Use of Decoys to Assess Effectiveness of Aerial Surveys for Sea Otters

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ABSTRACT

Aerial surveys are regularly used to assess the abundance and distribution of sea otters (*Enhyrda lutris*). However, it has long been recognized that abundance may be underestimated using aerial surveys, as a result of perception bias (primarily visibility bias, as opposed to availability bias). We used sea otter decoys deployed on the ocean to assess perception bias using standard techniques for aerial surveys for sea otters. We conducted trials under a variety of weather conditions, at altitudes of 200 ft. (N = 37), and 400 ft. (N = 18). We found that viewing condition (a function of cloud cover and sea state) strongly affected detectability of decoys. Under the best viewing conditions ("Excellent"), 82% of decoys were detected at the standard survey altitude of 200 ft. This decreased to 40% of decoys detected under "Good" viewing conditions. Mean detection probability of decoys detected under a range of viewing conditions from Good to Excellent (corresponding to typical conditions for most sea otter surveys in California) was 57%. Distance of decoys from the plane negatively affected detectability at the higher altitude of 400 ft., and when viewing conditions were less than excellent, and fewer decoys were detected at 400 ft. altitude than at 200 ft. Group size of decoys (ranging from 1 to 4) had a slight effect on detectability; group sizes of 4 were detected more frequently than smaller group sizes. A substantial number of false positive sightings (21% of sightings at 200 ft. altitude) were recorded; these were presumed to be derelict crab pot buoys. Observer experience did not affect detectability of decoys in this study, although more false positive sightings were reported by less experienced observers. Simple correction factors based on detectability of decoys by viewing condition were used in a preliminary analysis to correct actual sea otter survey data conducted under differing viewing conditions over two consecutive days. Use of these correction factors reduced the relative difference of the counts from 114% to 8%.

INTRODUCTION

Sea otters (*Enhydra lutris*) are of conservation and management concern throughout their range, and the Southern subspecies (*E. lutris nereis*) in California is listed as Threatened under the Federal Endangered Species Act. Assessing sea otter distribution and abundance is critical to resource managers, both for monitoring population trends, and for assessing potential threats to the species (including, but not limited to, oil spills). Distribution and abundance of Southern sea otters are currently assessed annually by the U.S. Geological Survey, the California Department of Fish and Wildlife, the Monterey Bay Aquarium, and other research partners, using a combination of ground (shore-based) counts and aerial surveys.

Ground counts for sea otters in California have been estimated to detect 95% of animals present out to 900 m from shore, allowing for fairly accurate measures of abundance (Estes and Jameson 1988). However, because ground counts are dependent on adequate vantage points and accessible coastline, this method is only feasible for approximately 50% of the current Southern sea otter range. Aerial surveys are used to survey the remaining sections of the Southern sea otter range that cannot be surveyed from shore, including shallow habitat (<60 m depth) too far offshore for reliable counts from shore (Appendix A). In addition, aerial surveys may be used at the time of oil spills to assess the real-time abundance and distribution of sea otters for both response planning and natural resource damage assessment.

Aerial surveys are effective for relatively quickly surveying large portions of the species' range not accessible from land, but bias (undercounting) in aerial surveys for various species has been well documented (Caughley 1974, Geibel and Miller 1984, Pollock and Kendall 1987). Because not all animals are detected on aerial surveys, uncorrected aerial survey counts are considered to be minimum counts of abundance. The current annual range-wide survey method for Southern sea otters, in use since 1982, uses uncorrected aerial survey data. In an effort to account for interannual variability in detectability of otters, a three-year running mean of uncorrected population abundance is used as an index of population size, and it is this index that is used as the criteria for recovery under the Federal Endangered Species Act (USFWS 2003). However, accurate estimates of true abundance would be useful for a variety of purposes, including oil spill risk assessment and damage assessment, and stock assessments under the Marine Mammal Protection Act.

Visibility bias in surveys of marine wildlife can be broken down into two components (Marsh and Sinclair 1989): availability bias (animals are not available to be counted if they are underwater) and perception bias (animals are available to be counted, but are not detected, for a variety of reasons). Availability bias due to sea otters being underwater during a survey is not considered to be a significant factor; in contrast to other marine mammals (e.g., Laake et al. 1997), sea otters spend the majority of their time on the surface of the water (Bodkin and Udevitz 1999). Perception bias, however, significantly affects counts of sea otters from the air. Perception bias can be a function of factors such as sun glare on the water, wind waves, presence of kelp beds, observer ability and fatigue, transect width, glare on plane windows, and survey speed and altitude.

Various methods can be used to develop correction factors, also referred to as ratio estimators, for aerial wildlife surveys (Pollock and Kendall 1987). These methods include repeated surveys of the same area , comparing abundance estimates from aerial surveys to known numbers of animals based on ground counts or presence of telemetered animals (Huber et al. 2006), and use of decoys to estimate accuracy of aerial surveys (Varoujean and Williams 1995, Pearse et al. 2008). In addition, it is possible to increase the accuracy of abundance estimates from aerial transects by using line transects, also known as distance sampling (Buckland et al. 1993), although this method can be challenging with wildlife species that occur in large groups or high densities.

A number of previous studies have attempted to quantify perception bias in aerial surveys for sea otters, by comparing relatively accurate ground count data to aerial survey data for the same area (Odemar and Wilson 1970, Wild and Ames 1974, Samuel and Pollock 1981, Geibel and Miller 1984, Wendell et al. 1986, Bodkin and Udevitz 1999, C. Kreuder-Johnson unpubl. data). These studies found that aerial surveys typically detected from 50% to 75% of the otters detected from shore (although Wendell et al. [1986] found that only 21% of pups were detected by aerial surveys, and Doroff et al. [2003] found that only 28% of all otters were detected by aerial surveys, compared to boat-based surveys of the same area in Alaska).

Our goal was to quantitatively assess perception bias in aerial surveys for sea otters under a variety of viewing conditions, and to develop correction factors that could be applied based on viewing condition. Viewing conditions have been recorded consistently on aerial surveys for Southern sea otters since 2003, and correction factors based on viewing condition could potentially be applied to these historic as well as current surveys. To quantify perception bias, we avoided any potential uncertainty or variability in the accuracy of ground counts by using a known number of sea otter decoys. To the best of our knowledge, this is the first study to use decoys to assess detectability of sea otters from aerial surveys.

METHODS

Decoy Deployment

Sea otter decoys were constructed out of polystyrene foam glued to supporting plywood (Fig. 1). Decoys were shaped like resting sea otters and were painted dark brown (most were also painted with a slightly lighter face to mimic otter grizzling). Each decoy was 1 m in length and weighed approximately 1.6 kg, including a detachable counterweight to keep the decoy facing up (although it was later determined that the counterweight was probably not necessary to keep the decoys upright). A screw eye was located on the bottom beneath the head for anchoring.

Surveys were conducted off the coast of San Mateo County, near Half Moon Bay, California. This area was chosen to be north of the primary occupied range of Southern sea otters, to avoid confusion between decoys and real otters. Four specific survey sites were used (Fig. 2), all within 5 km of shore: 1) from approximately Miramar to Pomponio State Beach (4 km x ~23 km); 2) from approximately Martin's Beach to Pomponio State Beach (4 km x ~ 10 km); 3) from approximately Martin's Beach to Pescadero Creek (4 km x ~5 km); and 4) off Pacifica (4 km x ~5 km). For each survey, between 8 and 44 decoys were deployed by boat (mean = 21; SD = 10). The majority of decoys were in groups of one, but some groups of two, three, and four decoys were also deployed (mean group size = 1.2; SD = 0.5). Proportion of decoys in different group sizes and spatial distribution were based on actual aerial survey data from previous years. Each deployment of decoys was called a "set"; from one to three different sets were deployed (one at a time) each day (Table 1). Groups of decoys were deployed to pre-determined random locations; group locations were recorded again at the time of pick-up (using a GPS on the deployment boat) and any movements of decoys were noted.

Aerial Surveys

Aerial surveys were conducted using the same general methods as the annual range-wide survey (Appendix A). A Partenavia P-68 Observer airplane was used for all surveys, flown at a speed of 167 km/hr (90 knots), and an altitude of either 200 ft. (61 m) or 400 ft. (122 m). The front seats were occupied by the pilot and a data recorder. Observers facing out through bubble windows on each side of the plane.

For each survey (or "trial"), five transects were oriented parallel to the shoreline (approximately north-south; alternating directions), and spaced 800 m apart, covering the survey area. One observer on each side surveyed a strip from below the plane to 400 m out, and noted any decoy sighting, with group size. The data recorder marked a GPS waypoint for each sighting. Sightings were also assigned to one of four distance categories by the observer at the time of sighting: under (0-10 m), near (10 to 60 m), middle (60 to 200 m), and far (200 to 400 m).

To assist observers in delineating the 400 m survey area, a "calibration string" was set on the water outside the survey area before each survey, with a buoy marking the centerline and buoys on either side 400 m from the center. The plane flew over the center buoy, allowing observers to calibrate their strip width using the buoys 400 m on either side of the plane (as well as buoys at 60 m and 200 m from the centerline).

Viewing conditions were recorded by the data recorder at the beginning of the survey and any time that viewing conditions changed. Viewing condition was determined based sky condition (overcast vs. mostly sunny) and an estimate of wind wave size (Table 2). Based on past experience, these factors act in combination to affect visibility of sea otters from the air.

For a given decoy set on a given day, multiple trials were sometimes flown with different observers and/or at different altitudes. Between 2003 and 2007, 55 trials were conducted, using 24 decoy sets over 12 days (Table 1). One additional day of surveys (two trials) in March 2003 was conducted as a pilot study, but data collection inconsistencies prevented us from using those data for analyses. A few additional surveys were conducted at an altitude of 300 ft. (91 m), but those surveys were also excluded from analyses in this report.

Analyses
After each survey, decoys and sightings were mapped to determine which decoys were sighted and whether there were any false positives or double-counts (i.e., decoys sighted in the same location in the "far" category from adjacent transects). The observers and data recorder viewed these overlaid projected map layers soon after each flight (typically within 1 hour) for a "debrief" to help assess which decoys were sighted and if decoys were double counted. We compiled data (viewing conditions, number of decoys in group, observer team) on all decoys seen, decoys not seen, and false positives. Distance between each decoy and the survey trackline was measured using ArcView9.1 GIS. Observers were categorized as either experienced (had previously conducted at least one actual aerial sea otter survey) or inexperienced (had not previously conducted aerial surveys for sea otters).

Most analyses were conducted on the dataset of surveys flown at 200 ft. altitude, since this is the altitude at which standard sea otter surveys have been flown. To assess detectability of decoys as a function of various factors (e.g., viewing conditions), we calculated the proportion of decoys sighted as the sum of decoy groups sighted at that factor level divided by the sum of all decoy groups available to be detected at that factor level. We also conducted a multivariate analysis using logistic regression (in program R; www.r-project.org) to determine the effects of various factors (viewing condition, distance to decoy, decoy group size, survey location, and observer experience) on detectability of decoys at an elevation of 200 ft.

RESULTS

Overall Detectability and Multivariate Analysis
Thirty-seven trials were conducted at the standard altitude of 200 ft. (61 m). For these surveys, viewing condition ranged from 2 to 10 (although only 2 decoys of 748 were surveyed in viewing conditions of 2), and mean viewing condition (for all decoys available to be detected) was 6.6. Overall detectability for all viewing conditions at 200 ft. was 38.5% (288 of 748 decoys were detected), although due to the wide range of viewing conditions, this should not be considered to correspond to typical aerial surveys for sea otters (most surveys in California are conducted under Good to Excellent conditions). Anecdotally, experienced observers noted that decoys seemed more difficult to detect than real sea otters.

The best-fit logistic regression model for predicting decoy detection at 200 ft. altitude included viewing condition, distance to decoy, location (among the four survey sites), and decoy group size (Table 3). The top four models (which were all strongly supported) all included viewing condition and distance to decoy; excluding either of these variables from the model resulted in a substantially poorer fit. Although including location did improve model fit (i.e., there was a weak effect of location on decoy detectability) we did not address location as a factor in additional analyses, due to an interaction effect of location and viewing condition (mean viewing condition ranged from 5.5 at location 4, to 8.9 at location 1), and the fact that 3 of the 4 survey areas were overlapping in space. Observer experience was not included as a predictor in any top ranked model.

Effect of Viewing Conditions and Distance

Proportion of decoys sighted increased with improved viewing conditions (Fig. 3, Table 4). At viewing condition of 10 (Excellent), a maximum of 82% of decoys were detected. At viewing condition 6 (Good minus) 24% of decoys were detected, and at viewing condition of less than 6, 19% of decoys were detected. For average conditions between Good and Excellent (i.e., Viewing Code 8.5), roughly corresponding to average viewing conditions for typical sea otter surveys in California, mean decoy detectability was 57%. This figure is based on the mean of detection probabilities for each viewing code category (7 through 10), rather than the combined detectability of all decoys in that range of viewing conditions combined, which would be artificially weighted by the sample size of decoys surveyed in each category.

Proportion of decoys sighted decreased with increasing distance from the plane, but this relationship was strongly affected by viewing conditions (Fig. 4). Under better viewing conditions (Good and better), detectability of decoys did not decline appreciably with distance, remaining close to 50%. In contrast, under worse viewing conditions (Good minus and worse), detectability declined dramatically with distance (Fig. 4). Only under excellent viewing conditions did detectability reach 100% at any distance (from 100-199 m from the plane).

Effect of Group Size

For all surveys conducted at an altitude of 200 ft., there did not appear to be an effect of group size on detectability among groups of one to three decoys (Fig. 5). All groups of four decoys were detected (and group size was a factor included in top-ranked logistic regression models), but the extremely small sample size for this category (n = 4) precludes any strong inferences about a potential increase in detectability for groups > 3.

Effect of Altitude

Because surveys were conducted at an altitude of 400 ft. (122 m) on only 6 of 12 days, a full range of viewing conditions was not available for these surveys. To compare surveys conducted at 200 ft. vs. 400 ft., we used only data from the 6 days in which both altitudes were used (this also minimized any potential confounding effects of different observers). At all viewing conditions (for this limited set of paired surveys), detectability (0.21) at 400 ft. was 85% that (0.25) at 200 ft. . At 400 ft., detectability decreased with distance but was not strongly affected by viewing condition (Fig. 6). In contrast, at 200 ft., detectability decreased considerably more with distance under worse viewing conditions (good minus, and worse) than it did under good and better conditions.

False Positives and Double-Counts

On some trials, observers noted “detections” in the absence of a decoy. Based on observations from the decoy deployment boat, it was determined that these sightings were likely of derelict crab pot buoys covered in brown algae (in a few cases, observers also identified and recorded real otters—these were ignored for this study). Boat-based surveys conducted during our study period revealed a high density of derelict crab pots in the study area. The ratio of false positives to actual decoys detected was 0.28 (80 to 288) at an altitude of 200 ft., and 0.33 (19 to 58) at an altitude of 400 ft. Thus, if these false positives were included, raw counts of “otters” would have been inflated by approximately 30%. At an altitude of 200 ft. (with a greater sample size), the ratio of false positives was greater for inexperienced observers (0.40; 29% of sightings) than for experienced observers (0.21; 17% of sightings). Viewing conditions did not have a large effect on the proportion of false positives, although the ratio of false positives under good viewing conditions (Code 7 and better) was slightly lower (0.26) than under poorer viewing conditions (0.33).

Relatively few decoys were double counted (counted twice from adjacent transects). Overall, 5% of decoys (14 of 288) were double counted at an altitude of 200 ft., and 2% of decoys (1 of 58) were double counted at an altitude of 400 ft. At an altitude of 200 ft., the proportion of double counts increased with improving viewing conditions (Fig. 7). When both observers were experienced, there were more double counts (8%; 9 to 115) than if only one of the two observers was experienced (3%; 5 to 168).

DISCUSSION

Use of decoys allowed us to better quantify the accuracy of aerial surveys for sea otters. Previous studies attempted to assess accuracy of aerial surveys using land-based (Geibel and Miller 1984) or boat-based (Doroff et al. 1995, Bodkin and Udevitz 1999) counts as the baseline. By using decoys deployed in known numbers and locations, we avoided uncertainty associated with land-based or boat-based counts. Thus, we were able to accurately assess effects of viewing conditions on detectability, and accurately assess how detectability decreases with increasing distance.

One potential drawback of using decoys is that decoy survey data may not be directly comparable to survey data from real otters. Group size and habitat use of real otters (particularly in nearshore areas) may vary from the decoy arrays we used, and activity of real otters will affect survey results. Any correction factor for real otters based on observations of decoys may be appropriate to compensate for perception bias (if decoys are close to identical in appearance to real otters), but will not address availability bias (Marsh and Sinclair 1989). However, availability bias (to account for otters missed while they are diving) could potentially be modelled from other studies of sea otter activity (Estes and Jameson 1988). In addition, perception bias may be overestimated in our study if (as observers thought), decoys are more difficult to detect from the air than real sea otters, and this may potentially compensate for any unassessed availability bias.

Factors Affecting Decoy Detection

Unsurprisingly, we confirmed that viewing conditions strongly affected the detectability of sea otter decoys. Although this is the first study to document an effect of environmental conditions on detectability of sea otters (or at least sea otter decoys) from aerial surveys, sun glare has previously been documented as a confounding factor for aerial surveys of other marine mammals (Lowry and Forney 2005) and marine birds (Briggs et al. 1985). We found that under good viewing conditions, there was no appreciable decline in detectability with distance, up to the edge of the strip transect at 400 m from the plane. However, under poorer viewing conditions, there was a sharp decline in the detection of decoys farther from the plane, with fewer than 5% of decoys >300 m away being detected.

Fewer decoys were detected on surveys conducted at an altitude of 400 ft. than on surveys conducted at 200 ft., confirming that the standard protocol of 200 ft. altitude for southern sea otter surveys is probably appropriate. In contrast, Bodkin and Udevitz (1999) found no significant difference in otter detectability among altitudes of 200, 300, and 400 ft., although their surveys were presumably conducted under very good or excellent viewing conditions. In addition to an overall lower detection rate, our surveys conducted at the higher altitude resulted in slightly more false-positives. False positive identifications were assumed to be derelict crab pot buoys covered in brown algae, and were likely more difficult to distinguish from decoys at the higher altitude.

Like Estes and Jameson (1988), we found that observer experience had little effect on overall detection of otter decoys. However, experienced observers were more likely to double-count decoys (perhaps due to a slightly greater detection rate at the outer edge of the transect), and less likely to record false positive sightings (presumably because of greater experience in identifying sea otters from the air).

We also found little effect of group size on detectability of decoys, although we had a very small sample size of groups of 4, and no groups >4. Estes and Jameson (1988) found that group size was positively correlated with detection of otters from shore, but groups >4 animals were common in their study, whereas individual animals are quite common in the Southern sea otter range. Individual animals may be harder to detect if they are actively foraging (Estes and Jameson 1988), and with real otters (as opposed to decoys), there may be a greater effect of group size on detectability, due in part to the relationship between activity and group size (groups are more likely than individuals to stay on the surface of the water).

Potential Correction Factors

This study could potentially be used as a basis to develop correction factors to improve the accuracy of aerial surveys for sea otters. Our overall 38% detection rate for decoys should not be used as a direct correction factor, or be compared directly with other studies assessing detectability of sea otters, given that in our study we conducted some surveys in poor weather conditions that would be unrealistic for an actual sea otter survey. However, correction factors based on viewing condition could potentially be used to improve the accuracy of aerial survey abundance estimates.

As expected, we found that detectability of sea otter decoys increased with improving viewing conditions. Viewing conditions of 9 and 10 (Excellent- and Excellent) correspond to Beaufort sea state of 0 to 1, with overcast skies. Under these conditions, mean detectability of decoys was 74% at the standard altitude of 200 ft. Including all viewing conditions of Good (Code 7) or better, an average of 57% of decoys were detected. These values (which correspond to more realistic conditions for typical aerial surveys in California) are comparable to the 61% to 69% of otters detected on previous aerial surveys in California (Geibel and Miller 1984), and the 52% to 72% of otters detected on aerial surveys in Alaska (Bodkin and Udevitz 1999), although the surveys in Alaska were conducted at a higher altitude of 300 ft.

Bodkin and Udevitz (1999) recommend intensively censusing (while circling for several minutes) subsamples of aerial strip transects to develop correction factors specific to each observer on each survey. Using this method, they found that initial otter detection probabilities differed significantly between two observers. However, they did not assess effects of viewing conditions, which may have explained a substantial portion of the variation between observers.

One potential method of correcting aerial censuses for sea otters would be to correct for detectability using the proportion of decoys detected under different viewing conditions. For each survey or survey segment, the raw census data could be corrected based on viewing conditions as shown in Table 4. For best results, a new survey segment would have to be started any time viewing conditions changed, and correction factors specific to that segment would be used. One concern with use of direct multipliers as correction factors is that counts of zero otters cannot be corrected if in fact otters were present but not detected. It should be noted that correction factors based on detection of decoys (Table 4) may result in overestimates of true abundance if decoys were in fact harder to detect than real otters. However, there was no availability bias associated with the decoys (they never dove underwater), and this may have made up for a slightly lower detectability than real sea otters.

Based on this study, false positive identifications would have substantially affected survey results, inflating survey totals by 25% or more. We believe that crab pots were considerably more abundant in our survey area than in most of the Southern sea otter range, however, this could change in the future. In addition, false positives were reported more often by inexperienced survey teams. Observers should receive training specific to distinguishing otters from crab pot buoys, and if necessary, additional correction factors could be developed to compensate for error associated with these false positives.

Our data on the decrease of detectability with increasing distance from the plane may not be relevant for development of direct correction factors, but provides good information on the mechanism behind decreasing detectability under poor viewing conditions. These data could be very important if aerial surveys are used to sample rather than census sea otter populations, as a basis for developing detection functions for distance sampling. In addition, implications of these data could also be important if strip transects are used to census (or survey/sample) sea otters, and otter distribution is not random with respect to distance from the plane. For example, if the outer portion of a strip transect has a higher density of sea otters (e.g., due to closer distance to shore, or presence of kelp beds), correction factors may not be adequate to account for animals missed.

PRELIMINARY VALIDATION OF CORRECTION FACTORS

To assess the efficacy of using correction factors generated by this study, we conducted a preliminary analysis using actual sea otter survey data from northern Monterey Bay. A standard aerial survey was conducted on 4 November 2003, under Fair Minus to Good conditions, and 79 sea otters were detected. The same area was surveyed the next day (5 November) under Good to Excellent conditions, and 287 sea otters were detected. These paired surveys conducted under different viewing conditions provided a good opportunity to assess correction factors based on Viewing Code, under the assumption that the dramatically lower count on 4 November was due to the worse viewing conditions. Although it is possible that some otters moved into or out of this survey area during this 24-hour period, we expect that the overall abundance for this area remained fairly stable during this short period of time. Using condition-based correction factors (Table 4), we corrected raw counts of sea otters detected on each survey, by viewing condition (Figure 8), resulting in corrected total counts of 374 otters on 4 November and 404 otters on 5 November. This reduced the relative percent difference (the difference divided by the mean) between daily counts from 113% for uncorrected counts to 8% for corrected counts. This preliminary analysis is promising, and we hope to further validate potential correction factors with additional sea otter survey data.

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Table 1. Information on sea otter decoy trials. See text for descriptions of the four locations off San Mateo County, California.

Year	Date	Location	Set ID	Number of Decoys in Set	Number of Trials at 200 ft. Altitude	Number of Trials at 400 ft. Altitude
2003	2-Sep	1	3	19	1	0
			4	10	1	0
	3-Sep	1	5	16	1	0
			6	40	1	0
			7	44	1	0
2004	20-Jul	2	8	20	1	0
			9	21	1	0
	21-Jul	2	10	21	1	0
			11	24	1	0
2005	26-Sep	2	12	29	2	0
			13	35	2	0
	27-Sep	2	14	28	2	0
			15	26	2	0
2006	1-Sep	3	16	8	1	1
			17	11	1	1
2007	23-Jan	3	18	8	1	1
	3-Apr	4	19	8	2	2
			20	17	2	2
	4-Apr	4	21	11	2	2
			22	18	2	2
	23-Oct	4	23	19	2	1
			24	19	2	2
	24-Oct	4	25	26	2	2
			26	17	3	2

Table 2. Viewing condition codes used for this study. Sea State and sky condition combined affect glare on the water, but glare alone was not considered to be the sole determinant of viewing condition.

Viewing Code	Viewing Condition	Sea State (Beaufort) with sunny or mostly sunny skies.	Sea State (Beaufort) with bright overcast skies.
10	Excellent	n/a	0
9	Excellent –	n/a	1
8	Good +	0	2 -
7	Good	1	2 +
6	Good -	2 -	3 -
5	Fair +	2 +	3 +
4	Fair	3 -	4 -
3	Fair -	3 +	4 +
2	Poor +	4	5
1	Poor	5	6

Table 3. Top ten models explaining whether a given decoy was detected or not, based on logistic regression.

Model	AIC	dAIC
ViewingCond + Distance + Location + GroupSize	857.43	-
ViewingCond + Distance + Location	860.47	-3.04
ViewingCond + Distance + GroupSize	861.71	-4.28
ViewingCond + Distance	864.47	-7.04
ViewingCond + Location + GroupSize	882.12	-24.69
ViewingCond + Location	884.93	-27.50
ViewingCond + GroupSize	885.52	-28.09
ViewingCond	888.06	-30.63
Distance + Location + GroupSize	918.25	-60.82
Distance + Location	921.74	-64.31

Table 4. Potential survey correction factors, based on proportion of decoys detected, by Viewing Condition.

Viewing Condition	Proportion of Decoys Detected	Correction Factor (multiplier)
10 (Excellent)	0.82	1.2
9 (Excellent –)	0.65	1.5
8 (Good +)	0.41	2.4
7 (Good)	0.40	2.5
6 (Good -)	0.24	4.2
<6 (Poor to Fair+)	0.19	5.3

Figure 1. Bottom view (left) and top view (right) of otter decoy used for this study.

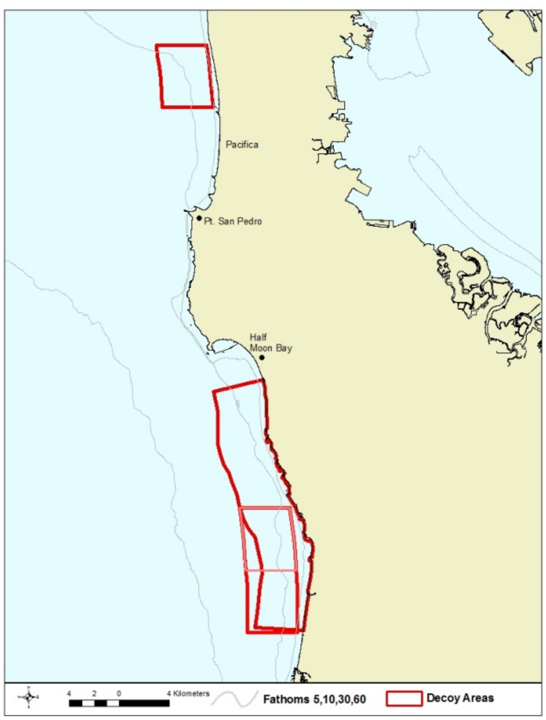

Figure 2. Map showing the four study areas used off San Mateo County, California. The three southern study areas overlapped with each other.

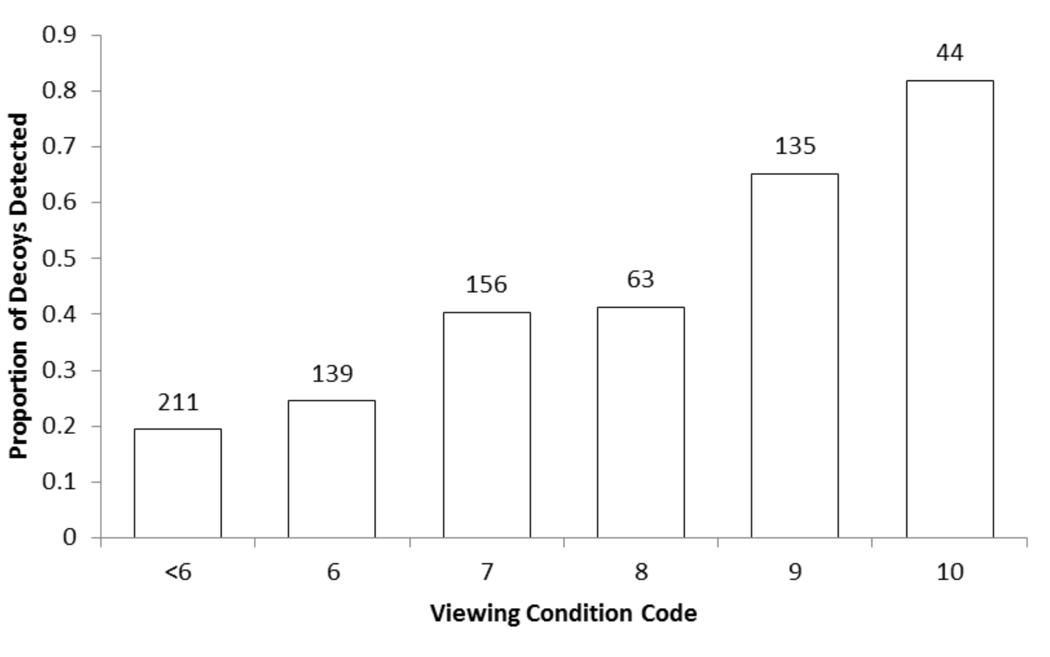

Figure 3. Proportion of decoys detected in all surveys conducted at 200 ft. altitude, by viewing condition. Number of decoys available to be detected for that range of viewing conditions is shown above each bar.

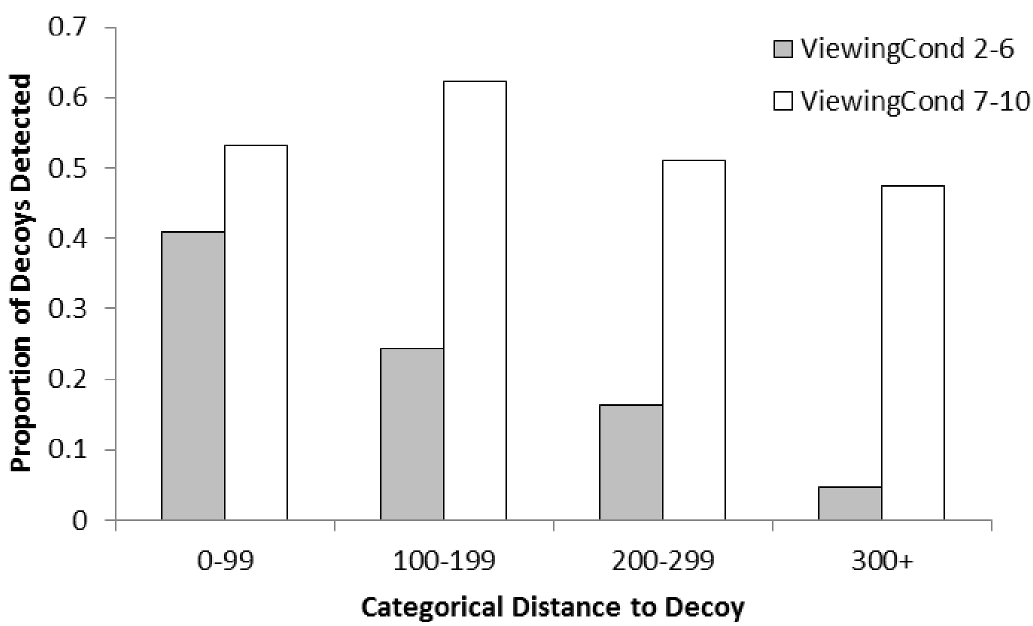

Figure 4. Proportion of decoys detected in surveys conducted at 200 ft. altitude by distance to decoy (in meters) and viewing condition.

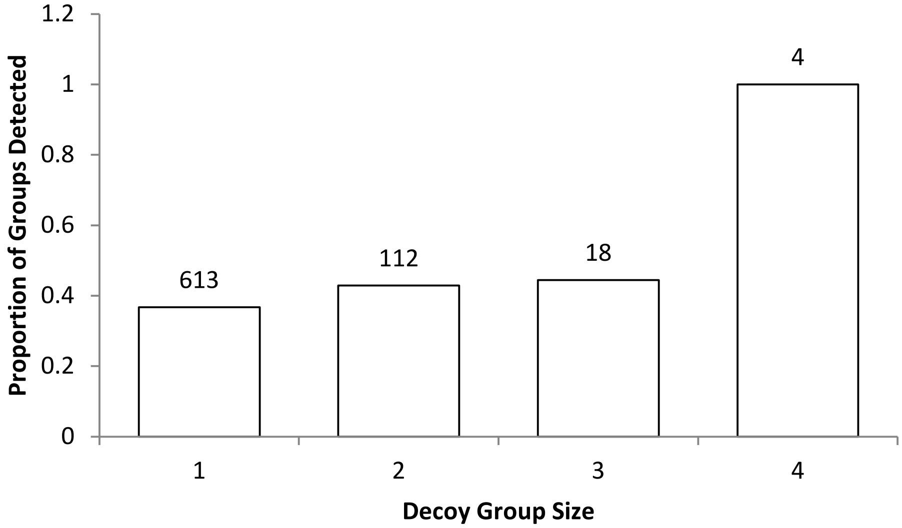

Figure 5. Proportion of decoy groups detected by group size, for all surveys conducted at an altitude of 200 ft. Number of groups available to be detected is shown above each bar.

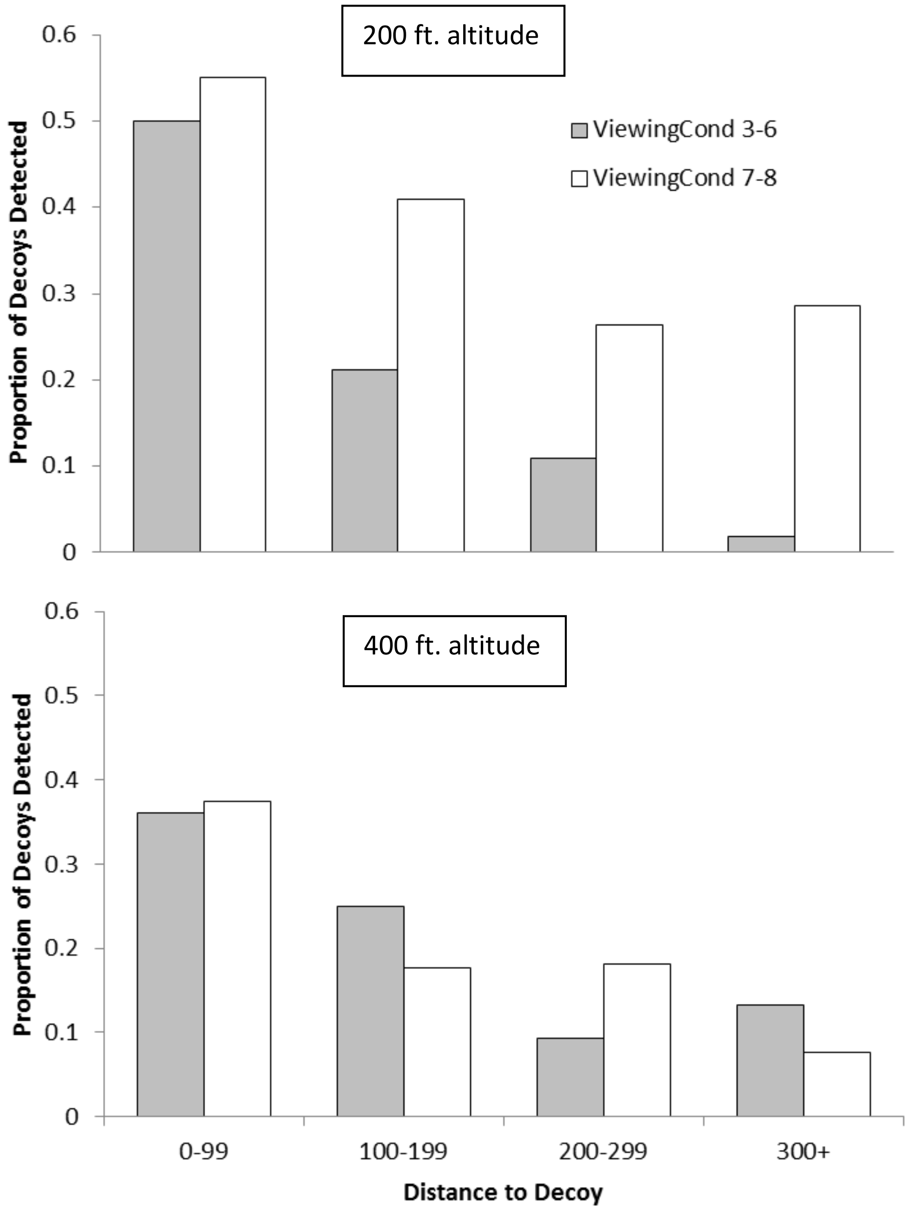

Figure 6. Proportion of decoys detected at 200 ft. altitude (top) and 400 ft. altitude (bottom), by viewing conditions and distance to decoy, for surveys with paired altitude data.

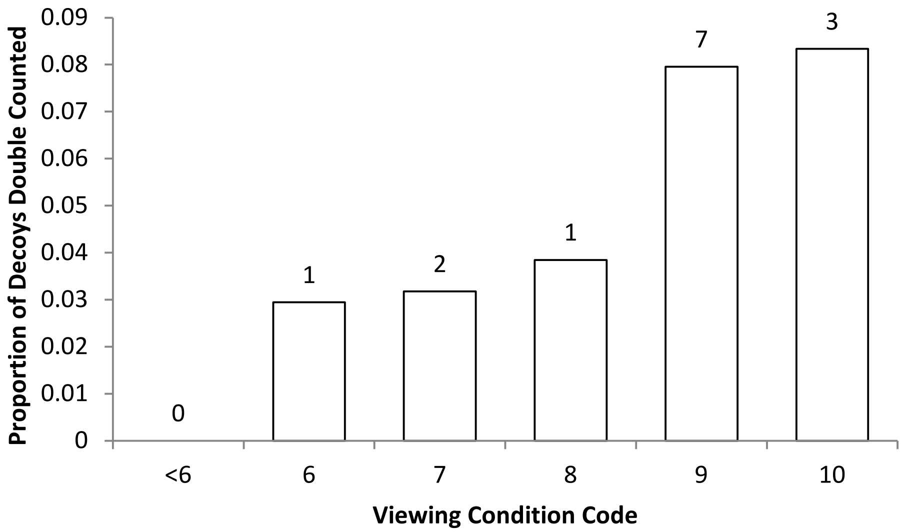

Figure 7. Proportion of decoys that were double counted on all surveys conducted at an altitude of 200 ft., by viewing condition. Number of decoys double counted shown above each bar.

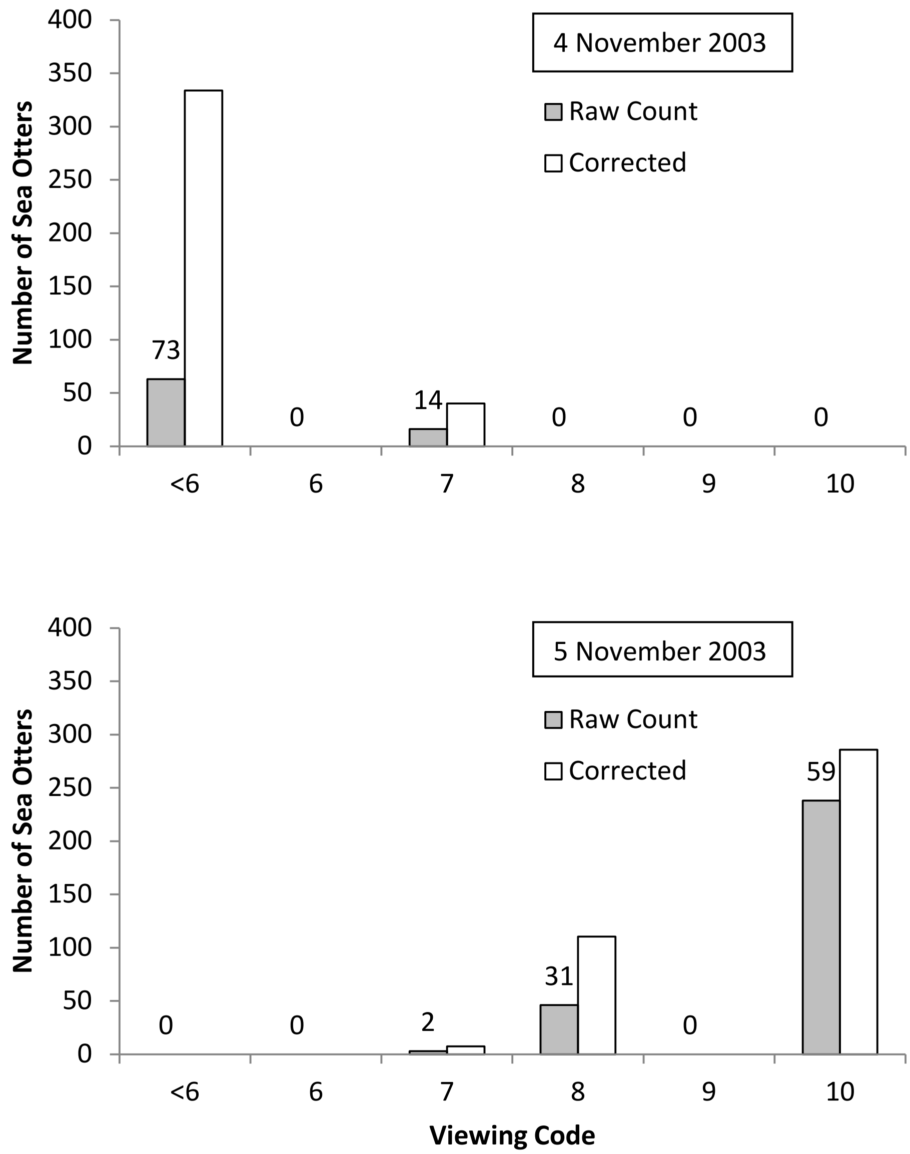

Figure 8. Number of sea otters detected in a survey of northern Monterey Bay on 4 November 2003 (top; grey bars) and abundance estimates based on correction factors in Table 4 (white bars); and similar data from a survey of the same area on 5 November 2003 (bottom). For both surveys, number of minutes spent surveying at a given Viewing Code is shown above the raw count.

APPENDIX A

Standard southern sea otter survey methods (courtesy of USGS, 2014). Aerial surveys are typically initiated only if conditions are "Good" or better.

Census Methods

During each census, the entire mainland range of the sea otter in coastal California is counted by one of two methods: aerial surveys or shore-based counts. The latter method is used in all areas that are accessible by ground-based observers, except in a few regions where otters often move far off shore (such as shallow, sandy embayments) and are therefore difficult to count reliably from the shore. For the majority of the sea otter's range, however, ground surveys are practical, and are considered the more reliable means of censusing. It has been estimated that shore-based observers generally detect about 90-95% of the otters located in a given area (Estes and Jameson 1988). The ground survey area is divided into sections and each section is assigned to a team of observers. Each team consists of two individuals, a primary and secondary observer. The primary observer in every case is an individual with considerable experience counting and observing sea otters. Generally, the secondary observer has less experience than the primary, but in some cases the teams consisted of equally skilled individuals. Occasionally, small areas are counted by a single individual, but this occurs infrequently, and in every instance the individual is highly skilled with many years of experience and intimately familiar with the area to be surveyed. Each team is equipped with a high resolution 50-80X telescope and each member has binoculars (10X).

Shore-based procedures are as follows: the team starts at one end of their assigned section and selects an observation point that provides good viewing of a "viewable area of habitat", which generally consists of 100-300m of coastline and all waters out to approximately 1.5 km from shore. In most cases observers use the same counting locations year after year, for consistency. The observers scan the area with unaided eye and binoculars for otters or objects that are suspected to be sea otters. Large groups and suspicious objects are scanned by the primary observer with the aid of the telescope while the secondary observer continuously scans the area with binoculars for foraging or resting otters missed during the initial scan. After having taken sufficient time (15-30 minutes) to make a thorough count of all otters within this first area of habitat, the observers move down the coast to another location that provides good viewing of the next area of habitat, contiguous with the first area. This process is continued until the entire section is counted.

All sea otter observations are marked as points directly onto field maps (scale 1:6000) that show all major features of the area (including offshore rocks and kelp beds) for reference. These features allow data to be precisely placed on the maps, and reduce the chances of recounting or undercounting when the team moves to the next observation point. In addition to the otter locations, associated data recorded directly onto the maps include the following: number of independent otters, number and relative age of pups (pups are classed as either small or large depending primarily on the presence or absence of the natal pelage, but sometimes on relative size or behavior), behavior (resting, foraging, or "other"), group size, and micro-habitat type (open water, kelp, or hauled out). Time and general counting conditions are also recorded. Viewing conditions are rated from excellent to poor (coded 4 to 0). Teams are instructed to not begin surveying if conditions are "poor", or to abort the survey if conditions deteriorate to "poor". Because each team is headed by an experienced observer, it is left to that individual to determine if conditions are suitable for counting.

For those portions of the range where ground counting is impossible or impractical, aerial surveys are conducted using a Partenavia PN68 "Observer" fixed-wing plane. The plane carries three observers and a pilot, and flies at an air speed of approximately 167 kilometers per hour (90 knots) at an altitude of approximately 60 meters (200 feet). Pilot and data recorder/observer occupy front seats; principal observers occupy middle seats viewing out through bubble-type viewing windows. The flight path is a predetermined track line constructed using GIS software and loaded into a GPS for the pilot to follow. Transects are oriented parallel to the coastline, with the nearshore transect line centered approximately 300 meters from shore. At survey section boundaries, the plane turns offshore, reverses direction and flies parallel to the first transect, continuing to follow pre-established tracklines on the pilot's GPS. The distance moved offshore is dependent of habitat type: transects over kelp habitat are spaced 600 meters apart (300 meter viewing area to each side of the plane), while transects over open water are spaced 800 meters apart (400 meter viewing area to each side of the plane). The survey transects are established to cover all waters within 60m of depth (30 fathoms). In some areas, such as Pismo Beach, this includes over 10 transects spaced at 800 meters. The survey track line and waypoints for otter sightings are recorded on a separate handheld GPS unit. Additional information on each sea otter sighting is recorded onto data sheets which are later transferred to a spreadsheet. The data fields include group size (with adults and pups tallied separately), observer, and viewing conditions (ranked on a 1-10 scale).