Radar Monitoring of Xantus's Murrelets (*Synthliboramphus hypoleucus*) at Anacapa Island, California in 2003 After Eradication of Black Rats (*Rattus rattus*)

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TABLE OF CONTENTS

INTRODUCTION

Xantus's Murrelets (*Synthliboramphus hypoleucus*) nest in loose colonies on the Channel Islands off southern California, USA, and islands off northwestern Baja California, Mexico (Hunt et al. 1979, 1980; Murray et al. 1983; Carter et al. 1992; Drost and Lewis 1995). Currently, they are known to breed on twelve islands groups along the southwest coast of North America from San Miguel Island, California, USA, to Islas San Benitos, Baja California, Mexico (Jehl and Bond 1975; Hunt et al. 1979; Sowls et al. 1980; Carter et al. 1992; Everett and Anderson 1991; Springer et al. 1993; Whitworth et al. 2003a). Xantus's Murrelets are considered one of the alcids (Family Alcidae) most vulnerable to imminent extinction because of their limited geographic range, small global population size (<10,000 to 20,000 breeding individuals), extensive predation from introduced feral cats (*Felis catus*) and rats (*Rattus* spp), extensive predation from natural predators (especially Deer Mouse *Peromyscus maniculatus* and owls) and the significant threat of mortality from oil pollution (Drost and Lewis 1995, Gaston and Jones 1998; McChesney and Tershy 1998; Carter et al. 2000).

Nest sites of Xantus's Murrelets occur mainly in rock crevices, and to a much lesser extent under plants and artificial structures. At many colonies, a large proportion of nests apparently occur in cliffs and steep slopes that are not easily accessible by foot to humans, without extensive climbing skill and equipment. Nest sites are visited only at night during the long incubation period (averaging 34 days); parents take long incubation shifts (between 1-6 days) and eggs are periodically neglected (for 1-4 days). Chicks are precocial at hatch and depart from nest sites accompanied by adults at 2 days old for further rearing at sea (Murray et al. 1983). The use of largely inaccessible island habitats, nocturnal and non-daily nest visitations, and foraging far from shore makes it difficult to find colonies, estimate population size, and monitor population changes.

In the Channel Islands, several colonies were discovered only recently with the use of nocturnal vocal detection surveys off inaccessible nesting habitats and nest searches in sea caves in 1991-96 (Carter et al. 1992, 1997, unpubl. data). Knowledge of murrelet population size and factors affecting these colonies is poorly known on most islands, with much of the information concerning their status relying on historical accounts and anecdotal observations.

Fortunately, there is one key behavior of this alcid that assists biologists in detecting colonies and estimating population sizes. Xantus's Murrelets congregate at night on the ocean adjacent to colonies during the breeding season (Murray et al. 1983; Carter et al. 1992, 1997, 2000; Drost and Lewis 1995; Whitworth et al. 1997, 2000, 2002a). The function of at-sea congregations appears to be multi-fold: some birds appear to stage in the late evening before flying to nearby nesting habitats; some birds appear to remain all night for social purposes (e.g., courtship, pairing, maintenance of pair bonds); and some birds attend in preparation for and during chick departure. Similar non-feeding aggregations near colonies are known for other *Synthliboramphus* murrelets (Gaston 1992).

At Anacapa Island (ANA), substantial numbers of murrelets in at-sea congregations and nesting in sea caves were discovered in 1994-96, using vocal detection surveys, at-sea captures, and sea cave searches (Carter et al. 1997, unpubl. data; Whitworth et al. 1997). Additional nest searches of accessible areas were conducted in 1997 (McChesney et al. 2000). Eradication of introduced Black Rats (*Rattus rattus*) at Anacapa Island, in the northern Channel Islands, California, was planned by federal and state trustee agencies with funds obtained from the 1998 settlement of litigation related to the 1990 *American Trader* oil spill (ATTC 2001). As part of this rat eradication program, the American Trader Trustee Council recognized that additional effort was needed to develop a long-term population monitoring program for Xantus's Murrelets at Anacapa Island to measure the expected beneficial effects (i.e., larger population size and higher breeding success) from rat eradication. Despite pioneering work to document the existence and approximate size of the Anacapa colony in 1994-97, it was clear that inadequate baseline data on the murrelet population existed to quantitatively measure changes in the population after rat eradication. From 2000-2003, a team of biologists developed new monitoring techniques and gathered baseline data for a long-term Xantus's Murrelet population monitoring program (ATTC 2001; Hamer and Carter 2002 a, b; Hamer et al. 2003b). Three techniques emerged with substantial data useful for long-term monitoring; a) radar surveys; b) spotlight surveys; and c) seacave nest monitoring.

Ornithological surveillance radar techniques have been recently applied to successfully monitor and study aspects of the biology of other seabirds nesting in inaccessible habitats in old-growth forests (e.g., Marbled Murrelets *Brachyramphus marmoratus*; Hamer et al. 1995; Burger 1997; Cooper and Blaha 1997; Hamer and Meekins1998a,b; Singer and Hamer 1999), at offshore islands (Cassin's Auklets *Ptychoramphus aleuticus*; Cowen et al. 1997), or in high mountains (e.g., Newell's Shearwaters *Puffinus puffinus newelli*; Day and Cooper 1995). In these studies, the radar was either mounted on boats for offshore work or mounted on a camper unit and 4-wheel drive truck for terrestrial work. Radar monitoring techniques have provided a new opportunity to measure changes in abundance and distribution of Xantus's Murrelets at Anacapa Island over time. Several types of radar have been effective tools in ornithological research for more than four decades (Eastwood 1965). Marine radar is probably the easiest and least expensive to operate, and has additional benefits of high resolution, small minimal sampling range, high availability, and high portability (Cooper et al. 1991, Hamer et al. 1995).

Radar surveys have a distinct advantage over many types of surveys because they are able to detect flying birds: regardless of light levels and in complete darkness and fog; regardless of whether or not they are vocalizing; and small birds (e.g., Xantus's Murrelet) can be tracked out to a 1.2 km radius, much farther than by eye during daylight (Hamer et al. 1995). Radar also provides valuable information on bird flight speed, flight direction, behavior, and use areas. When comparing radar and ground survey monitoring studies for Marbled Murrelets, radar typically detected 2–10 times greater numbers of murrelets present at one point in time and allowed estimation of the total number of birds flying in and out of an area each day (Hamer et al. 1995; Singer and Hamer 1999).

In 2003, we successfully applied radar monitoring techniques to measure changes in post-eradication numbers of Xantus's Murrelets attending nest sites in inaccessible habitats in steep slopes and cliffs at Anacapa Island. Radar monitoring in 2003 was conducted in conjunction with systematic nocturnal spotlight surveys. Anacapa Island data were collected at a standardized location off the south side of Middle Anacapa Island at East Fish Camp (Fig. 1.1).

Data were collected in 2003 to examine nightly and seasonal activity patterns of Xantus's Murrelets and analyze the coefficient of variation of radar counts between nights and years for long-term trend detection and for planning additional future monitoring efforts.

In this report, we summarize 2003 post-eradication data from ornithological radar surveys at Anacapa Island and compare these data with 2000-02 pre-eradication baseline data. The eradication of rats using poison bait occurred in two steps: a) East ANA and the east tip of middle ANA in fall 2001; and b) West and Middle ANA in fall 2002. In a separate report we analyzed data from 2000-02 to develop a suitable long-term radar monitoring strategy for Xantus's Murrelets that can be used to detect future population changes in response to rat eradication (Hamer and Schuster 2003a).

STUDY AREA

Anacapa Island (ANA) occurs within Ventura County, California and lies 15 km off the southern California mainland near the city of Ventura. ANA is the easternmost and smallest of the northern four island groups within the Channel Islands (Fig. 1.1 and 1.2). ANA is comprised of three small islets (West, Middle, and East Anacapa) that are managed by Channel Islands National Park (CINP). The waters extending 6 miles offshore of ANA are managed by the Channel Islands National Marine Sanctuary (CINMS). The narrow island chain is approximately 7.5 km long, surrounded by 17.5 km of steep rocky slopes and cliffs, topped by flat or more gently sloping plains, and the coastline harbors over 100 sea caves (Bunnell 1993). West ANA is the largest in area (1.7 km^2) and highest (284 m), followed by Middle ANA (0.6 km^2, 99 m) and East ANA (0.5 km^2, 73 m).

At ANA, radar surveys in all four years were conducted from a research vessel anchored off the south side of Middle ANA (34°$^{\circ}$ 00'.322" N; 119°$^{\circ}$ 22'.910" W), approximately 300 m off East Fish Camp. This standardized location allowed approximately 1.5 km of radar coverage of potential nesting habitat from the Coast Guard Reservation to the “Gap”, separating Middle ANA from East ANA (Fig. 1.2). From this location the radar sampled approximately 15.8% of the total shoreline of Middle and East Anacapa combined.

METHODS

Equipment

Radar surveys were conducted using a Furuno model FCR-1411, 10-kW, X-band radar unit, with a flexible 2-m long slotted wave-guide array antenna. Pulse length could be set at .08, 0.6, or 1.0 *u* sec, depending on range setting. The radar beam had a vertical span of 25 degrees and a horizontal beam width of 2 degrees. We mounted the radar equipment on and conducted radar surveys from the CINMS vessel *Shearwater* in 2003. The radar was mounted on a specially fabricated 6' aluminum post located on the top deck.

We installed a Furuno model PG-1000 flux-gate compass to the radar which fixed the image on the radar monitor regardless of any movements of the research vessel. A stern anchoring system also was used to reduce anchor swing and drag plus associated boat rolling. While some backscatter from the vessel's other radar towers at times affected the clarity and number of echoes of murrelet images to the bow of the boat, the stern anchoring system kept the boat with the stern pointed toward the island such that murrelet echoes near island-cliff nesting habitats were not affected by this problem.

In 2002, we also refined our radar tilting-protocol to minimize the variation in murrelet detections rates during periods of poor weather. The angle of the radar antenna could be raised (in 5° increments) off the water to minimize wave clutter. But since echo sizes of targets near the surface of the ocean became smaller with each increment, we established a maximum radar tilt of 10° to minimize variation in radar detections. Through several 2002 trials under different weather conditions, a tilt of $\leq$ 10° was found to reduce wave clutter without reducing the overall detection rate or increasing the difficulty of identifying murrelets.

In addition, working under high SW winds in particular tended to clutter-out portions of the water within 100 m of the shoreline in the "cliff zone" where we were recording detections. Radar counts typically show a reduction with higher winds (producing wave clutter on the radar screen) and radar tilt positions > 10°. In 2002, we determined that $\geq$ 50% of the shoreline must be free of clutter for the majority of the four-hour period to complete an adequate survey. All data in 2000-2003 were collected under relatively calm sea conditions with a radar tilt of 0-10° and, if increasing wave clutter prevented a complete four-hour survey from 23:00 to 03:00, the survey was cancelled or data were not used in all analyses. Exceptions to this rule included several nights in May 2001 when radar tilt was elevated to 15°. This data were included in analyses because low numbers of murrelets may have been flying in and out of nesting habitats by this time. In addition, two survey nights in 2003 where only 2 to 3 hours of a four-hour survey were suitable were also included in analyses.

These various improvements served to increase the numbers of nights of data collection per year (by allowing data collection during marginal conditions) and improved data quality (by facilitating interpretation of echo trails) but we believe that data were still comparable between years.

Due to the difficulty of detecting a small murrelet-type target at great distances with the radar, we found the 0.5 nm setting (1.1 km radius) was the most appropriate scale for monitoring. The radar completed one scan every 2.5 sec with a plotting function set to 30 sec. Therefore, each radar target would leave an echo trail with each echo retained for 30 sec. The echo trail could be subsequently plotted and measured, allowing us to estimate flight speeds by using a hand-held scale and measuring the distance between three or more echoes.

Data Collection

A biologist experienced in interpretation of radar echoes monitored the screen and recorded murrelet detections on a data sheet. Echoes on the radar screen were also recorded for the duration of each survey using a Sony 8mm video camera to enable biologists to review survey sessions at a later date.

In 2003, sites were monitored during the main incubation period in April and May, based on average timing at the SBI colony (Murray et al. 1983, Drost and Lewis 1995). In 2000, radar surveys were conducted throughout the night from 20:00 to 05:00 (PDT). This monitoring schedule in 2000 allowed us to document activity patterns of murrelets throughout each night. In 2001-03, radar surveys were conducted at night during a four-hour period from 23:00 to 03:00 (PDT). This four-hour period was chosen for the long-term monitoring program because in 2000, these sampling hours had the smallest coefficient of variation in radar counts (Hamer et al. 2003b).

For all radar detections we recorded: identification number, time, flight zone, flight behavior, distance between echoes on the radar screen (mm), flight speed (mph), and the number of radar echoes. In 2000, we segregated all murrelet detections into three zones of activity: a) cliff zone – murrelet targets detected within 100 m of the coastline; b) middle zone – murrelet targets detected seaward but within 101-400 m of the coastline; and c) sea zone – murrelet targets detected seaward > 400 m from the coastline. In 2001-03, we just recorded detections that occurred within the cliff zone since these counts had the lowest coefficient of variation in 2000 and murrelets detected flying into or out of steep slopes and cliffs at a distance of $\leq$ 100 m from shoreline were more likely to be directly arriving or departing from the monitoring area, reducing possible double-counting (Hamer et al. 2003b).

Birds detected outside the cliff zone could be arriving at Anacapa from distant feeding areas but first attending at-sea congregations before flying up to nest sites in the cliff zone. Similarly, birds departing from nest sites may attend at-sea congregations prior to departing from the island. Such behavior could cause multiple detections of individuals in middle and sea zones. In 2000-01, large samples of flight paths in the cliff zone were plotted on U.S. Geological Surveys 7.5' topographic maps, when time allowed. In 2002-03, we standardized this procedure and mapped the first detection observed at the beginning of every five minute interval.

Within the cliff zone, we recorded four categories of flight behaviors: a) *inbound* - targets flying towards the island within ± 45 degrees of the coastline axis; b) *outbound* - targets flying away from the island within ± 45 degrees of the coastline axis; c) *circling* - targets detected circling with a minimum of a 1/4 arc and; d) *unknown* - targets flying parallel to coastline or at angles > 45 degrees of the coastline axis or targets that had no initial or final bearing from the shoreline. In 2000-01, we recorded weather conditions at the beginning and end of each survey period. In 2002-03, we increased the frequency of weather data collection with weather and sea state information recorded at the beginning of each survey hour, including: percent cloud cover, horizontal visibility (good, fair, poor), wind speed (mph), wind direction, precipitation, air temperature (C°), sea surface temperature (C°), cloud ceiling height (m), and moon phase (quarterly). We also collected data on light intensity (lumens/sqf) using a *stow-a-way®* data logger attached to the top deck of the vessel. To minimize the effect of the anchor light (which is required on each vessel by law) on the data logger, the light was turned off at the beginning of each hour for 15 minutes while the logger retrieved information.

Species Identification

Flight speeds, flight directions, and echo size were the main criteria for the identification of Xantus's Murrelet detections using radar. Targets with less than three echoes were not recorded since accurate flight speeds could not be calculated. When possible, four or more echoes were used to measure and calculate flight speed. For Xantus's Murrelets, only birds flying ≥ 31 mph were recorded as murrelets to minimize the number of non-murrelet targets recorded. Echo sizes for Xantus's Murrelets varied from 2.0 to 2.5 mm. Echo sizes varied with the distance of the target from the radar and the orientation of the bird with respect to the radar.

To help distinguish Xantus's Murrelets from other seabirds that frequent the nearshore region at ANA, daytime radar surveys in 2000 were conducted concurrently with an outside observer to gather data on flight speeds and echo sizes of other species (Hamer and Meekins 2002). The main species examined were cormorants, Brown Pelicans (*Pelecanus occidentalis*), and Western Gulls. The only smaller body-sized seabird species known to be active at night and numerous at ANA are Xantus's Murrelet and Ashy Storm-petrels (*Oceanodroma homochroa)*, although a small colony of Cassin's Auklets (*Ptychoramphus aleuticus*) occurs nearby at Scorpion Rock on the east end of Santa Cruz Island (Carter et al. 1992, Adams et al. 2002) and one Cassin's Auklet egg was found on Anacapa Island in 1997 (McChesney et al. 2000). We also occasionally heard Black Oystercatchers (*Haematopous bachmani*) at night but rarely were they seen flying and only directly on the shoreline. To assist us in defining murrelet echoes, we identified a small sample of murrelets in 2000 recorded by the radar and through visual confirmation relayed by radio when flushed from the water by personnel in inflatable boats during at-sea capture attempts (Whitworth et al. 2002a,b).

Data Analysis

In 2000, for the all-night radar surveys conducted at middle ANA we calculated nightly and hourly means, maximums, minimums, standard deviations and coefficients of variation (CV) for radar detections. For hourly detection rates, we compiled data on the total number of targets and by four behavior categories. We then examined a different combination of behaviors by one-hour sampling periods and converted these to estimates of the number of targets per hour for each sampling period (Hamer et al. 2002). The purpose of looking at different combinations of radar counts by zone and behavior was to determine which type of counts yielded the lowest CVs for hourly and nightly means. Mean counts with low CVs were considered to have the greatest power to detect a population trend over time. We graphically examined CV values for hourly detection rates for all nights combined to identify periods of the night where CVs were the lowest. To determine if significant differences in mean hourly detections existed we ran a three-way ANOVA to test for differences between means. In all tests, $\alpha = 0.05$.

For comparisons of count data and CVs between nightly sampling periods and years (2000-03), we only used summed counts of inbound and outbound detections in the cliff zone recorded during the four hour period from 23:00 to 03:00 (PDT). Birds recorded as circling or unknown flight behaviors were not used because total 2000 counts of inbound and outbound detections had lowest CVs (Hamer et al. 2002). We compared differences in mean radar counts between each hour of sampling for each independent year using a One-Way ANOVA and a post hoc multiple comparison test to determine which means were significantly different. We used Levene's test for homogeneity of variance to test whether the factors being examined had equal variances. For tests with unequal variances, Tamahane's T2 multiple comparison test was used. We compared differences in CVs for each of four sampling hours averaged over the three years using a One-Way ANOVA and a post hoc multiple comparison test to determine which means were significantly different. To compare differences in the mean radar counts and CV between years, we also used a One-Way ANOVA and Tamahane's T2 post hoc multiple comparison test. We used Pearson's correlation coefficient (r) to test for evidence of a linear relationship between radar counts and "season" (i.e. data within the survey period which also reflected progression of the breeding season). Seasonal data were fit with polynomial trendlines (order 2). Data analysis was performed using SPSS 10.0 for Windows statistical software (SPSS, Inc. 1999).

RESULTS

Sampling Effort

Ten nights of radar sampling were conducted at ANA between 27 March and 28 May 2003 (Table 1). A total of 40 h of nocturnal radar sampling were conducted at colonies. A total of 992 Xantus's Murrelet targets (536 inbound and 456 outbound) were recorded in the cliff zone at ANA during the ten nights of sampling.

Due to inclement weather and availability of the research vessel, we were unable to complete surveys in late April and early May. Out of a total of 23 nights at sea, 8 complete four-hour surveys and 2 partial two to three hour surveys were conducted (43%).

Detection Rates and Behavior

Hourly and Nightly Variation in Radar Counts

Using data collected in 2003, the number of detections in the cliff zone was summarized for three flight behavior categories within each four-hour period (Table 1). The mean hourly detection rate, minimum, maximum, standard deviation, and CV for in/outbound behaviors in the cliff zone at ANA were determined for 2003 (Table 2). For the 23:00 – 03:00 period at ANA in 2003, there were no significant differences in mean detection numbers between hours (One-Way ANOVA, $F = 2.87$, $P = 0.361$).

Seasonal and Annual Variation in Radar Counts

Numbers of radar detections at ANA were negatively correlated with season in 2000 ($r = -0.802$, $p < 0.03$) and 2001 ($r = -0.934$, $p < .000$) (Hamer et al. 2003b). Detections in 2002 ($r = -0.504$, $p > 0.10$) were not significantly negatively correlated with season but instead were more stable over time. Detections in 2003 started relatively low (73-84 in/outbound detections), and then climbed sharply in early April (188 in/outbound detections). Counts likely reached a plateau through late April and early May (no surveys were completed during this period) and were still high in mid-May when surveys resumed before detection numbers dropped again as the breeding season ended (Figure 2).

The mean number of detections at ANA for 2000, 2001, 2002, and 2003 were 73.67, 42.33, 70.71, and 99.2 respectively (Table 3), and were not significantly different between years (One-Way ANOVA, F = 2.95, p = .076)

DISCUSSION

Sampling Effort

Radar monitoring was found to be an effective method of gathering quantitative data on the numbers of Xantus's Murrelets flying into and out of nesting habitats at ANA on specific survey nights. The greatest limitation for conducting radar monitoring was weather and research vessel availability. Wind speeds of ≥ 15 mph, particularly from the SW, sometimes caused significant wave clutter at ANA and in some cases rendered us unable to perform a complete survey.

We reduced the effects of weather and corresponding wave clutter by: a) selecting radar survey locations that had some protection from predominant NW winds; b) modifying radar mounting and vessel anchoring; c) using a flux-gate compass and modifying radar tilt ≤ 10° and: d) using data from the cliff zone for all analyses. These actions allowed us to maximize the number of suitable survey nights each year within the April-May survey period. However, annual weather conditions still affected the number and spacing of surveys. Although we were not able to visit

SBI in 2003, sufficient data was collected at ANA in the early and late breeding season for monitoring purposes.

Suitable protected anchorage sites will be the most important factor in the application of our radar monitoring approach to future monitoring at other sites at ANA and SBI, or other islands. Long-term monitoring sites need to be somewhat protected from the weather to reduce the effects of wave clutter on the radar screen and shallow enough with suitable substrates to securely place the vessel's anchor, as selected in work for 2000-03. Since CVs and detection rates have been shown not to be significantly different between hours during the four-hour nightly sampling period, by reducing our sampling period to one or two hours per night, we may be able to eliminate the need to anchor the vessel and also increase the number of successful surveys nights with adequate weather conditions. With sufficient good weather conditions, a few nights of radar monitoring could be conducted at other less protected areas at ANA to provide valuable information on numbers of birds visiting other portions of the colony. In particular, large numbers of murrelets have been observed in at-sea congregations on the south side of East ANA and on the north side of East, Middle, and West ANA in 2000-02 (Whitworth et al. 2002a,b, 2003b), suggesting that large numbers of murrelets may currently nest in these habitats. Similarly, large numbers of murrelets have been observed in at-sea congregations off the north side of SBI which also should be examined with radar to further assess population trends at this colony and for long-term comparison to ANA trends. Fortunately, radar is able to sample large areas so that a much larger proportion of some islands (12 to 16% of SBI and ANA respectively) can be sampled by adding a single monitoring site.

Shore-based radar monitoring also should be tested in certain locations to determine its suitability as an alternative radar monitoring approach since it would eliminate wave clutter due to boat movements and problems with the availability of suitable anchorage sites. However, shore-based monitoring would be best conducted from a beach or level rocky area near the water and a limited number of these kinds of sites exist at ANA or SBI.

Species Identification and Flight Speeds

Xantus's Murrelets likely represented the vast majority of birds with smaller echoes, high flight speeds, and direct flight lines detected by radar at night off middle ANA and SBI. In particular, the Xantus's Murrelet was the only species in the study area in 2000 to exhibit direct nocturnal inbound or outbound movements (i.e., flying in and out of potential nesting areas) with any consistency (Hamer and Meekins 2002). In addition, Xantus's Murrelet flight speeds in 2000 were faster than all other diurnal species examined except the cormorant. Xantus's Murrelet flight speeds averaged 36.3 mph (n=1,838, range=27-61, s.d=5.2) in 2000. Only cormorants (*Phalacrocorax spp.*; all three species were identified nearby during daylight hours) overlapped murrelet flight speeds, averaging 34.1 mph (n = 75, range = 15-54, s.d. = 6.0) (Hamer and Meekins 2002). However, cormorants most often flew parallel to the coastline during the day and were not observed from inflatable boats at night (i.e., presumably at nest sites [all three species breed at ANA] or roosting away from the East Fish Camp area). The flight speed and radar echo size of Cassin's auklets (*Ptychoramphus aleuticus*) would be expected to be similar to Xantus's Murrelets. Nocturnal survey transects of at-sea congregations of Xantus's Murrelets from a small boat detected Cassin's auklets sitting on the water in 2003 but these were never seen flying into or out of potential nesting areas. Only two Cassin's auklets nests were found on north side of ANA away from our study area (Whitworth et al. 2003c). For these reasons, misclassification of Xantus's Murrelet targets using radar was likely minimal over the four years of sampling.

Detection Rates and Behavior

Hourly and Nightly Variation in Radar Counts

Three factors helped us to select the 23:00 – 03:00 period for analyses of radar count data collected from 2000-02: 1) 2000 data showed that highest mean counts were obtained from 23:00-03:00; 2) this period showed more consistency in total number of detections than any other period of the night; and 3) this period had the lowest nightly CV in 2000 (Hamer and Meekins 2002). However, no clear pattern was discernible as to which hour within this period had consistently lower CVs or larger mean counts in 2000-02. For exploratory work to locate and quantify additional sites at ANA or SBI, or other colonies of murrelets at other islands, any of the four sampling hours could be used to gather data on numbers of detections and map areas of slopes and cliffs used by nesting birds. To survey several sites per nights, the vessel could be moved to a new site after an hour of data collecting and larger portions of an island could be covered in a short period. A shorter sampling period would also help us deal with rapidly changing weather conditions. For long-term monitoring at current sites at ANA and SBI, all four hours should continue to be surveyed to achieve the most accurate estimate of the population on each survey night, reduce nightly variation, and increase the likelihood of detecting a trend in the population.

For 2000-02 data, the summed counts of in/outbound detections in the cliff zone had the lowest nightly CVs and provided the best chance of detecting smaller trends in this population in the shortest period of time possible (Hamer et al. 2003b). Counts of birds in the cliff zone are likely most important for detecting breeding birds actually landing at or departing from nesting areas versus counts of birds in the middle zone (101-400 m from shore) and sea zone (>400 m from shore) which also include birds flying into and out of at-sea congregations which may lead to double counting of some individuals and recording of birds that are not attending nesting areas on survey nights.

At-sea congregations of murrelets had been previously discovered along the northwest coast of CAI in 1996, using vocal detection surveys (Carter et al. 1997, unpubl. data). While breeding has been assumed at this part of CAI, no nests have in fact been documented. The description of in/outbound flight paths in 2000 using radar monitoring has provided additional information suggestive of breeding in these inaccessible cliffs (Hamer and Meekins 2002). Radar monitoring could also be used at other colonies where breeding is suspected but not confirmed and where population size has been difficult to estimate. Differences in radar detection rates between ANA, SBI, and CAI in 2000 corresponded to the differences in population numbers estimated using nest searches and vocal detection surveys (Hunt et al. 1979, 1980; Carter et al. 1992, 1997, 2000, unpubl. data; McChesney et al. 2000).

Seasonal and Annual Variation in Radar Counts

Numbers of murrelet detections in 2000-01 at ANA and SBI showed a tendency to decline rapidly very early in the season (Hamer et al. 2003) (Figure 2). A seasonal decline in at-sea congregation numbers at ANA in 2001 also was documented but not for SBI in 2001 and not for ANA or SBI in 2002 (Whitworth et al. 2002b, 2003b). Seasonal decline noted in 2001 at ANA was not related to earlier breeding in 2001 (Whitworth et al. 2002b) and may have reflected an exodus of birds that were not still incubating by early May. The exodus might have included: many failed breeders (due to rat predation or foraging conditions) that might still attend the colony after failure for some time; some family groups dispersing at sea after successful hatch; and a few subadult birds that may largely attend the colony or at-sea congregations during the main incubation period. If nests monitored in sea caves at ANA were representative of all habitats on the island, higher rates of nest failure occurred in 2001 than in 2000 (Whitworth et al. 2002b). Our lowest radar counts occurred in 2001 (mean = 42.3 detections/night) (Table 3).

Similar to our radar results, Whitworth et al. (2003b) did not detect a significant seasonal decline in at-sea numbers at ANA in 2002. Lack of decline in 2002 was likely due to the partial eradication of rats on ANA that took place in fall 2001 leading to a greater stability in radar detection numbers throughout the season. Lack of predation to a portion of the colony would have allowed breeding to continue for some pairs of birds for a longer time period and with a higher nest success rate. It is likely that more birds would have been visiting nest sites for a longer period of time since a larger proportion of nests would have been active to the fledging stage (incubation averages 34 days). Therefore, radar counts in 2002 were much more stable throughout the breeding season compared to 2000-01 where predation was uncontrolled (Figure 2).

Overall detection numbers were higher and more stable in 2002-03 than in 2000-01, especially later in the breeding season. Full eradication of rats was completed by fall 2002. While 2003 detection numbers in the first week of April, before the onset of nesting, were roughly similar to previous years, counts in the middle of April and late May were some of the highest ever recorded at ANA (Figure 2). Mean detection rates in 2003 (99.2 detections per night) were 25.6% higher than mean numbers in 2000 (73.7 detections per night) and 134.3% higher than 2001 (42.3 detections per night) (Table 3). Unfortunately, no surveys were conducted during the middle of the breeding season in 2003. However, it is likely that numbers reached a plateau during this time as they were still high (103-205 in/outbound detections) by mid-May. The evidence suggests that complete rat eradication in the fall of 2002 allowed larger numbers of Murrelets to successfully breed in 2003. The decline in 2003 counts in the last week of May was likely due to the natural conclusion of the breeding season, since murrelet adults were seen departing the island during this time period and most monitored nests had successfully fledged young (Whitworth et al. 2003c). The strong early seasonal declines observed in 2000 and 2001 were likely to due to high predation at nest sites where most pairs of birds failed in their nesting attempts and stopped visiting nest sites. This pattern would have led to rapid declines in radar counts in the cliff zone as the season progressed.

The polynomial curves fitted to each year show a drastic change in shape in 2003 compared to the previous three years. High predation rates at nest colonies will likely produce radar counts that rapidly decline early in the season as depicted by the polynomial detection curves for 2000 and 2001 (Figure 3). Nest colonies that have relatively less predation will likely produce high and stable radar counts depicted by the polynomial curve in 2003. Radar count data collected in the future at other islands may be able to assess the relative rate of predation at other nesting colonies by examining these seasonal detection curves.

The timing of radar surveys in relation to timing of breeding will have a significant effect on numbers of murrelets detected flying into and out of nesting habitats. A shorter survey period in 2000 (last survey was 4 May as compared to 17 May in 2001, 15 May in 2002 and 27 May in 2003) prevented us from drawing significant initial conclusions about seasonal variation in numbers of murrelet detections. With increased vessel time and better weather, surveys conducted in 2001 and 2002 sufficiently captured seasonal variation, but the coefficient of variation of daily counts also increased, indicating that numbers fluctuated significantly from day to day as well as changing over the season. Lack of surveys in late April and early May also prevented us from drawing statistically significant conclusions about the seasonal trend in 2003; although it appears that capturing both the early and late breeding season when birds began arriving at ANA and then departing contributed to the high seasonal variation. This type of variation would be expected if radar surveys sufficiently captured the full breeding season. Assuming future years continue to capture the full breeding season, counts can be expected to follow a pattern of growth, stabilization, and then decline rather than initial high counts followed by progressive declines as in 2000 and 2001 when predation was uncontrolled. In addition to this change in pattern in seasonal variation, radar counts may continue to increase in future years as young birds are recruited into the population and begin nesting in areas previously unavailable because of intense predation. Future radar monitoring should continue to be conducted over the entire two-month season in order to ensure adequate numbers of survey nights and to measure seasonal variation so that both daily and seasonal variation can be incorporated into future population trend analyses.

Variability in murrelet radar counts was expected because: 1) surveys were spaced over a two-month period to attempt to maximize sample sizes at both ANA and SBI; 2) incubating murrelets only visit nests every 1-6 days (2-4 days on average) and factors affecting the length of incubation shifts (e.g. egg neglect) are poorly known; 3) the timing of breeding is not highly synchronized between individuals; 4) high levels of rat predation in 2000, 2001, and possibly 2002, likely led to large numbers of failed breeders whose continued attendance of nest sites likely differs from birds that are actively incubating and; 5) the degree of replacement eggs is not known at ANA although they often occur at SBI.

Comparison of Potential Nest Site Abundance to Radar Detection Rates

Data collected in 2002 indicated that there is a positive correlation between murrelet detection rates and coastal sections with a higher abundance of potential nest sites. The greater overall frequency of murrelet detections in 2003 prohibited us from mapping the same proportion of detections as we did in 2002 (13.0% as compared to 31.1% in 2002). If murrelet detection rates continue to increase in subsequent survey years, we will likely need to map fewer flight paths. If the relationship to potential nest abundance does hold true, refining information on the numbers of potential nest sites for various coastal segments of ANA may be an important indicator of the potential carrying capacity of an area for breeding birds. Radar data in 2002 showed that flight paths can be mapped in a consistent manner for determining which coastal segments within the survey area are being utilized most frequently by Xantus's Murrelets (Hamer et al. 2003b).

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LITERATURE CITED

Adams J., J.Y. Takekawa, and H.R. Carter. 2002. Foraging areas and movements of radio-marked Cassin's Auklets at Prince Island and Scorpion Rock, California, in 2000. *In* Orthmeyer, D.L., J.Y. Takekawa, H.R. Carter and R.T. Golightly (Eds.). At-sea distribution of seabirds and marine mammals in the Southern California Bight: 2001 Progress Report. Unpublished report, U.S. Geological Survey, Western Ecological

Research Center, Dixon and Vallejo, California; and Humboldt State University, Dept. of Wildlife, Arcata, California.

American Trader Trustee Council (ATTC). 2001. Final restoration plan and environmental assessment for seabirds injured by the American Trader oil spill. Published by American Trader Resource Trustee Council, U.S. Fish and Wildlife Service, California Department of Fish and Game, and National Oceanic and Atmospheric Administration.

Bunnell, D. 1993. Sea caves of Anacapa Island. McNally and Loftin Publishers, Santa Barbara, California.

Burger, A.E. 1997. Behavior and numbers of Marbled Murrelets measured with radar. Journal of Field Ornithology 68:208-223.

Carter, H.R., G.J. McChesney, D.L. Jaques, C.S. Strong, M.W. Parker, J.E. Takekawa, D.L. Jory, and D.L. Whitworth. 1992. Breeding populations of seabirds in California, 1989-1991. Volume I - Population estimates. Unpubl. draft report, U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Dixon, California..

Carter, H.R., D.L. Whitworth, W.R. McIver, G.J. McChesney, L.K. Ochikubo, T.W. Keeney, and M.O. Pierson. 1997. Distribution of Xantus' Murrelet nesting areas in the California Channel Islands, based on nocturnal vocal detection surveys. Pacific Seabirds 24: 11 (abstract).

Carter, H.R., D.L. Whitworth, J.Y. Takekawa, T.W. Keeney, and P.R. Kelly. 2000. At-sea threats to Xantus' Murrelets (*Synthliboramphus hypoleucus*) in the Southern California Bight. Pages 435-447. *In* D.R. Browne, K.L. Mitchell, and H.W. Chaney. (Eds.) Proceedings of the fifth California Islands symposium, 29 March to 1 April 1999. U.S. Minerals Management Service, Camarillo, California

Cooper, B.A., and R.J. Blaha. 1997. Evaluation of the Marbled Murrelet inland forest survey protocol with radar. Unpubl. report, Alaska Biological Research Inc., Fairbanks, Alaska 44 pp.

Cooper, B.A., R.H. Day, R.J. Ritchie, and C.L. Cranor. 1991. An improved marine radar system for studies of bird migration. Journal of Field Ornithology 62: 367-377.

Cowen, L., D. Bertram, and A. Burger. 1997. The use of radar to monitor Cassin's Auklet activity patterns. Unpublished report, Department of Biology, Simon Fraser University, Burnaby, British Columbia.

Day, R.H., and B.R. Cooper. 1995. Patterns of movements of Dark-Rumped Petrels and Newell's Shearwaters on Kauai. Condor 97: 1011-1027.

Drost, C.A. and D.B. Lewis. 1995. Xantus' Murrelet (*Synthliboramphus hypoleucus*). *In* A. Poole and F. Gill (editors), The Birds of North America, No. 164. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and The American Ornithologists' Union, Washington, D.C.

Eastwood, E. 1967. Radar Ornithology. Methuen and Co., Ltd., London, United Kingdom. 278 pp.

Everett, W.T. and D.W. Anderson. 1991. Status and conservation of the breeding seabirds on offshore Pacific islands of Baja California and the Gulf of California. Pages 115-139. *In* J. Croxall (Ed.). Seabird status and conservation; a supplement. ICBP Technical Publication No. 11.

Gaston, A.J. and I.L. Jones. 1998. The Auks. Bird families of the world, Vol. 4. Oxford University Press Inc., New York.

Gaston 1992. The Ancient Murrelet: A natural history in the Queen Charlotte Islands. T&AD Poyser, London, United Kingdom.

Hamer, T.E. and H.R. Carter (Eds.). 2002a. Population monitoring of Xantus's Murrelets (*Synthliboramphus hypoleucus*) at Anacapa Island, California: 2000 annual report. Unpublished report, Hamer Environmental, Mount Vernon, Washington; and Humboldt State University, Arcata, California. 64pp.

Hamer, T.E. and H.R. Carter (Eds.). 2002b. Population monitoring of Xantus's Murrelets (*Synthliboramphus hypoleucus*) at Anacapa Island, California: 2001 annual report. Unpublished report, Hamer Environmental, Mount Vernon, Washington; and Humboldt State University, Arcata, California. 65pp.

Hamer, T.E., B.A. Cooper, and C.J. Ralph. 1995. Use of radar to study the movements of Marbled Murrelets at inland sites. Northwestern Naturalist 76:73-78.

Hamer, T.E., and D.J. Meekins. 1998a. Use of radar to monitor Marbled Murrelets at inland sites in the North Cascades of Washington. Unpublished report, Hamer Environmental L.P., Mount Vernon, Washington. 25 pp.

Hamer, T.E., and D.J. Meekins. 1998b. Use of radar to determine the presence or absence of Marbled Murrelets in the Green River Watershed, Washington. Unpublished report prepared for Plum Creek, Inc., Seattle, WA by Hamer Environmental L.P., Mount Vernon, Washington. 14 pp.

Hamer, T.E., and D.J. Meekins. 2002. Radar monitoring of Xantus's Murrelets at Anacapa Island, California, in 2000. Pages 6-37. *In* T.E. Hamer and H.R. Carter (Eds.). Population monitoring of Xantus's Murrelets (*Synthliboramphus hypoleucus*) at Anacapa

Island, California: 2000 annual report. Unpublished report, Hamer Environmental L.P., Mount Vernon, Washington; and Humboldt State University, Arcata, California.

Hamer, T.E. and S. M. Schuster. 2003a. Radar Monitoring Plan for Xantus's Murrelets (*Synthliboramphus hypoleucus*) at Anacapa Island, California after Eradication of Black Rats (*Rattus rattus*). Unpublished report, Hamer Environmental L.P., Mount Vernon, Washington.

Hamer, T.E., D.J. Meekins, C. Short, M. Spies, and H.R. Carter. 2003b. Radar monitoring of Xantus's Murrelets (*Synthliboramphus hypoleucus*) at Anacapa Island, California, in 2000-02, prior to eradication of black rats (Rattus rattus). Unpublished report, Hamer Environmental L.P., Mount Vernon, Washington; and Humboldt State University, Arcata, California. 62 pp.

Hunt, G.L., Jr., R.L. Pitman, M. Naughton, K. Winnett, A. Newman, P.R. Kelly, and K.T. Briggs. 1979. Summary of marine mammals and seabird surveys of the Southern California Bight area, 1975-1978. Vol. 3. Investigator's reports, pt. 3: seabirds of the southern California Bight, book 2: distribution, status, reproductive biology and foraging habits of breeding seabirds. Report to Bureau of Land Management, Regents of the Univ. of California, Irvine.

Hunt, G.L., Jr., R.L. Pitman, and H.L. Jones. 1980. Distribution and abundance of seabirds breeding on the California Channel Islands. Pages 443-459. *In* D.M. Power (Ed.). The California Islands: Proceedings of a Multidisciplinary Symposium. Santa Barbara Museum of Natural History, Santa Barbara, California.

Jehl, J.R., Jr., and S.I. Bond. 1975. Morphological variation and species limits in the genus Endomychura. Transactions of the San Diego Society of Natural History 18(2): 9-23.

McChesney, G.J., F. Gress, H.R. Carter, and D.L. Whitworth. 2000. Nesting habitat assessment for Xantus' Murrelets and other crevice-nesting seabirds at Anacapa Island, California, in 1997. Unpublished report, U.S. Geological Survey, Western Ecological Research Center, Dixon, California; and Department of Wildlife, Humboldt State University, Arcata, California.

McChesney, G.J. and B.R. Tershy. 1998. History and status of introduced mammals and impacts to breeding seabirds on the California Channel Islands and Northwestern Baja California Islands. Colonial Waterbirds 21: 335-347.

Murray, K.G., K. Winnett-Murray, Z.A. Eppley, G.L. Hunt, Jr., and D.B. Schwartz. 1983. Breeding biology of the Xantus' Murrelet. Condor 85: 12-21.

Singer, S.W., and T.E. Hamer. 1999. Gazos Creek Marbled Murrelet monitoring program: 1999 Annual Report. Unpublished Report, Singer Environmental and Ecological Services, Santa Cruz, California.

Sowls, A.L., A.R. DeGange, J.W. Nelson, and G.S. Lester. 1980. Catalog of California Seabird Colonies. U.S. Department of the Interior, Fish and Wildlife Service, Biological Services Program. FWS/OBS 37/80. 371 p.

Springer, A.M., A.Y. Kondratyev, H. Ogi, Y.V. Shibaev, and G.B. van Vliet. 1993. Status, ecology, and conservation of *Synthliboramphus* murrelets and auklets. Pages 187-201. In K.Vermeer, K.T. Briggs, K.H. Morgan, and D. Siegel-Causey (Eds.). The status, ecology, and conservation of marine birds of the North Pacific. Special Publication, Canadian Wildlife Service, Ottawa, Ontario, Canada.

SPSS Inc. 1999. SPSS Base System User's Guide, Release 10.0 Edition. SPSS Inc., Chicago, IL. 828pp.

Whitworth, D.L., H.R. Carter, F. Gress, and S. Fangman. 2002a. Nocturnal observations of at-sea congregations and seacave nest monitoring of Xantus's Murrelets at Anacapa Island, California, in 2000. Pages 28-42. *In* T.E. Hamer and H.R. Carter (Eds.). Population monitoring of Xantus's Murrelets (*Synthliboramphus hypoleucus*) at Anacapa Island, California: 2000 annual report. Unpublished report, Hamer Consulting, Mount Vernon, Washington; and Humboldt State University, Arcata, California.

Whitworth, D.L., H.R. Carter, R.J. Young, E. Creel, F. Gress, and S. Fangman. 2003c. Nocturnal spotlight surveys of at-sea congregations and nest monitoring of Xantus's Murrelets (*Synthliboramphus hypoleucus*) at Anacapa Island, California, in 2003. Unpublished report, California Institute of Environmental Studies and Humboldt State University, Department of Wildlife, Arcata California. 35 pp.

Whitworth, D.L., H.R. Carter, R.J. Young, E. Creel, W.R. McIver, F. Gress, and S. Fangman. 2003b. Monitoring of at-sea congregations and nest success of Xantus's Murrelets (*Synthliboramphus hypoleucus*) at Anacapa Island, California, in 2000-02, prior to eradication of Black Rats (*Rattus rattus*). Unpubl. Report, Humboldt State University, Department of Wildlife, Arcata, California. 47 pp.

Whitworth, D.L., H.R. Carter, R.J. Young, F. Gress, and S. Fangman. 2002b. Nocturnal observations of at-sea congregations and seacave nest monitoring of Xantus's Murrelets at Anacapa Island and Santa Barbara Island, California, in 2001. Pages 30-65. *In* T.E. Hamer and H.R. Carter (Eds.). Population monitoring of Xantus's Murrelets (*Synthliboramphus hypoleucus*) at Anacapa Island, California: 2001 annual report. Unpublished report, Hamer Consulting, Mount Vernon, Washington; and Humboldt State University, Arcata, California.

Whitworth, D.L., B.S. Keitt, H.R. Carter, G.J. McChesney, J.W. Mason, W.R. McIver, and A.J. Hebshi. 2003a. Preliminary assessment of the status of Xantus's Murrelets (*Synthliboramphus hypoleucus*) at the San Benito Islands, Baja California, Mexico, in

March 2002. Unpubl. Report, Humboldt State University, Department of Wildlife, Arcata, California, and Island Conservation and Ecology Group, University of California, Santa Cruz, California.

Whitworth, D.L., J.Y. Takekawa, H.R. Carter, and W.R. McIver. 1997. Night-lighting as an at-sea capture technique for Xantus's Murrelets in the Southern California Bight. Colonial Waterbirds 20: 525-531.

Table 1. Xantus's Murrelet hourly detection rates from 23:00 to 03:00 at Anacapa Island in 2003.

Sampling Site	Date	Hour	Cliff Inbound	Cliff Outbound	Cliff In/Outbound
Anacapa	4/8/03	23:00 – 00:00	14	10	24
		00:00 – 01:00	8	10	18
		01:00 – 02:00	8	8	16
		02:00 – 03:00	2	13	15
		Totals	32	41	73
	4/9/03	23:00 – 00:00	16	18	34
		00:00 – 01:00	10	8	18
		01:00 – 02:00	6	15	21
		02:00 – 03:00	1	10	11
		Totals	33	51	84
	4/11/03	23:00 – 00:00	28	48	76
		00:00 – 01:00	26	19	45
		01:00 – 02:00	18	24	42
		02:00 – 03:00	10	15	25
		Totals	82	106	188
	4/16/03	23:00 – 00:00	42	8	50
		00:00 – 01:00	34	11	45
		01:00 – 02:00	28	11	39
		02:00 – 03:00	22	5	27
		Totals	126	35	161
	5/16/03	23:00 – 00:00	36	25	61
		00:00 – 01:00	32	18	50
		01:00 – 02:00	28	25	53
		02:00 – 03:00	23	18	41
		Totals	119	86	205
	5/20/03	23:00 – 00:00	14	18	32
		00:00 – 01:00	20	8	28
		01:00 – 02:00	17[1]	13[1]	30[2]
		02:00 – 03:00	17[1]	13[1]	30[2]
		Totals	68[1]	52[1]	120[2]
	5/21/03	23:00 – 00:00	28	17	45
		00:00 – 01:00	5	5	10
		01:00 – 02:00	8	14	22
		02:00 – 03:00	14[1]	12[1]	26[2]
		Totals	55[1]	48[1]	103[2]

Table 1. Continued.

Sampling Site	Date	Hour	Inbound	Outbound	In/Outbound
Anacapa	5/22/03	23:00 – 00:00	3	5	8
		00:00 – 01:00	7	2	9
		01:00 – 02:00	0	3	3
		02:00 – 03:00	2	2	4
		Totals	12	12	24
	5/23/03	23:00 – 00:00	1	2	3
		00:00 – 01:00	2	7	9
		01:00 – 02:00	1	2	3
		02:00 – 03:00	0	4	4
		Totals	4	15	19
	5/27/03	23:00 – 00:00	1	1	2
		00:00 – 01:00	3	4	7
		01:00 – 02:00	0	1	1
		02:00 – 03:00	1	4	5
		Totals	5	10	15
	2003	**Totals**	**536**	**456**	**992**

[1] Data were not available due to poor weather conditions.

[2] Total counts were extrapolated based on the actual completed hours of survey time. The average number of in/outbound detections per hour was calculated for all hours successfully sampled during the survey night. This average was then applied to each hour of missing data and then added to the completed hours to calculate the four-hour total.

Table 2. Xantus's Murrelet mean hourly detection rates from 23:00 to 03:00 at Anacapa Island in 2003 using in/outbound detections in the cliff zone.

Sampling Site	Hour	n	Mean	Min.	Max.	S.D.	C.V.
Anacapa	23:00-00:00	10	33.5	2	76	25.02	0.75
	00:00-01:00	10	23.9	7	50	16.93	0.71
	01:00-02:00	10	23.0	1	53	17.96	0.78
	02:00-03:00	10	18.8	4	41	12.82	0.68

Table 3. Xantus's Murrelet mean detection rates (detections per night) by year. Data was collected from 23:00 to 0:300 h (PDT) at Anacapa Island in 2000-03 using in/outbound detections in the cliff zone.

Sampling Site	Year	n	Mean	Min.	Max.	S.D.	C.V.
Anacapa	2000	6[1]	73.67	45	99	20.23	0.27
	2001	9	42.33	3	95	31.15	0.74
	2002	7[2]	70.71	52	113	21.78	0.31
	2003	10[3]	99.20	15	205	69.47	0.70

[1] One survey day on 4 May, 2000 was included although anchorage location was not at exact standard location.

[2] One survey day on 8 April, 2002 was not included because two radar observers were present for training.

[3] One survey day on 27 March, 2003 was not included because two radar observers were present for training.

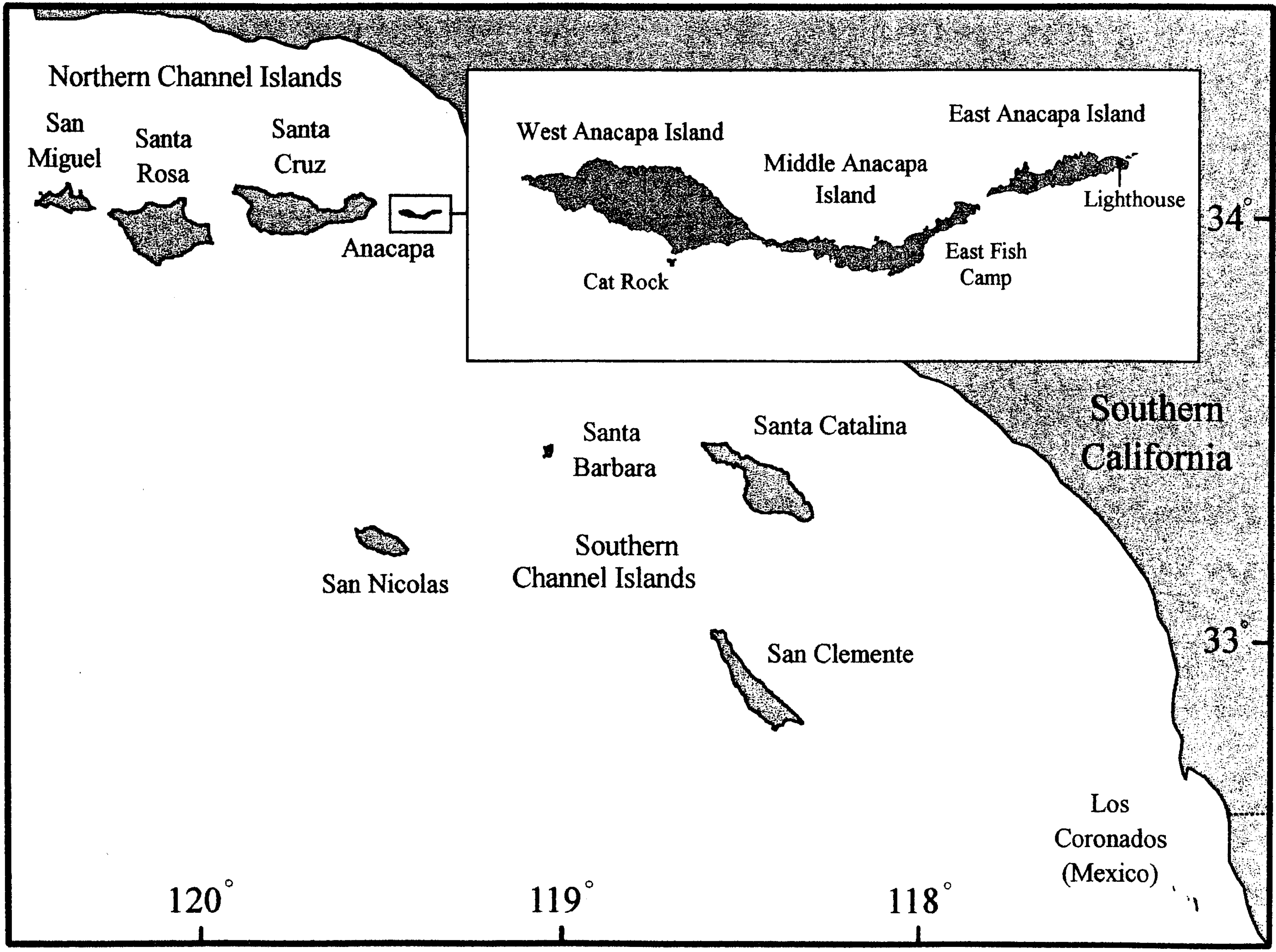

Figure 1.1. Southern California Channel Islands, with inset showing Anacapa Island.

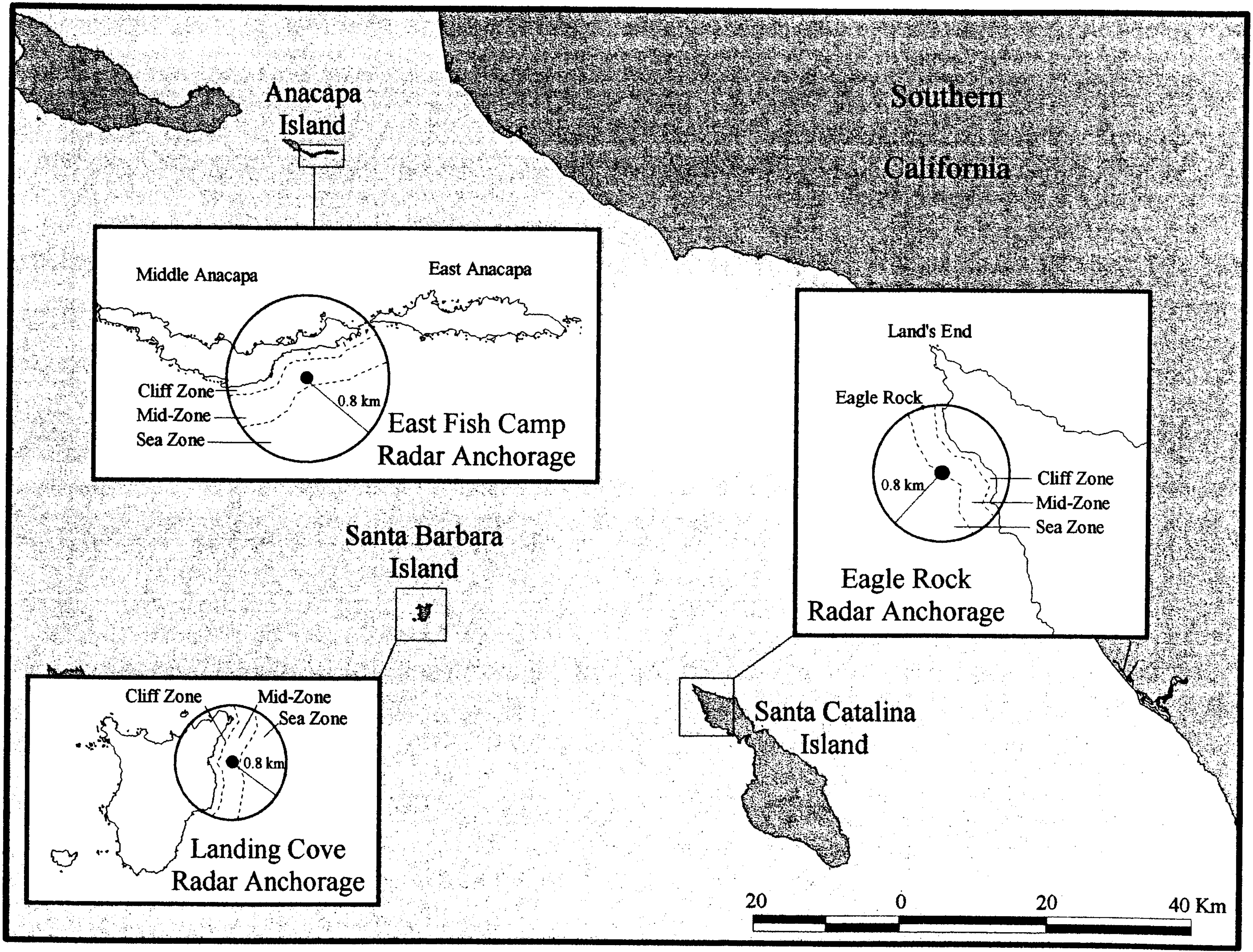

Figure 1.2. Radar survey stations at Anacapa, Santa Barbara and Santa Catalina islands in 2000.

Fig 2. Total numbers of in/outbound detections in the cliff zone from 23:00 to 03:00 (PDT) at Anacapa Island in 2000, 2001, 2002, and 2003. A polynomial curve (order 2) was fitted for each year.