A Double-Survey Estimate for Sighting Probability of Sea Otters in California

James A. Estes; Ronald J. Jameson

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A DOUBLE-SURVEY ESTIMATE FOR SIGHTING PROBABILITY OF SEA OTTERS IN CALIFORNIA

JAMES A. ESTES, U.S. Fish and Wildlife Service, Institute of Marine Sciences, University of California, Santa Cruz, CA 95064
RONALD J. JAMESON, U.S. Fish and Wildlife Service, P.O. Box 70, San Simeon, CA 93452

Abstract: We developed an estimator for the probability of sighting sea otters (*Enhydra lutris*) by shore-based counters, based on simultaneous double-surveys. We then estimated probability of sighting sea otters in California and evaluated the estimator's principal assumptions. The overall probability of sighting sea otters on 5 replicated double-surveys at each of 6 study areas was 0.945. Estimated probability of sighting did not vary ($P > 0.05$) among study areas or over time and was not correlated ($P > 0.05$) with distance of otters from observers. Probability of sighting was affected ($P < 0.05$) by sea otter activity and group size. Activity-specific probabilities of sighting were: resting = 0.990, foraging = 0.769, and other = 0.885. All animals missed by 1 observer team were in groups of ≤ 2 otters, whereas 52% of the animals sighted during the study were in groups ≥ 3. Observer teams may have varied slightly in sighting ability, but this variation did not substantially affect population estimates.

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The sea otter population in California ranges between Santa Cruz (36°56′N) and Shell Beach (35°09′N) (U.S. Fish and Wildl. Serv. 1984). The population probably contained <100 individuals in the early 1900's (Ralls et al. 1983), but due to legal protection, it gradually increased in size and range (U.S. Fish and Wildl. Serv. 1984). Few survey data are available from before the mid-1960's, and various methods were used through the 1970's, making trends in the population difficult to assess. In 1982, the California Department of Fish and Game and the U.S. Fish and Wildlife Service began a collaborative program to use a single method to survey otters, thereby providing a better means of assessing future population trends. Currently, sea otters are counted from shore throughout approximately 70% of their range in California, with the remaining area counted from aircraft.

Estimates of otter population size are important to evaluate past survey data, interpret consequences of incidental mortality from net entanglement, and determine how many animals might be removed to establish another colony in California. We first developed an estimator for the probability of sighting sea otters by shore-based observers. We then estimated this probability in a field study, and evaluated its consistency over space and time. Finally, we examined the estimator's principal assumption, that all animals in the population are equally sightable, by analyzing the effects of activity, group size, and distance from observer on the probability of sighting. There are few reports of double-survey methods in the literature on wildlife population assessment. We are aware only of Caughley's (1974) use of double-surveys to estimate bias in aerial counts of African elephants (*Loxodonta africana*). Although our paper deals specifically with sea otters in California, the problems, methods, and analyses have broader application in wildlife ecology.

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THE PROBLEM

Abundance is perhaps the most fundamental and often used parameter in biological population analysis (Seber 1982). Estimates of population abundance are, however, notoriously uncertain because they often are imprecise and/or biased to an unknown extent. Precision is easy to measure by adequate replication but imprecise estimates often are difficult to improve. Bias usually is difficult to measure, but once known, is easily incorporated into population estimates.

THE MODEL

Consider the situation where 2 observers simultaneously, but independently, count sea otters in a small area. Let A = the number of otters seen by both observers, B_1 = the number seen by observer 1 only, B_2 = the number seen by observer 2 only, and C = the number missed by both observers. Assume that all animals are equally observable. If p_i is the probability of sighting by the ith observer, then the joint probability function of A, B_1, B_2, and C is given by:

$$\frac{N!}{A!B_1!B_2!C!}(p_1p_2)^A(p_1q_2)^{B_1}(p_2q_1)^{B_2}(q_1q_2)^C,$$

where N is the number of individuals in the viewing area. As noted by Magnusson et al. (1978), the above is the model for the Petersen capture-recapture experiment, and the maximum-likelihood estimates are approximately: $\hat{N} = (A + B_1)(A + B_2)/A = n_1n_2/A$, and $\hat{p}_i = n_i/N$, where n_i = number seen by the ith group. Thus $\hat{p}_1 = A/n_2$ and $\hat{p}_2 = A/n_1$.

When both observers are equally skilled, so that $p_1 = p_2$, the number of animals observed by a single observer from a population of N individuals is distributed as a binomial with mean = Np and variance = Npq (Hoel 1971). Further, p^2 = the probability of an otter being sighted by both observers, $2pq$ = the probability of an otter being sighted by only 1 or the other observer, and q^2 = the probability of an otter being missed by both observers. Thus $p^2 + 2pq + q^2 = 1$ and $N = Np^2 + 2Npq + Nq^2$. From the earlier definitions:

$$A = Np^2, \qquad (1)$$

$B = 2Npq$, and $C = Nq^2$, when $B = B_1 + B_2$.

We wish to estimate p in terms of the measurable parameters A and B. Because $q = 1 - p$, $q^2 = 1 - 2p + p^2$, and

$$Nq^2 = N - 2Np + Np^2, \qquad (2)$$

by rearranging and combining terms,

$$p = (2Np^2 + 2Npq)/2N. \qquad (3)$$

Equations (1), (2), and (3) have solutions $\hat{N} = A/p^2$ and $\hat{p} = 2A/(2A + B)$.

METHODS AND STUDY SITES

Sea otters in California have been surveyed from shore with teams of 2 experienced counters since 1982. Team members consult to confirm sightings; thus, presumably reducing counting errors and the number of missed animals. The range of the population is divided into 4 or 5 segments, each of which may be counted in several days. Each team, aided by binoculars and spotting scopes, is responsible for counting 1 segment. Observers travel along the coast and count sea otters from favorable vantage points. The size and boundaries of each viewing area are chosen at the observers' discretion.

Our study used experienced observers and similar counting methods, except viewing areas were counted simultaneously by 2 teams of 2 individuals. Both teams counted from the same location, but were separated from each other by 5–10 m. Each team recorded on a map the location, group size, and activity of all observed sea otters. The maps were compared immediately to determine which animals were observed by both teams or by only 1 team. The teams did not distract each other, and they seldom disagreed on whether an animal was observed by 1 or both teams.

Counts were replicated 5 times (on different days) at each of 6 study sites. Each study site contained 3–4 contiguous viewing areas of similar sizes and boundaries to those used in the range-wide surveys. Study sites differed in the extent and species composition of kelp (*Macrocystis pyrifera* and *Nereocystis leutkeana*) canopy; height of vantage points above the ocean; and coastal orientation to the direction of prevailing winds, sea, and sun. They were selected in an effort to include the normal range of conditions and habitats encountered during range-wide population surveys. The 3 northern-most sites were counted by 1 set of observers and the 3 southern-most sites were counted by another set of observers. More area could not be sampled in the daily time window judged adequate for viewing (i.e., about 0830 to 1230 hr; Estes et al. 1986). Each day the observers decided if viewing conditions were suitable for counting otters. As with the range-wide surveys, periods of strong wind, high seas, and poor visibility were avoided.

To evaluate the potential effect of increased sighting probability as observers gained familiarity with the study areas, we calculated probabilities of sighting for each time replicate. Probabilities were transformed to arcsine square root percent values for linear correlation analyses with replicate numbers. The northern and southern 3 study sites were analyzed separately because different teams of observers worked in the 2 areas, often on different days.

We analyzed sighting data by individuals and by groups. Groups of sea otters were loosely defined as those individuals within several body lengths of their nearest neighbors. All group sizes (N = 1–12 individuals) were treated equally in the analyses by groups. Females with pups were treated as separate individuals, except in the group size analyses they were considered as 1. Solitary individuals were treated as groups of size 1. Distances of all observed groups from the observers were measured with a digitizer from plotted locations to the nearest 25 m.

We independently measured the offshore distribution of sea otters by flying transects from shore seaward to about 9,000 m offshore. The survey aircraft was flown at an altitude of 65–85 m and a velocity of 50 m/second. Two observers, 1 seated on each side of the aircraft, called out the number of otters seen as they appeared adjacent to the aircraft, and a third person recorded these data at intervals determined from a timer started when the aircraft passed over the shoreline. Forty transects were flown throughout the areas counted from shore during range-wide population surveys. Eighteen of the transects were flown in double-survey study sites, 3 each in each of the 6 sites. Eighteen transects were flown at arbitrarily chosen points along the coast where we knew sea otters occurred but had no prior knowledge of their distribution offshore. The remaining 4 transects were flown between Point Sierra Nevada (35°44'N) and Ragged Point (35°46'N) where juvenile sea otters frequently occur several km offshore. All transects were flown during near ideal viewing conditions (i.e., winds generally calm, sea surface glassy or with a light wind-riffle). These viewing conditions probably made otters easier to see in open water offshore than in kelp beds near shore.

Our sighting probability estimator assumes that all observer teams are equally competent. We evaluated this assumption in the following way. First, we separated the data by the northern and southern groups of study sites. From the total number of animals seen by 1 team only, we assigned misses to appropriate teams. Although substitute observers were used on several occasions, ≥1 of the primary observers was always present and thus the teams were always definable. Following Magnusson et al. (1978), we estimated $\hat{p}_1 = \hat{p}_2$. We tested the null hypothesis p_1 and p_2 (where p_i = probability of sighting by the ith team) by assuming that B_i takes a Poisson distribution with mean $= (B_1 + B_2)/2$, and then calculating the probability that $B_1 < B_i < B_2$. Population estimates ($\hat{N}$) were derived by 2 methods. In the first, $\hat{N}$ = number observed/0.945. Because 0.945 was the overall probability of sighting, this estimate would be used if each team were equally competent. In the second method, $\hat{N} = (A + B_1 + 1)(A + B_2 + 1)/(A + 1)$, and would be used if the teams were not equally competent (Magnusson et al. 1978).

RESULTS

Variation Among Observer Teams

In the northern and southern areas A = 329 and 367, B_1 = 12 and 14, and B_2 = 29 and 26, respectively. The Poisson test indicated marginal (i.e., $0.9 < P < 0.95$) to insignificant differences in sighting abilities by each of the 2 teams (northern area, P = 0.91; southern area, P = 0.74).

The effect of observer team variation on sea otter population estimates was small. Assuming

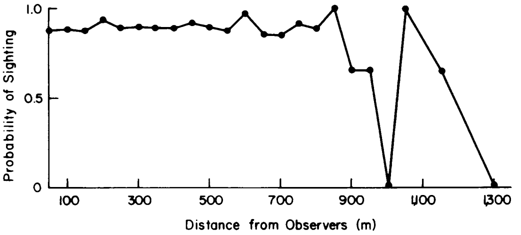

Fig. 1. Probability of sighting sea otters versus distance from observers in California, 1985.

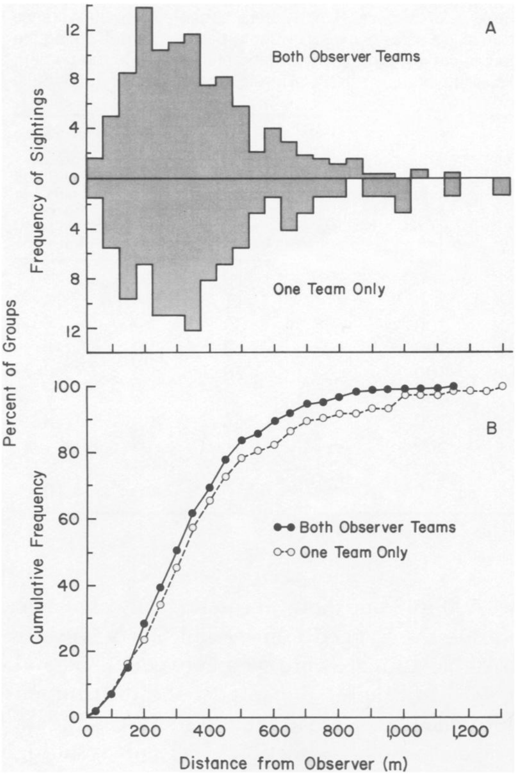

Fig. 2. Frequency distribution (a) and cumulative frequency distribution (b) of sea otter sightings (considered by groups) made during double-survey experiments in central California, 1985, as a function of distance from observers, for animals seen by both observer teams and by 1 team only.

equal team competence, estimates of the number of sea otters inhabiting the northern and southern study areas, respectively, made from data gathered by each team summed over the 5 replicate counting days, were 375 versus 361 and 416 versus 403. Assuming unequal team competence, using the method of Magnusson et al. (1978), estimates for these respective areas were 367 and 408 otters. These results indicate that variation among observer teams in sighting ability was insufficient to substantially affect population estimates. Estimates based on the data obtained by different teams varied by 3–4% for the northern and southern study areas.

Probability of Sighting

During the study 402 groups, consisting of 905 individual sea otters, were seen and recorded by study site, viewing area, and sample replicate. Probability of sighting otters did not increase ($P > 0.05$) as observers gained familiarity with either the northern ($r = 0.05$) or southern ($r = 0.11$) study areas. Probability of sighting otters among the 6 study sites was also similar ($F = 1.208$; 5,24 df; $P = 0.34$).

Effects of Distance

The probability of sighting otters from shore did not vary over observation distances of 50–850 m (Fig. 1). The slope of the linear regression did not differ from zero ($F = 0.640$; 1,21 df; $P > 0.10$). At distances >900 m, sighting probability fluctuated greatly because of the small numbers of observations. Of the 402 group observations, 329 were made by both teams and 73 by only 1 team. The frequency of group observations versus distance from observers were similar for animals seen by both observer teams and animals seen by 1 observer team (Fig. 2) ($\chi^2 = 12.72$, 24 df, $P = 0.97$). About 50% of the observations were ≤300 m, and about 90% within 600 m of the observers. Collectively, these data indicate that few otters occurred at distances from shore beyond the observers' viewing ranges and that distance from observer had no significant effect on probability of sighting within the range that most animals occurred.

The onshore/offshore distribution of sea otters observed during the double-survey experiment and in the aerial transects differed ($\chi^2 = 45.92$, 16 df, $P < 0.01$). However, most of the population occurred within viewing range of shore-based observers (Table 1). Only 12 of 242 sea otters seen in the aerial transects were >1,300 m from shore, the maximum estimated distance from an observer that an otter was seen during the double-survey experiment. Seven of these 12 animals were counted on 1 transect (at Ragged Point on 3 June 1986) and had been observed from shore several days earlier (by RJJ on 30 May 1986 at a distance estimated at 2–3 km). Even so, the occurrence of sea otters at such great distances from shore probably is unusual in California as only 2 animals were seen

Table 1. Numbers of sea otters observed versus distance from shore as determined by shore-based counters during the double-survey experiment and in aerial transects run perpendicular to shore, central California, May and June 1985–86.

		No. counted from air		
Distance from shore (m)	No. counted from shore	Double-survey sites (n = 18 transects)	Other sites (n = 18 transects)	Between Point Sierra Nevada and Ragged Point (n = 4 transects)
0–100	250	19	25	8
200	274	1	15	3
300	198	38	19	
400	104	19	9	
500	64	20	3	6
600	7	3	6	1
700	4	2		2
800	2	1	5	
900			5	
≥1,000	2	6	16	10

>1,600 m from shore in the 36 transects flown outside the Ragged Point/Point Sierra Nevada area. No animals were seen between 3,350 and 9,000 m offshore. We suspect the distribution difference between aerial and shore-based data is a methodological artifact, perhaps resulting from the fact that exact locations of otters far beyond the kelp beds are difficult to determine from shore.

Effects of Activity and Group Size

Counts were made during time periods (0830–1230 hr) when a maximum proportion of the population was resting (Estes et al. 1986). Resting, foraging, and other animals comprised 54 and 74.8%, 14.5 and 28.2%, and 10.7 and 17.8% of the respective groups and individuals seen. Five and 1.9% (for groups and individuals, respectively) of the observations of resting animals were seen by 1 team only. In contrast, 37.8 and 37.5% (for groups and individuals, respectively) of the observations of foraging animals were made by 1 team only. Among animals in the other activity category (which consisted mainly of grooming, swimming, and interacting), 19.7 and 20.5% (for groups and individuals, respectively) were seen by 1 team only. The proportion of observations made only by 1 team differed among activity categories (for individuals, χ^2 = 39.68; for groups, χ^2 = 32.73; 2 df and $P < 0.001$ for both). Thus, sighting probability varied among activity categories: resting, $\hat{p}$ = 0.990; foraging, $\hat{p}$ = 0.769; and other, $\hat{p}$ = 0.885. The probability of sighting for the combined activity categories was 0.945.

The frequency distribution of group sizes also varied ($P < 0.01$) by activity (Fig. 3). About 80% of the resting animals seen occurred in groups of 2–12 individuals. In contrast, foraging animals nearly always were alone. Only about 2% of foraging animals occurred in groups of 2 individuals, and none were seen in larger groups. The distribution of group sizes among otters categorized as other was intermediate between foraging and resting, but most similar to that of foraging animals. Twenty-eight percent of these individuals were in groups of ≤3.

Although confounded with activity, group size appears to affect probability of sighting (Fig. 3). Only 6 (11%) of otters seen by 1 team only were in groups, and none of these groups contained >2 animals. In contrast, 474 (69%) of the animals seen by both teams were in groups of ≥2 animals.

DISCUSSION

Numerous methods have been used to estimate abundance of sea otter populations. Most studies (Kenyon 1969, Wild and Ames 1974, Estes 1977) reported that animals probably were missed during surveys and thus included corrections for the suspected biases, but estimates of bias were not rigorously evaluated. Geibel and Miller (1984) attempted to estimate bias in sea otter surveys in California by using a mark-recapture estimate and counting sea otters in small areas simultaneously from shore and from aircraft. However, the necessary assumptions of any mark-recapture estimate (Seber 1982) were not evaluated.

The estimate of bias in shore-based counts of sea otters, derived and used herein, is based on the binomial distribution; thus, its validity depends on how well it satisfies the conditions of the binomial. These conditions are (1) the population under consideration consists of discrete elements, in this case sea otters along some arbitrary length of coast; (2) each element is associated with 2 mutually exclusive and exhaustive events, in this case sea otters are either seen or not seen by an observer team; and, given these conditions, (3) the number of animals seen are distributed as a binomial if each animal has an equal probability of being seen at the onset of viewing an area. Conditions 1 and 2 apply, by definition. However, condition 3 may not.

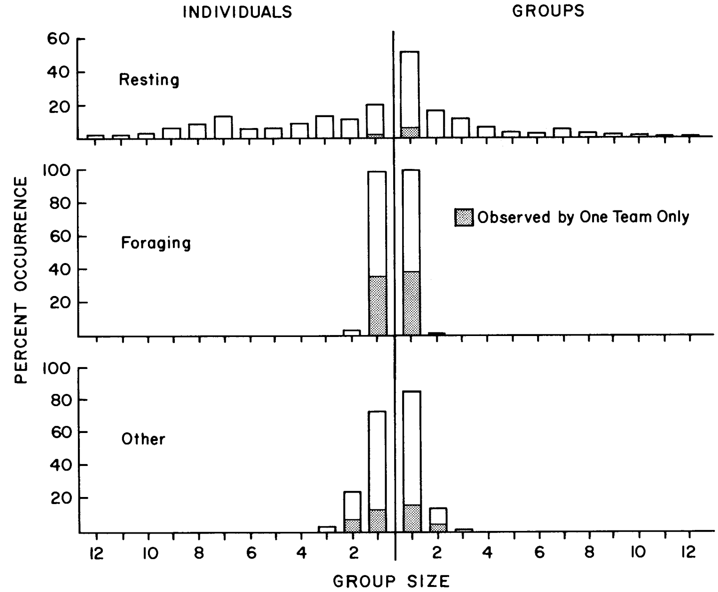

Fig. 3. Distributions of group size by activity for sea otters observed during double-survey experiments in central California, 1985.

We have evaluated the effects of several factors on the probability of seeing sea otters. Activity and group size have important influences on probability of sighting, although these effects are confounded. Thus, estimates of total population size must be made with caution because they carry the assumption that frequency distributions of activity and group size are similar to those that occurred during this study. Highest counts will be obtained when most of the animals are resting in groups. During daylight hours, maximum numbers of resting animals occur between 0830 and 1230 hours (Estes et al. 1986). Conditions influencing group size are less certain. Conversely, the probability of seeing an otter does not appear to be affected by the animal's distance from the observer (and implicitly, distance from shore). Some sea otters may be missed because they are located far from shore but the error appears small in comparison with the probability of not seeing an animal that is within viewing range. Similarly, our results show no effect of time or area on the probability of seeing sea otters. This suggests that our bias estimate is applicable to the California population and that changes in group size and activity over time (among days when weather is suitable for counting) may be small. As a further cautionary measure, however, we advise observers to record activity and group size during future shore-based surveys. If necessary, stratified population estimates could be made based on the distributions of group size and activity recorded during any given survey. Finally, there is no evidence that observer variation in counting ability is important.

Although we have shown that certain factors influence the probability of seeing sea otters, the probability of being seen over time may vary among individuals. Our approach assumes that individuals have equal sighting probabilities, at least within certain categories (e.g., activities or group size). Even though most population estimators are based on similar assumptions they are seldom tested. If the assumptions are not true, estimated population size could be biased. Of course, the only definitive test of any population estimator is comparison to a population of known size. Unfortunately, this is rarely possible.

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EFFECT OF GRAZING BY CANADA GEESE ON THE WINTER GROWTH OF RYE

MICHAEL R. CONOVER, Department of Plant Pathology and Ecology, Connecticut Agricultural Experiment Station, P.O. Box 1106, New Haven, CT 06504

Abstract: Canada geese (*Branta canadensis*) often graze during the fall and winter in fields of rye that are planted as cover crops to reduce soil erosion and improve soil qualities. I used exclosures to document whether grazing by Canada geese had an adverse impact on rye. In 11 Connecticut fields frequented by geese, the leaf biomass of rye by mid-winter was 535% higher inside exclosures than in grazed portions of the same fields. By spring, rye leaf biomass was 177% higher inside than outside of the exclosures. In another experiment, rye was clipped to simulate grazing by Canada geese to determine whether leaf loss slowed the rye plants' growth during winter and spring. Plants that suffered leaf loss had lower total biomass, leaf and stem biomass, and root biomass than uninjured plants regardless of time during fall and winter when the leaves were clipped. Plants receiving multiple clippings grew slower than those receiving only a single clipping.

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Canada geese often graze during the fall and winter in grain fields. The damage they cause by grazing and trampling plants can be substantial (Hunt 1984). The damage, however, may be less than initial appearances suggest because of the growing plants' ability to compensate for damage. Pirnie (1954) was unable to document any loss in wheat yields caused by grazing by Canada geese on dormant wheat plants in Michigan, and Allen et al. (1985) reported losses ≤13% in Maryland. Clark and Jarvis (1978) observed no difference in seed production between ryegrass plots which had been grazed by Canada geese and those which had not. In contrast, Kahl and Samson (1984) allowed captive Canada geese to graze on wheat, and in some cases heavy grazing resulted in shorter plants and lower grain yields.

Tests with other goose species have not demonstrated that grazing by geese has an adverse impact on the plants. Kear (1963*b*) noted that grazing on winter oats and winter wheat by a captive flock of graylag (*Anser anser*) and pink-footed geese (*A. brachyrhynchus*) had no effect on grain or straw yields at harvest time. Clipping to simulate goose damage on winter wheat and silage grass also had no effect on harvest yields (Kear 1963*b*). Cargill and Jefferies (1984) showed that grazing by lesser snow geese (*A. caerulescens caerulescens*) in a sub-arctic salt marsh increased primary production of a stoloniferous grass (*Puccinellia phryganodes*) and a sedge (*Carex subspathacea*), possibly by accelerating nitrogen cycling in the marsh.

In many parts of North America rye is grown in fields during winter as a cover crop for soil