# INITIAL RECOVERY OF XANTUS'S MURRELETS FOLLOWING RAT ERADICATION ON ANACAPA ISLAND, CALIFORNIA

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**SUMMARY**

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At Anacapa Island, California, breeding effort, hatching success and nesting distribution of Xantus's Murrelets *Synthliboramphus hypoleucus* increased in the years following the eradication of Black Rats *Rattus rattus* (2003–2005) as compared with pre-eradication years (2000–2002). Within sea-cave study areas, nest-site occupancy increased from 36% to 51%, nesting attempts increased 42%, hatching success increased from 42% to 80% and nest depredation decreased from 52% (by rats) to 7% (by endemic Deer Mice *Peromyscus maniculatus anacapae*). Post-eradication, murrelets and Cassin's Auklets *Ptychoramphus aleuticus* began nesting in habitats previously occupied by rats, including Cat Rock, where murrelet breeding was last reported in 1927. Initial post-eradication signs of recovery of Xantus's Murrelets at Anacapa Island are encouraging for eventual restoration of this important colony, but additional monitoring is needed to better document the rate and process of recovery.

Key words: Anacapa Island, Black Rat, breeding, eradication, introduced predator, *Rattus rattus,* recovery, restoration, *Synthliboramphus hypoleucus,* Xantus's Murrelet

## INTRODUCTION

The catastrophic effects that introduced mammals have wrought on island-breeding seabirds are well known, often resulting in great population reductions or local extinctions (Moors & Atkinson 1984, Bailey & Kaiser 1993, Burger & Gochfeld 1994). In the 19th and 20th centuries, nonnative mammalian predators, especially cats *Felis catus* and rats *Rattus* spp., were introduced on many coastal islands used for breeding by Xantus's Murrelets *Synthliboramphus hypoleucus* in southern California and northwestern Baja California, causing reductions in murrelet population sizes, restricted distributions and possible extirpations (Jehl & Bond 1975, Jehl 1984, Drost & Lewis 1995, McChesney & Tershy 1998, Keitt 2005). At Anacapa Island, California, the severe impact on the murrelet population of nonnative Black Rats *Rattus rattus* has been recorded since at least early in the 20th century (Collins 1979, Hunt *et al.* 1979, Carter *et al.* 1992, McChesney & Tershy 1998, McChesney *et al.* 2000, Whitworth *et al.* 2003a). Anacapa Island harbors abundant potential nesting habitat, but only a remnant murrelet population persisted in the 1990s by nesting in habitats such as sea caves, steep slopes and cliffs, although evidence of rats and rat-depredated murrelet nests were found even in those relatively inaccessible habitats (McChesney *et al.* 2000; Whitworth *et al.* 2003a; H. Carter, unpubl. data).

With 1998 litigation settlement funds related to the 1990 *American Trader* oil spill, the American Trader Trustee Council (ATTC) sponsored a seabird restoration program on Anacapa Island by eradicating Black Rats (ATTC 2001). Island Conservation and the National Park Service eradicated rats from Anacapa Island using helicopter-broadcast poison pellets on East Anacapa in December 2001 and Middle and West Anacapa in November 2002 (Howald *et al.* 2005). Breeding seabirds were expected to greatly benefit from rat eradication at Anacapa Island, but adequate baseline data did not exist for population size, breeding distribution or breeding success for nocturnal crevice-nesting species before the introduction of rats. Previous eradication programs had eliminated introduced predators on several murrelet breeding islands since about 1970 without quantifying the degree and rate of murrelet recovery (Hunt *et al.* 1979, McChesney & Tershy 1998). At Anacapa Island, the Xantus's Murrelet population was expected to benefit from rat eradication because the potential extirpation of this small remnant colony could be prevented and much suitable nesting habitat would be available for restoration of a relatively large colony (McChesney *et al.* 2000).

During 2000–2003, a monitoring team (Humboldt State University, California Institute of Environmental Studies, Channel Islands National Marine Sanctuary, and Hamer Environmental) gathered pre-eradication and first year post-eradication baseline data on murrelet population size, distribution and breeding success at Anacapa, using spotlight surveys and nest monitoring over the entire island (Whitworth *et al.* 2003a) and radar surveys over a portion of Middle Anacapa (Hamer *et al.* 2003, 2005). With reduced funding in 2004/05, the California Institute of Environmental Studies and Channel Islands National Marine Sanctuary continued sea-cave nest monitoring and nest searches in other sample areas (begun in 2003) to provide cost-effective annual information on the progress of recovery after eradication. In this paper, we summarize the results of nest monitoring at Anacapa Island during 2000–2005, compare breeding indices pre- and post-eradication, and discuss initial signs of recovery of the Anacapa murrelet colony. Greater detail on methods and results is available in annual reports (Whitworth *et al.* 2002a, 2002b, 2003a, 2003b, 2004, 2005).

## METHODS

### Study area

Anacapa Island, the easternmost and smallest of the northern four California Channel islands, lies 15 km southwest of Ventura, California. It comprises three small islets (West, Middle and East Anacapa; Fig. 1) separated by narrow channels forming a chain approximately 7.5 km long with 17.5 km of coastline composed of steep, rocky cliffs indented with more than 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 Channel Islands National Park, which maintains quarters for staff and facilities for campers on East Anacapa, but otherwise the island is uninhabited.

### Nest monitoring

During 2000–2005, we searched for and monitored nests in 10 sea caves on Middle and West Anacapa (Fig. 1) where evidence of murrelet nesting had been observed in 1994–1997 (McChesney *et al.* 2000; H. Carter, unpubl. data). These caves included Refuge, Lava Bench #1, Lava Bench #2, Respiring Chimney, Lonely at the Top, Confusion, Pinnacle, Moss, Aerie and Keyhole (names after Bunnell 1993). We monitored nests every one to three weeks in April–July 2000, weekly in March–June 2001–2004 and biweekly in April–June 2005. All potential nesting habitat in sea caves was searched using hand-held flashlights during each visit. Access to sea caves and other sample areas involved drop-off and pick-up with a 3.8-m inflatable craft.

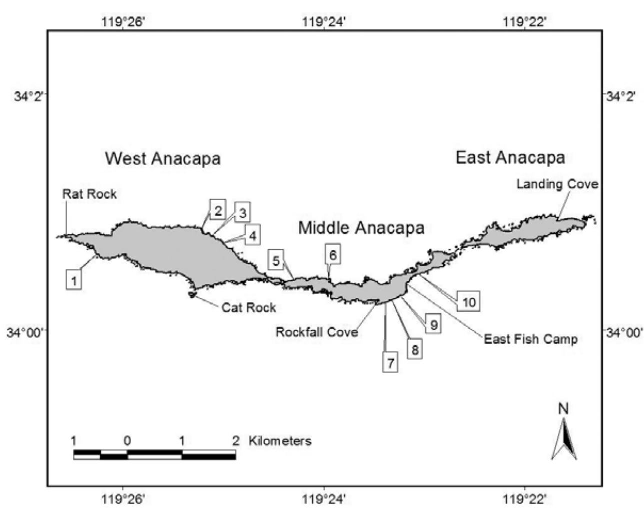


**Fig. 1.** Locations of 10 sea caves and other areas at Anacapa Island, California, where Xantus's Murrelet nest sites were monitored during 2000–2005. (1) Lonely at the Top; (2) Confusion; (3) Pinnacle; (4) Moss; (5) The Aerie; (6) Keyhole; (7) Respiring Chimney; (8) Lava Bench #2; (9) Lava Bench #1; and (10) Refuge. Other monitored areas are named, and larger coastal sections also are outlined in black.

Monitored sites were identified as suitable crevices or sheltered sites with evidence of current or past use as a nest (i.e. incubating or brooding adult, intact unattended eggs, broken or hatched eggshell fragments, or eggshell membranes). Site locations were marked with small numbered metal tags. We recorded the contents of each monitored site and any newly discovered nests during each visit. To prevent nest abandonment, incubating adults were observed briefly with a flashlight and occasionally photographed, but were not handled or prodded.

Systematic efforts to examine potential murrelet nesting areas in cliff, shoreline and offshore rock habitats began in 2003 and were expanded in 2004/05. We used methods similar to sea-cave nest monitoring to thoroughly search

- cliffs in Landing Cove on East Anacapa (2003–2005),
- Cat Rock (offshore rock) and Rat Rock (rocky peninsula) off West Anacapa (2003–2005),
- shoreline area of East Fish Camp on the south side of Middle Anacapa (2004–2005), and
- Rockfall Cove on the south side of Middle Anacapa (2005).

All previously tagged nests in those sample areas were checked during each visit, but more extensive nest searches were conducted only once or twice during the breeding season after egg laying had commenced in the sea caves.

Annual hatching success was determined as the percentage of active nests where at least one egg hatched, as determined by the presence of chicks or hatched eggshell fragments (dried or bloody membrane separated from the shell) found in or near the nest site. Nests that failed to hatch were classified as depredated (broken eggshells in or near the site, or eggs missing and presumed removed by rats or mice before hatching) or abandoned (intact unattended eggs over two consecutive checks). Rat-depredated eggs had larger bite marks on shell edges or crushing of eggshells; mouse-depredated eggs had smaller bite marks on shell edges with little or no crushing. Once nest fate had been determined, we removed any abandoned, broken or hatched eggshells to avoid confusion between previous and future nesting efforts.

Annual nest occupancy was the percentage of all monitored sites found between 2000 and 2005 in which nesting attempts occurred in a given year. All sea caves were searched thoroughly during each visit; therefore, we believe that untagged potential sites were unoccupied before the first evidence of nesting was observed and the nest was tagged. Using this method, the occupancy calculated for past years will decrease as new sites are added in future years, until all potential nest sites in each cave have been occupied. Determining occupancy rates in this way will best reflect growth of the murrelet population. Estimates of occupancy in sample areas outside the sea caves were calculated similarly, but because systematic nest searches began in different years (as described earlier), the total number of monitored sites used to calculate occupancy differed among years.

Timing of breeding was estimated using murrelet breeding biology data from Murray *et al.* (1983) to determine the midpoint of the range of possible clutch initiation dates for each active nest and at-sea observation of chicks accompanied by adults as they left the island. For statistical comparison of murrelet performance pre- and post-eradication of rats, we used *G*-tests, including the Yates correction ($G_c$) for 2×2 tables (Zar 1999).

## RESULTS

### Nest monitoring in sea caves

During 2000–2005, we recorded 28 murrelet nest sites in nine caves on Middle and West Anacapa Island (Table 1), but found none in Confusion Cave. In 2000, we monitored 13 nest sites, including nine occupied sites and four non-occupied old sites. Only three new sites (+23%) were added from 2000 to 2002, compared with 12 new sites (+75%) since 2002. We recorded eight new sites in 2003, the first breeding season after rat eradication on Middle and West Anacapa. From 2000 to 2005, 75 nesting attempts were initiated, with increasing numbers each year except 2004, when overall murrelet breeding was delayed and much reduced. The number of nests initiated increased 42% after eradication. Annual nest occupancy ranged from 32% to 61% (Table 1) and increased from 36% pre-eradication to 51% post-eradication, although the increase was not significant ($G_c = 3.50$, df = 1, $P > 0.05$).

Differences in the frequencies of nest fates were observed in the post- and pre-eradication periods ($G = 20.06$, df = 2, $P < 0.001$). Overall hatching success was 64%, but was much higher ($G_c = 9.65$, df = 1, $P < 0.005$) post-eradication (80%) than pre-eradication (42%). Post-eradication hatching success was consistently high (73%–83%; Table 1, Fig. 2); pre-eradication, it was quite variable (18%–78%). However, high hatching success in 2000 did not take into account rat-depredated eggs of unknown origin (i.e. eggs removed from monitored sites before nesting was detected or from non-monitored nest sites in a few inaccessible deep crevices) found in several caves in 2000/01.

During 2000–2005, the nest failure rate was 36%, with 19 depredated nests (25%) and eight abandoned nests (11%). Abandonment was similar ($G_c = 0.39$, df = 1, $P > 0.25$) pre- and post-eradication (14% and 6% respectively), but depredation was much lower ($G_c = 17.49$, df = 1, $P < 0.001$) post-eradication (7%) than pre-eradication (52%; Table 1, Fig. 2). Highest depredation rates were recorded pre-eradication in 2001 and 2002. No depredated nests were noted in 2005, although a missing egg in 2003 and two depredated nests in 2004 were attributed to endemic Deer Mice *Peromyscus maniculatus anacapae.* Two depredated adult murrelets were found in sea caves. One partly eaten carcass, likely killed by a rat, was found inside a monitored site in March 2001 before egg laying. In the second instance, raptor-depredated plucked murrelet feathers and mouse-depredated eggs were found outside an active site in 2004.

### Colony expansion

During 2003–2005, 12 nesting attempts in 10 sites were discovered in cliffs, shoreline or offshore rocks where none had been found during sporadic nest searches since 1991 (Table 2). Occupied murrelet nest sites were first found in the Landing Cove cliffs (one site) and Cat Rock (one site) in 2003. Two more occupied nest sites were discovered in 2004, one in Landing Cove and another along the shoreline of East Fish Camp. The latter site was destroyed by a landslide during storms in the winter of 2004/05. Six new occupied sites were found in 2005, four in Landing Cove and two in Rockfall Cove. Occupancy in monitored nest sites outside sea caves was low in 2003 (29%) and 2004 (25%), but increased to 89% in 2005. Nearly all (92%) of these nesting attempts successfully hatched, with only one abandoned and no depredated nests.

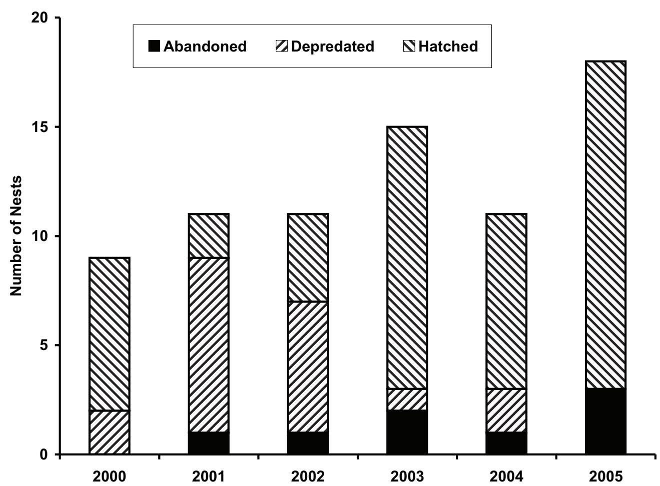


**Fig. 2.** Number of abandoned, depredated and hatched Xantus's Murrelet nests in sea caves at Anacapa Island, California, 2000–2005.

**TABLE 1**
**Breeding effort and success of Xantus's Murrelets in sea caves at Anacapa Island during 2000–2005**

| Nest site summary | Pre-eradication year | | | | Post-eradication year | | | |
|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2000–2002 | 2003 | 2004 | 2005 | 2003–2005 |
| Tagged & monitored | 13 | 15 | 16 | 16 | 24 | 25 | 28 | 28 |
| Potential | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| Nesting attempts | 9 | 11 | 11[a] | 31 | 15 | 11 | 18[a] | 44 |
| Occupied | 9 | 11 | 10[a] | — | 15 | 11 | 17[a] | — |
| (occupied/potential) | 32% | 39% | 36% | 36% | 54% | 39% | 61% | 51% |
| Hatched | 7 | 2 | 4 | 13 | 12 | 8 | 15 | 35 |
| (hatched/nesting attempts) | 78% | 18% | 36% | 42% | 80% | 73% | 83% | 80% |
| Depredated | 2 | 8 | 6 | 16 | 1 | 2 | 0 | 3 |
| (depredated/nesting attempts) | 22% | 73% | 55% | 52% | 7% | 18% | 0% | 7% |
| Abandoned | 0 | 1 | 1 | 2 | 2 | 1 | 3 | 6 |
| (abandoned/nesting attempts) | 0% | 9% | 9% | 6% | 13% | 9% | 17% | 14% |

[a] Two nesting attempts in one site treated as separate nesting attempts.

### Timing of breeding

Murrelet nests were initiated between 3 March and 3 June during 2000–2005. Mean annual clutch initiation dates ranged from 30 March (± 11 days) in 2000 to 2 May (± 14 days) in 2005. Assuming little error in using midpoints to estimate the date of clutch initiations, timing of breeding differed significantly from year to year (ANOVA $F_{5,87} = 12.41$, $P < 0.0001$), with later initiation in 2004 and 2005 than in 2000–2003 (Tukey HSD test; all $P < 0.03$).

### Other nesting seabirds

Two Cassin's Auklet *Ptychoramphus aleuticus* nests were discovered on Rat Rock in 2003, and both fledged chicks. Only one of these auklet nests was occupied in 2004, but the egg was soon abandoned. Egg laying occurred in both nest sites in 2005, but breeding success could not be determined because of concern for potential disturbance to nearby breeding Brandt's Cormorants *Phalacrocorax penicillatus.* Eight Pigeon Guillemot *Cepphus columba* nests were discovered in two sea caves during 2003–2005, but breeding success could not be determined. Two guillemot nest sites occupied annually since 2003 were located in sites formerly used by murrelets; in one case, an occupied murrelet nest was usurped by guillemots.

## DISCUSSION

Nesting effort and breeding success of Xantus's Murrelets at Anacapa Island have improved after the eradication of Black Rats from the island in 2002. The number of monitored nests sites increased 75%, the number of nesting attempts increased 42%, occupancy increased from 36% to 51%, hatching success increased from 42% to 80% and nest depredation decreased from 52% to 7%. In addition, nesting distribution increased, with 10 nest sites discovered in sample areas outside of sea caves during 2003–2005, where none had been found since 1991. With this initial response to rat eradication, we are confident that rat predation has been the primary negative impact on the Anacapa murrelet colony over the past century, although serious impacts from the 1969 Santa Barbara oil spill also likely occurred (McChesney & Tershey 1998, Carter *et al.* 2000, McChesney *et al.* 2000).

**TABLE 2**
**Breeding effort and success of Xantus's Murrelets in sample areas outside of sea caves at Anacapa Island, 2003–2005**

| Nest site summary | 2003 | 2004 | 2005 | 2003–2005 |
|---|---|---|---|---|
| Tagged & monitored | 2 | 4 | 9[a] | 9[a] |
| Potential | 7 | 8 | 9[a] | 9[a] |
| Nesting attempts | 2 | 2 | 8 | 12 |
| Occupied | 2 | 2 | 8 | — |
| (occupied/potential) | 29% | 25% | 89% | 50% |
| Hatched | 2 | 1 | 8 | 11 |
| (hatched/nesting attempts) | 100% | 50% | 100% | 92% |
| Depredated | 0 | 0 | 0 | 0 |
| (depredated/nesting attempts) | 0% | 0% | 0% | 0% |
| Abandoned | 0 | 1 | 0 | 1 |
| (abandoned/nesting attempts) | 0% | 50% | 0% | 11% |

[a] Excludes one tagged site destroyed by a landslide (see text).

Nest searches and monitoring were limited to 10 sea caves during 2000–2002, because these were the only accessible areas for monitoring with recent known nesting. Fortunately, we found sufficient nest sites for monitoring in these caves to obtain a comparable baseline for describing murrelet breeding conditions pre-eradication. Standardized comparisons of breeding effort and success within sea caves effectively demonstrated initial improvements in murrelet breeding conditions for three years post-eradication. However, available habitat for new nests is limited in these caves and may be saturated soon, allowing future measurement of breeding success only.

With limited funding after 2003, we used nest searches in sample areas to augment cave monitoring and to detect when murrelets began colonizing nesting areas where prior breeding was prevented by rats. Occasional nest searches during 1991–2002 failed to find any nests at Landing Cove cliffs and Cat Rock, although single depredated nests were found at Landing Cove cliffs in 1987 and 1988, and fragments of depredated eggs were found on West Anacapa in 1991 and 1997 (Carter *et al.* 1992; McChesney *et al.* 2000; Whitworth *et al.* 2003a; H. Carter, unpubl. data). We suspect that few nests were initiated in sample areas before 2003, but once nests become more abundant, monitoring should be shifted to these and other accessible areas to further document colony growth. Rapid colony expansion into suitable but previously unoccupied nesting habitats on Anacapa Island (particularly the cliffs in Landing Cove) is encouraging for rapid colony growth to much higher population levels. Sufficient nesting habitat exists at Anacapa Island to support thousands of breeding pairs (McChesney *et al.* 2000), and indeed murrelets were once considered common breeding birds on Anacapa (Howell 1917). Museum specimens collected in the early 20th century revealed that murrelets once nested much more widely at East and West Anacapa and Cat Rock (McChesney *et al.* 2000; H. Carter, unpubl. data).

Post-eradication breeding by Cassin's Auklets on Rat Rock further illustrated the benefits of rat eradication for nocturnal crevice-nesting seabirds. Auklets probably nested on Anacapa in the early 1900s (Willett 1910), but the only direct evidence of breeding pre-eradication was one depredated egg found in a sea cave in 1997 (McChesney *et al.* 2000). Pigeon Guillemots have long nested at Anacapa Island (Hunt *et al.* 1979, Carter *et al.* 1992), but monitoring suggests that their numbers and distribution also may expand post-eradication. Wider habitat searches and use of other monitoring techniques such as mist-netting will be needed to detect establishment and growth of other seabird colonies, including Ashy Storm-Petrels *Oceanodroma homochroa,* which may already nest in small numbers on Anacapa Island (Carter *et al.,* in press). To prevent disturbance to other sensitive seabird species, nest searches in upper habitats at West Anacapa will need to be conducted in the fall, after Brown Pelicans *Pelecanus occidentalis* and Double-crested Cormorants *Phalacrocorax auritus* have finished breeding (McChesney *et al.* 2000).

Detectable increases in the overall Anacapa murrelet population were not expected for several years, because murrelets, like all alcids, have relatively low reproductive rates, strong natal philopatry and deferred sexual maturity (Murray *et al.* 1983, Drost & Lewis 1995, Gaston & Jones 1998). The congeneric Ancient Murrelet *S. antiquus* colony on Langara Island in British Columbia appears to be slowly recovering following the eradication of introduced Norway Rats *R. norvegicus* in 1995. A halt in the population decline at the colony had been noted by 1999 (Drever 2002). By 2004, increases in breeding population size, colony area and burrow occupancy—plus the establishment of a small Cassin's Auklet colony—emphasized the improvement in breeding conditions for seabirds on Langara since the removal of rats (Regehr *et al.,* in press).

High hatching success and increased nesting effort by murrelets at Anacapa from 2003 to 2005 should contribute to strong recruitment in 2006 and beyond. By 2005, a relatively strong cohort of first-time breeders (probably 2–4 years, as in the Ancient Murrelet; Gaston 1990) may have recruited into the population following the first phase of rat-eradication on East Anacapa in 2001. However, some colony growth and expansion had begun by 2003, suggesting that subadults or nonbreeding adults already present in at-sea congregations (Whitworth *et al.* 1997, 2000) probably assisted early growth and expansion. We anticipate increased breeding effort and colony expansion in the near future, but factors unrelated to rat predation also could affect murrelet breeding.

Nesting effort and breeding success of murrelets in the Southern California Bight can vary dramatically between years and even between decades because of high variability in the availability of prey resources (Hunt & Butler 1980; Drost & Lewis 1995; Whitworth *et al.* 2000; Hamilton *et al.* 2004, 2005; Roth *et al.* 2005). Fewer nesting attempts in 2004 and delayed breeding in 2004/05 at Anacapa Island likely reflected delayed prey availability in the Bight, although hatching success was not greatly affected. Survival to breeding age in alcids may also be affected by various natural and anthropogenic factors (Hudson 1985). Murrelets are extremely vulnerable to oil spills or light pollution near colonies (Carter *et al.* 2000, Burkett *et al.* 2003), which could hinder colony recovery.

Possible future impacts of endemic Deer Mice on Xantus's Murelets at Anacapa Island are difficult to predict. Wild Deer Mice were eliminated during the rat eradication, although a captive population was retained and released one year afterward. Mice quickly repopulated the island, although numbers in shoreline habitats did not reach higher levels until about one year after release (Howald *et al.* 2005; H. Gellerman & G. Howald, pers. comm.). Before eradication, mice on Anacapa were greatly reduced by rats, especially in shoreline habitats, and had little or no effect on murrelet nesting in sea caves. At present, Anacapa murrelets have higher hatching success and lower depredation rates than at Santa Barbara Island, where cyclically high mouse and owl densities in human-altered grassland habitats near murrelet breeding areas have led to high depredation rates (Murray *et al.* 1983, Drost & Lewis 1995, Schwemm & Martin 2005, Wolf *et al.* 2005). However, mice preyed upon small numbers of murrelet nests in 2004/05 and may have greater effects in the future.

Continued annual nest monitoring is needed to document expected colony growth, given initial signs of colony expansion. To identify and quantify overall changes in population size and distribution, spotlight surveys (which count birds at night on transects within at-sea congregations off East, Middle and West Anacapa) and radar surveys at Middle Anacapa should be conducted for comparison to pre-eradication surveys (Whitworth *et al.* 2003a; Hamer *et al.* 2003, 2005). Considering rapid changes during 2003–2005, changes in total population size and distribution should be examined in the near future.

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