Long-Term Monitoring of Marbled Murrelet Populations at Inland Sites in the Santa Cruz Mountains of Central California, 1999-2009

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INTRODUCTION

The Command Trustee Council contracted Hamer Environmental L.P. to continue a long term inland monitoring study of Marbled Murrelet (*Brachyramphus marmoratus*) populations in the Santa Cruz Mountains. The five watersheds we monitored were first surveyed in 1998 or 1999, with additional surveys conducted over the ensuing ten years as funding allowed (Singer and Hamer 1998, 1999, 2000; Hamer 2001, 2002; Singer and Hamer 2004, 2006, 2008). The results of these studies will be used by various resource managers to assess the trend of these populations over time and the relative use of different forested watersheds in the Santa Cruz Mountains.

The objectives of this monitoring program were to:

1) Document the daily numbers and flight patterns of any murrelet-type targets that were detected;
2) Using repeated measures regression analysis, investigate potential trends in Marbled Murrelet detection at the five watersheds;
3) Conduct a prospective graphical power analysis to estimate the number of years it would take to detect 1%, 5%, 10%, and 20% decline in radar counts at the current rate of sampling.

BACKGROUND

The Marbled Murrelet was listed as threatened by the U.S. Fish and Wildlife Service in 1992 and was listed as endangered by the State of California in 1992 (USFWS 1997). The Marbled Murrelet is a medium sized Pacific seabird that nests some distance from the coast in conifer forests with old growth characteristics in the Pacific Northwest and in remnant old-growth redwood (*Sequoia sempervirens*) stands in California south to the Santa Cruz Mountains (Carter and Sealy 1987, Paton and Ralph 1990, Ralph et al. 1990, Singer et al. 1991, Hamer et al. 1994, Grenier and Nelson 1995). The central California Marbled Murrelet populations are genetically distinct from other murrelet populations and are somewhat physically isolated with over 160 km (100 mi) of separation from populations in Northern California (Ralph and Miller 1995, Beissinger and Nur 1997, Beissinger and Peery 2003, McShane et al. 2004). Marbled Murrelet populations in central California are the most vulnerable to extinction due to their low population numbers, physical isolation and recent years of low breeding success (McShane et al. 2004), which makes the study of these populations critically important.

Collecting biological information on the inland flight patterns of this species is extremely difficult because of the height at which the birds fly and the poor observation conditions for audio-visual observers. Some of the challenges for observing the bird during its inland flights include: low ambient light levels during dawn and dusk activity periods, limited viewing capability in closed canopy forests, as well as the species' small size, rapid flight speed, cryptic plumage, and secretive behavior. The rare visual observations are short in duration and offer only limited glimpses of much longer flight paths and behaviors (Hamer et al. 1995).

An inland audio-visual survey protocol for detecting the Marbled Murrelet in forested habitat was first developed in 1990 (Paton et al. 1990) and then updated in 2003 (Evans et al. 2003). With this protocol, murrelets could be detected by both auditory and visual observations. However, in regions that receive little use by Marbled Murrelets, detections are still extremely rare. It is suspected that birds may vocalize less frequently when few other birds are present. Eighty-five to ninety percent of murrelets are detected audibly (Hamer and Cummins 1990), and therefore silent birds are extremely difficult to detect. In addition, ground observers can detect a murrelets by sight within 50-75 m (164-246 ft) of a survey station and by sound within a 200-m radius (656 ft or 30 ac). Therefore, the standard audiovisual survey protocol (Evans et al. 2003) has limited value in determining the presence of murrelets within a large area or landscape, especially in areas with low populations.

Because of these problems, a new method was needed to detect Marbled Murrelets within a watershed and monitor the inland flight activity. Several types of radar have proven to be effective tools for ornithological research over the last four decades (Eastwood 1967). Of these, marine radar is probably the easiest and least expensive to operate, and has additional benefits such as high resolution, ability to sample at small ranges, high availability, and high portability (Cooper et al. 1991, Hamer et al. 1995).

Evidence from radar studies indicates breeding birds may be flying inland before the start of the audiovisual survey period or during the early part when low ambient light levels may preclude visual detection (Cooper et al. 1996, Burger 1997, Hamer and Meekins 1998). Radar studies on the Olympic Peninsula, Vancouver Island, and in the North Cascades found an initial peak of silent murrelets 45 to 60 minutes before sunrise when low light levels preclude detection by audio-visual surveys (Cooper and Blaha 1997, Burger 1997, Hamer and Meekins 1998). It is possible that the early influx of silent birds consists primarily of breeding individuals that would be very difficult to detect using standard audiovisual surveys.

In contrast to audiovisual surveys, radar is able to detect murrelets that are silent. Radar is also able to detect murrelets passing over a landscape out to a distance of 1.5 km (0.93 mi), which is more than 50 times the area a typical ground observer can detect birds. In addition, radar can detect murrelets flying through darkness and fog (Hamer et al. 1995) and can provide information on flight speed, flight direction, and flight behavior.

Radar typically detects 2–10 times the number of murrelets compared to audiovisual surveys and also provides much more accurate estimates of the number of birds using an area compared to the audio-visual survey protocol (Evans et al. 2003, Bigger et al. 2004) which was not designed to measure or provide an index of abundance. In addition, there is high variation in audio-visual counts that would require extremely high survey intensities to detect population trends (Jodice et al. 2001, Smith and Harke 2001). Therefore, radar provides a more efficient tool for determining murrelet presence on the landscape and documenting the numbers of birds using an area compared to the audiovisual survey protocol, and has been used to monitor murrelet populations in British Columbia, Washington, Oregon, and California.

STUDY AREA

The watersheds under investigation were located in San Mateo and Santa Cruz Counties of central California. We monitored portions of five watersheds including Gazos Creek, Little Butano Creek, Butano Creek (referred to as Big Butano Creek in this report), Pescadero Creek and Waddell Creek (Figure 1) using one radar monitoring site in each watershed (Table 1). The radar monitoring sites selected had reasonable vehicle access, open areas to place the radar system, and low amounts of ground clutter (from trees and mountain sides) on the radar screen thus maximizing our ability to detect Marbled Murrelets. There was the potential for some survey coverage overlap between some of the survey stations, such as between Big Butano, Little Butano, and Gazos.

The five survey sites selected were permanently marked in 1998/1999 for relocation in future survey years. One survey site, Pescadero, was relocated in 2009 due to lack of access at the original site. The new Pescadero site was located 450 m (1,476 ft) north of the original. The radar coverage of Pescadero Creek in 2009 was very similar to the original survey site since both sites had complete coverage of the valley bottom where most of the murrelet detections occurred. Murrelets flight paths are highly constricted here since the valley is less than 500 m wide and is surrounded by ridges reaching 305 m (1,000 ft) in elevation.

METHODS

Radar surveys were completed during the morning activity period beginning approximately 75 minutes before official sunrise and ending 75 minutes after sunrise for a total of 2.5 hours of sampling each day. This period encompasses the known peak of daily murrelet activity (Burger 1997, Evans et al. 2003) for central California. Official sunrise times were obtained from Half Moon Bay Area NOAA Sunrise/Sunset tables. The timing of peak activity may vary between years. To minimize any variation due to this variability, annual surveys to each site were planned so that they occurred during the same month, and in many cases, within the same two week period each year the site was sampled. Therefore, all survey used in the analyses were conducted in July, except for 4 surveys conducted in June of 1999. Surveys conducted in August in 1999 were not used as Marbled Murrelet activity declines sharply during this period. Three morning surveys were conducted at each of the five sites in July 2009.

In 2009, radar tracking was performed using a high-frequency marine surveillance radar (Furuno Model FCR-1510, Furuno Electric Company, Nishinomiya, Japan) transmitting at 9,410 MHz (i.e. X-band) with a 2 m (6.6 ft) long (slotted wave guide array antenna with a peak power output of 12 kW. Pulse length could be set at 0.07, 0.15, or 0.3 µs. To enhance the detection of small targets at a distance, the pulse length was set to 0.07 µs. The radar beam had a vertical span of 25° and a horizontal beam width of 2°. The radar was operated at a range of 1.5 km radius (0.93 mi). In prior survey years a 10kW radar was utilized with a range setting of 0.93 km radius (0.58 mi). To compare 2009 data with data collected in previous years using the 10 kW radar, with a different area of coverage (scale), murrelet-type detections recorded and mapped between 0.93 and 1.5 km from the radar in 2009 were removed from analysis. The radar unit was powered by a 2000 kW Honda quiet generator positioned within 10 m (33 ft) of the radar lab. During each monitoring session the radar screen was recorded using a Sony 8mm video camera. Radar detections could then be reviewed using video playback if necessary. The radar was mounted on a 4-wheel-drive SUV (Figure 2).

We gathered the following information for each murrelet-type target identified by radar: time, radar species identification, flight behavior, overall flight direction, species' flight direction in relation to the drainage (i.e. landward, seaward, circling, unknown), flight speed, farthest distance detected from the radar unit, and flock size. In 2009, we also mapped the flight path of each murrelet-type detection on a transparency overlay of the radar screen. To determine target flight directions, for each site, a straight line was drawn representing the dominant stream channel direction within the 0.5 nm or 1.5 km (for 2009) radar sampling area. This stream channel direction was then used to determine landward and seaward flight paths. We categorized targets as flying landward or seaward if they were flying within ±45° of long axis of the stream cannel direction being sampled. Targets flying outside of these directions were classified as "unknown". We defined targets as "circling" if the target flight path created an arc of at least ½ circle.

Murrelet targets detected on radar were distinguished from other avian species by the target size, flight speed, flight path, and time of day. At inland sites in Northern California, Hamer et al. (1995) found the only other common inland species of similar size and flight speed to the murrelet was the Band-tailed Pigeon (*Columba fasciata*), which overlapped at the lower end of murrelet flight speed. For radar monitoring, only birds flying ≥59.5-65.2 km/hr (37 – 40.5 mph) were recorded as murrelets to minimize the number of non-murrelet targets recorded. Although the original recommendation in the protocol was to use >64.4 km/hr (40 mph) as a speed threshold (Evans et al. 2003), we can only record the distance between echoes on the radar screen to the nearest millimeter. Therefore, different types of radar monitors and different scale settings will determine the final speed threshold that can be accurately used.

In general, the faster the flight speed the more likely the target could be a murrelet. In addition, murrelet type targets will sometimes show a somewhat higher mean flight speed for seaward versus landward flights. This discrepancy results from murrelets losing altitude after visiting nest sites in the nearby hills and mountains as they descend back to sea level. Murrelets heading landward (inland) to nest sites usually have to gain some altitude to fly over nearby ridges and hills and this can slow their flight speed.

The more direct flight paths of murrelets along drainages and landward-seaward flight directions on their way to and from marine waters can also help distinguish the murrelet from other species. From previous studies, we have found that the radar could commonly detect murrelet-sized targets up to 1.3 km (0.81 mi) away (Hamer et al. 1995). Under ideal conditions murrelet type targets can be detected beyond this distance, commonly up to 1.5 km (0.93 mi). When operating at the range of 1.5 km (0.93 mi) if hills or trees were not obscuring the radar beam, we could detect murrelets in a 1.5 km (0.93 mi) radius circle surrounding the radar.

In addition to speed and flight direction, a Marbled Murrelet's compact body and relatively large muscle mass make comparatively large, round, echo sizes on the radar monitor. The timing of the detections was also considered. Murrelets start flying landward before sunrise when most other birds are not yet active. Therefore, targets flying landward pre-dawn are more likely to be murrelets. In addition, daily murrelet type detections will usually show a pulse of early landward detections and then a pulse of seaward detections some time later in the morning. The difference between the landward and seaward flight times is due to the time it takes the birds to exchange incubation duties or feed young along with the time it takes to fly back to the ocean. These criteria, when considered together, assist in the identification of murrelet targets using radar.

On two survey mornings in 2009 we conducted simultaneous audiovisual surveys at the radar sites to detect murrelets and Band-tailed Pigeons in order to identify radar detections to species. On both mornings there proved to be little overlap between birds detected by sight or sound and birds detected by radar. We suspect that most murrelets detected by radar are flying too high to be seen by ground observers.

The following weather information was collected at the beginning and end of each survey session: wind direction, average wind speed at ground level, estimated cloud cover (%), average ceiling height (in meters) above ground level, visibility, precipitation, and air temperature (ºC).

Three different data filters were used to analyze the 1998 – 2009 surveys and best determine the Marbled Murrelet population trends at these five watersheds. The three data filters applied to the raw data were: 1) no filters (inclusion of all data); 2) filtering out all circling and unknown flight paths (i.e., using landward and seaward targets only) and; 3) filtering out all seaward, circling, and unknown targets (i.e., using landward targets only). This first method may be problematic because of the potential for non-target species (especially Band-tailed Pigeons) being misidentified by the radar technician as Marbled Murrelets. This is because all targets are accepted as being murrelets without regard to flight direction or flight behavior. The second filter was designed to filter out the targets with the lowest probability of being Marbled Murrelets (e.g., fast-moving migrants moving north to south, circling raptors, etc.) by only accepting targets with easterly and westerly flight directions and more direct (straight) flight paths typical of murrelets. The third (most restrictive) filter was designed not only to accept targets with easterly and westerly flight directions and more direct (straight) flight paths, but also to exclude those targets after a certain point in the morning, when other avian species, particularly Band-tailed Pigeons, become much more active. Because Band-tailed Pigeons roost in the Santa Cruz Mountains at night and fly west or seaward in the morning to feed in the agricultural fields near the coast, by filtering out all seaward or westerly flying targets each morning we are able to remove the majority of Band-tailed targets from the data.

For each site, a graphical power analysis was conducted for each data filter utilizing the ratio of within year (daily) to between year variance combined with the average number of surveys conducted per year. The filter that most consistently yielded the highest power to detect a 10% change in the number of detection per year using a repeated measures regression analysis (see below) was used for the regression test. A prospective graphical power analysis using the variance ratios above was then used to estimate the number of years it would take to detect 1%, 5%, 10%, and 20% declines in radar counts of murrelet-type targets at the current rate of sampling.

A repeated measures regression analysis was used to investigate potential trends in marbled murrelet detections at the five watersheds. The significance of the trends was assessed using the P-value associated with the slope term from the repeated measures regression. The average decline in the number of detections per year was calculated using the start and end points of the regression line in combination with its slope.

RESULTS

Five sites were monitored over 99 mornings from 1999-2009 (Figure 3). A total of 247.5 hours of radar sampling were conducted. Of these, 2.37 hours (142 minutes) were lost due to inclement weather or equipment malfunctions, leaving 294.63 hours of usable sampling (99.2%). After removing surveys conducted in August, 87 days of sampling remained. Over the 11 year period and 87 survey mornings, we recorded 2,877 murrelet-like radar targets (Figure 3) for an average radar detection rate of 33.1 murrelet-type detections per survey morning. This total and mean detection rate includes landward, seaward, unknown and circling murrelet-type targets.

Mean number of landward radar detections at the five sites over the years of sampling ranged from 5.3 (Big Butano) to 21.4 (Pescadero) detections per survey morning with standard errors ranging from 0.8 to 3.5 (Table 2). Of the 2,993 (including August data) Marbled Murrelet-type targets recorded over the 11 year period, 1,035 were flying landward (35%), 1,191 seaward (40%), and 767 in other directions (26%).

All five sites exhibited a great deal of within and between year variability in murrelet-like detections during the years sampled (Figure 3). Detection rates of landward targets did not appear to be affected by the presence of fog ($t = 0.2777$, $df = 66.575$, p-value = 0.782; Figure 4) or clouds (Figure 5). Overall trends combining all sites were more difficult to assess as not all sites were surveyed in all years (Figure 3).

In some cases, the low sample size of observations within a site (and therefore higher variability) made the apparent differences observed in power to detect trends between the three different data filters somewhat suspect (Figure 6). Therefore, greater weight was given to power analyses of sites with larger sample sizes (i.e., Double Low Gazos and Waddell Creek) when choosing the most appropriate filter to analyze the data. The retrospective power analysis indicated that a repeated measured regression using only landward flights would yield the greatest power to detect a trend, though the difference in some cases (Waddell and Double Low Gazos) was small (Figure 6). As this filter was also most effective at discriminating marbled murrelets against other similar radar targets (e.g. Band-tailed pigeons), it was used for the analyses.

The numbers of detections at all five sites showed negative trends, although, with the current number of years of sampling, none were statistically significant (P=0.632, 0.139, 0.579, 0.068, 0.162 for Big Butano, Little Butano, Double Low Gazos, Pescadero, and Waddell, respectively; Figure 7). Mean annual percent declines estimated from the linear model ranged from 5.5% at Pescadero to 1.3% at Double Low Gazos (Figure 7). The power analysis suggested that only the Double Low Gazos site had been sampled adequately to detect a 10% change in the number of detections, and none of the sites had yet been sampled adequately to detect changes of smaller magnitudes (Figure 8).

DISCUSSION

In areas where murrelets are present, the early morning period is often characterized by landward targets while the latter part of the morning is often characterized by seaward targets flying to the west and returning to the ocean after visiting inland nest sites. Our data showed that same trend each morning with 1,035 murrelet-type targets flying landward (35%), 1,191 seaward (40%), and 767 in other directions (26%). It was fortunate that the retrospective power analysis indicated that a repeated measured regression using only landward flights would yield the greatest power to detect a trend. In some regions, the proportion of misidentified murrelet-type targets on radar can increase dramatically late in the morning survey period when most murrelets are heading seaward toward the ocean (Cooper et al. 2001) and other diurnal species that could be confused with murrelets become more active. In this region, the one species most commonly misidentified on radar with Marbled Murrelets is the Band-tailed Pigeon, which usually do not become active until 10-20 minutes after sunrise (Hamer and Schuster 2002), and no other shorebird or seabird would be as likely to be flying landward as early as a Marbled Murrelet. In addition, Band-tailed Pigeons roost at night in the Santa Cruz Mountains and consistently fly westward (seaward) in the morning to feed in open agricultural lands near the coast. Therefore, by only using landward targets for our trend analysis, we effectively eliminated almost all identification errors associated with Band-tailed Pigeon activity due to the unique morning flight direction of Band-tailed Pigeons and their timing of activity. Other researchers have also used only landward detections for their final analyses of radar monitoring data of Marbled Murrelet populations (Burger 2001, Burger et al. 2004, Cooper et al. 2006).

An initial examination of the data revealed what appeared to patterns in numbers of radar detections at each of the five watersheds. All sites that were surveyed in 2002 (Double Low Gazos, Big Butano, Pescadero, and Waddell) showed apparent declines in comparison to the previous year sampled. All of these but Pescadero also showed an apparent rebound during the subsequent sampling year. Some of these differences could be due to differences in breeding effort that may have occurred in these years. However, only Double Low Gazos was sampled between 2002 and 2009. The apparent periodicity in detections at Double Low Gazos was noted previously by Verschuyl (2008), who showed two separate significant declines of similar magnitude within the six sampling years between 2000 and 2008, but no overall statistically significant trend in detections throughout that period. Audio-visual surveys and at-sea counts in recent years allude to a population collapse or dramatic decline in Marbled Murrelet populations in central California during the period from 2003-2008 that coincides with the second decline detected here (Peery et al. 2008). However, at-sea detections of Marbled Murrelets were higher in 2009 compared to 2008, and have included detection of 2 juveniles (Zach Peery, pers. Comm.). If increased power associated with sampling in future years reveals the declining trends at Big Butano, Little Butano, Pescadero and Waddell to be significant, declines in this population have likely been occurring since at least 1999.

From two years of telemetry data collected in central California, Peery et al. (2004) found that only 30% of the landward murrelet flights were made by nesting birds in the first year, while 83% of the landward flights were made by nesting birds in the second year. Using weighted averages based on the number of birds radio-tagged each year, they concluded that in the combined two-year study period 68% of the landward flights were made by nesting birds, then went on to imply that this would be the case in most single years as well. If this premise holds true, then years where low proportions of murrelets attempt to breed in the Santa Cruz Mountains should result in lower numbers of radar detections at inland sites. Radar counts could then be used as an index (indicator) of breeding effort each year, along with at-sea data and audio-visual surveys, and be valuable as a comparison to at-sea data. Peery goes on to recommend that inferences from radar counts of murrelets should be limited to indices of the size of the potential breeding population and not the actual breeding or regional population size. He states that this index would be expected to fluctuate annually due to variation in breeding effort. Even with the numbers of non-nesters making inland flights, he concludes that if conducted over a reasonable period, radar surveys should detect declines in the breeding population (Peery et al. 2004).

Peery et al. (2006) concluded that, based on low levels of documented reproductive success, the central California population should show a consistent annual decline in the absence of immigration. However, at-sea data collected from 1999 to 2003 did not show such a decline. An analysis of the genetic parentage of Santa Cruz murrelets captured at-sea shows the population appears to be supplemented by a low level of immigration (approximately 2–6% annually) (Peery et al. 2008). Peery et al. (2008) state that immigration into this population (possibly from northern California) without recruitment could potentially be artificially supporting population numbers making it difficult or impossible to detect annual declines using an at-sea survey approach. However, if immigrants mixing into the central California population are non-breeders, and unlikely to fly inland during the breeding season, radar could be a valuable tool to detect annual declines in this population; without the confounding effects of the immigrant population masking the decline.

The apparent failure of the regression to detect significant changes in the number of detections was likely a product of the low numbers of years during which many of the sites have been sampled. Most current models suggest that marbled murrelet populations are declining at rates from 2.2-6.4% per year (McShane et al. 2004). Based on at-sea studies, population declines for conservation zones 1-5 have been estimated at 2.2% (95%CI = -5.6%-+1.3%) (Lance et al. 2008). However, McShane et. al. (2004) suggests that the declines in the Santa Cruz population may be as high as 6.4% per year, assuming a 2% immigration rate and constant oil spill/gill net mortality. Though the possible declines shown in this analysis appear to fall within this range, the power analysis outlined above suggests that the sites with the most intensive sampling regime (i.e., Double Low Gazos – surveyed 2-7 times per year for eight years) would have to be sampled for ~12 sampling years to be able to detect a 5% change in the number of radar detections with 80% power (see Figure 8). Since we have conducted eight years to date, this leaves an additional four sampling years necessary to detect a change in the number of detections of the magnitude alluded to by this model and the literature. At their current rates of sampling (3-5 radar surveys per year), Big Butano, Little Butano, Pescadero and Waddell would require 5, 12, 15, and 10 years of additional sampling respectively to detect 5% population changes with 80% statistical power. In comparison, in a radar monitoring study on the Olympic Peninsula, Cooper et al. (2006) calculated a ≥80% likelihood of detecting a 2% annual decline in 15 years, with 3 surveys per year and seven total sites sampled. In a radar monitoring study in northern California, Bigger et al. (2006) estimated that four radar surveys per year at 22 sites would be needed to detect a 2.5% annual decline in 10 years with 80% power.

However, if we increased the number of surveys per year at each site (similar to the 7 surveys at Double Low Gazos), we would decrease the amount of within year variation. thereby decreasing the number of sampling years necessary to detect a 5% change in the number of radar detections per year with 80% power.

Perry et al. (2008) believes that the low productivity observed by researchers studying this population since 1996 foretell an inevitable decline for these birds over time. Because of this, it will be important to continue a radar monitoring program in this region to provide an independent index of abundance that can be used to help assess and compare any population trends detected by at-sea surveys. It will also be beneficial to continue audiovisual surveys at known breeding sites since such surveys are the only type of surveys that can link murrelet activity to actual nesting attempts.

An additional value of radar counts is that they can assess the usage and trends for specific watersheds in the region. If declines in radar counts in particular watersheds are more severe than others, these declines can then be linked to watershed conditions such as proportion of suitable habitat, level of forest fragmentation, stand ages, campground densities, road densities and other factors, which may affect murrelet productivity and murrelet predator populations. At-sea counts, although valuable, are much more difficult to relate to specific watersheds.

TABLES

Table 1. Coordinates of the locations of the radar lab for each site sampled (NAD27).

Site Name	UTM Coordinates (10S)	
	X Coordinate	Y Coordinate
Double Low Gazos	0558944	4115725
Little Butano	0558114	4117751
Big Butano	0557698	4119095
Pescadero	0560181	4124305
Waddell	0564127	4106757

Table 2. Mean, minimum, and maximum numbers of landward radar detections at each site from 1998-2009 shown with standard deviation (SD), standard error (SE), and daily coefficient of variation (CV).

Site	Mean	Minimum	Maximum	SD	SE	Daily CV
Big Butano	5.33	1	11	3.58	1.03	0.67
Little Butano	7.86	5	13	3.02	1.14	0.38
Pescadero	21.38	11	36	10.03	3.55	0.47
Waddell	20.54	4	43	12.44	3.45	0.61
Double Low Gazos	9.72	0	21	5.49	0.8	0.56

Table 3. The mean number of detections (plus or minus one standard deviation) at each of the survey sites from 1999-2009. If no standard deviation is given, only one survey was completed at that site during that year.

	Big Butano	**Little Butano**	**Pescadro**	**Waddell**	**Double Low Gazos**
1999	11			34	13±4.2
2000	10	11	34		14.0±1.4
2001	6.3±2.3	6		30.5±9.3	7.4±2.6
2002	1.8±1.0		27.5±11.4	12±13.4	3.7±1.9
2003					
2004					15.1±3.7
2005					
2006					14.6±4.0
2007					
2008					4.0±2.9
2009	5.7±3.1	6.3±1.5	16.0±2.0	13.7±4.7	10.0±2.6

FIGURES

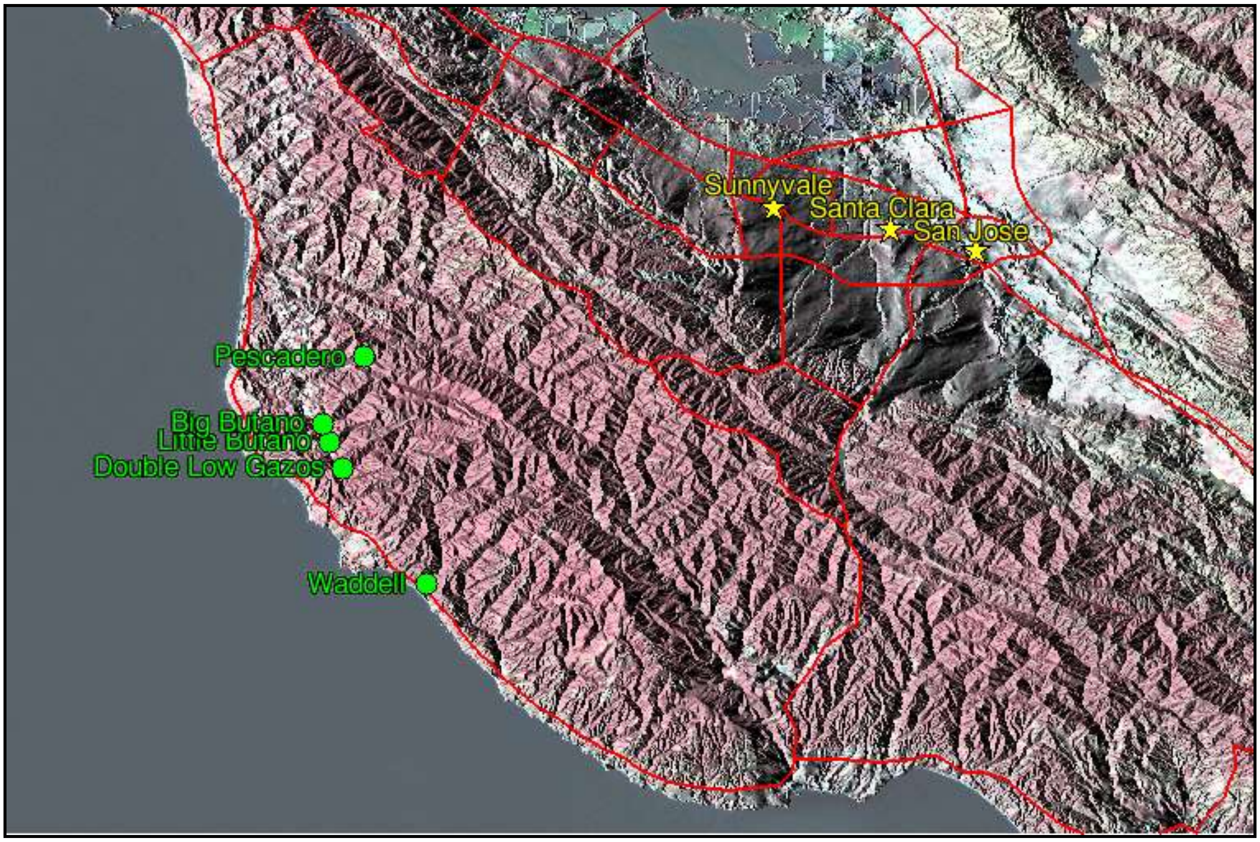

Figure 1. Location of the five radar survey stations (pictured in green) in the Santa Cruz Mountains, California, 1998-2009.

Figure 2. Radar lab set-up at Little Butano Creek, July 16, 2009.

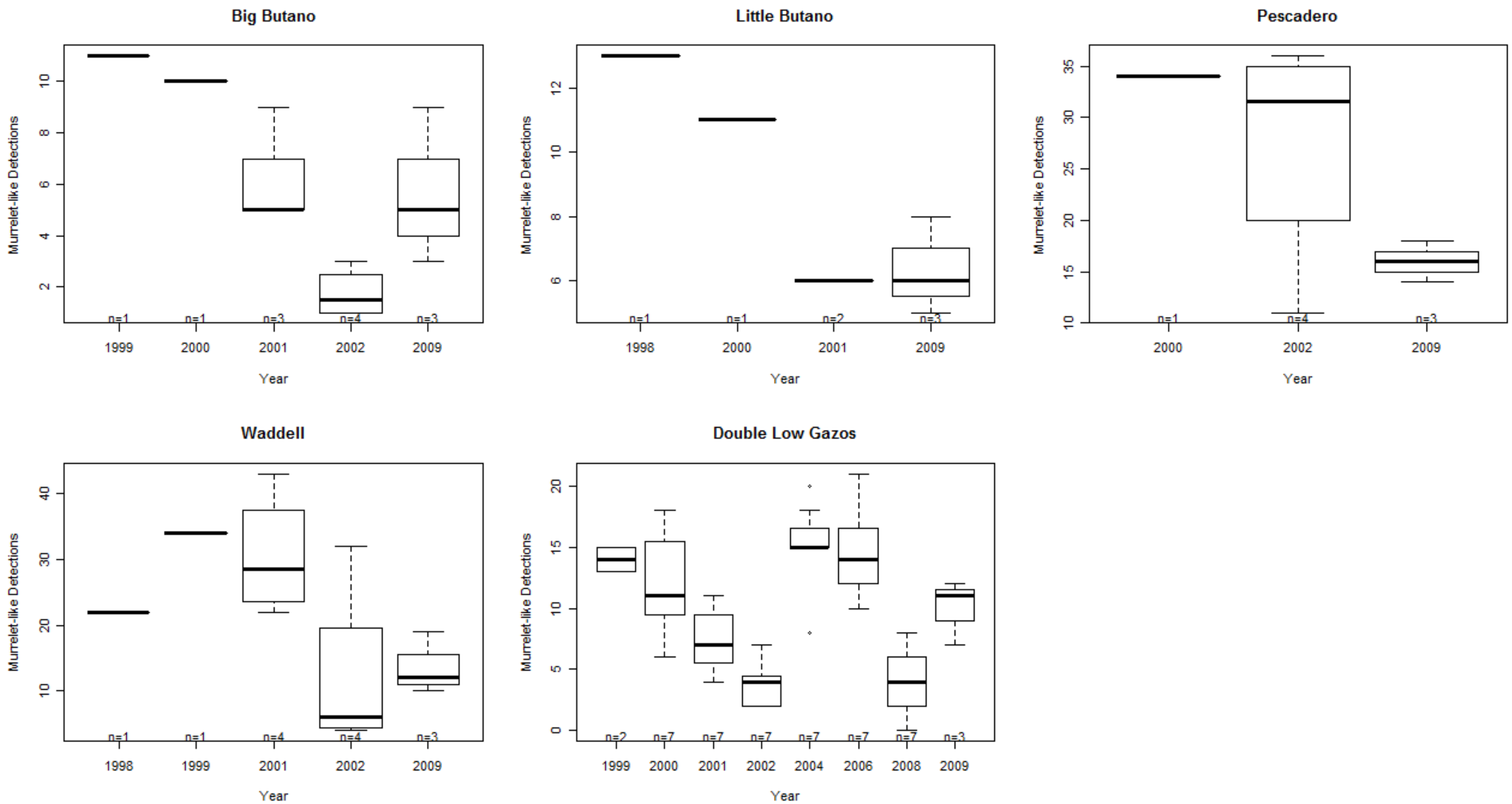

Figure 3. Box-and-whisker plot showing the numbers of landward Marbled Murrelet-like detections and number of mornings surveyed each year (n) at each of the five radar survey sites from 1998-2009. Bold center lines represent the median number of observations, and the box is bounded by the first and third quartiles. The "whiskers" extend 1.5 times the interquartile distance from the upper and lower bounds of the box. Observations that lie outside this range are represented individually as potential outliers.

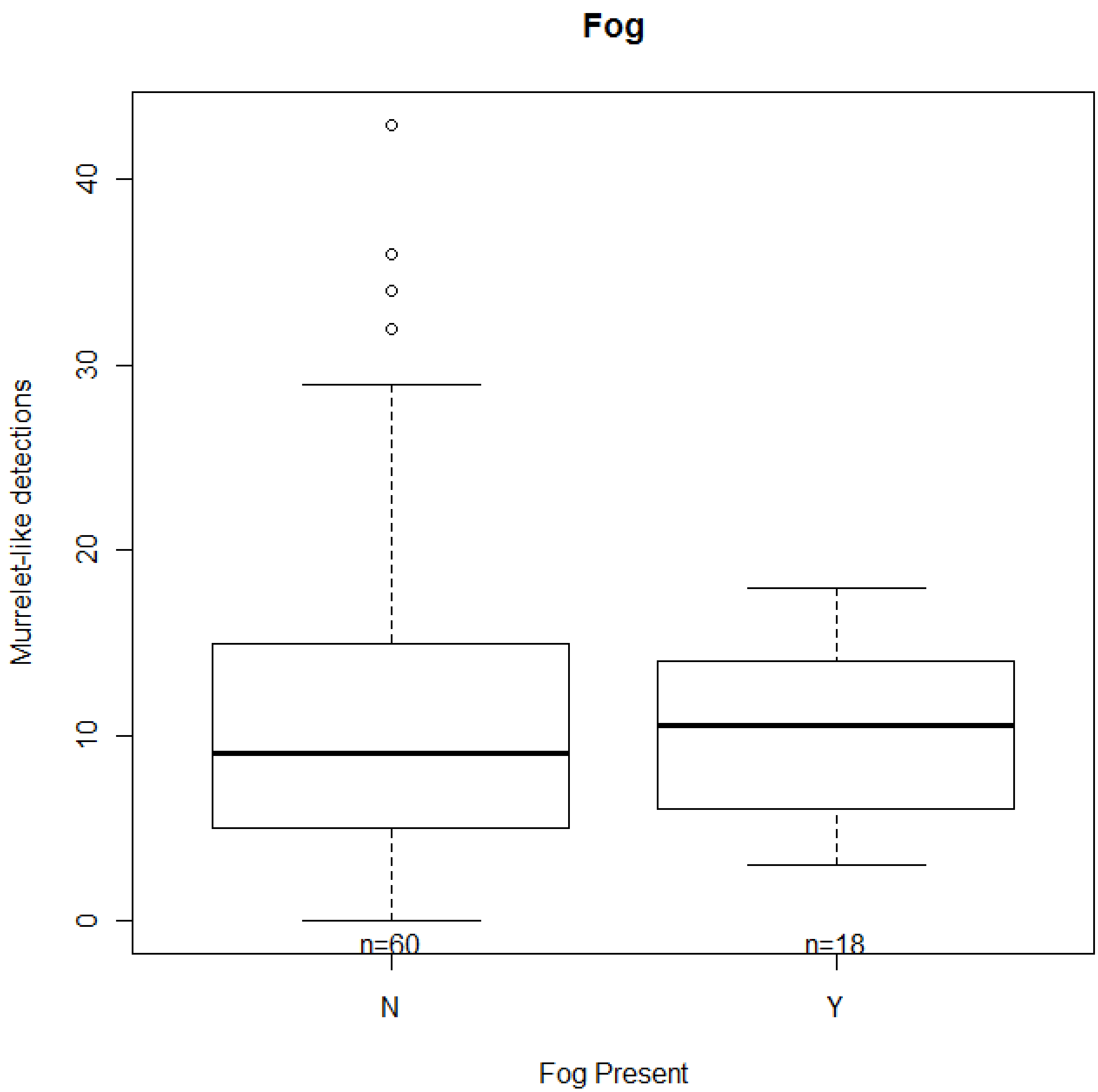

Figure 4. The effect of fog on the number of landward Marbled Murrelet-like detections for the study period from 1998-2009 for all five watersheds combined.

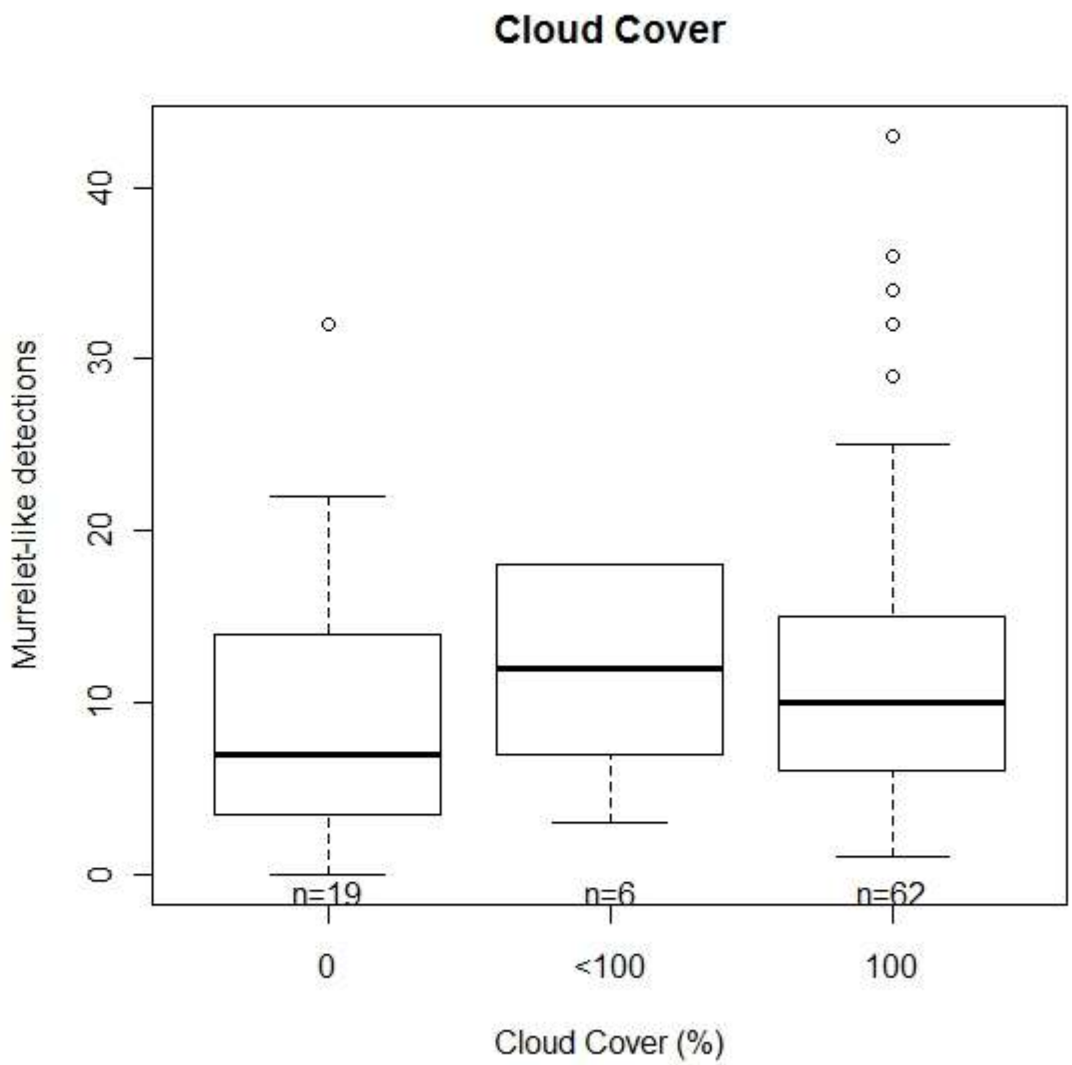

Figure 5. The effect of cloud cover on the number of landward Marbled Murrelet-like detections for the study period from 1998-2009 for all five watersheds combined.

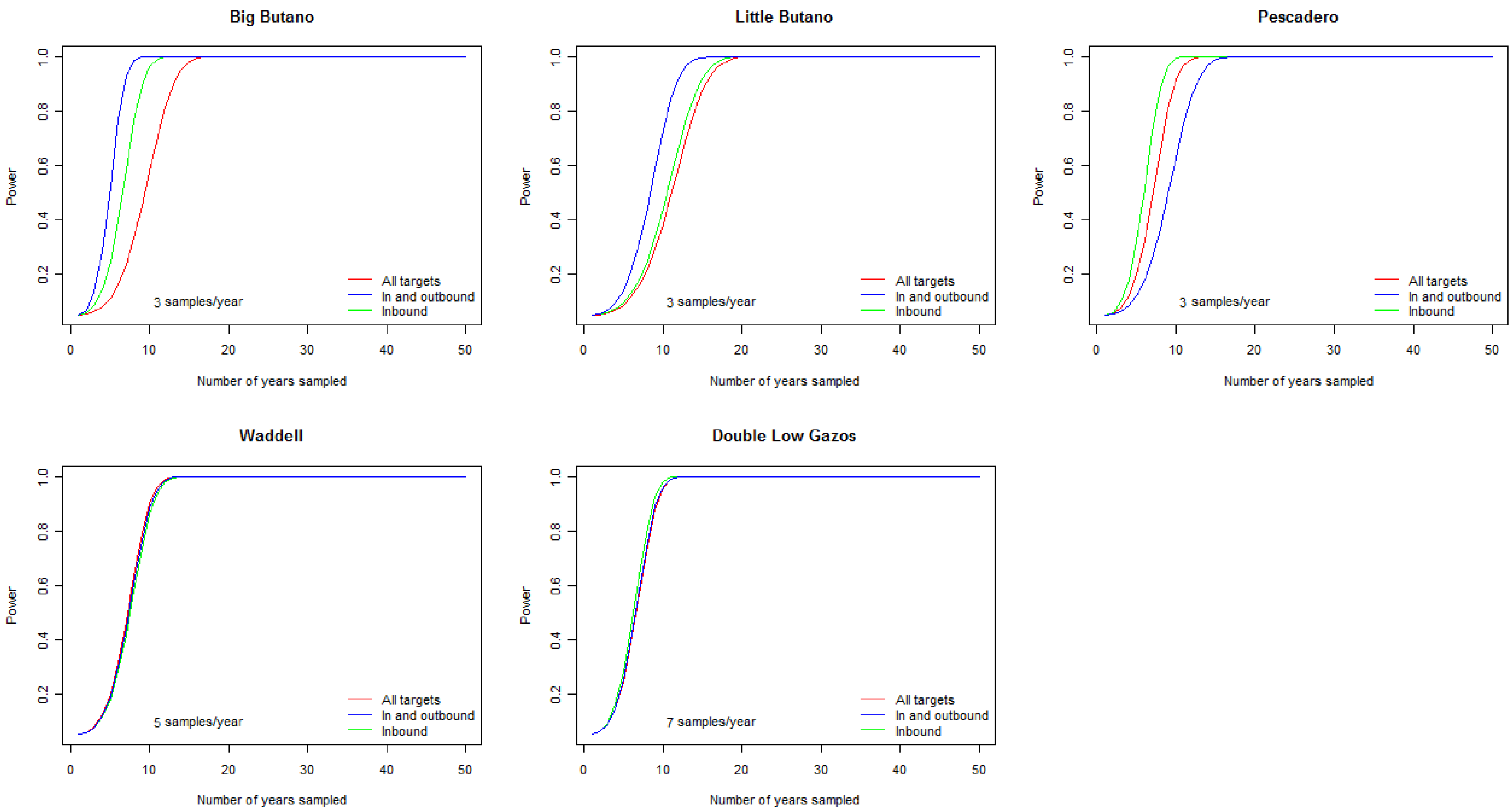

Figure 6. Comparison of the relative abilities of each of the three data filters (all targets, landward and seaward targets only, and landward targets only) to detect a 10% change in the number of radar detections.

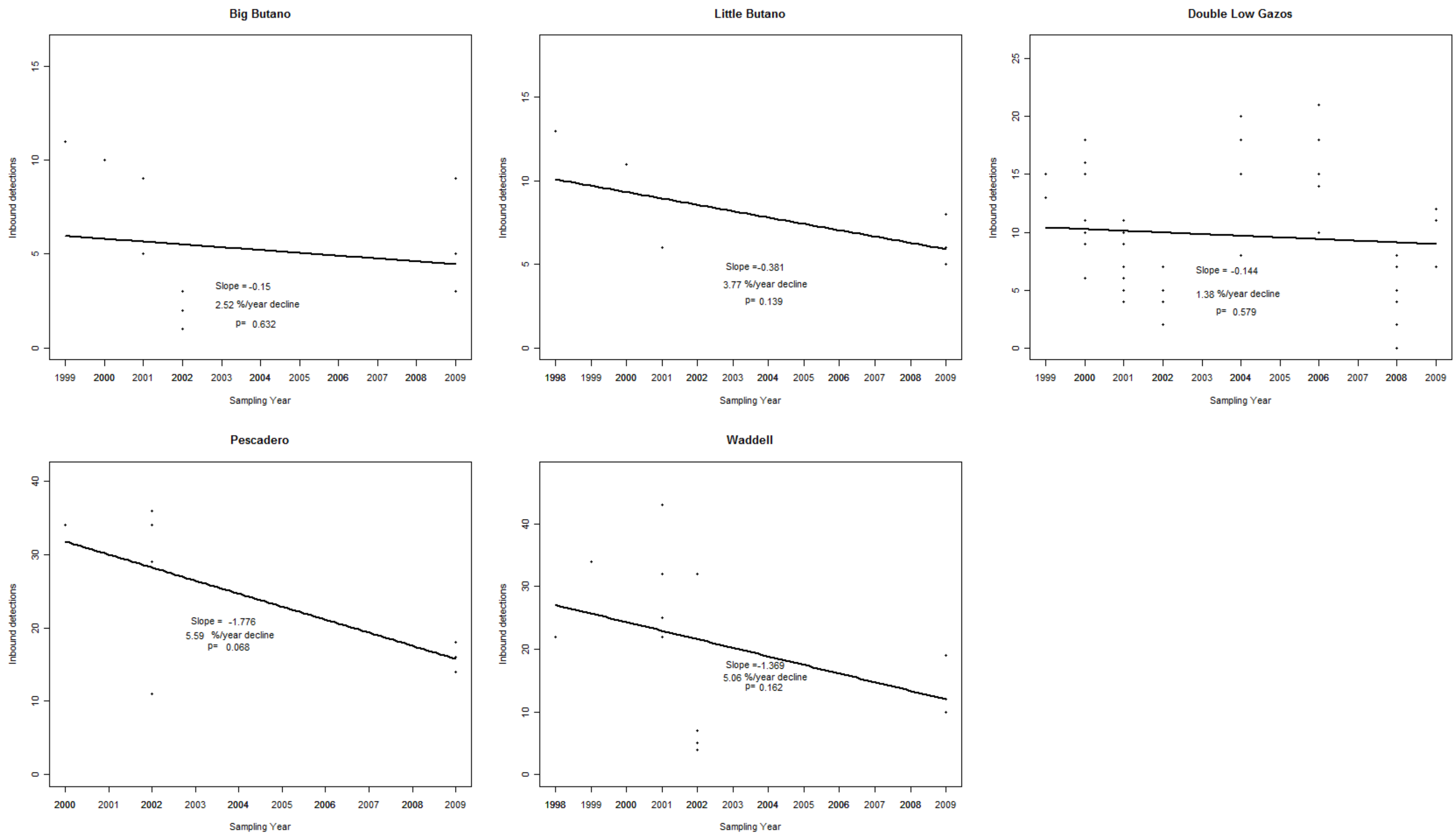

Figure 7. Regression lines and slopes for the number of landward murrelet-like targets detected each year at each of the five watersheds.

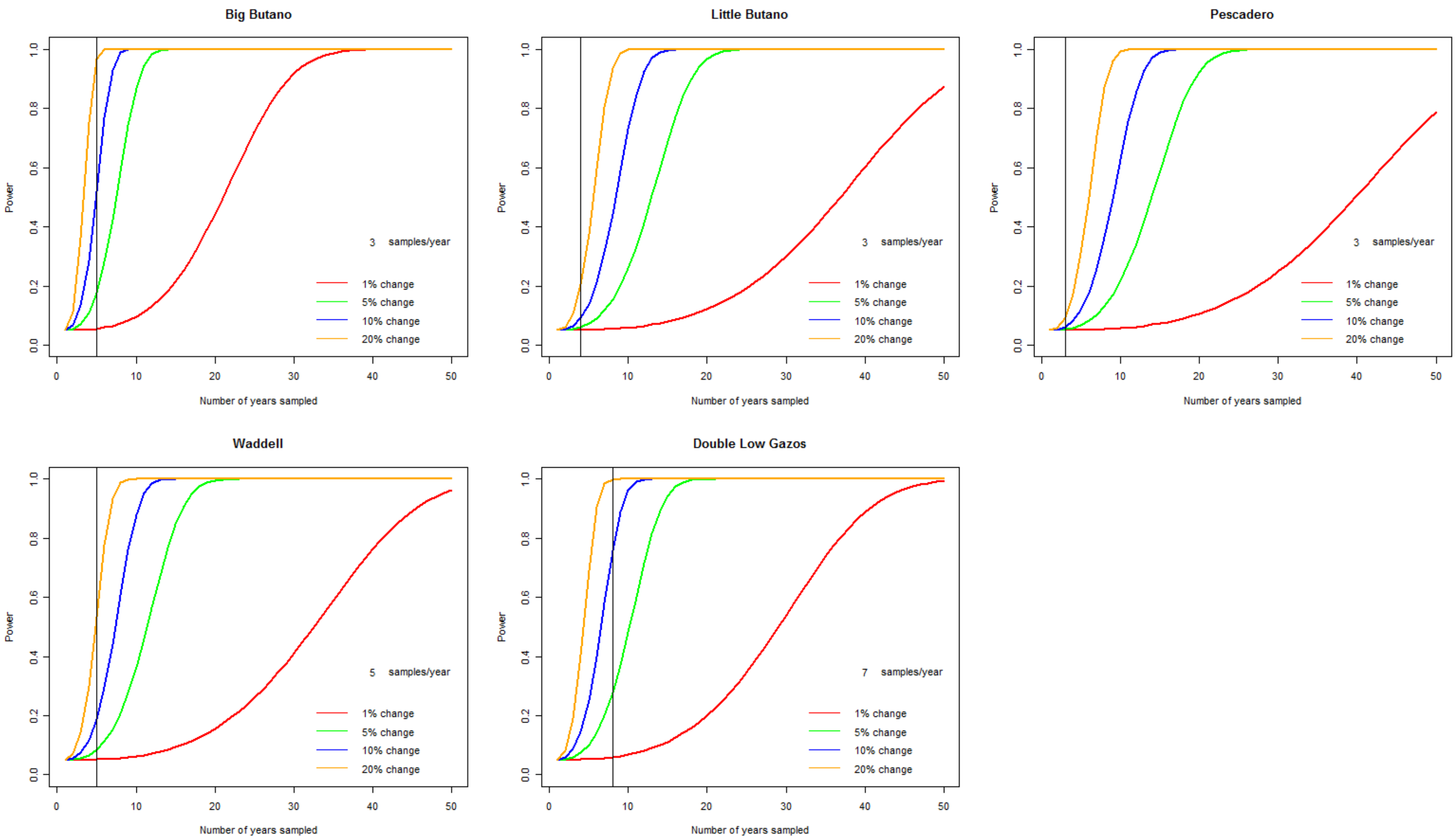

Figure 8. Graphical power analysis showing the number of years of sampling necessary to detect a 1%, 5%, 10%, and 20% change per year in the number of landward murrelet-like detections at each of the five watersheds given the current rate of sampling (listed above the legend). The number of years already completed is shown with the vertical black line.

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Appendix 1

Sample Yearly Radar Detections Of Marbled Murrelets (Mamu) for 2009

Site Name	Date	Sunrise	Time 1st MAMU	Total MAMU	Landward	Seaward	Circling	Unkown	1st BTPI	Fog?
Waddell	7/23/2009	607	523	18	10	7	0	1	600	Y
Waddell	7/22/2009	606	516	22	19	3	0	0	553	N
Waddell	7/21/2009	605	517	18	12	6	0	0	556	N
Pescadero	7/20/2009	605	510	30	18	6	2	4	600	Y
Pescadero	7/19/2009	604	454	32	14	13	0	5	553	Y
Pescadero	7/18/2009	603	457	28	16	10	0	2	559	N
Little Butano	7/17/2009	602	448	14	5	6	0	3	612	Y
Little Butano	7/16/2009	602	516	14	6	7	1	0	609	Y
Little Butano	7/15/2009	601	509	34	8	22	1	3	626	Y
Big Butano	7/14/2009	600	452	14	5	4	0	5	551	N
Big Butano	7/13/2009	600	445	21	9	5	0	7	539	N
Big Butano	7/12/2009	559	450	39	3	24	0	12	557	Y
Double Low Gazos	7/11/2009	558	458	66	11	42	1	12	551	Y
Double Low Gazos	7/10/2009	558	505	33	12	17	0	5	529	N
Double Low Gazos	7/9/2009	557	503	49	7	35	0	6	605	N