# Measuring the Response of Scripps's Murrelets (*Synthliboramphus scrippsi*) 12 Years after the Eradication of Black Rats (*Rattus rattus*) at Anacapa Island, California: Nocturnal Spotlight Surveys and Nest Monitoring

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*Scripps's Murrelet family group departing East Anacapa Island, May 2003*

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# EXECUTIVE SUMMARY

- In 2014, we conducted Scripps's Murrelet (*Synthliboramphus scrippsi*) monitoring at Anacapa Island, California to measure the improvement in hatching success and the increase in population size after the eradication of Black Rats (*Rattus rattus*) in 2002.

- Two monitoring techniques were employed: (1) spotlight surveys of murrelets attending nocturnal at-sea congregations near breeding areas conducted in 2001-2006 and 2014; and (2) nest monitoring conducted in 2001-2010 and 2014.

- Standard spotlight surveys (ST) were conducted on parallel inshore and offshore transects (1.9 km each) located 200 m and 500 m off the south shore of East Anacapa. Round-island surveys (RI) were conducted on a 19.2 km transect circumnavigating Anacapa at roughly 200-400 m from shore.

- In 2014, 12 ST spotlight surveys were conducted over 8 nights between 15 March and 24 May, and 4 RI surveys between 24 March and 7 April. Poor ocean conditions prevented spotlight surveys from 8 April to 11 May.

- ST survey counts in 2014 ranged from 55 to 583 murrelets ($\bar{x}$ = 289 ± 192), while RI survey counts ranged from 71 to 1386 murrelets ($\bar{x}$ = 869 ± 592).

- From 2001 to 2014, we conducted a total of 142 ST surveys over 66 nights in 7 years and 16 RI surveys in 5 years. The overall mean ST count was 149 murrelets (± 113 *s.d.*; range = 0-583), while the overall mean RI count was 375 murrelets (± 417 *s.d.*; range = 29-1386). A very strong correlation was detected between consecutive ST-RI counts.

- No consistent seasonal trends within years were detected in ST or RI survey counts. ST survey annual maximum counts occurred from 2 days before to 32 days after the annual mean nest initiation date (AMNID), while RI annual maximum counts occurred from 2 days before to 35 days after the AMNID.

- Log-transformed time series regressions (TSR) detected significant increases for all 3 ST spotlight survey datasets and both RI spotlight survey datasets.

- Slopes of the TSR lines ranged from 0.065 to 0.084 for ST surveys and 0.110 to 0.115 for RI surveys, indicating per annum increases in the number of murrelets attending at-sea congregations of 6.7-8.8% for ST surveys and 11.6-12.2% for RI surveys.

- Mean ST and RI counts were significantly higher in 2014 than in baseline years (2001-2003). Simple comparisons of spotlight counts between baseline years and 2014 yielded large increases for the ST mean (106%), ST maximum (116%) and RI maximum (146%) counts, but much higher increases for the RI mean (319%) counts.

- Proportions of RI counts in 6 survey sectors remained remarkably consistent over time, with no obvious shifts in the distribution of murrelets from 2002 to 2014.

- Estimates of murrelet population size at Anacapa based on maximum RI survey counts increased nearly 150% from 450-600 breeding birds in 2001-2003 to 1100-1450 breeding birds in 2014.

- Standardized nest monitoring was conducted in 10 sea caves (SC) in 2001-2010 and 2014. In 2003 and 2005, we expanded nest monitoring to include "non-cave plots" (NCP) in accessible cliff, shoreline and offshore rock habitats on all 3 Anacapa islets.

- In 2014, a total of 86 sites were monitored, 56 in SC and 30 in NCP. The number of occupied nests at Anacapa increased over 5-fold (445%) from 11 in 2001 to 60 in 2014. The number of occupied nests increased 272% in SC (2001-2014) and 375% in NCP (2003-2014).

- The slope of the TSR line for the log-transformed number of occupied murrelet nests was 0.141 at Anacapa (all areas combined), 0.104 in SC, and 0.171 in NCP, indicating per annum increases of 15.1% at Anacapa, 11.0% in SC, and 18.6% in NCP.

- Considering greater potential biases in the ST spotlight survey and nest monitoring datasets, we currently believe murrelet population increases at Anacapa from 2001 to 2014 were best approximated by the RI spotlight survey datasets (11.6-12.2%).

- Local biases in the ST spotlight survey, NCP nest monitoring, and to a lesser extent, the SC nest monitoring datasets indicated that they probably did not reflect overall breeding conditions at Anacapa from 2001 to 2014, but did reflect local breeding conditions on SE Anacapa and in the SC and NCP monitoring plots.

- Future Scripps's Murrelet monitoring at Anacapa should include: (1) annual SC and NCP nest monitoring conducted every 10-14 days through the breeding season; and (2) ST and RI spotlight surveys conducted for at least 2 consecutive years every 5-6 years. A minimum of 8 (preferably 10-15) ST survey nights and 4-5 RI surveys should be conducted each year.

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# INTRODUCTION

Despite the recent proliferation of restoration programs involving eradication of non-native mammalian predators from islands to benefit seabirds, little detailed data is available to assess the post-eradication responses of the seabird species affected (Lavers et al. 2010, Buxton et al. 2014). A restoration program focused on eradication of introduced Black Rats (*Rattus rattus*) on Anacapa Island, California in 2001-2002 (American Trader Trustee Council [ATTC] 2001; Howald et al. 2005, 2009) has been one of the few eradications to implement baseline and post-eradication monitoring for assessing the recovery of key target species. Removal of rats was expected to benefit small crevice-nesting seabirds on Anacapa, especially the Scripps's Murrelet (*Synthliboramphus scrippsi*), a rare alcid that breeds on just 12 islands (or island groups) off the coast of southern California and north-central Baja California. A remnant population of Scripps's Murrelets was found nesting at Anacapa during surveys in 1994-1997 (Carter et al. 1997, Whitworth et al. 1997, McChesney et al. 2000). Murrelet nest monitoring in 2000-2002 collected baseline data on numbers of nests and hatching success in sea caves (Whitworth et al. 2005) prior to the eradication of rats on East Anacapa in 2001 and on West and Middle Anacapa in 2002. By 2010, post-eradication nest monitoring in sea cave and non-cave plots at Anacapa had produced a compelling case study that demonstrated a strong positive response in the first 8 years following the eradication of rats, including: (1) a nearly a 3-fold increase in hatching success after eradication; (2) a 14% per annum increase in the number of occupied nests in sea caves and non-cave plots; and (3) limited colony expansion into a few previously vacant habitats on Anacapa (Whitworth et al. 2013). Cassin's Auklets (*Ptychoramphus aleuticus*), another small crevice-nesting alcid which had been extirpated (or nearly so) by rats in the early 20$^{th}$ century, were also discovered nesting in previously vacant breeding habitats on Anacapa within 1-7 years of eradication (Whitworth et al. 2015b). Furthermore, the first nest of the Ashy Storm-Petrel (*Oceanodroma homochroa*) was found at West Anacapa in 2011 (Harvey et al. 2016), although possible breeding by a remnant population likely restricted to inaccessible cliffs had been suspected since 1994 (McChesney et al. 1999, Carter et al. 2008; Carter and Whitworth 2013).

Scripps's Murrelet nest monitoring at Anacapa has presented particular challenges. Throughout their breeding range, murrelets nest exclusively in concealed sites on offshore islands, most often in habitats that have limited or no access by land, especially on those islands with native or introduced mammalian predators (Murray et al. 1983, Drost and Lewis 1995, McChesney and Tershy 1998). After over a century of impacts from rats (probably introduced by a shipwreck in 1853, but possibly during later sheep ranching; Collins 1979; Roberts 1983; K. Faulkner, pers. comm.), most of the remnant murrelet population at Anacapa was restricted to inaccessible steep cliffs, with only small numbers nesting in shoreline sea caves, most of which offered limited or periodic access to rats. Vocal detection surveys and at-sea captures at Anacapa in 1994-1997 detected many more murrelets in near-shore nocturnal at-sea congregations (Carter et al. 1997, Whitworth et al. 1997) than could be accounted for by the few nests found in sea caves during searches at Anacapa in 1994-1996 (Carter et al. 1997). Clearly, the bulk of the Anacapa murrelet population was nesting in inaccessible habitats prior to the eradication of rats. Since nest monitoring could be conducted only in researcher accessible habitats, we suspected that possible biases may have affected our assessment of murrelet population growth post-eradication, mainly: (1) the baseline occupancy rate for suitable nest crevices in some monitored habitats was lower than in inaccessible habitats where rats had less or no impact; and (2) the growth rate in the number of murrelet nests in monitored areas might be higher than for the overall population, especially during early stages of population recovery (Whitworth et al. 2013).

During baseline nest monitoring at Anacapa in 2001-2003, we also developed a nocturnal spotlight survey to count murrelets attending the seasonally predictable at-sea congregations that occur in near shore waters adjacent to breeding areas (Whitworth and Carter 2014). Murrelets are conspicuous and vocal in the at-sea congregations which appear to be: (1) social gatherings for breeding related activities (i.e., mate attraction, pair bonding, chick departure); and (2) staging areas for adults and subadults prior to or after visits to island nesting areas (Whitworth et al. 2000; Whitworth and Carter 2014). Given strong natal philopatry and colony fidelity in alcids (Gaston and Jones 1998, Hudson 1985), Scripps's Murrelets observed in at-sea congregations at Anacapa were likely either adults breeding at Anacapa or subadults attending the colony prior to breeding. Thus, spotlight survey counts of murrelets in the at-sea congregation should serve as a representative index for measuring trends in the population (Whitworth and Carter 2014). Baseline spotlight survey data was gathered at Anacapa in 2001-2003 (Whitworth et al. 2003).

Post-eradication nest monitoring was conducted annually from 2003 to 2010, but funding for spotlight surveys was discontinued after 2003, although smaller samples of surveys were conducted opportunistically in 2004-2006. In 2014, the California Institute of Environmental Studies (CIES) and Channel Islands National Park (CINP) resumed nest monitoring, with funding from the ATTC. CIES recognized that spotlight surveys also needed to be conducted in 2014 and fieldwork could be affordably combined with nest monitoring. Additional funding was obtained for spotlight surveys from the National Fish and Wildlife Foundation (NFWF). The primary goal of nest monitoring in 2014 was to update the progress of colony restoration by measuring murrelet hatching success and the number of nests in all previously monitored areas (Whitworth et al. 2015a). The primary goals of spotlight surveys in 2014 were to: (1) update the progress of colony restoration by determining whether an increase in the number of murrelets attending at-sea congregations had occurred since eradication; and (2) compare estimates of population growth as determined from nest monitoring and spotlight survey data. In this report, we present details of spotlight survey monitoring conducted in 2001-2006 and 2014, summarize results of nest monitoring in 2001-2010 and 2014, and compare these techniques to assess the extent and rate of murrelet population increase and population size for 12 years after the eradication of rats at Anacapa Island.

# METHODS

## Study Area

Anacapa Island is the easternmost and smallest of the northern Channel Islands and is located 15 km southwest of Ventura, California (Fig. 1). It is comprised of 3 small islets (West, Middle, and East Anacapa; Figs. 1-2) separated by narrow channels that are sometimes exposed at low tide. The island chain is approximately 8 km long and is surrounded by 17.5 km of rocky cliffs and steep slopes punctuated with over 100 sea caves (Bunnell 1993). West Anacapa is the largest (1.7 $km^2$) and highest (284 m) of the 3 islets, followed by Middle Anacapa (0.6 $km^2$, 99 m), and East Anacapa (0.5 $km^2$, 73 m). Anacapa is managed by CINP which maintains quarters for staff and facilities for campers on East Anacapa, but West and Middle Anacapa are uninhabited and access is restricted. Surrounding waters are managed by Channel Islands National Marine Sanctuary (out to 9.7 km [6 miles] from shore), California Department of Fish and Wildlife (out to 4.8 km [3 miles] from shore), and CINP (out to 1.6 km [1 mile] from shore).

**Nocturnal Spotlight Surveys**

From 2001-2006 and again in 2014, we conducted nocturnal spotlight surveys following the methods developed at Anacapa (Whitworth and Carter 2014). Two types of spotlight surveys were conducted: (1) standard surveys (ST) on parallel inshore and offshore transects (1.9 km each) located 200 m and 500 m, respectively, off the south side of East Anacapa; and (2) round-island surveys (RI) on a transect (19. 2 km) that circumnavigated all 3 Anacapa islets at roughly 200-400 m from shore (Fig. 1).

ST surveys were conducted in 3 nightly periods (all times PST); "evening" (21:00-00:00), "night" (00:00-03:00), and "morning" (03:00-sunrise), although fewer morning surveys were conducted after 2002 and none after 2005 (Whitworth and Carter 2014). Because multiple counts within nights were not independent for statistical comparisons, we used only the nightly maximum ST counts in trend analyses (Whitworth and Carter 2014). Correlations between survey periods within nights also indicated that data from nights when only 1 ST survey was conducted were adequate to serve as nightly maximum counts (Whitworth and Carter 2014).

RI surveys were conducted in the evening or night periods by continuing on to the RI transect after completion of the ST survey inshore transect (Fig. 1). Only 1 RI survey could be conducted per night due to the greater time needed for this survey.

<u>Data Analysis</u> - We visually inspected time series graphs of the ST survey counts to assess seasonal trends in at-sea congregation attendance. To account for annual differences in timing of breeding and the number of murrelets attending congregations, we standardized the survey data to allow for comparisons among years by: (1) dividing all ST counts by the annual maximum count that year to obtain proportional counts; and (2) subtracting the annual mean nest initiation date (AMNID) from the survey calendar date to determine survey efforts in relation to AMNID. We excluded surveys in 2006 from all analyses because samples were small (3 nights) and occurred early in the breeding season (i.e., 12-41 days prior to AMNID).

We analyzed inter-annual trends in ST spotlight survey counts (2001-2005, 2014) using 3 datasets: (1) annual means of the nightly maximum ST counts collected during the peak congregation attendance period (i.e., between 15 days before and 40 days after the AMNID; *see Results*) (hereafter referred to as the "ST mean"); (2) annual means of the 3 highest nightly maximum ST counts regardless of when the surveys were conducted (hereafter referred to as "3 highest ST counts"); and (3) annual maximum ST counts (hereafter referred to as "ST maximum". We created these 3 ST survey datasets to investigate how the systematic exclusion of sub-samples of the data affected measures of variability in the annual samples for better estimation of population trends.

We analyzed inter-annual trends in RI spotlight survey counts (2001-2003 and 2014) using 2 datasets: (1) annual means of all RI counts (hereafter referred to as the "RI mean"); and (2) annual maximum RI counts (hereafter referred to as "RI maximum"). We excluded the single RI count in 2004 and RI surveys were not conducted in 2005 or 2006.

Statistical Tests - We used a Student's *t*-test for independent samples to examine differences in ST and RI survey mean counts between 2014 and baseline years (2001-2003). We used linear correlation (Pearson *r*) to examine the relationship between ST surveys and the subsequent RI survey counts (after subtracting all murrelets observed on the ST portion of the RI transect). We used linear regression (Pearson *r*) to assess expected increases in the log-transformed time series data for the 3 ST and 2 RI survey datasets. We used one-tailed tests ($p < 0.05$) to determine whether significant increases in the spotlight counts had occurred after eradication, ignoring the possibility of decreases in spotlight survey counts over time. The per annum rate of increase in spotlight counts was estimated from the antilog of the slope of the log-transformed time series regression lines (TSR) (Nur 1999, Eberhardt and Simmons 1992).

Murrelet Distribution – We roughly assessed the distribution of murrelets in at-sea congregations around Anacapa by dividing the island into 6 sectors on the north and south shores of West, Middle and East Anacapa (Figs. 1-2). We then determined the number of murrelets in each sector for the 5 highest RI counts (3 in 2014 and 1 each in 2002 and 2003). Counts for each sector were divided by the RI survey total to obtain proportional counts for comparisons among surveys. We limited our assessment to nights with high RI counts because nights of low attendance may not adequately reflect the distribution of murrelets around the island.

**Nest Monitoring**

In 2001-2010 and again in 2014, we conducted Scripps's Murrelet nest searches and monitoring following the standardized methods developed at Anacapa (Whitworth et al. 2005, 2013, 2015a). Nest monitoring was conducted in all years at 10 sea caves (SC), but monitoring in 3 "non-cave plots" (NCP) began after eradication: (1) in 2003 at Landing Cove (steep but accessible slopes on the northeast shore of East Anacapa); (2) in 2003 at Cat Rock (an offshore rock off the south side of West Anacapa); and (3) in 2005 at Rockfall Cove (a protected cove with large scree piles on the south side of Middle Anacapa) (Fig. 2). All accessible potential nesting habitat in SC and NCP was searched using hand-held flashlights during each visit. The interval between monitoring visits varied from 7 to 15 days during the egg-laying and incubation periods. Monitored nest sites were identified as suitable crevices or sheltered sites which contained evidence of past or present breeding in at least 1 breeding season since 1994. Such evidence included an incubating or brooding adult, whole unattended eggs, and hatched or broken eggs or eggshells. During the first visit each year, caves were carefully inspected and any remaining eggshell fragments from the past breeding season were removed to avoid possible confusion with subsequent nesting efforts.

Data Analysis – Analyses of nest monitoring data generally followed Whitworth et al. (2013, 2015a). In this report, we limited analyses of nest monitoring data to determination of trends and per annum rates of increase in the number of occupied nests in all monitored plots at Anacapa, as well as the SC and NCP subsamples. To better compare TSR between the nest monitoring and spotlight survey data, we used 2001 as the baseline year (rather than 2003) for the Anacapa and SC datasets, assuming: (1) no nests were occupied in NCPs in 2001 or 2002; and (2) two nests found in Rockfall Cove in 2005 were occupied in 2003-2004, as suggested by the rapid occupation of nest crevices observed in other NCPs after eradication.

Statistical Tests - As for spotlight counts, we used Pearson *r* to perform TSR using log-transformed counts of the annual number of occupied nests in all monitored areas, the SC and NCP. The per annum rate of increase in the number occupied nests was estimated from the antilog of the slope of the log-transformed times series regression line.

# RESULTS

## Spotlight Surveys 2014

We conducted a total of 12 ST spotlight surveys over 8 nights between 15 March and 24 May (including 5 nights between 15 March and 7 April, and 3 nights between 12 May and 24 May), and 4 RI surveys between 24 March and 7 April (Tables 1-2). Another RI survey was attempted on 15 March, but had to be suspended off the south side of West Anacapa (partial count = 491 murrelets) due to poor ocean conditions. Poor ocean conditions also prevented ST spotlight surveys during scheduled trips to Anacapa between 8 April and 11 May.

ST survey counts in 2014 ranged from 55 to 583 murrelets ($\bar{x}$ = 289 ± 192; Table 1), while RI counts ranged from 71 to 1386 murrelets ($\bar{x}$ = 869 ± 592; Table 2).

## Standard Spotlight Surveys (2001-2014)

We conducted a total of 142 ST spotlight surveys over 66 nights in 7 years (Table 1). The overall mean count was 149 murrelets (± 113 *s.d.*) and ranged from 0 to 583 (Table 1).

Seasonal Trends – We did not detect consistent seasonal trends in ST counts, even after controlling for annual differences in timing of breeding, with considerable variability in murrelet attendance in at-sea congregations observed throughout the breeding season (Figs. 3-4). Maximum annual counts were obtained as early as 2 days before (2002) and as late as 32 days after (2003) the AMNID (Fig. 4). ST surveys were conducted 0-10 days after the AMNID in all years. While surveys in 2003 and 2005 yielded relatively high counts (> 90% annual maximum) during this period, relatively low counts (< 20% annual maximum) were obtained during the same period in 2004 and 2014, and mostly intermediate counts occurred in 2001 and 2002 (Fig. 4). However, ST counts were invariably low (i.e., < 60% of the annual maximum) more than 15 days before and 40 days after the AMNID (Fig. 4), so counts conducted during these periods were excluded from the ST survey annual means.

Inter-Annual Trends – Log transformed TSR detected significant increases (all $r^2 \geq 0.63$, all $p <$ 0.04) in spotlight counts for all 3 ST survey datasets (Tables 3-4, Fig. 5). Generally, regression coefficients were higher and significance levels increased as the sample sizes decreased for each dataset (Tables 3-4). Slopes of the TSR lines for ST spotlight surveys datasets ranged narrowly from 0.065 to 0.084 (Table 4), indicating per annum increases of 6.7-8.8%. However, the 95% CI for the regression slopes were relatively wide, most likely due to small sample sizes (6 years in each dataset). The lower end of the 95% CIs ranged from -0.006 to 0.016, while the upper end ranged from 0.114 to 0.175 (Table 4).

Pre-Eradication (2001-2003) vs. Post Eradication (2014)

ST spotlight survey counts were significantly higher ($t_{45}$ = -4.14, $p < 0.0002$) in 2014 ($\bar{x}$ = 316 ± 201, n = 8) compared to the baseline years in 2001-2003 ($\bar{x}$ = 153 ± 69, n = 39). The mean and maximum ST counts in 2014 were 106% and 115% greater, respectively, than in 2001-2003.

**Round-Island Spotlight Surveys (2001-2014)**

We conducted a total of 16 RI surveys over 5 years (Table 2; Figs. 6-7). The overall mean count was 375 (± 417 *s.d.*) murrelets and ranged from 29 to 1386. Excluding the ST survey inshore portion of the RI transect from the RI counts, we noted a very strong correlation ($r^2$ = 0.92, n = 16, $p < 0.0001$) between consecutive ST-RI counts (Fig. 8).

Seasonal Trends - Obvious seasonal trends were not evident in RI survey data, even after controlling for annual differences in timing of breeding (Figs. 6-7), but annual samples were likely too small to detect seasonal trends. All RI surveys were conducted during periods of peak congregation attendance, as determined from ST surveys. Maximum annual RI counts were obtained as early as 2 days before (2002) the AMNID and as late as 35 days after (2003) the AMNID (Fig. 7).

The 3 RI counts in 2001 occurred on nights when proportional ST counts were only 9%, 35%, and 59% of the annual maximum, while the 3 RI counts in 2003 occurred on nights when ST counts were 44%, 62%, and 79% of the annual maximum ST count. In contrast, the annual maximum RI count in 2002 was conducted on the same night as the annual maximum ST count, but other RI surveys in 2002 occurred on nights when ST counts were just 5-54% of the annual maximum ST count.

Inter-Annual Trends – Despite the small number of survey years, TSR detected significant increases (all $r^2 \geq 0.84$, all $p < 0.04$) in spotlight counts for the 2 RI datasets (Table 4, Fig. 5). Slopes of the TSR lines ranged from 0.110 (95% CI = -0.036 to 0.255) to 0.115 (95% CI = 0.069 to 0.162) (Table 4), indicating per annum increases of 11.6-12.2%. The relatively wide CIs for the slopes were most likely due to the small sample sizes (i.e., 4 years) in each dataset.

Pre-Eradication (2001-2003) vs. Post Eradication (2014)

RI spotlight survey counts were significantly higher ($t_{14}$ = -3.72, $p < 0.003$) in 2014 ($\bar{x}$ = 869 ± 592, n = 4) compared to the baseline years in 2001-2003 ($\bar{x}$ = 211 ± 155, n = 12). The mean and maximum RI counts in 2014 were 319% and 146% greater, respectively, than in 2001-2003.

Estimates of murrelet population size based on maximum RI survey counts (D. Whitworth and H. Carter, unpubl.data) increased nearly 150% from 450-600 breeding birds or 225-300 pairs in 2001-2003 to 1100-1450 breeding birds or 550-725 pairs in 2014.

Murrelet Distribution - Considering the variation in RI counts, the proportion of the total count within each sector remained remarkably consistent among the 5 surveys (Table 5; Fig. 9). The proportional counts were invariably highest in the ST survey area off the south side of East Anacapa which accounted for 31-42% of total RI total counts. Counts were also consistently high off the south side of Middle Anacapa which accounted for 15-27%. In contrast, proportional counts were consistently low off the north side of Middle Anacapa which accounted for only 4-9%. Each of the other 3 sectors accounted for just 4-16% of the total RI counts.

East Anacapa accounted for the highest proportions of the total RI counts (42-56%) compared to Middle Anacapa (22-34%) and West Anacapa (20-29%). These proportional counts did not correspond to overall island size; in fact, West Anacapa is by far the largest of the 3 islets but had the lowest proportional counts. The south side of all 3 islets accounted for 59-78% compared to just 22-41% for the northern side. Obvious shifts in the distribution of murrelets attending at-sea congregations were not evident from 2002-2003 to 2014 (Fig. 9).

**Nest Monitoring**

By 2014, we had a sample of 86 monitored murrelet nest sites on Anacapa, not including 7 sites lost to erosion or other natural processes during the study. All but 1 of the monitored sites were occupied by nesting murrelets during at least 1 year of this study; the lone exception was a monitored site in Refuge Cave which was occupied only in 1994 (H. Carter, unpubl. data). The sample of monitored sites included 56 nests in SC and 30 nests in NCP.

Assuming no nesting in NCP pre-eradication, the annual number of occupied nests at Anacapa increased over 5-fold (445%) from 11 nests in 2001 to 60 nests in 2014 (Fig. 10). Over the same period, the number of occupied nests in SC increased (272%) from 11 to 41 nests. The number of occupied nests in NCP increased nearly 5-fold (375%) from 4 to 19 nests from 2003 to 2014. Other details of nest monitoring results from 2001-2010 and 2014 are presented in Whitworth et al. (2013, 2015b).

Inter-Annual Trends - TSR analyses of the log-transformed annual data demonstrated significant increases in the overall number of occupied nests at Anacapa ($r^2 = 0.91$, $p < 0.0001$), as well as for subsamples in SC ($r^2 = 0.90$, $p < 0.0001$) and NCP ($r^2 = 0.80$, $p < 0.001$) (Fig. 11). Slopes of the log-transformed TSR lines were 0.141 for Anacapa (95% CI = 0.109 – 0.174), 0.104 in SC (95% CI = 0.078 – 0.129), and 0.171 in NCP (95% CI = 0.094 – 0.249) (Table 4). The TSR slopes indicated per annum increases in the number of occupied nests of 15.1% at Anacapa, 11.0% in SC, and 18.6% in NCP.

## DISCUSSION

**Scripps's Murrelet Recovery at Anacapa Island**

Nocturnal spotlight surveys and nest monitoring at Anacapa Island provided 2 independent indexes for measuring Scripps's Murrelet population trends which have both confirmed extensive population benefits after the eradication of Black Rats in 2002. Without considering interannual variation or estimation error around annual values, 5 basic metrics demonstrated a considerable increase in murrelet population size at Anacapa post-eradication:

(1) the number of occupied nests at Anacapa increased over 5-fold (445%) from 11 in 2001 to 60 in 2014;

(2) 30 new murrelet nest sites were established from 2003 to 2014 (with 19 occupied in 2014) in 3 NCP where nesting was not known to occur prior to eradication;

(3) the 3 highest RI spotlight counts all occurred in 2014 and the maximum 2014 count (1386) was 146% higher than the maximum count in 2001-2003 (564 in 2002);

(4) annual mean and maximum ST spotlight counts in 2014 were 106% and 115% greater, respectively, than in 2001-2003; and

(5) estimates of murrelet population size at Anacapa based on maximum RI survey counts increased nearly 150% from 450-600 breeding birds in 2001-2003 to 1100-1450 breeding birds in 2014.

TSR analyses of the occupied nest data (SC and NCP) and spotlight survey data (RI and ST) also demonstrated statistically significant increases for all of the datasets examined. However, caution is warranted when assessing statistical results for the TSR as several potential analytic issues made interpretation of the results somewhat speculative. Many of these issues were related to insufficient survey effort in some years or the small sample sizes. We were aware of most of these issues prior to 2014 surveys, but felt that comparisons between nest monitoring and spotlight survey data were urgently needed to confirm or modify the recent assessment of post-eradication murrelet population trends based solely on nest monitoring data in 2003-2010 (Whitworth et al. 2013). Ideally, 1-2 more years of spotlight surveys in 2015-2016 and continued nest monitoring after 2014 would have allowed for a much more robust statistical analysis of the trend data. Unfortunately, funding was not available for 2015-2016 and has not yet been secured for future monitoring and surveys.

**Standard and Round-Island Spotlight Surveys**

To identify spotlight survey data that was most representative of the overall size of the "colony" (i.e., including adults and subadults), we examined all the survey data and systematically excluded surveys which were least representative. First, we excluded all counts obtained outside the peak breeding period (i.e., between 15 days before and 40 days after the AMNID) when murrelet attendance in at-sea congregations was demonstrably low (Figs. 3,4,6,7). Second, we created subsamples of spotlight survey datasets to examine the effects of removing low survey counts obtained during the peak breeding season when attendance in at-sea congregations is variable and unpredictable (Figs. 3,4,6,7). Exclusion of low counts did have the desired effect of reducing variability in the survey data for improved trend analyses of the ST survey counts. TSR regression coefficients ($r^2$) and significance levels ($p$) increased as sample size in the datasets decreased (i.e., ST mean had the lowest $r^2$ and least significant $p$ values, while the ST maximum had the highest $r^2$ and most significant $p$ values) (Table 4). In contrast, the RI maximum dataset provided a more poorly fitting (but still statistically significant) TSR line compared to the RI mean (Table 4), most likely due to failure to conduct RI surveys on nights when annual maximum ST counts were obtained in 2001 and 2003 (*see below*).

Four potential issues that may have affected TSR trend analysis include:

> (1) *The great influence of the isolated data point for 2014 at the right end of TSRs made the slope of the regression lines (and estimates of the per annum rate of increase) less reliable*. The ST and RI survey data had 9 year and 11 year gaps between the isolated 2014 data point and the nearest previous data point (2005 and 2003, respectively). The great influence of the isolated 2014 data point is made clear by example. Removing the minimum RI survey count in 2014 increased the annual mean from 869 (± 592) to 1135 (± 317), which in turn increased the slope of the TSR considerably from 0.115 to 0.137.
>
> (2) *Small samples sizes for TSRs in the RI (n = 4), and to a lesser extent, the ST (n = 6) survey datasets*. Although the slopes of TSR lines for ST and RI survey datasets were not widely dissimilar, the wide ranges in the 95% CIs for the slopes of the ST and RI datasets indicates a relatively high degree of uncertainty in the estimated slopes (Table 4).
>
> (3) *One-tailed statistical tests*. These tests were used to determine increases in the spotlight survey TSR, ignoring the possibility of decreases over time. We felt that use of one-tailed tests in this instance was legitimate as they offered more power to detect "expected" increases in the number of murrelets attending congregations after the eradication of Black Rats, especially considering the documented increase in number of nests at Anacapa. More traditional two-tailed tests still would have detected statistical increases for 2 ST survey datasets (i.e., 3 highest counts and annual maximum) and the RI mean dataset, but the other datasets would have been marginally not significant.
>
> (4) *Failure to conduct RI surveys on nights when annual maximum ST counts were obtained in 2001 and 2003* (*see Results*). Higher mean and annual maximum RI counts in 2001 and 2003 would have decreased the slope of the regression line to a level more consistent with the ST survey TSRs (*see below*).

Slopes of the TSR regressions for ST surveys (0.065-0.084) off the south side of East Anacapa were considerably lower than for RI surveys (0.110-0.115) around the rest of Anacapa (Table 4, Fig. 5). We do feel that this lower rate of increase in ST survey counts noted after eradication accurately reflected local conditions on the south side of East Anacapa where the extensive inaccessible habitats likely contained a significant proportion of the remnant nesting population prior to eradication (Table 5; Fig. 9). Thus, smaller increases in ST spotlight counts may have reflected smaller increases in the actual number of nests on the south side of East Anacapa. The high sheer cliffs off the south side of East Anacapa (Fig. 12) may have been much less accessible to rats resulting in much lower historical rat impacts on murrelets and relatively high occupancy of suitable crevices compared to West Anacapa, Middle Anacapa and the north side of East Anacapa before eradication (Fig. 9). Despite the relatively large number of murrelets in at-sea congregations off the south side of East Anacapa, we could not monitor nests in this area to verify high crevice occupancy because these habitats were largely inaccessible to researchers.

Another important factor to consider is that, since 1984, the National Park Service had an extensive rat control program at East Anacapa, that kept the rat population at a lower level compared to West and Middle Anacapa (Erickson and Halvorsen 1990). Rat impacts may have been greatly reduced at East Anacapa for about 18 years prior to eradication which may have allowed murrelet population growth in some areas of the islet, especially on the south side adjacent to the building compound area where rat control was extensive. However, more accessible areas of the Landing Cove NCP, also near the compound, were apparently not occupied by murrelets in 1991-2001, indicating that rats still excluded murrelets from many areas on East Anacapa.

An early post-eradication increase in ST spotlight counts in 2003 may have been due to increased hatching success on East Anacapa in 2002 (i.e., the first breeding season after rat eradication on this islet in fall 2001) that resulted in a spike of first-year subadult birds attending the congregation. However, very little is known regarding congregation attendance for subadult Scripps's Murrelets or *Synthliboramphus* murrelets in general. First-year Ancient Murrelets (*S. antiquus*) apparently visit breeding islands only infrequently, although their attendance in at-sea congregations has not been studied (Gaston 1992). In contrast, a decrease in ST spotlight counts in 2004 compared to previous years (Table 1) may have been due to decreased nesting in this generally poor breeding year which reduced congregation attendance on most nights (Fig. 10), although the maximum 2004 annual count was similar to 2001-2003. We also may have missed several nights of high congregation attendance due to the small samples of surveys in 2004, as well as in 2006.

**Number of Occupied Nests in Sea Caves and Non-Cave Plots**

The nest monitoring TSRs demonstrated statistically significant increases in the number of murrelet nests in SC and NCP over time and provided reliable estimates for the rate of increase in these sample areas. However, we detected significant differences between the SC and NCP datasets that indicated breeding conditions varied considerably in these subsamples. Despite these differences, we feel that the current rate of overall murrelet population increase may lie between these two estimates, and that at present, the combined SC and NCP dataset (Anacapa) may provide the most reliable data for assessing overall murrelet population trends with nest monitoring data alone. In the future, NCP monitoring may better represent the overall population, after murrelets expand further into unused habitats and SC habitats become saturated.

In some respects, the nest monitoring data had considerable advantages compared to spotlight surveys, as 2 potential issues identified for TSR analysis of the spotlight survey data were not issues for analyses of nest monitoring data:

> (1) adequate sample sizes were available for reliable TSR analysis of the Anacapa ($n = 11$), SC ($n = 11$) and NCP ($n = 9$) datasets; and
>
> (2) calculated $p$ values for Anacapa, SC and NCP were highly significant (all $p < 0.001$), making the issue of 1 vs. 2 tailed tests irrelevant.

As for the spotlight survey TSRs, the influence of the isolated data point (year 2014) at the far right end of the nest monitoring TSR is of concern, but not nearly to the extent as for spotlight surveys. The Anacapa, SC and NCP nest monitoring datasets all had 4 year gaps between 2010 and 2014 compared to the 9-11 year gap for spotlight TSRs. Furthermore, the greater number of years in the nest monitoring datasets likely compensated somewhat for the 4-year gap to increase the reliability of slopes and estimates of the per annum increases.

The reliability of the Anacapa nest monitoring dataset for estimating population trends was dependent on the degree that: (1) subsamples (SC and NCP) accurately reflected conditions in these habitat types over the entire island; and (2) subsamples in the Anacapa dataset accurately represented the proportions of these habitat types over the entire island. We suspect that inclusion of the NCP data in the Anacapa dataset may have introduced biases that resulted in overestimation of the overall population increase. While the NCP datasets accurately reflected conditions in these small plots, other evidence suggested that these plots did not reflect conditions in most other accessible non-cave habitats at Anacapa. In fact, the choice of NCP locations was not random, but based on the searches in 2003-2005 which identified these plots as among the few non-cave areas at Anacapa where murrelets expanded nesting shortly after eradication, but were also accessible to researchers without disturbance to breeding Brown Pelicans (*Pelecanus occidentalis*), Double-crested Cormorants (*Phalacrocorax auritus*) and Brandt's Cormorants (*P. penicillatus*). In October 2009 (after the seabird breeding season), extensive nest searches of other shoreline and upper island habitats similar to the NCP habitats (*see Methods* for a description of these habitats) located only a handful of isolated nests in shoreline areas and none in upper island habitats, indicating that: (1) despite significant population increases since eradication, most of that increase was limited to areas at or near previously occupied remnant breeding habitats; and (2) widespread expansion of the colony into previously vacant habitats had not occurred (Whitworth et al. 2012, 2013).

Significant differences in growth rates between the SC and NCP were probably due to: (1) relatively larger numbers of suitable nest crevices available in the vacant NCP habitat in the early post-eradication period; and (2) the zero baseline level of nesting at the time eradication in NCP (Whitworth et al. 2013). Small numbers of nesting murrelets were documented in SC prior to eradication (McChesney et al. 2000), but, other than historical nesting on Cat Rock in the early 1900s, murrelet nests were not documented in the other NCPs where rapid reoccupation after eradication was likely facilitated by small numbers of isolated murrelet pairs that nested in nearby inaccessible habitats (Whitworth et al. 2013).

We had previously speculated that growth in the number of occupied nests in SC would decrease over time as the number of suitable breeding crevices became limited, while growth in the NCPs would continue over a longer period (Whitworth et al. 2012, 2013). To date, overall increases in the number of occupied nests in SC have remained relatively steady through 2014, although changes in the number of nests have varied considerably among the individual sea caves, some of which may already be saturated (Whitworth et al. 2015a). In contrast, the sharp increase in NCP from 2003-2010 appears to have moderated since 2010. The NCP regression slope decreased markedly with inclusion of 2014 data (0.171 with vs. 0.243 without), but the SC regression slope changed little with inclusion of 2014 data (0.104 with and 0.103 without). Data were lacking from NCP in 2011-2013 to assess whether the decreased NCP slope in 2014 indicated a consistent trend after 2010 and, if so, which year the inflection point occurred.

We currently consider changes in the number of occupied nests to be the most reliable index of murrelet population change based on nest monitoring data. However, population growth rates based on occupied nests may be somewhat conservative if multiple clutches within a breeding season were laid by different pairs in some nest sites. Slopes of TSR lines for the number of clutches in monitored nests were 0.123 in SC and 0.189 in NCP, slightly higher than for occupied nests. If future studies verify significant use of the same nest site by different murrelet pairs within a breeding season, population growth rates might be better represented by the overall number of clutches.

**Assessing Overall Murrelet Population Trends with Spotlight Counts and Nest Monitoring**

For the best possible assessment of Scripps's Murrelet population trends from this study, one should consider: (1) the relative strengths and weaknesses of each monitoring dataset (i.e., ST and RI spotlight surveys, and the Anacapa, SC and NCP nest monitoring); (2) the degree of concordance in the amount and direction of change in population size, based on simple metrics; and (3) the degree of concordance among the estimated rates of population change (i.e., slopes of the TSR) for each dataset. Considering the concordance in trend direction among all the datasets, it is clear that significant population increases have occurred at Anacapa since eradication. However, estimating the actual rate of increase is much more complicated. Considered separately, spotlight surveys and nest monitoring all suffered from potential biases that complicated this assessment (Table 6). Despite the limited samples of surveys in some years and the small number of survey years, we believe that the RI surveys appeared to be most reliable for estimating population trends and were likely to be more representative of the overall Anacapa murrelet population due to the complete spatial coverage compared to nest monitoring and ST surveys. ST surveys and nest monitoring (Anacapa, SC and NCP datasets) shared the same major limitation: incomplete spatial coverage relative to the total amount and various types of potential breeding habitats available to murrelets at Anacapa. We estimated that ST surveys covered about 10% and nest monitoring less than 3% of the total available breeding habitat. As a result, some doubt existed as to whether the ST survey area and the small NCP and SC plots on all 3 islets were representative of breeding conditions around the entire island.

The primary weakness of the RI survey datasets was the small annual samples in some years (e.g., 2001 and 2003) and our failure to conduct surveys on nights of near-maximum congregation attendance in 2001 and 2003. More difficult ocean conditions off the more exposed portions (i.e., northern and extreme southwestern) of Anacapa prevented RI surveys on many nights. In contrast, sample sizes were not a relevant factor in the ST survey and nest monitoring TSR datasets. Compared to RI surveys, larger samples of ST surveys could be obtained in waters protected from the prevailing NW winds on the south side of East Anacapa. The strong correlation between ST and RI counts indicated that ST surveys were generally representative of the entire island and provided reliable monitoring data. In fact, we believe that overall murrelet population trends at Anacapa eventually could be measured solely with larger sample sizes of ST surveys once: (1) population growth rates at the different islets are no longer affected by differences in past rat impacts; and (2) other factors such as avian predation and anthropogenic impacts remain roughly similar among the 3 islets.

Estimated rates of murrelet population increase ranged rather widely from 6.7-8.4% (ST surveys) to 15.1% (Anacapa nest monitoring), with RI surveys (11.6-12.2%) intermediate (Table 6). If, as we suspect, the Anacapa nest monitoring dataset is biased high by the 18.6% growth rate observed in NCP, then the actual growth rate is likely much closer to that observed in SC (11.0%). The 10 sea caves were located in widely separated areas on both sides of the West and Middle islets (but not the East islet), such that: (1) monitoring may have adequately represented a greater variety of potential breeding habitats in proportions roughly similar to those present on Anacapa; and (2) the concordance in murrelet population trends between the SC nest monitoring (11.0%) and RI survey datasets (11.6-12.2%) indicated that both techniques may have provided adequate estimates of the actual post-eradication population increases through 2014.

**Future Murrelet Monitoring at Anacapa**

The recovering Scripps's Murrelet colony at Anacapa is now one of the largest, if not the largest, colony in the world. Continued annual monitoring should be a priority for CINP and other federal and state agencies. However, funds from ATTC for extensive Scripps's Murrelet nest monitoring at Anacapa were exhausted in 2014, and spotlight surveys in 2014 were supported primarily by NFWF. Alternate funds to continue the monitoring program at Anacapa have not yet been identified. Continuation of murrelet monitoring using methods comparable to 2001-2010 and 2014 efforts is critical for best documentation of the rate and pattern of recovery of this colony until it reaches a "recovered" condition. The long-term value of rat eradication (in terms of improvement in murrelet population size and breeding distribution at Anacapa) and the time required to obtain eradication benefits will not be measured without at least periodic monitoring for at least the next 2 decades. If low-quality or no data are gathered, a great opportunity to understand and measure how this population of a relatively rare seabird species responds over time to rat eradication will have been lost.

High-quality annual data are preferable to reliably measure the nature and rate of recovery of this colony after rat eradication. However, financial constraints may prevent annual monitoring that includes both nest monitoring and spotlight surveys. Given these financial considerations, our best assessment of the previous monitoring data in 2001-2014 indicates that a rigorous Scripps's Murrelet population monitoring program at Anacapa Island should include:

(1) annual nest monitoring conducted every 10-14 days throughout the breeding season. Annual variability in timing of breeding in 2001-2014 indicated that nest monitoring should begin in early-mid March and proceed until all clutch fates have been determined;

(2) ST and RI spotlight surveys conducted in at least 2 (but preferably 3) consecutive years every 5-6 years (i.e., 2-3 years on and 3 years off). This monitoring schedule will avoid isolated data points that are problematic in TSR analyses and ensure that non-representative years with poor prey availability or other impacts do not result in flawed analyses;

(3) an adequate number of ST survey nights (minimum 8, but preferably 10-15 or more) throughout the breeding season to account for variability in murrelet congregation attendance and ensure that nights of near-maximum attendance are sampled. Two ST

surveys should be conducted each night in the evening and night survey periods; and

(4) at least 4-5 RI surveys conducted in each survey year to ensure that nights of peak attendance are sampled. Given the limits imposed by often poor weather conditions and the large time commitment to complete a single RI survey (2.5-3.0 hours), these should be conducted primarily on nights when ST surveys indicate higher murrelet attendance at Anacapa, although occasional surveys should be conducted on other nights to confirm the correlation between RI and ST survey counts.

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Table 1. Standard spotlights surveys for Scripps's Murrelets off the south side of East Anacapa in 2001-2005 and 2014.

| Year (Range of survey dates) | Surveys (Nights) | Survey Period[1] | | | Number of Murrelets | |
|---|---|---|---|---|---|---|
| | | E | N | M | Mean ± *s.d.* | Range |
| 2001 (16 Apr – 20 Jun) | 29 (12) | 10 | 12 | 7 | 88 ± 70 | 0-269 |
| 2002 (8 Apr – 22 May) | 33 (14) | 11 | 11 | 11 | 117 ± 62 | 8-270 |
| 2003 (27 Mar – 28 May) | 28 (13) | 13 | 11 | 4 | 163 ± 63 | 26-262 |
| 2004 (13 Apr – 1 Jun) | 12 (6) | 4 | 6 | 2 | 105 ± 86 | 5-285 |
| 2005 (30 Mar – 7 Jun) | 22 (10) | 10 | 10 | 2 | 210 ± 133 | 20-470 |
| 2014 (15 Mar – 24 May) | 12 (8) | 7 | 5 | - | 289 ± 192 | 55-583 |

[1]Codes: E, evening period; N, night period; and M, morning period. See methods.

Table 2. Scripps's Murrelet nocturnal spotlight surveys on the round-island transect at Anacapa Island in 2001-2003 and 2014.

| Year | Date | Number of Murrelets | Annual Mean ± *s.d.*; CV |
|---|---|---|---|
| 2001 | 17 April | 260 | 178 ± 105; 0.59 |
| | 1 May | 215 | |
| | 16 May | 59 | |
| 2002 | 8 April | 564 | 249 ± 202; 0.81 |
| | 12 April | 192 | |
| | 25 April | 156 | |
| | 29 April | 305 | |
| | 15 May | 29 | |
| 2003 | 8 April | 240 | 240 ± 128; 0.53 |
| | 11 April | 112 | |
| | 16 May | 367 | |
| 2014 | 24 March | 71 | 869 ± 592; 0.68 |
| | 3 April | 778 | |
| | 6 April | 1240 | |
| | 7 April | 1386 | |

Table 3. Nightly maximum counts of Scripps's Murrelet during standard spotlight surveys off the south side of East Anacapa in 2001-2005 and 2014. Datasets include nightly maximum counts from: (1) surveys conducted from 15 days before to 40 days after the annual mean nest initiation date that year (annual standard mean); and (2) the 3 highest nightly maximum standard counts each year.

| | Standard Mean[1] | | 3 Highest Standard Mean[2] | |
|---|---|---|---|---|
| Year | Mean ± *s.d.* (n) | CV; Range | Mean ± *s.d.* (n) | CV; Range |
| 2001 | 131 ± 78 (11) | 0.60; 23-269 | 213 ± 49 (3) | 0.23; 180-269 |
| 2002 | 139 ± 57 (13) | 0.41; 49-270 | 216 ± 57 (3) | 0.26; 157-270 |
| 2003 | 219 ± 32 (10) | 0.15; 176-262 | 257 ± 8 (3) | 0.03; 248-262 |
| 2004 | 137 ± 115 (5) | 0.84; 18-285 | 197 ± 83 (3) | 0.42; 119-285 |
| 2005 | 347 ± 93 (6) | 0.27; 251-470 | 428 ± 41 (3) | 0.10; 388-470 |
| 2014 | 404 ± 199 (5) | 0.49; 95-583 | 529 ± 77 (3) | 0.15; 440-583 |

[1] Mean of all nightly maximum surveys conducted from 15 days before to 40 days after the annual mean initiation date.
[2] Mean of the 3 maximum counts each year.

Table 4. Time series regression statistics (Pearson *r*) for datasets from the standard spotlight surveys, round-island spotlight surveys and nest monitoring plots at Anacapa Island in 2001-2014. Regressions were conducted on log-transformed spotlight survey and occupied nest count data. See Figures 5 and 11 for spotlight survey and nest monitoring time series graphs.

| Survey Type | Time Series Data | Years | $r^2$ | *p* | slope | 95% C.I. |
|---|---|---|---|---|---|---|
| Spotlight | Standard Mean[1] | 2001-2005, 2014 | 0.63* | < 0.04 | 0.084 | -0.006 - 0.175 |
| | 3 Highest Standard Mean[2] | 2001-2005, 2014 | 0.70* | < 0.02 | 0.073 | 0.006 - 0.141 |
| | Standard Maximum | 2001-2005, 2014 | 0.77* | < 0.02 | 0.065 | 0.016 - 0.114 |
| | Round-Island Mean[1] | 2001-2003, 2014 | 0.98* | < 0.005 | 0.115 | 0.069 - 0.162 |
| | Round-Island Maximum | 2001-2003, 2014 | 0.84* | < 0.05 | 0.110 | -0.036 – 0.255 |
| Nest Monitoring | Anacapa | 2001-2010, 2014 | 0.91* | < 0.0001 | 0.141 | 0.109 – 0.174 |
| | Sea Caves | 2001-2010, 2014 | 0.90* | < 0.0001 | 0.104 | 0.078 – 0.129 |
| | Non-Cave Plots | 2003-2010, 2014 | 0.80* | < 0.001 | 0.171 | 0.094 – 0.249 |

[1] Mean of nightly maximum surveys conducted from 15 days before to 40 days after the annual mean initiation date.
[2] Mean of the 3 maximum counts each year.

Table 5. Number (proportion of total count) of Scripps's Murrelets counted off all 3 Anacapa islets during the 5 highest round-island spotlight survey counts in 2001-2014.

| | Islet | 8 April 2002 | 16 May 2003 | 3 April 2014 | 6 April 2014 | 7 April 2014 |
|---|---|---|---|---|---|---|
| South Shore | East Anacapa (2.4 km) | 220 (39%) | 146 (40%) | 323 (42%) | 400 (32%) | 435 (31%) |
| | Middle Anacapa (3.9 km) | 155 (27%) | 54 (15%) | 137 (18%) | 279 (23%) | 323 (23%) |
| | West Anacapa (3.4 km) | 66 (12%) | 15 (4%) | 64 (8%) | 173 (14%) | 197 (14%) |
| North Shore | East Anacapa (3.0 km) | 27 (5%) | 58 (16%) | 106 (14%) | 189 (15%) | 159 (11%) |
| | Middle Anacapa (2.5 km) | 37 (7%) | 34 (9%) | 35 (4%) | 72 (6%) | 70 (5%) |
| | West Anacapa (4.1 km) | 59 (10%) | 60 (16%) | 113 (15%) | 127 (10%) | 202 (15%) |
| Total | (~19.2 km) | 564 | 367 | 778 | 1240 | 1386 |

Table 6. Quality of population monitoring data from times series regression (TSR) for Scripps's Murrelet spotlight surveys and nest monitoring in all areas at Anacapa Island in 2001-2014.

| Time Series Data | Spatial Coverage | n = TSR data points (Survey Years) | TSR Slope (% Increase Per Annum) | Trend Comparison with other Datasets |
|---|---|---|---|---|
| Standard Spotlight Surveys | Fair (~10%) | n = 6 (2001-2005, 2014) | 0.065-0.084 (6.7-8.8%) | RI spotlight survey: 2.8-5.5% ↓<br>Anacapa nest monitoring: 6.3-8.4↓ |
| Round-Island Spotlight Surveys | Complete (100%) | n = 4 (2001-2003, 2014) | 0.110-0.115 (11.6-12.2%) | ST spotlight survey: 2.8-5.5% ↑<br>Anacapa nest monitoring: 2.9-3.5% ↓ |
| Anacapa Nest Monitoring | Poor (<3%) | n = 11 (2001-2010, 2014) | 0.141 (15.1%) | ST spotlight survey: 6.3-8.4% ↑<br>RI spotlight survey: 2.9-3.5% ↑ |


**Figure 1**. Satellite photograph of Anacapa Island, with the standard and round-island transects where Scripps's Murrelet nocturnal spotlight surveys were conducted. The inset shows the location of Anacapa off the coast of southern California.

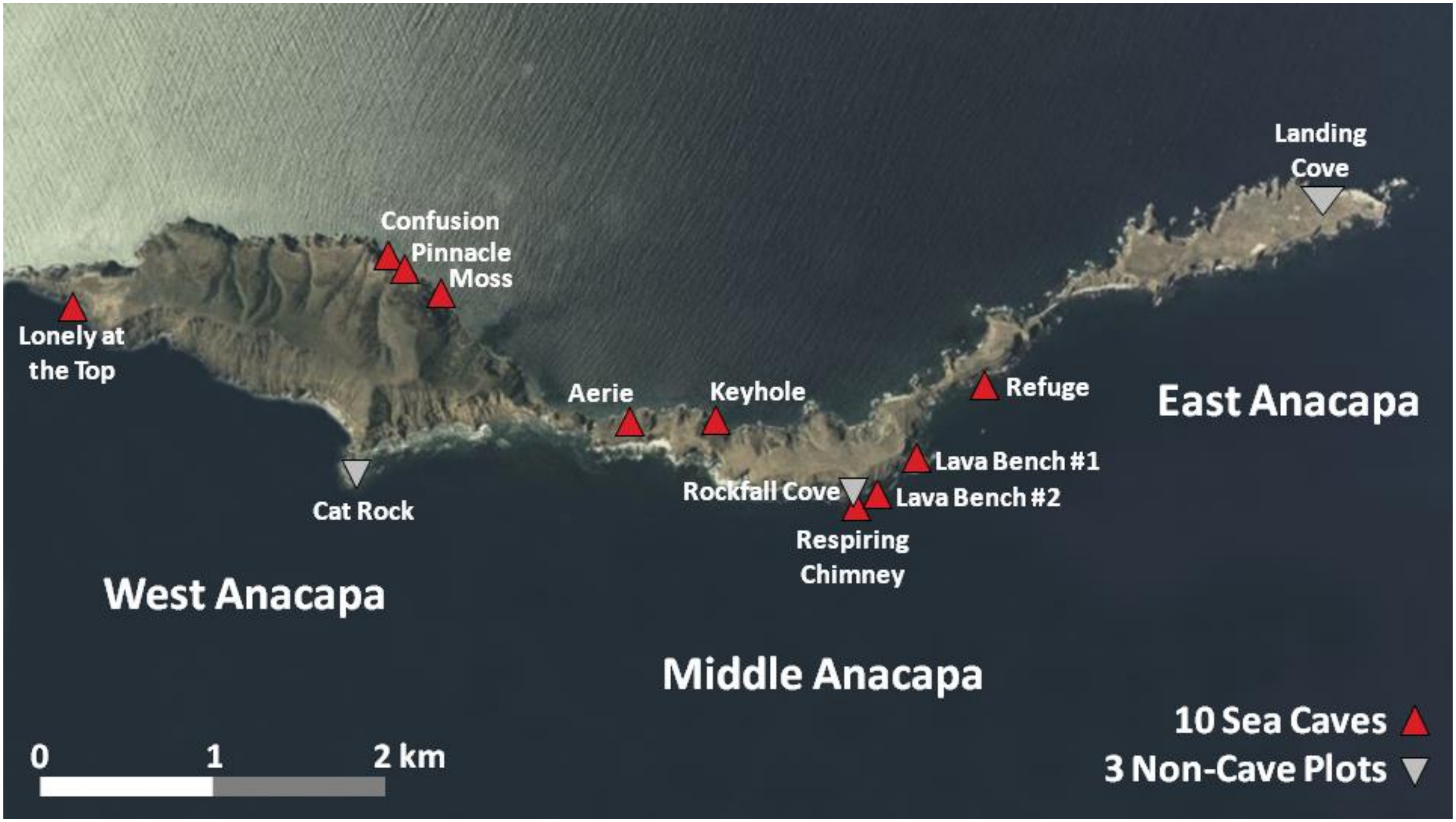


**Figure 2**. Satellite photograph of Anacapa Island, with sea caves (▲) and non-cave plots (▼) where Scripps's Murrelet nest searches and monitoring were conducted.

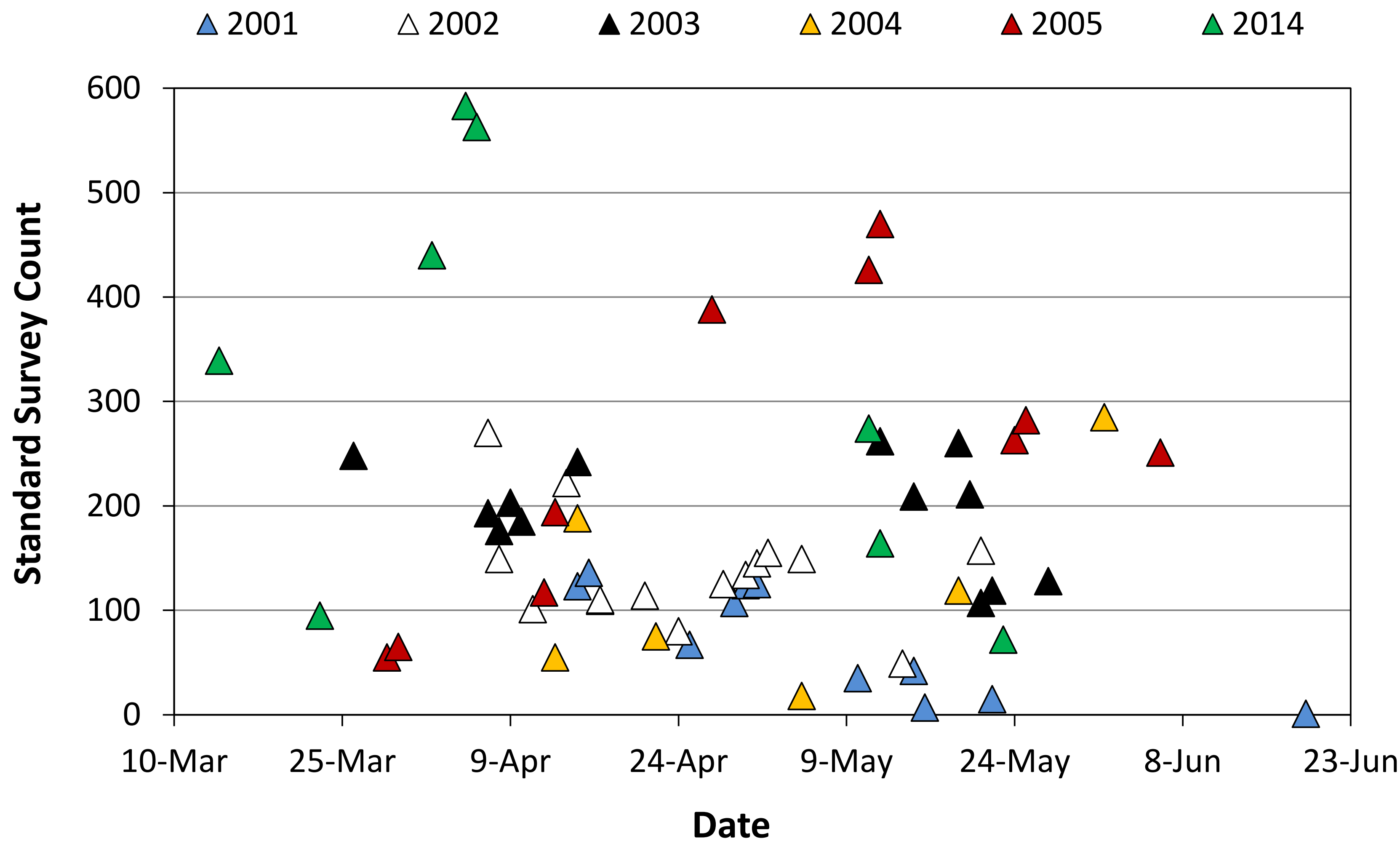


**Figure 3**. Scripps's Murrelet nightly maximum counts during standard spotlight surveys at East Anacapa in 2001-2005 and 2014.

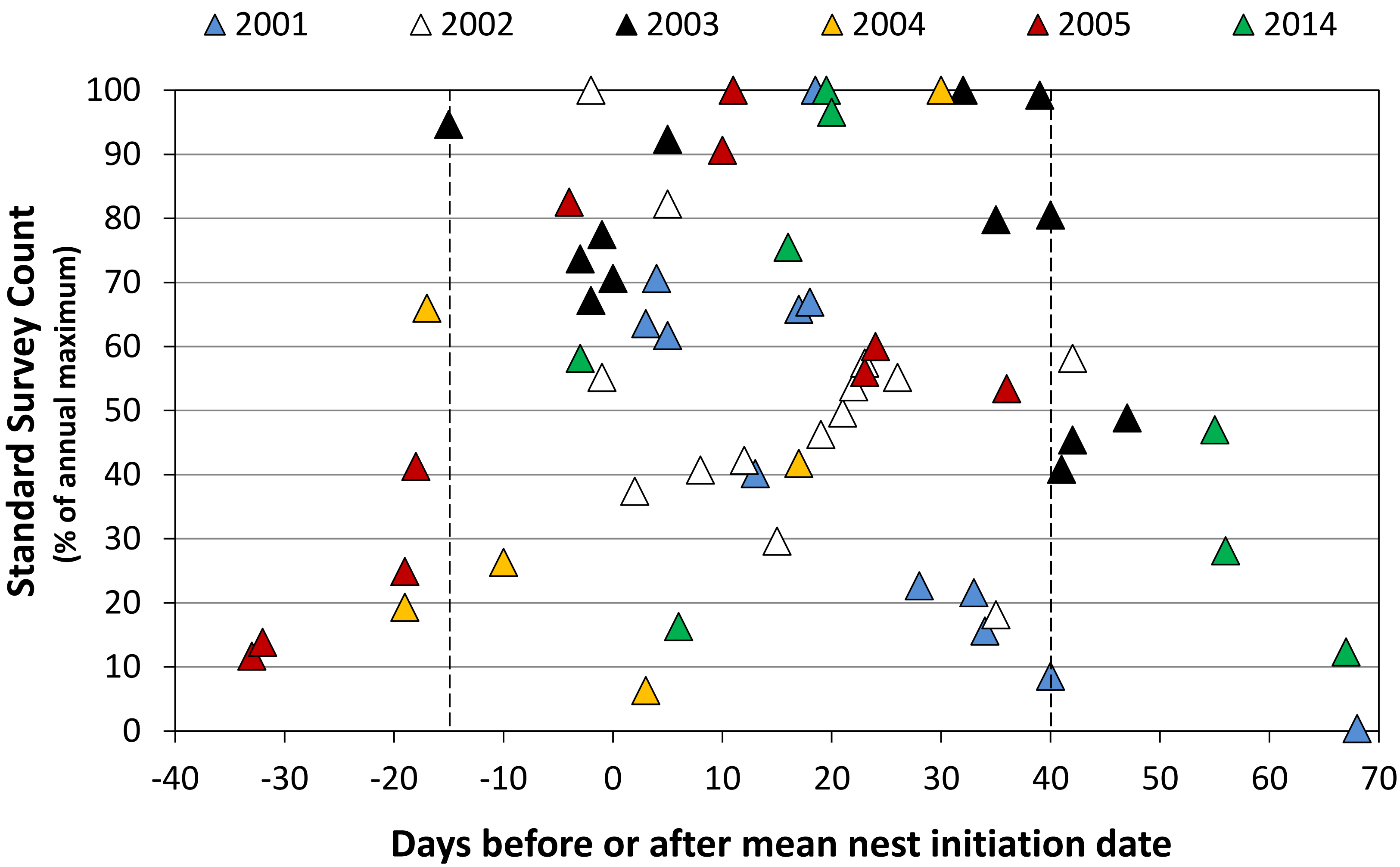


**Figure 4**. Proportional nightly maximum counts of Scripps's Murrelets during standard spotlight surveys at East Anacapa in 2001-2005 and 2014. Counts are presented as the proportion of the annual maximum count each year with survey dates in relation to the annual mean nest initiation date. Dashed lines indicate the cut-off date for surveys excluded from annual means (*see methods, results*).

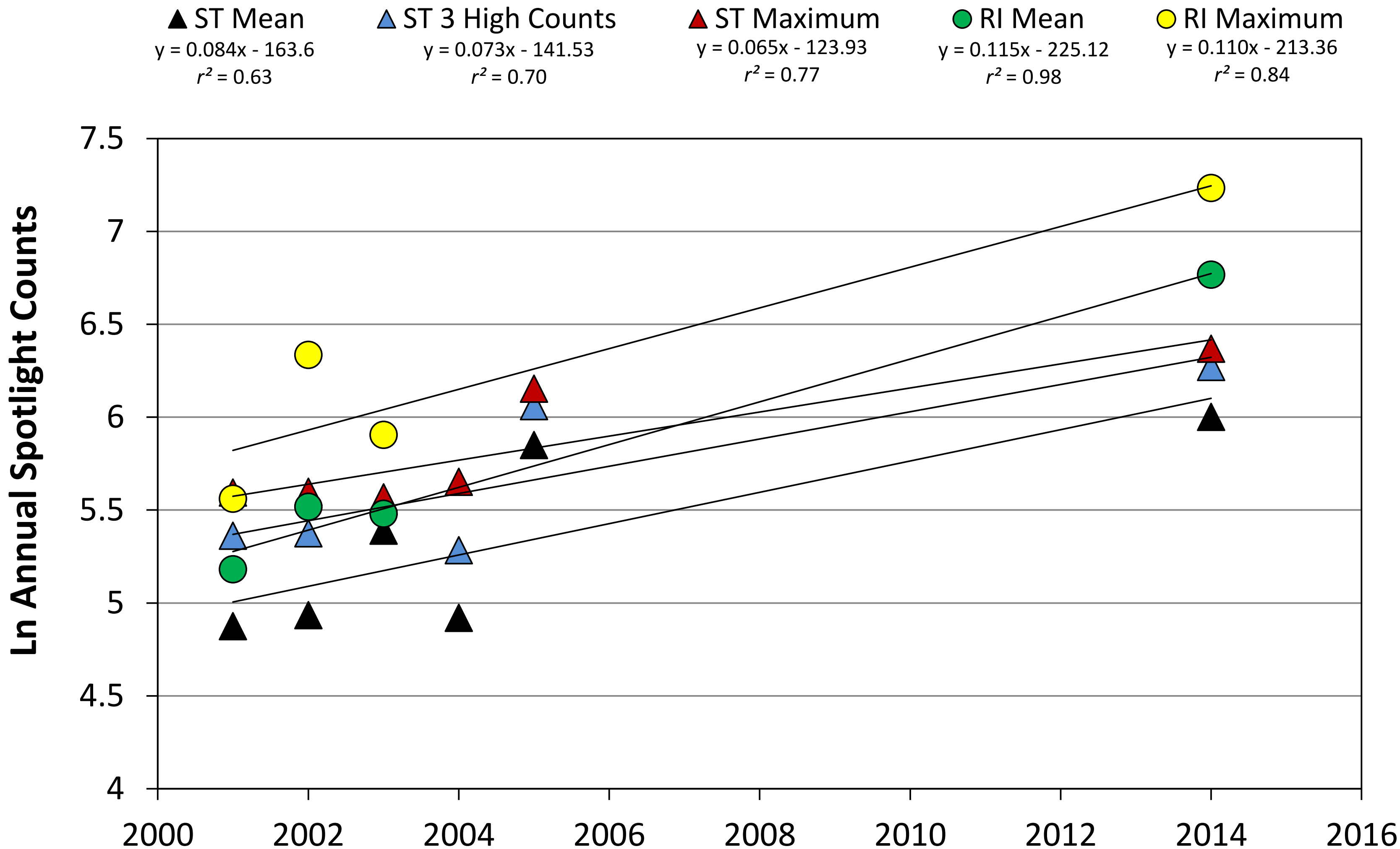


**Figure 5**. Time series regressions of the log-transformed data from Scripps's Murrelet standard (ST) and round-island (RI) spotlight surveys at Anacapa Island from 2001-2005 and 2014.

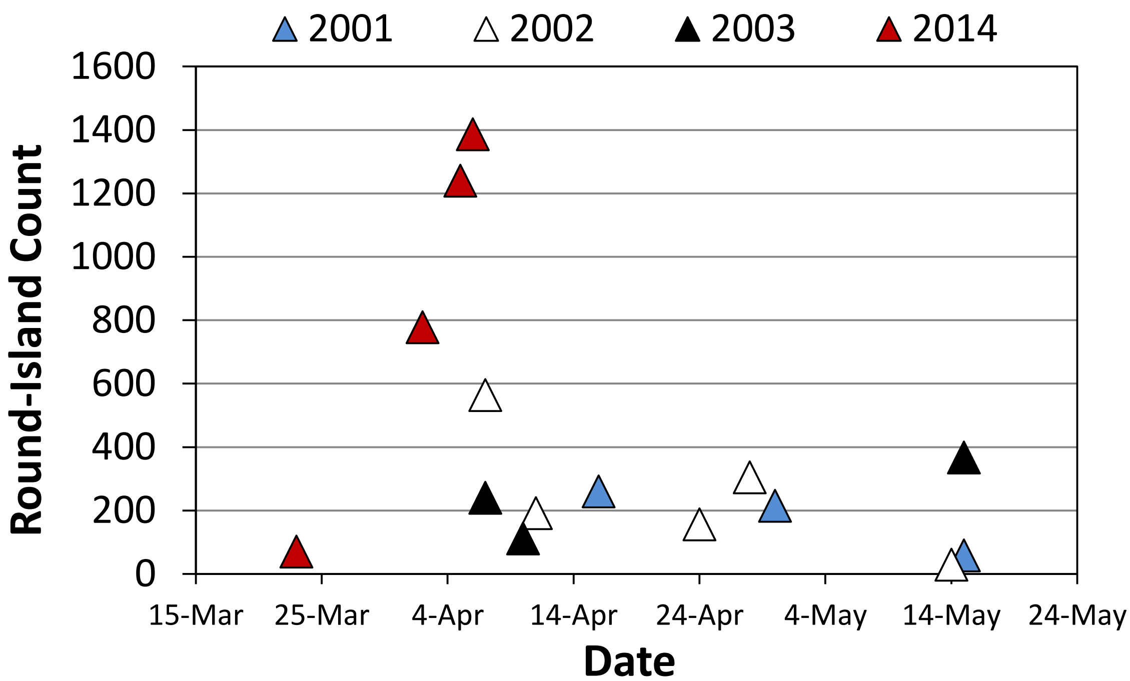


**Figure 6**. Scripps's Murrelet counts during round-island spotlight surveys at Anacapa Island in 2001-2003 and 2014.

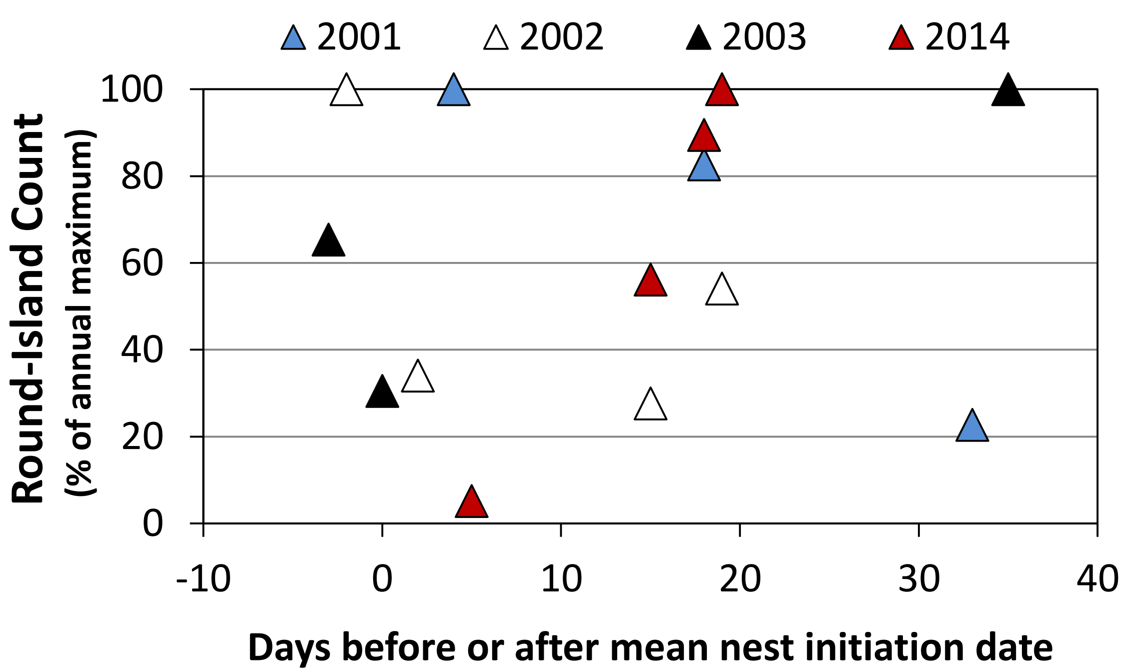


**Figure 7**. Proportional counts of Scripps's Murrelets during round-island surveys at Anacapa Island in 2001-2003 and 2014. Counts are presented as the proportion of the annual maximum count each year with survey dates in relation to the annual mean nest initiation date.

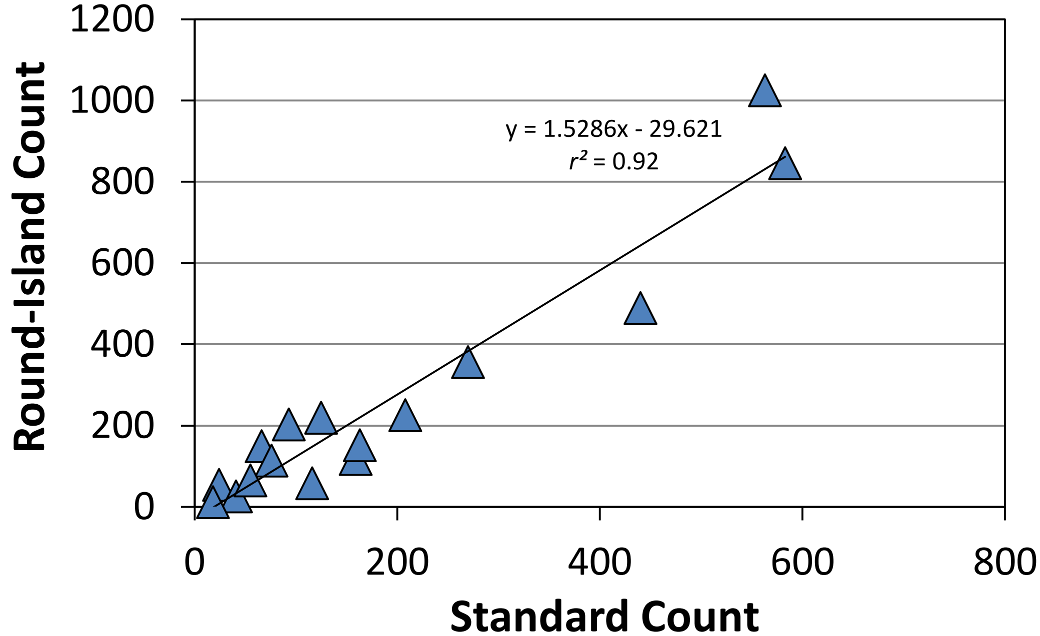


**Figure 8**. Relationship between Scripps's Murrelet counts during consecutive standard and round-island spotlight surveys at Anacapa Island in 2001-2004 and 2014. The round-island count does not include murrelets seen on the standard inshore portion of the round-island transect.

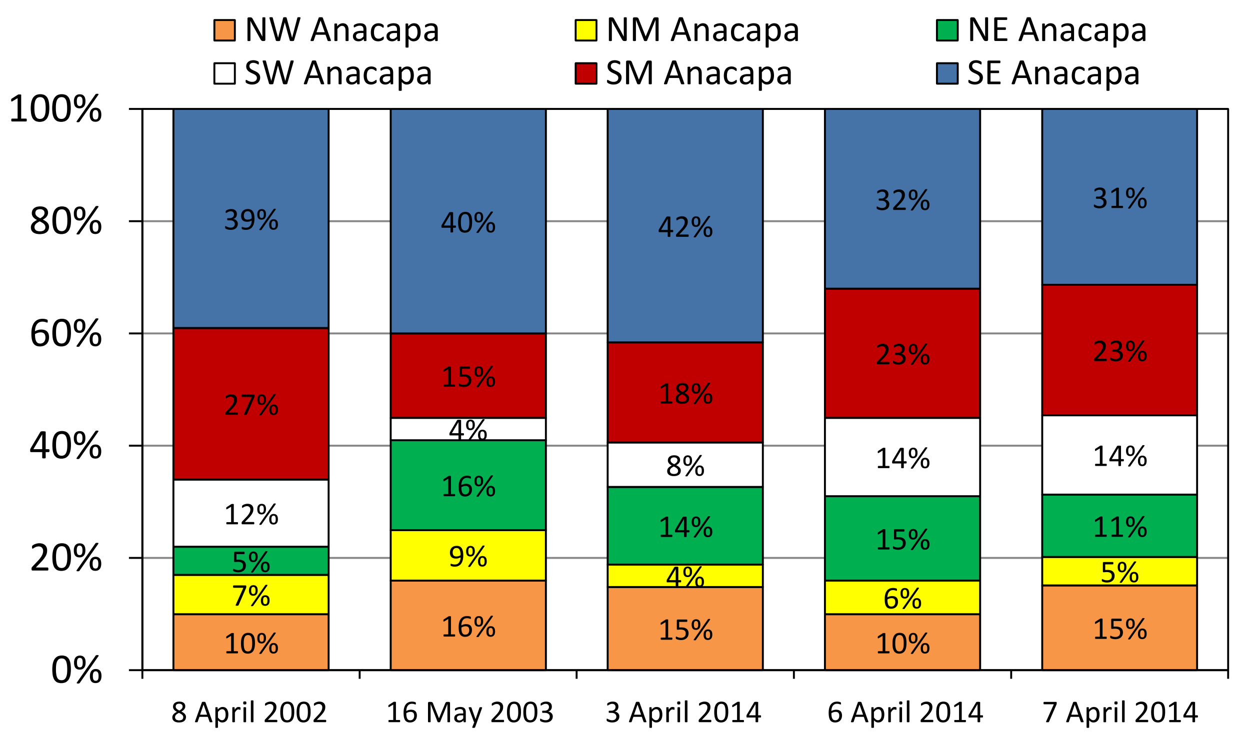


**Figure 9**. Proportional counts for Scripps's Murrelets in 6 sectors around Anacapa Island during the 5 highest round-island survey counts in 2002, 2003 and 2014.

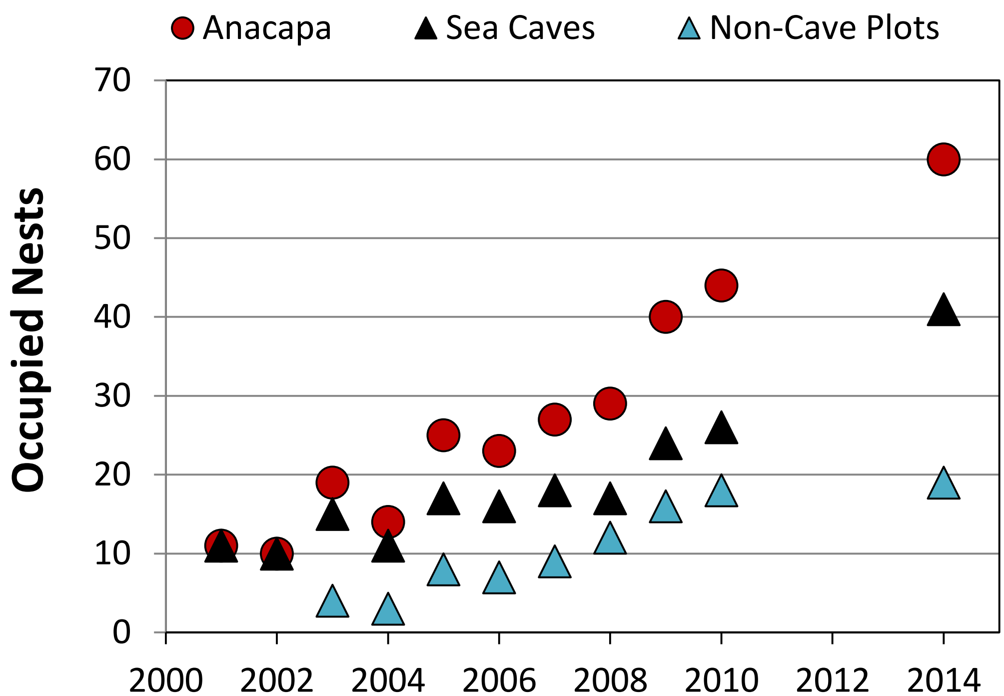


**Figure 10**. Number of occupied Scripps's Murrelet nests in sea caves, non-cave plots, and all monitored areas at Anacapa Island in 2001-2010 and 2014.

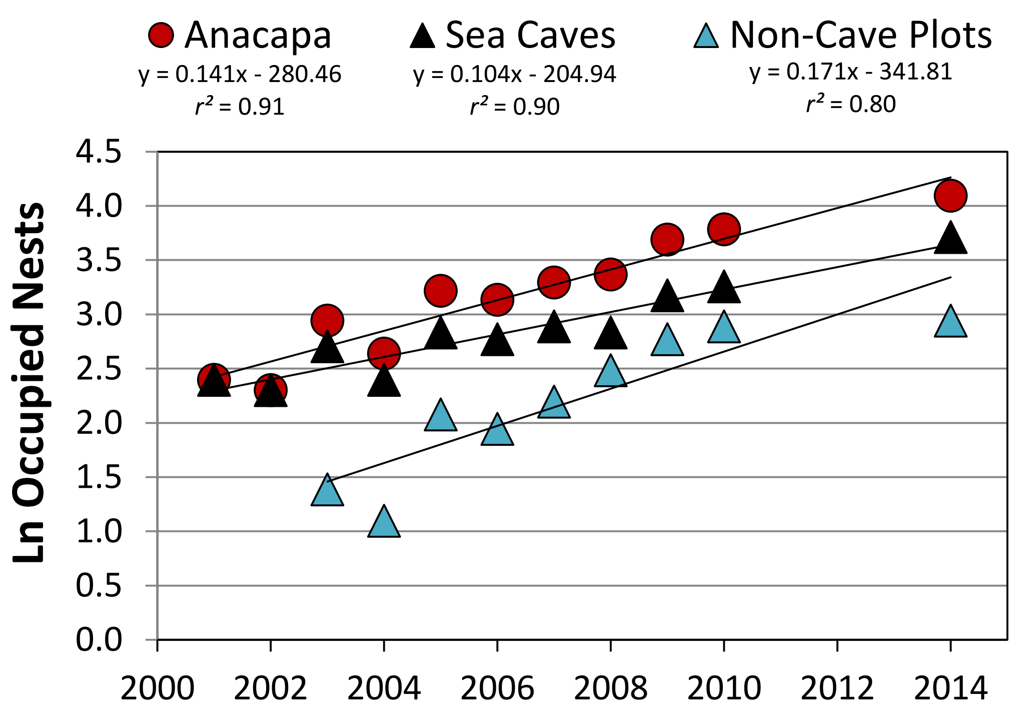


**Figure 11**. Log-transformed number of occupied nests for Scripps's Murrelets in sea caves, non-cave plots and all monitored areas at Anacapa Island, 2001-2010 and 2014.

**Figure 12**. Steep cliffs on the south side of East Anacapa, 15 March 2014. Standard inshore and offshore spotlight survey transects are located 200 m and 500 m, respectively from this shoreline. (Photo by D.L. Whitworth).