Oceanodroma* sp.) to provide minimal baseline data for assessing future changes. If substantial increases of murrelets are suggested from these expanded surveys, spotlight and radar surveys (Whitworth et al. 2003a; Hamer et al. 2005) are warranted to determine 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 2006.

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	1	1	1	0	0	0	1
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	4	2	2	1	0	1	0
Moss	4	3	3	3	0	0	0
Aerie	5	2	2	0	0	2	0
Keyhole	2	1	1	1	0	0	0
Sea Cave Total	28	16	16	12	0	3	1
Cat Rock	1	1	1	1	0	0	0
Rockfall Cove	2	1	1	1	0	0	0
East Fish Camp[1]	0	0	0	0	0	0	0
Landing Cove	8	5	5	4	0	1	0
Shoreline Total	11	7	7	6	0	1	0
Anacapa Total	39	23	23	18	0	4	1

[1]One monitored site in this area was destroyed by a landslide during storms over the winter 2004-05.

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 (Sea Caves Only)				Post-Eradication Year (Sea Caves + Other Areas)				
Nest Site Summary	2000	2001	2002	**2000-02**	2003	2004	2005	2006	**2003-06**
Tagged & Monitored	13	15	16	**16**	26	29[a]	36	39	**39**
Potential	28	28	28	**28**	37	38	39	39	**39**
Nest attempts	9	11	11	**31**	17	13	27	23 (22)[b]	**80 (79)**[b]
Occupied	9	11	10[d]	**--**	17	13	25[c,d]	23	**--**
(Occupied/Potential)	32%	39%	36%	**36%**	46%	34%	64%	59%	**51%**
Hatched	7	2	4	**13**	14	9	24	18	**65**
(Hatched/Nest attempts)	78%	18%	36%	**42%**	82%	69%	89%	82%	**82%**
Depredated	2	8	6	**16**	1	2	0	0	**3**
(Depredated/Nest attempts)	22%	73%	55%	**52%**	6%	15%	0%	0%	**4%**
Abandoned	0	1	1	**2**	2	2	3	4	**11**
(Abandoned/Nest attempts)	0%	9%	9%	**6%**	12%	15%	11%	18%	**14%**
Unknown Fate	0	0	0	**0**	0	0	0	1	**1**

[a]Includes one tagged site 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]Open site on cave floor with a single egg in 2005 was included as an active site that year, although the egg was abandoned and likely never incubated. This site was included for calculations of hatching success but was not tagged and was excluded from occupancy analyses.

[d]Two nesting attempts in one site (*see methods*).

Table 3: Breeding indices for Xantus's Murrelets in sea caves (2000-06) and cliff-shoreline-offshore rock habitats (2003-06) at Anacapa Island.

	SEA CAVES							OTHER AREAS			
Nest Site Summary	2000	2001	2002	2003	2004	2005	2006	2003	2004	2005	2006
Tagged & Monitored	13	15	16	24	25	27	28	2	4[a]	9	11
Potential	28	28	28	28	28	28	28	9	10	11	11
Nest attempts	9	11	11	15	11	19	16 (15)[b]	2	2	8	7
Occupied	9	11	10[d]	15	11	17[c,d]	16	2	2	8	7
(Occupied/Potential)	32%	39%	36%	54%	39%	61%	57%	22%	20%	73%	64%
Hatched	7	2	4	12	8	16	12	2	1	8	6
(Hatched/Nest attempts)	78%	18%	36%	80%	73%	84%	80%	100%	50%	100%	86%
Depredated	2	8	6	1	2	0	0	0	0	0	0
(Depredated/Nest attempts)	22%	73%	55%	7%	18%	0%	0%	0%	0%	0%	0%
Abandoned	0	1	1	2	1	3	3	0	1	0	1
(Abandoned/Nest attempts)	0%	9%	9%	13%	9%	16%	20%	0%	50%	0%	14%
Unknown Fate	0	0	0	0	0	0	1	0	0	0	0

[a]Includes one tagged site 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]Open site on cave floor with a single egg in 2005 was included as an active site that year, although the egg was abandoned and likely never incubated. This site was included for calculations of hatching success but was not tagged and was excluded from occupancy analyses.

[d]Two nesting attempts in one site (*see methods*).

Table 4: Initiation dates for Xantus's Murrelet clutches at Anacapa Island in 2000-06. Asterisks denote groups of years with no significant differences (LSD test, $P > 0.05$) in timing of breeding. Data from 2000 were excluded from inter-annual comparisons (*see methods*).

Year	Nest Initiation Date Mean (± sd)	Range (Dates)	Range (Days)	Nests
2000	30 Mar (± 11 d)	16 Mar - 14 Apr	29	9
2001	13 Apr (± 15 d)*	25 Mar - 5 May	41	12
2002[a]	10 Apr (± 16 d)*	7 Mar - 3 May	57	11
2003	9 Apr (± 11 d)*	26 Mar - 5 May	40	23
2004	1 May (± 20 d)**	6 Apr - 3 Jun	58	12
2005[a]	2 May (± 14 d)**	11 Apr - 2 Jun	52	26
2006	17 May (± 24 d)***	8 Apr – 20 Jun	73	22

[a]Includes lay dates for two nesting attempts in the same site in Respiring Chimney Cave in 2002 and 2005.

Table 5: Comparison of breeding indices for Xantus's Murrelets in sea caves prior to (2000-02) and after (2003-06) the eradication of Black Rats from Anacapa Island.

	2000-02	2003-06
Tagged & Monitored	16	28
Potential	28	28
Nest attempts	31[a]	61 (60)[a,b]
Occupied (Occupied/Potential)	-- 36%	-- 53%
Hatched (Hatched/Nest attempts)	13 42%	48 80%
Depredated (Depredated/Nest attempts)	16 52%	3 5%
Abandoned (Abandoned/Nest attempts)	2 6%	9 15%
Unknown Fate	0	1

[a]Includes two clutches in the same site in Respiring Chimney Cave in 2002 and 2005.

[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.

Table 6: Use of specific monitored nest sites of Xantus's Murrelet nest site at Anacapa Island in 2000-06. Active nests are indicated by letter A; inactive sites are blank. Shaded cells for cliff-shoreline-offshore rock plots indicate years before monitoring was initiated in those plots.

Cave or Plot	Nest #	2000	2001	2002	2003	2004	2005	2006	Years Active
Refuge	1		A				A	A	3
	2								0
	3			A					1
	4	A	A						2
	5						A	A	2
Lava Bench 1	1	A		A	A	A	A	A	6
Lava Bench 2	1	A	A	A	A	A	A	A	7
Respiring Chimney	1	A	A	A[1]	A	A	A[1]	A	7
	2		A	A	A		A		4
	3		A					A	2
Lonely at the Top	1				A	A			2
	2				A	A	A	A	4
	1111							A	1
Pinnacle	1		A						1
	2				A	A	A	A	4
	3a				A		A		2
	3b					A	A	A	3
Moss	1	A	A	A	A	A	A		6
	2	A	A	A	A	A	A	A	7
	3	A	A	A	A	A	A	A	7
	4				A		A	A	3
Aerie	1	A	A	A					3
	2				A				1
	3				A	A	A		3
	1101a						A	A	2
	1101b	A		A				A	3
Keyhole	1				A				1
	1103						A	A	2
Landing Cove	1				A				1
	2					A	A	A	3
	1102						A	A	2
	1104						A		1
	1105						A		1
	1106						A	A	2
	1109							A	1
	1110							A	1
Rockfall Cove	1107						A		1
	1108						A	A	2
East Fish Camp	1					A			1
Cat Rock	1				A		A	A	3

[1]Two nesting attempts in one site (*see methods*).

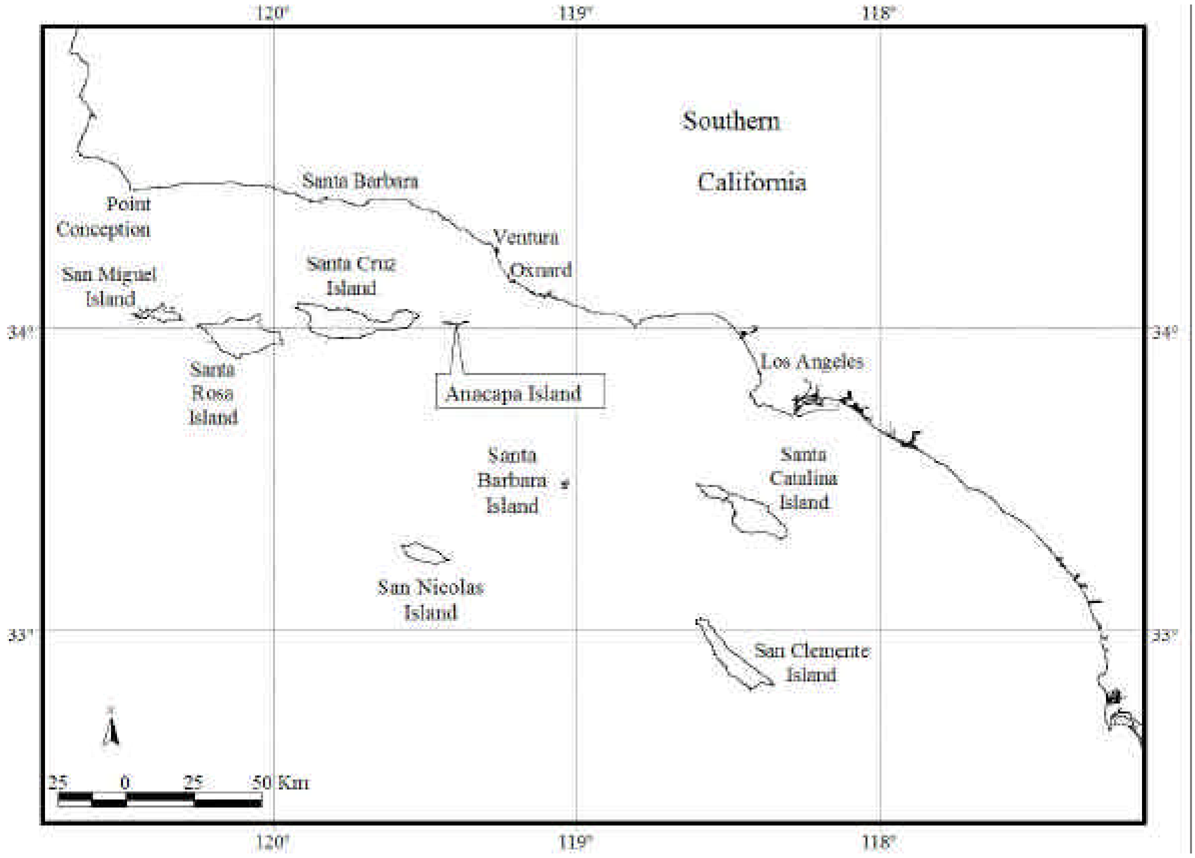

Figure 1. Map of the Southern California Bight and Channel showing the location of Anacapa Island.

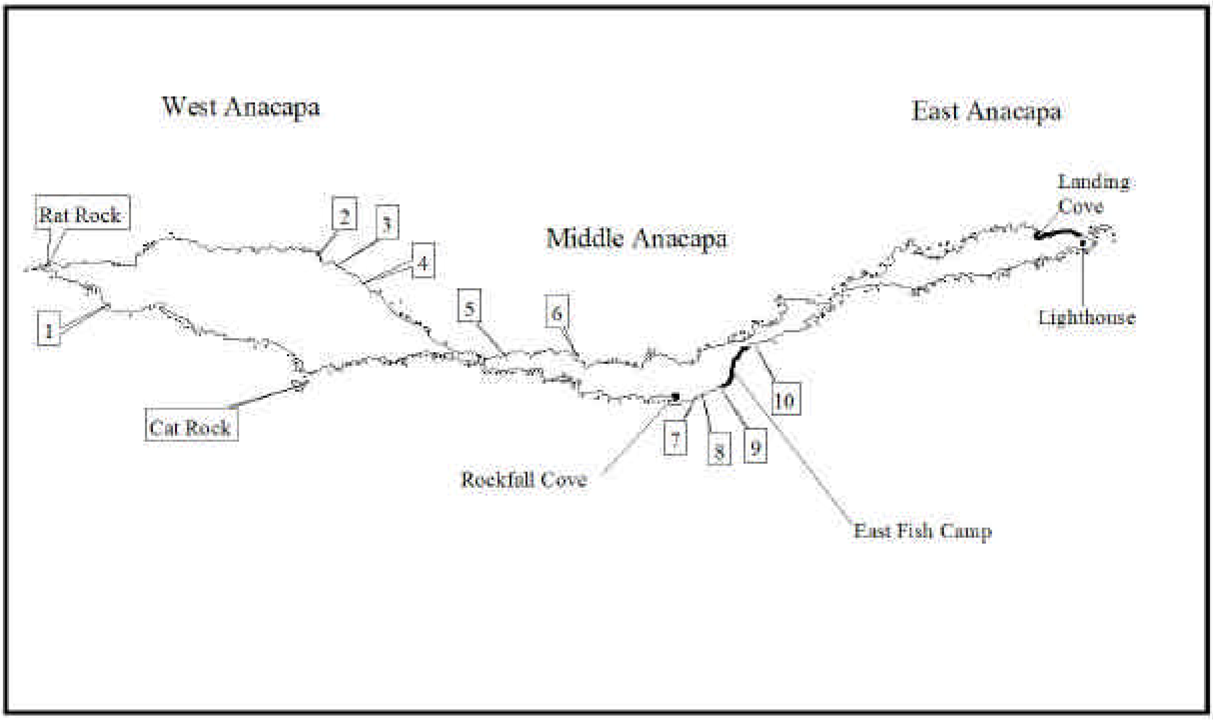

Figure 2. Map of Anacapa Island indicating ten sea caves monitored in 2000-2006 and Cat Rock, Rat Rock and other areas (black outline) monitored in 2003-06. Sea caves are numbered: 1) Lonely at the Top; 2) Confusion; 3) Pinnacle; 4) Moss; 5) The Aerie; 6) Keyhole; 7) Respiring Chimney; 8) Lava Bench #2; 9) Lava Bench #1; 10) Refuge.

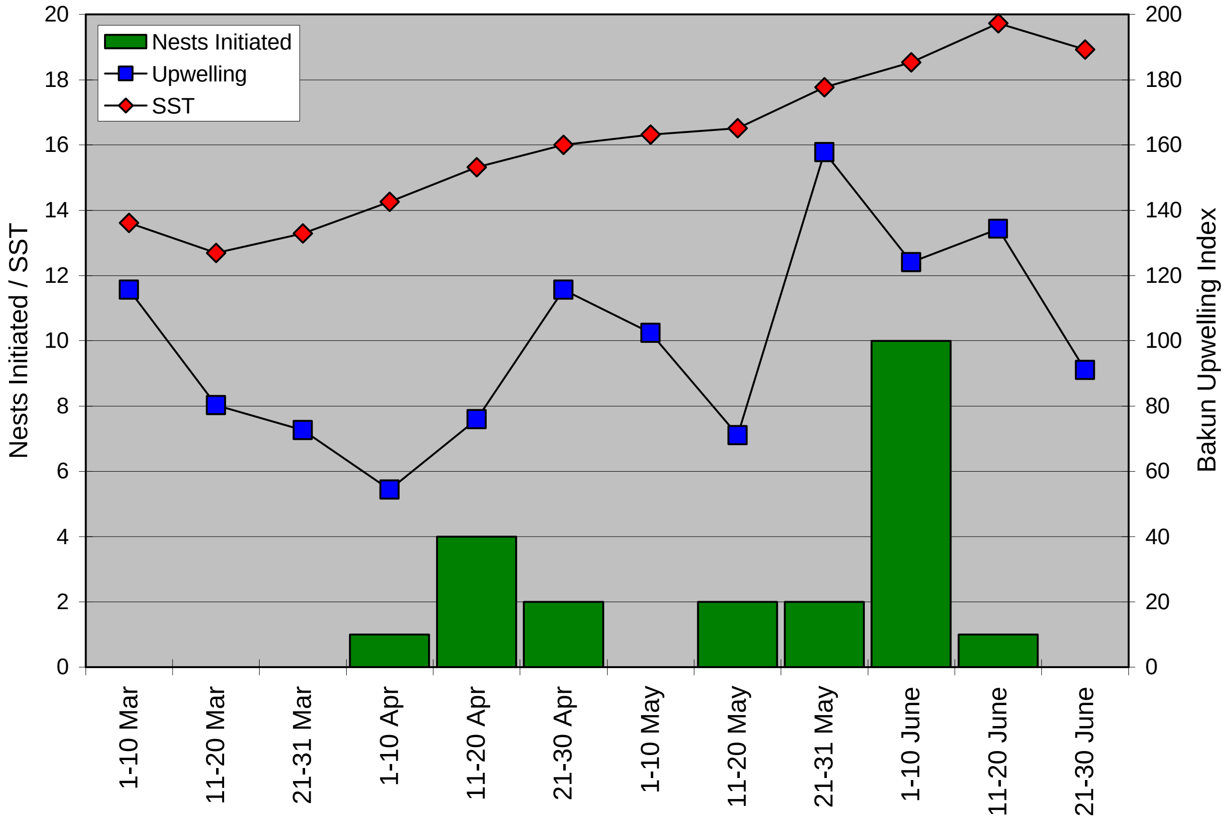

Figure 3. Timing of breeding (laying date of the first egg) for Xantus's Murrelets in monitored nests at Anacapa Island, California in relation to sea surface temperature (SST; Cº) and coastal upwelling (Bakun Upwelling Index; m^3 s^{-1} 100 m $coastline^{-2}$) in 2006.

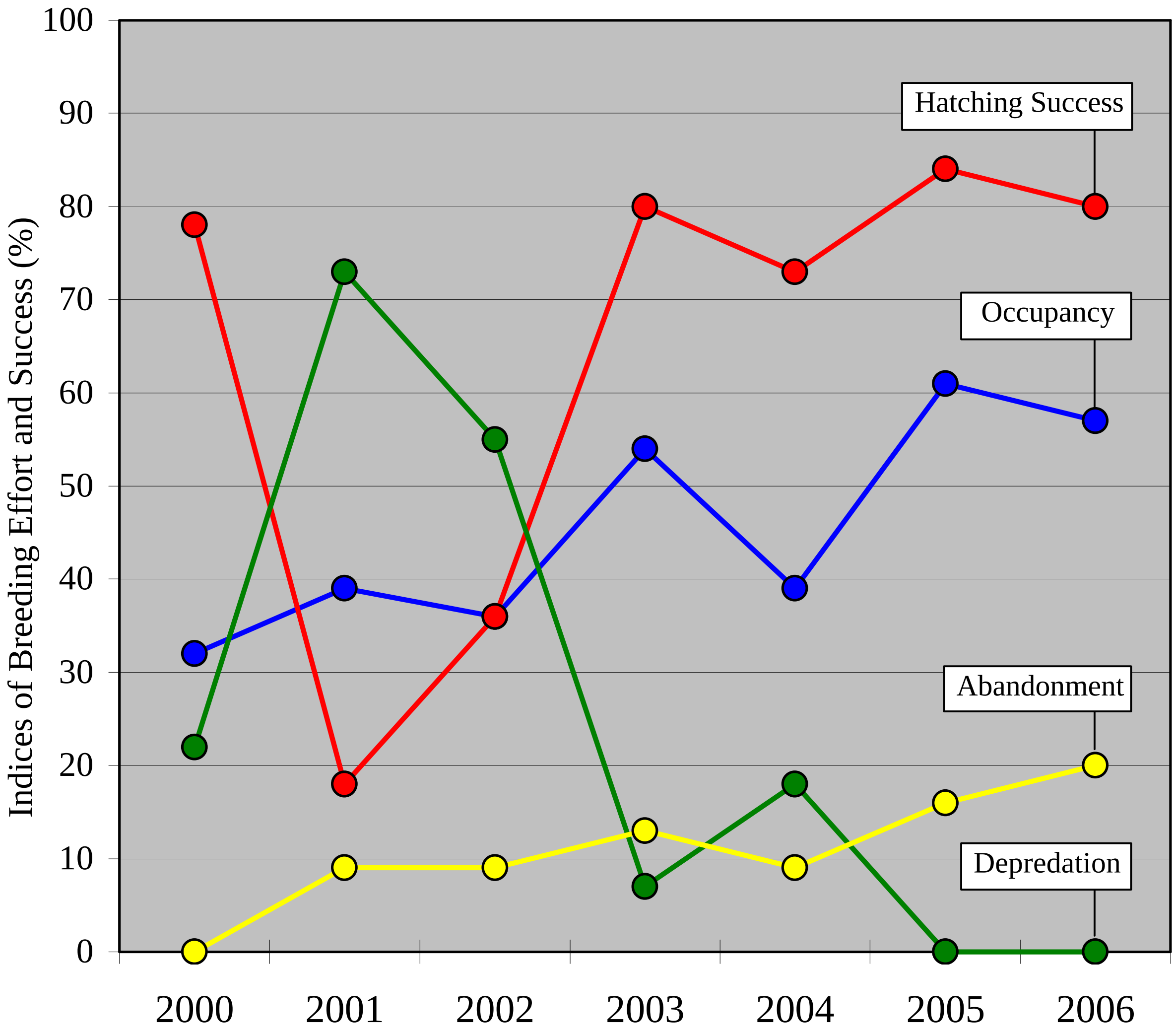

Figure 4. Indices of Xantus's Murrelet breeding effort and success in monitored sea cave nests at Anacapa Island, 2000-06. Breeding success indices in 2000-01 do not take into account several depredated eggs of unknown origin that may have been removed from monitored sites before nesting was detected.

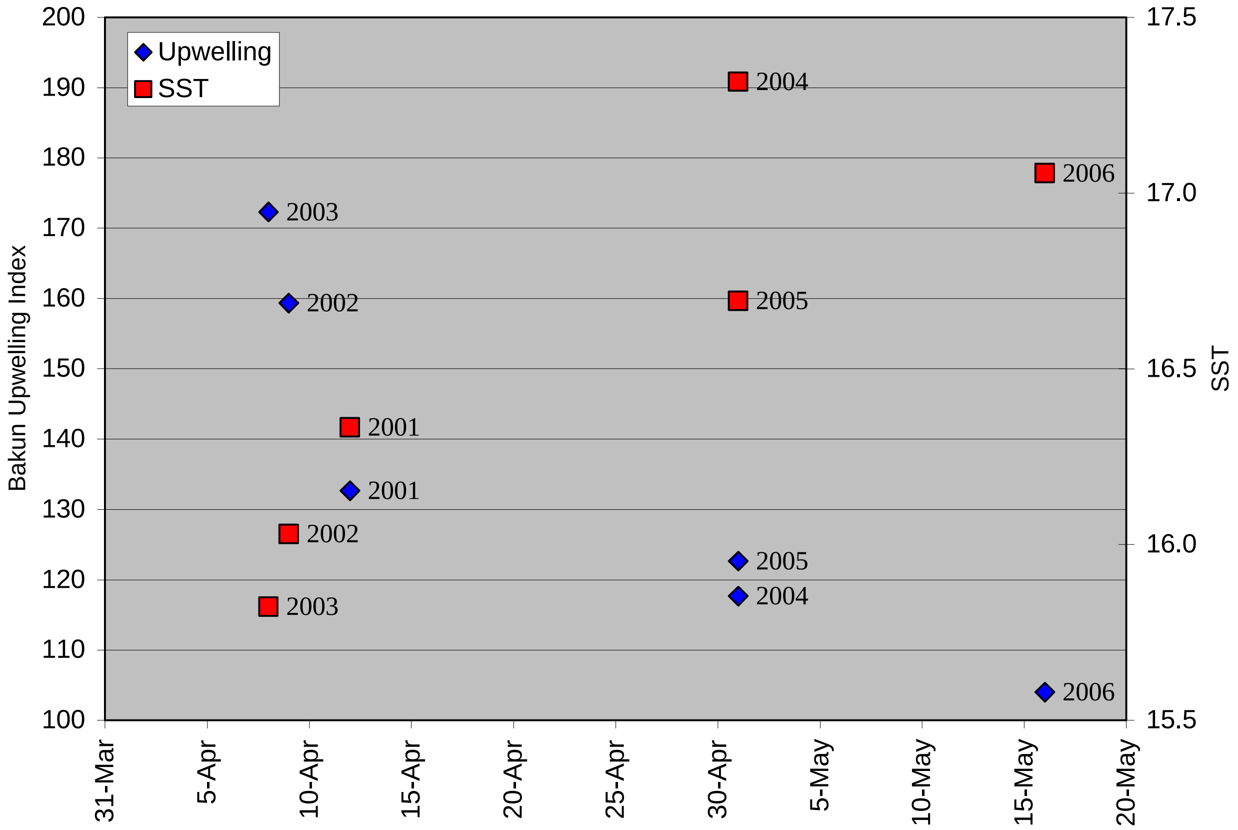

Figure 5. Timing of breeding (mean annual nest initiation date) in relation to indices of coastal upwelling (Bakun Upwelling Index; $m^3\ s^{-1}$ 100 m coastline^{-2}) and sea surface temperature (SST; Cº) during the breeding season (April-June) for Xantus's Murrelets at Anacapa Island, California, 2001-2006.

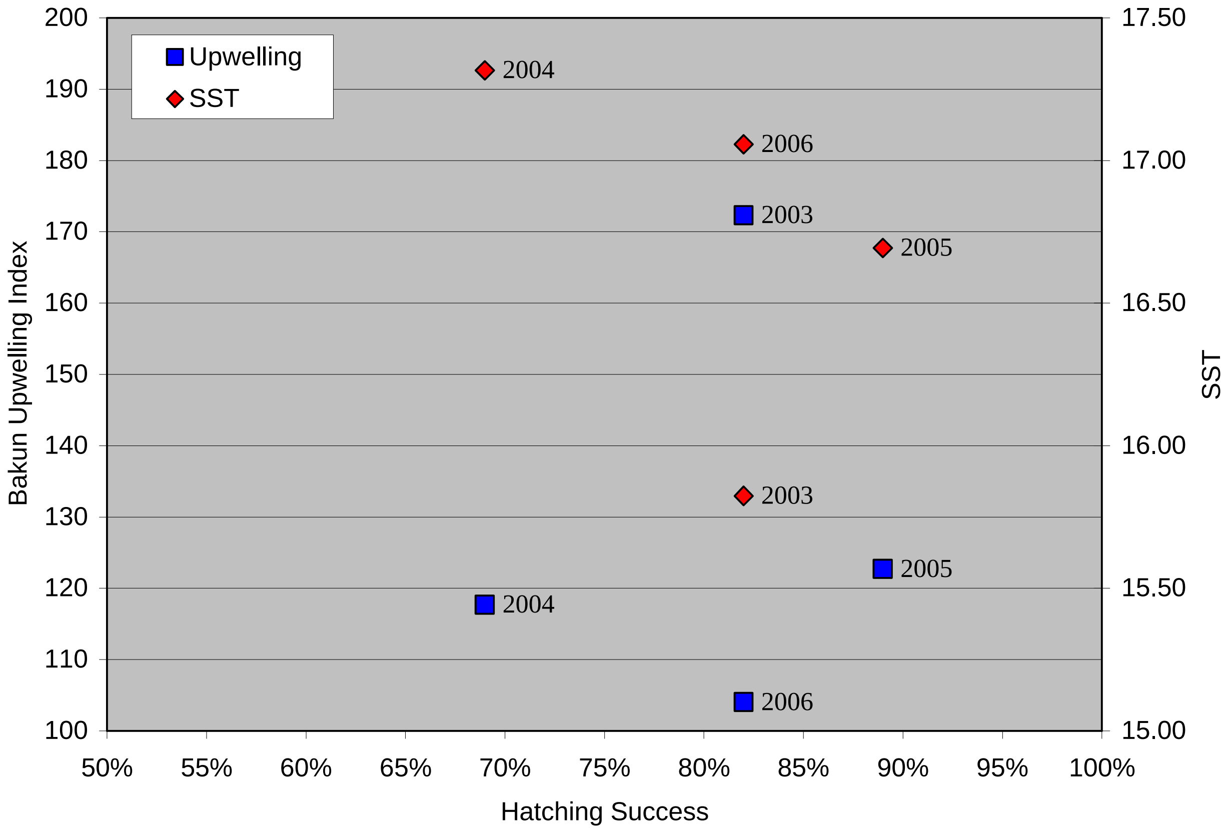

Figure 6. Hatching success in relation to indices of coastal upwelling (Bakun Upwelling Index; $m^3\ s^{-1}$ 100 m coastline^{-2}) and sea surface temperature (SST; C°) for Xantus's Murrelets at Anacapa Island, California, 2001-2006.

Figure 7. Xantus's Murrelet nests in unsheltered sites in Respiring Chimney (above) and Lava Bench #2 (below) caves on the south side of Middle Anacapa Island.