FINAL REPORT – PART I

RESULTS OF MARBLED MURRELET RADAR SURVEYS IN THE GAZOS CREEK WATERSHED 2000 – 2010

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INTRODUCTION

This is the final report of a multi-year radar monitoring program funded by the Apex Houston Trustee Council and the Sempervirens Fund in response to the 1998 purchase of marbled murrelet habitat and other lands at Gazos Mountain Camp. The property acquisition and history of the monitoring program is described more fully in the Singer and Hamer (2008) report.

This radar survey effort was implemented as a way to determine if the number of murrelets using the Gazos Mountain Camp area and greater Gazos Creek Watershed would change over time. The radar monitoring program was developed in 1998 and 1999 and fully implemented in 2000. The program consisted of 7 radar surveys per year at one site and represented a compromise between the optimal scientific rigor for radar sampling and the amount of funding available.

Using modified marine radar we tracked murrelet flights and assigned them to one of the following three categories: "Inbound" murrelets were flying toward their inland nesting area, "Outbound" murrelets were flying seaward, and "Other" murrelets were those with flight paths that were not oriented directly in or out. This terminology will be used throughout this report.

<u>2009 Study for the Command Trustee Council</u>

In 2009 we conducted a separate radar study (Colclazier, Stumpf, and Singer 2010) that revisited five of the earlier surveyed sites in the Santa Cruz Mountains including the Gazos (Double Low Gazos) radar site. That study included a statistical review of the Gazos radar data and found no significant population trend based on inbound murrelet flights only.

This report, funded by the Apex Houston Trustee Council and the Sempervirens Fund, includes new radar survey data from the Gazos radar site, a new statistical review of all the data looking at new discrimination parameters (total detections and the total of inbound and outbound detections), and a more comprehensive review of murrelet use of the Gazos Creek Watershed. This report is the culmination of a multi-year radar monitoring program that began in the Santa Cruz Mountains in 1998. It includes new insights about the population trends observed and provides recommendations for the future use of radar surveys in the Santa Cruz Mountains.

METHODS

In 1998 and 1999 the senior author and Tom Hamer, of Hamer Environmental LP, conducted radar surveys in the Santa Cruz Mountains at a variety of locations and at various times throughout the murrelet breeding season. The purpose of this effort was to locate marbled murrelet flyways, find suitable radar survey stations, and develop a program to monitor murrelet usage throughout the region. The results of those surveys were reported in Singer and Hamer (1998, 1999, and 2000) and Colclazier, Stumpf, and Singer (2010). Evolving from this initial work was the current radar monitoring program in the Gazos Creek Watershed.

Radar surveys were conducted at the Gazos (Double Low Gazos) radar site located in Butano Redwoods State Park (see Fig. 1 at end of the report). The station is located in a murrelet flyway we found in the Gazos Creek Canyon. It is approximately 2 kilometers downstream of Gazos Mountain Camp, and 2 kilometers upstream from the mouth of Gazos Creek. The UTM coordinates are X = 0558944 and Y = 4115725 (NAD27).

Radar surveys were conducted using a modified marine radar system with the antenna mounted onto the roof of a truck, camper, or SUV with four-wheel drive. From 2000 to 2008 we used a Furuno model FCR-1141, 10-kW, X-band radar unit with a 2 meter long slotted wave guide array antenna that is sensitive enough to detect birds at a distance of up to 1.2 km. Pulse length could be set at 0.8, 0.6, or 1.0 *u* sec, and the range was set at 0.5 nautical miles. The radar beam had a vertical span of 25 degrees and a horizontal beam width of 2 degrees. In 2010 we used a Furuno model FCR-1510, 12-kW, X-band radar unit with a 2 meter long slotted wave guide array antenna. Pulse length was set at 0.7 *u*s. The vertical span and horizontal width of the radar beam was similar to the model FCR–1141. The range was set at 0.58 nautical miles (1.5 km), but only that portion of the radar screen within 0.50 nautical miles was monitored for murrelet targets.

Each radar survey started 75 minutes before sunrise, lasted 2 ½ hours, and followed the general protocol for radar surveys found in Evans et al. (2003). The time, direction, speed, and flight path of each murrelet or cluster of murrelets was recorded by a trained radar biologist and a videotape of the radar screen was kept as a permanent record. Murrelet detections on the radar screen were distinguished from echoes made by other bird species on the basis of echo size, flight speed, and flight behavior. For a detection to be labeled as either “in-bound” or “out-bound”, the bird’s flight path had to be within 45 degrees of a line running along the long axis of the canyon. Murrelets flying in other directions or circling were categorized as "other".

Radar surveys were conducted on 7 days in July, usually consecutive, during the years 2000, 2001, 2002, 2004, 2006, 2008, and 2010. Our 2009 study (Colclazier, Stumpf, and Singer 2010) conducted 3 surveys at Double Low Gazos in July of 2009 but that data was not used in our statistical analysis for a number of reasons. These include the fact that only 3, not 7, surveys were done in 2009, and because in that year there was a problem with separating murrelet targets from band-tailed pigeon targets. This occurred despite the fact that there was no change in the person monitoring the radar screen from the years prior or after when discriminating between band-tailed pigeon targets and murrelet targets was not a problem. The band-tailed pigeon problem in 2009 was significant enough that for that report we looked only at inbound birds. Since this study has never used inbound birds as the detection parameter that we analyze, and since the outbound murrelet detection numbers from 2009 might inadvertently include some band-tailed pigeons, we have elected not to use the 2009 data in our statistical analysis, but have included the results of those surveys in the Appendix.

RESULTS AND DISCUSSION

Radar surveys were conducted in seven years within the 2000 – 2010 period at the Gazos radar survey station in Gazos Creek Canyon. A total of 122.5 hours of radar sampling was conducted over 49 mornings. A total of 1,738 detections were recorded throughout all seven survey years, for an average rate of 35.5 detections per morning.

A statistical review of the data from 2000 – 2008 (Verschuyl 2008) found that in terms of power and number of surveys needed to detect a trend, looking at either total detections or the total of inbound and outbound detections gave the most discrimination power and were equivalent in their results. So in this report we have decided to base our analysis on the total of inbound and outbound murrelets.

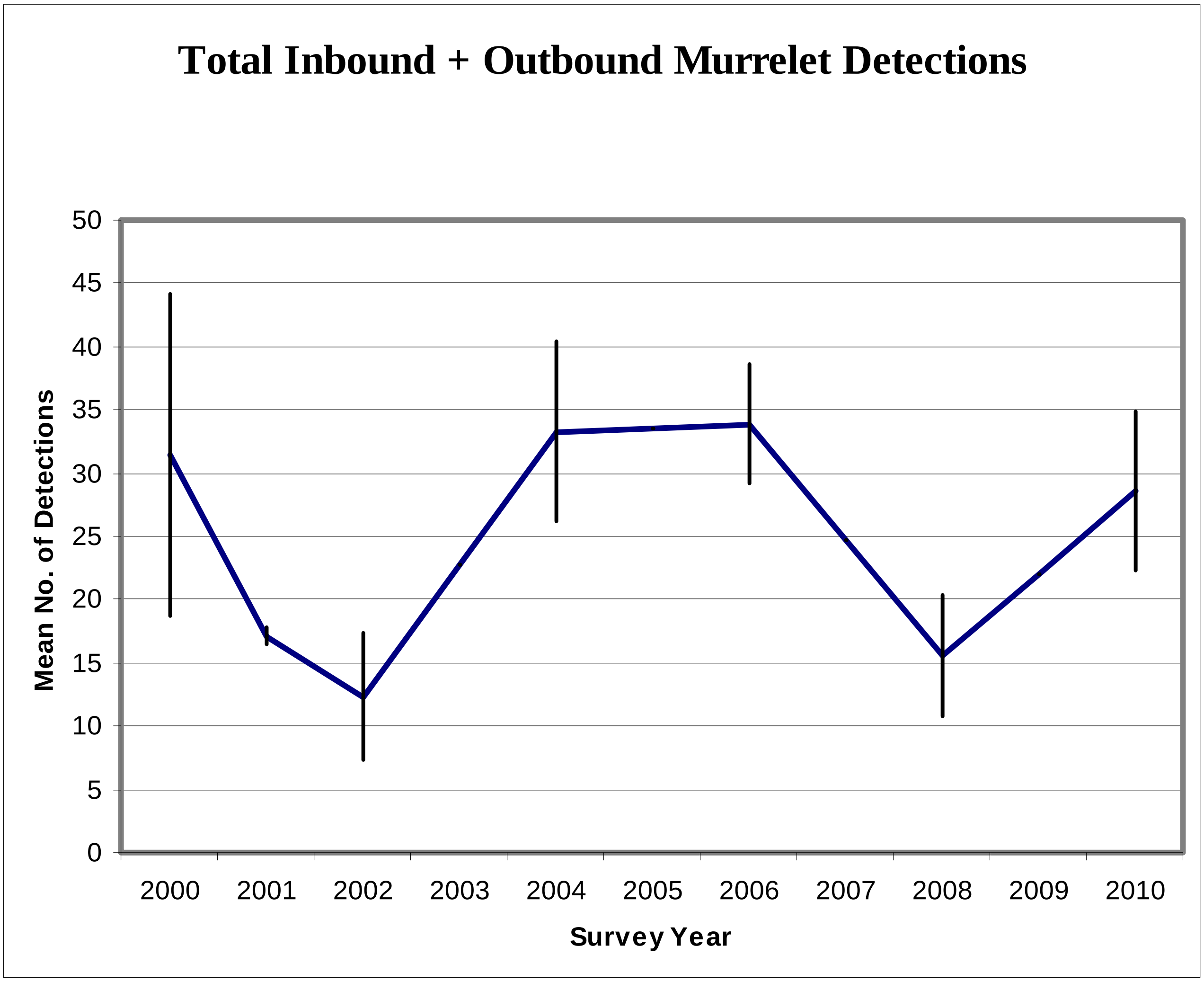
Table 1. 2010 results of radar murrelet surveys at the Gazos site. Values for the mean, standard deviation (STDV), and coefficient of variation (CV) are given in the bottom rows. N = 7.

Date	**In-Bound Detections**	**Out-bound Detections**	**Total No. of Inbound + Outbound Detections**	**Other Detections**	**Total Number Of Detections**
7/8/10	17	8	25	7	32
7/9/10	18	14	32	9	41
7/10/10	8	9	17	13	30
7/11/10	19	13	32	12	44
7/12/10	23	13	36	14	50
7/13/10	20	7	27	16	43
7/14/10	22	9	31	12	43
Totals	127	73	200	83	283
Mean	**18.1**	**10.4**	**28.6**	**11.9**	**40.4**
STDV	**4.9**	**2.8**	**6.2**	**3.0**	**7.0**
CV	**0.3**	**0.3**	**0.2**	**0.3**	**0.2**

The mean number of total inbound and outbound detections in 2010 was 28.6, which is not far from the value of 31.4 recorded on our first survey in 2000 (See Graph 1). During the intervening years there were some dramatically lower values (2002 and 2008), and, if the 2009 value was to be included, it would be a dramatically higher value of 41.3 (see Appendix). Thus the pattern we've observed has been one of fairly extreme variation between survey years.

Results of murrelet radar surveys from all survey years are provided in the Appendix to this report. Annual or biannual progress reports were prepared throughout the duration of this long-term monitoring effort and can also be consulted for more information on the detections in any specific year (Singer and Hamer 1998, 1999, 2000, Singer 2001, 2002, Singer and Hamer 2004, 2006, 2008).

Graph 1. Total of inbound and outbound detections at the Gazos radar site, 2000 – 2010, excluding the 2009 data. No surveys were conducted in 2003, 2005, or 2007. Error bars represent one standard deviation.



It is known that the number of individual murrelets flying inland varies from year to year due to factors other than population change (McShane et al. 2005, Peery et al. 2004a; Peery et al. 2004b). In a two-year study, Peery et al. (2004a) placed radio-tags on 46 murrelets and found that, within their tagged sub-populations, non-breeders didn't fly inland as often as breeders, and that the proportion of non-breeders in the regional population varied from year to year. There are several other sources of variability in the number of murrelets flying inland each year. These include local changes in prey availability at sea that alter the extent or timing of the breeding effort, changes in the location of ocean staging areas that influence the flight paths used by birds flying inland, and changes in the elevation of bird flights within inland flight corridors due to weather conditions or other factors. In addition, if murrelets were flying low enough they would pass below the portion of sky scanned by radar. Some or all of these factors may contribute to the variability shown in Graph 1.

Statistical Analysis of the Data

A biostatistician was hired to undertake a regression-based analysis of the radar data to date (Stumpf 2010). He did a linear analysis for "inbound-only" murrelets and for "inbound and outbound murrelets combined". The results of both regression analyses were weak, having R^2 values of less than 0.10 (see Stumpf 2010). We present only the "inbound plus outbound" analysis here since site conditions surrounding the Gazos radar survey station did not seem suitable for using an "inbound only" or "outbound only" regression analysis. Gazos Creek Canyon borders another canyon to the north, Little Butano Canyon, and the intervening ridge line is not very high. Murrelet nesting areas exist in both canyons. Murrelets have been observed crossing over this ridge (Singer, pers. obs.). It's quite possible that some birds might fly up one canyon and down the next or vice versa. For this reason, counting just inbound birds or just outbound birds could be problematic.

When looking at both inbound and outbound murrelets combined, the regression-based analysis found no significant trend in the number of detections recorded over the seven sampling years (Graph 2).

Graph 2 shows a slightly increasing trend line, but it would be a mistake to assume that murrelet numbers in the Gazos Creek Watershed are increasing. As Stumpf goes on to explain:

"The results of these analyses must be interpreted with caution for three reasons:

- Visual inspection of the pattern of detections from 2000 to the present indicated that the trends in detections at Gazos Creek may be non-linear and periodic (e.g. fluctuate up and down with some degree of regularity), rather than linear (Stumpf 2010,Verschuyl 2008). If this is the case, detecting long-term linear (i.e. upward or downward trends) can be problematic and take more sampling effort to detect than simple linear trends.
- The apparent periodicity of the data violates the assumption of linear regression that the relationship between the independent and dependent variable is linear in nature. Though regression can be somewhat robust to departures from this assumption and periodic cycles can show linear trends over time, these trends take much longer (e.g. many cycles or periods) to detect than strict linear trends.

- There is a great deal of within-and between-year variability in murrelet-type target counts taken from Gazos Creek. This reduces the statistical power of the regression analysis, making it difficult to draw valid inferences. The between year variability may be partly a result of the aforementioned cyclical trend in radar counts."

Graph 2. Regression results of the count of inbound and outbound marbled murrelet-type targets by sampling year (P = 0.520, R^2 = 0.009).

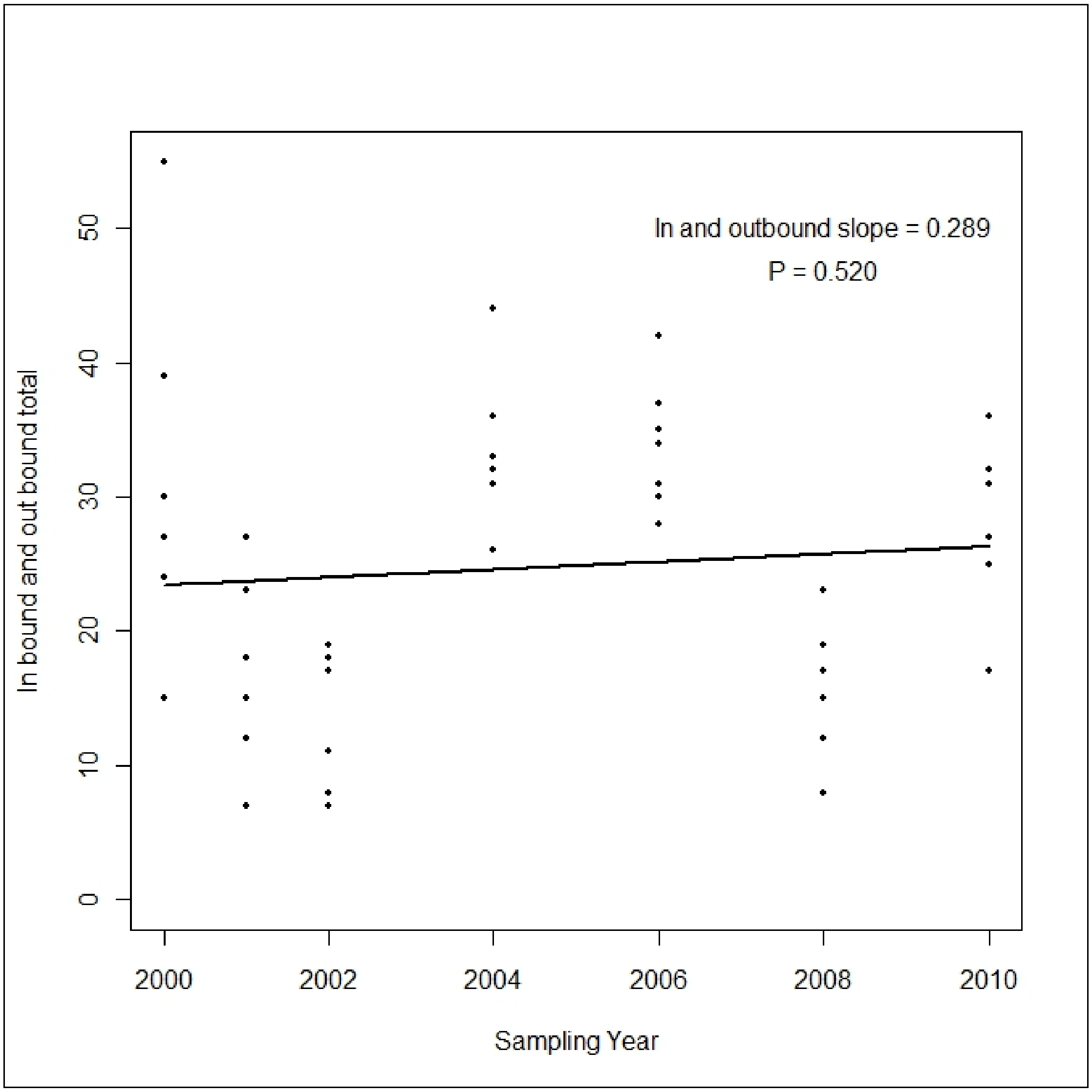


Table 3. Additional years of data collection necessary (beyond 2010) to detect different magnitudes of linear population trends with a range of power for the Gazos Creek radar survey site (adapted from Stumpf, 2010).

		POWER			
DATA USED	**DETECTABLE POPULATION TREND**	**80%**	**85%**	**90%**	**95%**
All Detections	**5%**	7	7	8	9
	10%	2	2	3	3
	20%	0	0	0	0
Inbound and Outbound Detections	**5%**	5	6	6	7
	10%	0	1	2	3
	20%	0	0	0	0

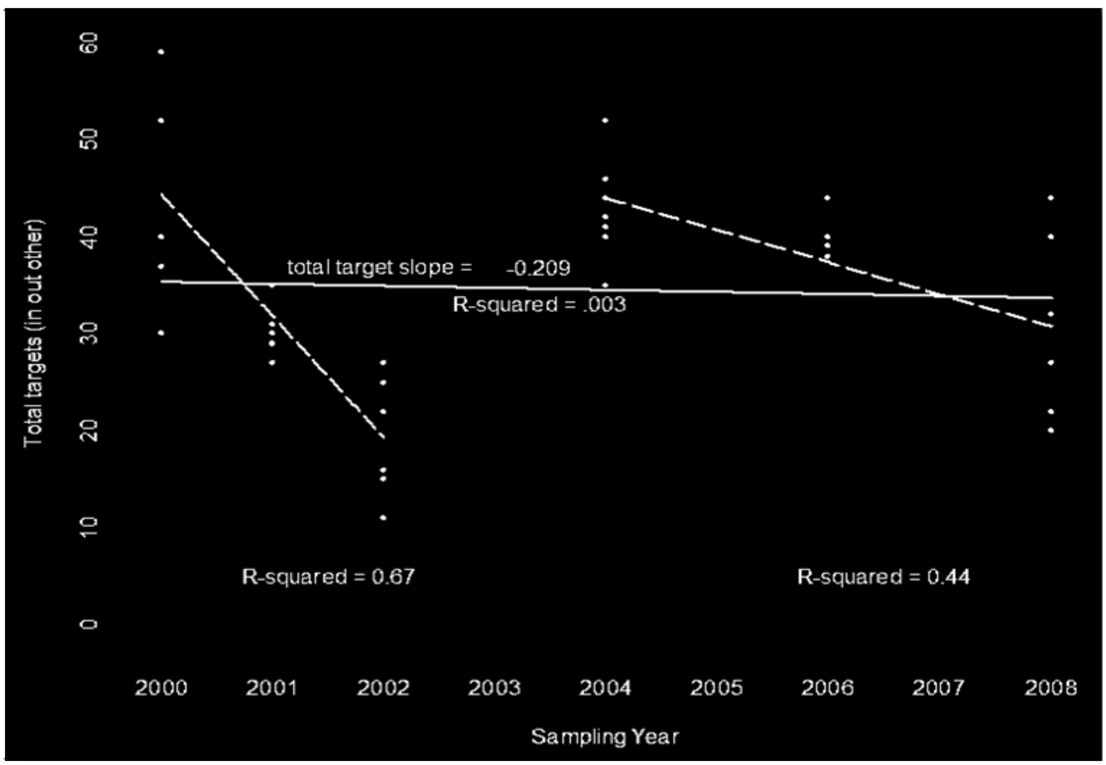
Linear or Cyclical Population Trend?

When running a repeated measures regression on murrelet detections for the 2008 progress report of this study, Verschuyl (2008) found that the data when plotted onto a graph could be logically divided into two separate lines that better fit the existing data – 2000 to 2002 and 2004 to 2008 (See Graph 3). Both lines had a significant negative slope with P values less than 0.01. Numbers rebounded between the end of the first decline and the start of the second decline. He suggested that the population trend at Double Low Gazos might be cyclical rather than linear. Stumpf (2010) performed a statistical analysis on the 2010 and previous Gazos murrelet detections, and agreed with Verschuyl that the population trend at Gazos might be cyclical. This could explain the dramatic ups and downs shown in Graph 1 and the increasing population trend reported in Graph 3. A third statistical analysis, this one on the audio-visual (A-V) survey data at Gazos Mountain Camp, came to the same conclusion, namely that the number of murrelets flying inland might be subject to periodic cycles (see Part II of this report).

A cyclical pattern would fit the breeding ecology of the marbled murrelet. The number of birds that fly inland each year is known to vary with the number of birds that are nesting or attempting to nest (Peery et al. 2004). It is also known that when ocean conditions limit food availability, as they do periodically, murrelets may forego nesting entirely (Becker and Peery 2007, McShane et al. 2004). Since these relationships do exist, it would make sense that the number of murrelets flying inland each summer would follow a periodic cyclical pattern.

If murrelet patterns are cyclical, it will take many more surveys to determine a trend with statistical validity. Power tables, like Table 3, assume a linear population trend. So if the trend is not linear, the predictions of the power table are invalid. So when the table indicates that we have collected enough data to know that, at 80% power there has not been a decrease or increase in numbers of 10% or more, that would not be correct. It would only be true if the murrelet population trend is linear in nature, which is probably not the case.

Graph 3. Regression results of total marbled murrelet detections through 2008 at the Gazos radar site. P> 0.05 for the regression across all years; P< 0.01 for the 2000 – 2002 regression and the 2004 – 2008 regression.



CONCLUSIONS

Although this radar monitoring program has been unable to determine the trend of murrelets in the Gazos Creek Watershed, as was intended at the onset, it has provided much valuable information about the Santa Cruz Mountains murrelet population over the years. The most notable program accomplishments are listed below:

● The combination of radar and A-V surveys has shown that there has not been a significant decline in murrelet use at Gazos Mountain Camp, so the protection of nesting habitat purchased with oil spill restoration funds has been a success.

● When at-sea surveys offshore of the Santa Cruz Mountains purported to show a severe decline of the murrelet population in 2008, the radar surveys did not show a decline, and at-sea surveys in 2009 and 2010 showed that murrelet numbers were back to "normal" levels. Radar surveys thus provided a check on the accuracy of at-sea surveys.

● This work allowed us to discover, during the start-up phase of our work, the presence of four of the five known major murrelet flyways in the Santa Cruz Mountains – Pescadero, Waddell, Gazos, and Big Butano. It also allowed us to find suitable radar monitoring stations within each of those flyways.

● Early work that included simultaneously surveying murrelet flyways by radar and A-V surveys found that ground observers could detect few if any of the murrelets passing overhead (Singer and Hamer 2001). Additional comparisons over the years led us to formulate this hypothesis - murrelets detected by radar are often flying too high to be seen by ground observers and murrelets detected by ground observers are often flying too low to be detected by radar (Colclazier, Stumpf, and Singer 2009).

● This project also allowed us to determine the best time for conducting murrelet radar surveys, by comparing the relative number of detections found in June, July, and August. July was the most active month, and June was the second-most active.

● Radar data analysis allowed us to discover that murrelet use of the Gazos Creek flyway is not closely following a linear trend, and that instead, it may be following a periodic cyclical trend whose trajectory will be more difficult to ascertain by any kind of a surveying effort (at-sea counts, A-V counts, or radar counts). Evidence for a non-linear or cyclical rather than linear trend has also been found in the A-V survey results from Gazos Mountain Camp (see Part II of this report).

● The statistical analyses presented here suggest that although the trend in murrelet detections at the Gazos Creek site does not appear to be linear, it has not been decreasing by 10% or more per year, and thus has been largely stable over the ten-year study period. In addition to the evidence provided by the radar counts, such a drop in numbers (e.g. 10% per year, reducing the current population to 33% of its 2000 level) likely would have been obvious to A.V. observers at Gazos Mountain Camp. Our original goal was to be able to detect a 5% annual change at the 80% power level, but we fell short of achieving that goal since we were assuming a linear trend.

RECOMMENDATIONS FOR RADAR MONITORING
(Note: Recommendations for A-V monitoring are in Part II)

Radar can be a powerful tool for murrelet monitoring in certain situations or it can be an expensive effort that does not produce clear results. If radar is to be used in the future in the Santa Cruz Mountains, its cost-effectiveness can be maximized by the following actions:

● Conduct radar sampling efforts in close conjunction with A-V survey and at-sea survey sampling efforts so that the same group of birds is being sampled at the same time by multiple means. This project included both A-V surveys and radar surveys, but due to logistical and funding constraints, we weren't able to do both the A-V surveys at Gazos Mountain Camp and the radar surveys at the Gazos radar site on the same mornings, except for a few occasions. All A-V surveys done since 2005 were done on a volunteer basis.

● If the monitoring of murrelet population trends is a goal, then sampling should be conducted during the same season from more than one flyway by using multiple survey stations. Simultaneous radar sampling in four of the major known waterways would be a very desirable endeavor and would likely yield some crucial information about the Santa Cruz Mountains population, thanks to the foundation that we have laid.

● Radar monitoring could be valuable in determining the relative importance of murrelet sites or determining their status (presence/absence) after long periods of time with little or no surveying effort. For example, radar surveys would be very helpful in clarifying the status of murrelet presence at small sub-populations in the Scott Creek Watershed (if a suitable and accessible survey station could be found) and in the Purisima Creek Watershed.

● Future radar monitoring and A-V studies could be redesigned to incorporate our newfound knowledge that these murrelet counts seem to follow a non-linear and variable cycle. Radar surveys, like the A-V surveys, could be conducted on an annual rather than biannual basis. Overall, radar monitoring should be designed to detect changes in the variability of counts or model periodic fluctuations rather than focus on linear models.

ACKNOWLEDGEMENTS

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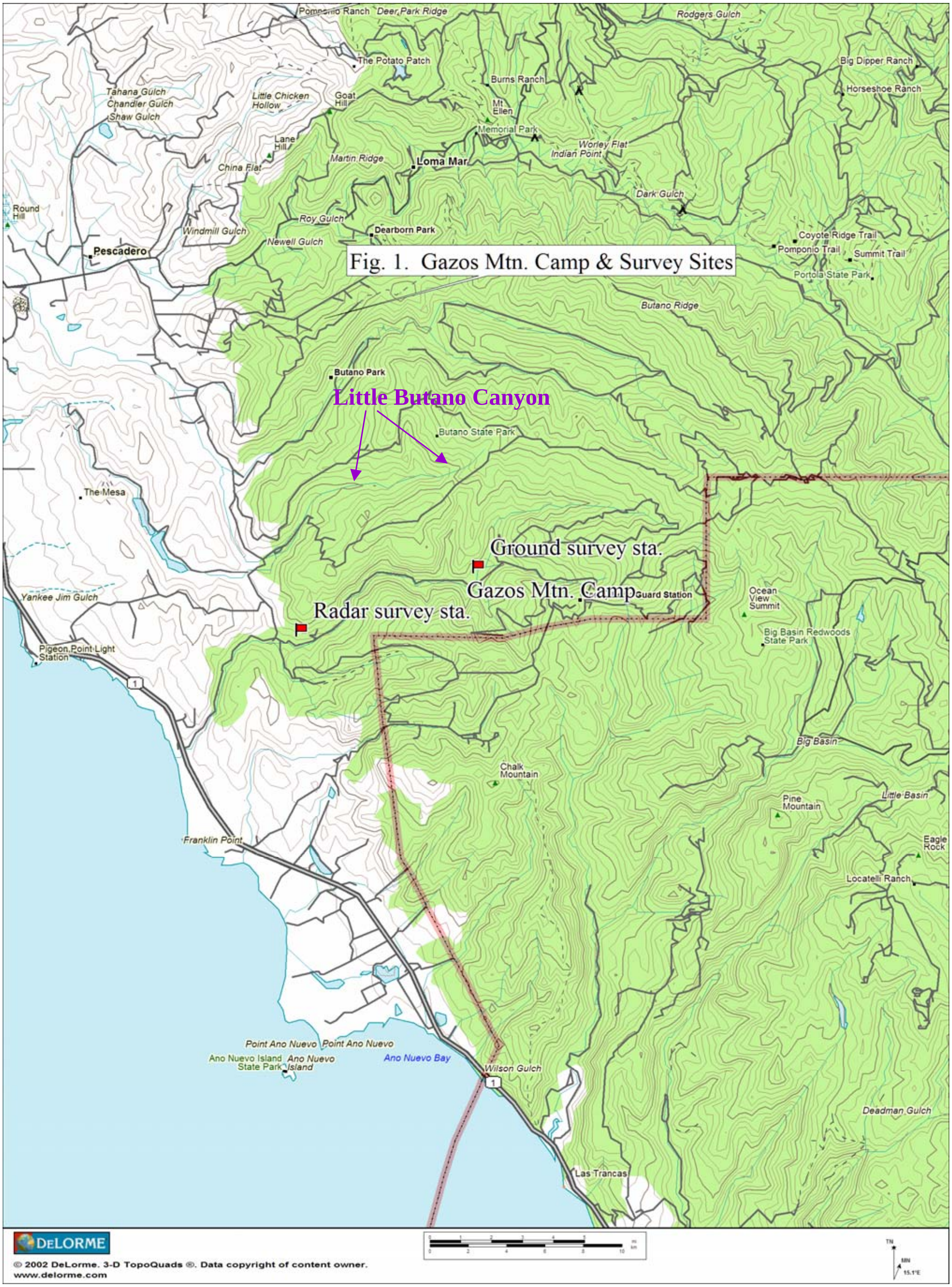
Fig. 1. Gazos Mtn. Camp & Survey Sites
Little Butano Canyon
Ground survey sta.
Gazos Mtn. Camp
Radar survey sta.
Guard Station
Pescadero
Loma Mar
Butano Park
Butano State Park
Butano Ridge
Dearborn Park
Big Basin Redwoods State Park
Ocean View Summit
Chalk Mountain
Pine Mountain
Pigeon Point Light Station
Franklin Point
Point Ano Nuevo
Ano Nuevo Island State Park
Ano Nuevo Island
Ano Nuevo Bay
Wilson Gulch
Las Trancas
Yankee Jim Gulch
The Mesa
Big Basin
Little Basin
Eagle Rock
Locatelli Ranch
Deadman Gulch
Memorial Park
Worley Flat
Indian Point
Dark Gulch
Coyote Ridge Trail
Pomponio Trail
Summit Trail
Portola State Park
Big Dipper Ranch
Horseshoe Ranch
Rodgers Gulch
Deer Park Ridge
The Potato Patch
Burns Ranch
Mt Ellen
Tahana Gulch
Chandler Gulch
Shaw Gulch
Little Chicken Hollow
Goat Hill
Lane Hill
Martin Ridge
China Flat
Roy Gulch
Windmill Gulch
Newell Gulch
Round Hill
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APPENDIX

2000 – 2010 Radar Detections – Double Low Gazos

Date	In-Bound	Out-Bound	Total In and Out	Unknown	Total All
7/14/2010	22	9	31	12	43
7/13/2010	20	7	27	16	43
7/12/2010	23	13	36	14	50
7/11/2010	19	13	32	12	44
7/10/2010	8	9	17	13	30
7/9/2010	18	14	32	9	41
7/8/2010	17	8	25	7	32
MEAN	**18.1**	**10.4**	**28.6**	**11.9**	**40.4**
STDV	**4.9**	**2.8**	**6.2**	**3.0**	**7.0**
CV	**0.3**	**0.3**	**0.2**	**0.3**	**0.2**
7/11/2009	11	42	53	13	66
7/10/2009	12	17	29	4	33
7/9/2009	7	35	42	7	49
MEAN	**10.0**	**31.3**	**41.3**	**8.0**	**49.3**
STDV	**2.6**	**12.9**	**12.0**	**4.6**	**16.5**
CV	**0.3**	**0.4**	**0.3**	**0.6**	**0.3**
7/14/2008	8	15	23	21	44
7/13/2008	5	10	15	25	40
7/12/2008	2	13	15	17	32
7/11/2008	4	8	12	10	22
7/10/2008	0	17	17	5	22
7/9/2008	2	6	8	12	20
7/8/2008	7	12	19	8	27
MEAN	**4.0**	**11.6**	**15.6**	**14.0**	**29.6**
STDV	**2.9**	**3.9**	**4.8**	**7.3**	**9.4**
CV	**0.7**	**0.3**	**0.3**	**0.5**	**0.3**
7/8/2006	14	28	42	2	44
7/7/2006	14	17	31	9	40
7/6/2006	21	16	37	3	40
7/5/2006	18	16	34	4	38
7/4/2006	15	15	30	8	38
7/3/2006	10	25	35	5	40
7/2/2006	10	18	28	11	39
MEAN	**14.6**	**19.3**	**33.9**	**6.0**	**39.9**
STDV	**4.0**	**5.1**	**4.7**	**3.4**	**2.0**
CV	**0.3**	**0.3**	**0.1**	**0.6**	**0.1**
7/13/2004	15	17	32	12	44
7/12/2004	20	24	44	8	52
7/11/2004	18	18	36	6	42
7/10/2004	15	16	31	9	40
7/9/2004	15	11	26	9	35
7/8/2004	8	23	31	15	46
7/7/2004	15	18	33	8	41
MEAN	**15.1**	**18.1**	**33.3**	**9.6**	**42.9**
STDV	**3.7**	**4.4**	**5.6**	**3.0**	**5.3**
CV	**0.2**	**0.2**	**0.2**	**0.3**	**0.1**

Date	**In-Bound**	**Out-Bound**	**Total In and Out**	**Unknown**	**Total All**
7/21/2002	2	16	18	4	22
7/20/2002	2	9	11	4	15
7/19/2002	2	5	7	4	11
7/18/2002	4	7	11	11	22
7/17/2002	5	3	8	8	16
7/16/2002	4	15	19	6	25
7/10/2002	7	10	17	10	27
MEAN	**3.2**	**9.2**	**12.3**	**6.2**	**18.5**
STDV	**1.3**	**5.3**	**5.0**	**2.9**	**5.4**
CV	**0.4**	**0.6**	**0.4**	**0.5**	**0.3**
7/21/2001	7	5	12	18	30
7/18/2001	5	2	7	29	35
7/17/2001	4	11	15	12	27
7/15/2001	11	12	23	6	29
7/14/2001	10	8	18	17	35
7/12/2001	6	12	18	13	31
7/10/2001	9	18	27	3	30
MEAN	**7.4**	**9.7**	**17.1**	**14.0**	**31.0**
STDV	**2.6**	**5.3**	**6.7**	**8.6**	**3.0**
CV	**0.4**	**0.5**	**0.4**	**0.6**	**0.1**
7/17/2000	11	16	27	25	52
7/16/2000	6	9	15	15	30
7/15/2000	15	15	30	10	40
7/14/2000	9	21	30	7	37
7/13/2000	18	37	55	4	59
7/11/2000	16	23	39	20	59
7/10/2000	10	14	24	13	37
MEAN	**12.1**	**19.3**	**31.4**	**13.4**	**44.9**
STDV	**4.3**	**9.1**	**12.7**	**7.3**	**11.7**
CV	**0.4**	**0.5**	**0.4**	**0.5**	**0.3**