National Park Service, Southeast Alaska Inventory and Monitoring Network

Monitoring Population Status of Sea Otters (*Enhydra lutris*) in Glacier Bay National Park and Preserve, Alaska—Options and Considerations

Open–File Report 2015–1119

U.S. Department of the Interior
U.S. Geological Survey

Cover: Sea otters resting near Boulder Island during an aerial survey in Glacier Bay National Park and Preserve (Photograph by James L. Bodkin, U.S. Geological Survey Scientist Emeritus, May 4, 2003).

Inset: Sea otter in kelp. Photograph by Benjamin Weitzman, U.S. Geological Survey.

Monitoring Population Status of Sea Otters (*Enhydra lutris*) in Glacier Bay National Park and Preserve, Alaska—Options and Considerations

By G.G. Esslinger, D. Esler, S. Howlin, and L.A. Starcevich

National Park Service, Southeast Alaska Inventory and Monitoring Network

Open-File Report 2015-1119

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2015

Suggested citation:
Esslinger, G.G., Esler, D., Howlin, S., and Starcevich, L.A., 2015, Monitoring population status of sea otters (*Enhydra lutris*) in Glacier Bay National Park and Preserve, Alaska—Options and considerations: U.S. Geological Survey Open-File Report 2015-1119, 42 p., http://dx.doi.org/10.3133/ofr20151119.

ISSN 2331-1258 (online)

Contents

Figures

Tables

Conversion Factors

International System of Units to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)

Datum

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27)].

Monitoring Population Status of Sea Otters (*Enhydra lutris*) in Glacier Bay National Park and Preserve, Alaska—Options and Considerations

By G.G. Esslinger[1], D. Esler[1], S. Howlin[2], and L.A. Starcevich[2]

Abstract

After many decades of absence from southeast Alaska, sea otters (*Enhydra lutris*) are recolonizing parts of their former range, including Glacier Bay, Alaska. Sea otters are well known for structuring nearshore ecosystems and causing community-level changes such as increases in kelp abundance and changes in the size and number of other consumers. Monitoring population status of sea otters in Glacier Bay will help park researchers and managers understand and interpret sea otter-induced ecosystem changes relative to other sources of variation, including potential human-induced impacts such as ocean acidification, vessel disturbance, and oil spills. This report was prepared for the National Park Service (NPS), Southeast Alaska Inventory and Monitoring Network following a request for evaluation of options for monitoring sea otter population status in Glacier Bay National Park and Preserve. To meet this request, we provide a detailed consideration of the primary method of assessment of abundance and distribution, aerial surveys, including analyses of power to detect interannual trends and designs to reduce variation around annual abundance estimates. We also describe two alternate techniques for evaluating sea otter population status—(1) quantifying sea otter diets and energy intake rates, and (2) detecting change in ages at death. In addition, we provide a brief section on directed research to identify studies that would further our understanding of sea otter population dynamics and effects on the Glacier Bay ecosystem, and provide context for interpreting results of monitoring activities.

----

[1]U.S. Geological Survey.
[2]Western Ecosystems Technology Inc., Cheyenne, Wyoming.

Introduction

Sea otters (*Enhydra lutris*) were extirpated from southeast Alaska by commercial fur hunters prior to 1911 (Kenyon, 1969). During the many decades that sea otters were absent from the ecosystem, invertebrate prey such as clams, crabs, urchins, and abalone became abundant to the benefit of several subsistence, commercial, and personal-use fisheries. In the late 1960s, the State of Alaska translocated 403 sea otters from other parts of Alaska to 6 sites along the outer coast of southeast Alaska (Burris and McKnight, 1973). Fueled by abundant prey resources, the translocated sea otter populations grew at about 18 percent annually through the early 1990s (Bodkin and others, 1999). This recovering sea otter population created hunting opportunities for Alaska Natives and conflicts with local shellfisheries (Pitcher, 1989; Esslinger and Bodkin, 2009). By 1993, sea otters had expanded their range to the mouth of Glacier Bay and by 1995 began to maintain a consistent presence within the bay proper, which is part of Glacier Bay National Park and Preserve.

In 1993, the U.S. Geological Survey (USGS) initiated a long-term study to evaluate effects of sea otters on invertebrate prey communities in Glacier Bay. The field work for this study is now completed, and data analyses are ongoing with publications in preparation. In short, study findings thus far demonstrate sea otter-induced changes in the nearshore community and suggest further changes will occur as sea otters continue to expand their range and increase in abundance within Glacier Bay. This report was prepared for the National Park Service (NPS), Southeast Alaska Inventory and Monitoring Network following a request for evaluation of options for monitoring of sea otter population status in Glacier Bay National Park and Preserve. To meet this request, we have prepared three chapters, which outline options for quantifying (1) sea otter abundance and distribution, (2) sea otter foraging, and (3) age distributions. In addition, we provide a brief section on directed research to identify studies that would further our understanding of sea otter population dynamics and effects on the Glacier Bay ecosystem, and provide context for interpreting results of monitoring activities.

Chapter 1. Estimating Sea Otter Abundance and Distribution Using Aerial Surveys

To evaluate effects of sea otters on invertebrate prey in Glacier Bay, the USGS conducted aerial surveys to document sea otter distribution and abundance (Bodkin and others, 2007a). A report summarizing results of the aerial survey work through 2012 was prepared to provide current information on sea otter abundance, distribution, and population growth in Glacier Bay (Esslinger and others, 2013). Continuation of these surveys, and the frequency at which they are implemented, depend on NPS resources and objectives, sea otter population trends, and the power and resolution of the survey data to document changes in abundance. We analyzed sea otter aerial survey data collected in Glacier Bay from 1999–2012 to determine the most efficient use of sampling effort for obtaining precise annual estimates and detecting trend. In this chapter, we present results of the analysis and present options for development of a plan for the continued monitoring of sea otter abundance and distribution in Glacier Bay using aerial surveys.

Methods

Aerial Surveys

Between 1999 and 2012, we used an aerial survey method specifically designed for estimating sea otter abundance (Bodkin and Udevitz, 1999) in Glacier Bay. Prior to each survey, we classified potential sea otter habitat within Glacier Bay as being either high or low density strata based on a combination of water depth and distance from shore (fig. 1-1). For each survey year, we determined the northern boundaries of the survey area based on knowledge of sea otter distribution from other surveys, anecdotal observations, and reconnaissance flights. We defined sea otter distribution as the area that contained groups of sea otters, excluding observations of aberrant individuals. We spaced transects systematically within each strata according to expected sea otter densities and time available for conducting the survey and no closer than 1,200 m to minimize the probability of double counting sea otters that moved during the survey (fig. 1-1). To conduct each survey, a pilot flew a high-wing aircraft with two seats in tandem at an altitude of 91 m, while an observer scanned from one side for sea otters within a 400 m wide strip defined by calibrated marks on the wing struts (fig. 1-2). Because sea otters can be difficult to sight in areas with kelp and are usually not visible when diving underwater to gather prey, we conducted intensive search units (ISUs) periodically throughout the survey area to estimate the proportion of sea otters being detected on transect. We used the detection probability to adjust the abundance estimate of each survey. We photographed and counted large groups (>20 otters) in their entirety and thus did not adjust these groups for detection. Each annual abundance estimate is a mean of three to five replicate surveys over the same area (table 1-1). Each replicate survey was a subset of transects randomly selected without replacement from a pool of transect sets that covered the entire survey area (fig. 1-1).

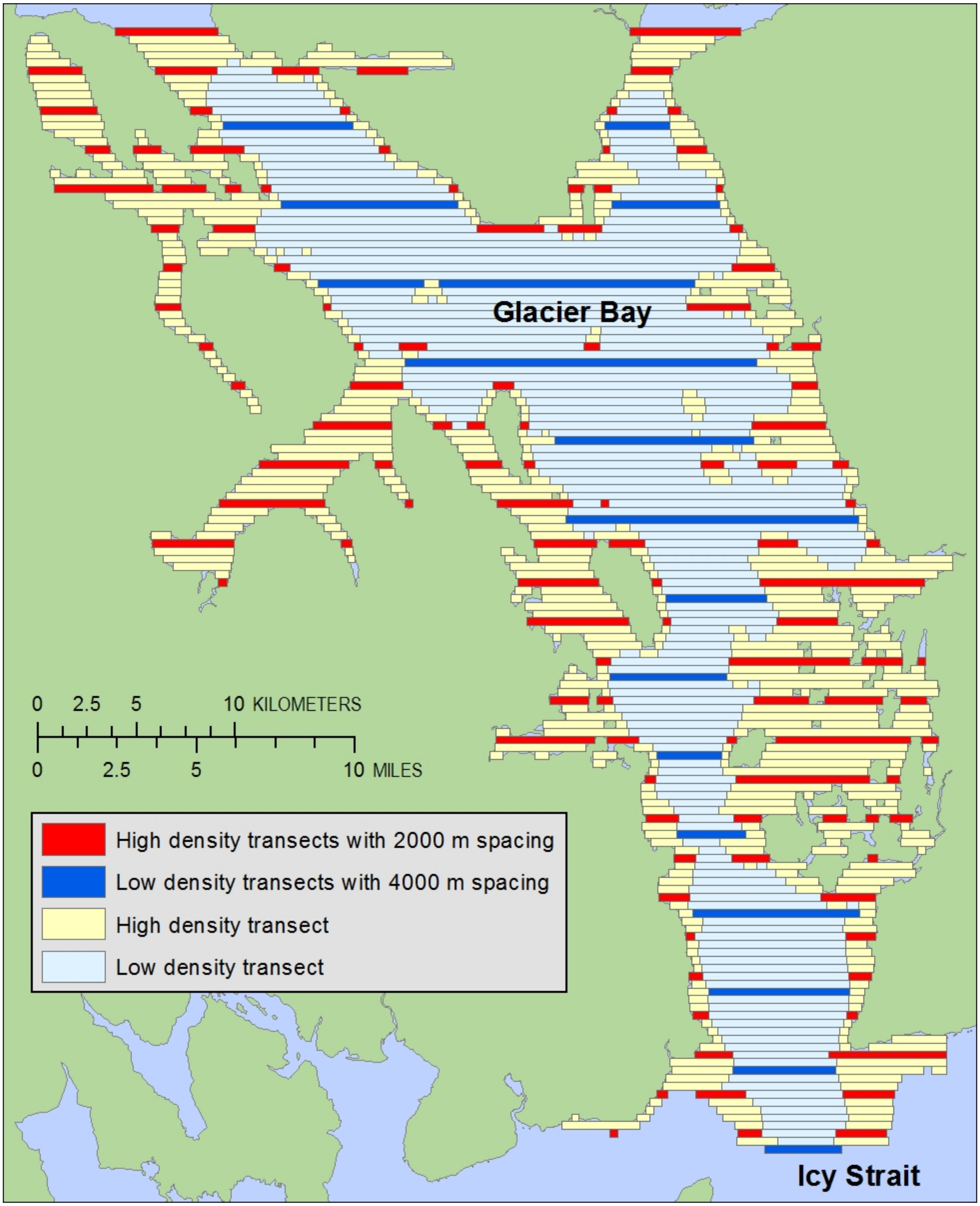


Figure 1-1. Map showing an example of a sea otter aerial survey designed for Glacier Bay, Alaska, and flown in May 2012. This set of transects represents a single replicate and was randomly selected from a pool of evenly spaced transect sets that covered the entire survey area.

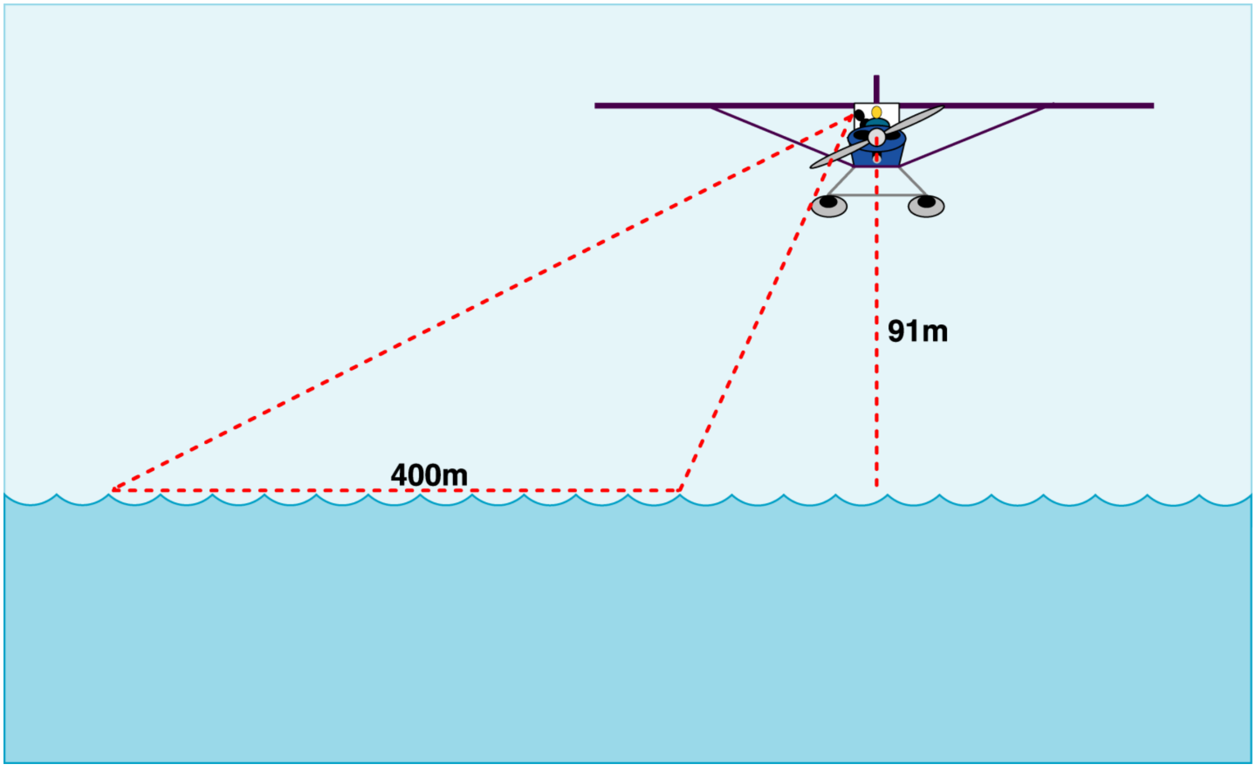


Figure 1-2. Depiction of a high-wing aircraft with two seats in tandem used in aerial surveys to estimate sea otter abundance in Glacier Bay, Alaska, 1999–2012. The observer counts sea otters within a 400 meter (m) wide strip delineated by calibrated marks on the wing struts.

Table 1-1. Sea otter abundance estimates in Glacier Bay, Alaska, 1999–2012.

[km^2, square kilometer; m, meter]

Survey year	Transect spacing		Stratum area (km^2)		Replicate No.	Number of transects	Abundance estimate	Standard error (SE)	Proportional standard error (SE)
	High density	Low Density	High density	Low density					
1999	1,200	2,400	272	274	1	163	135	99	0.73
					2	154	357	155	0.43
					3	154	367	161	0.44
					4	159	678	228	0.34
2000	1,200	2,400	272	278	1	151	698	294	0.42
					2	157	680	255	0.37
					3	158	559	202	0.36
					4	152	279	106	0.38
2001	1,200	2,400	272	278	1	155	1,477	600	0.41
					2	157	1,237	568	0.46
					3	146	835	347	0.42
					4	157	1,403	537	0.38
2002	1,200	2,400	272	278	1	149	1,555	368	0.24
					2	150	1,633	502	0.31
					3	152	1,008	272	0.27
					4	131	1,519	532	0.35
					5	140	617	203	0.33
2003	1,600	3,200	272	278	1	119	1,144	385	0.34
					2	114	943	337	0.36
					3	114	1,328	474	0.36
					4	127	3,229	1,183	0.37
					5	122	2,687	1,454	0.54
2004	1,600	3,200	272	278	1	128	1,959	771	0.39
					2	92	2,231	890	0.40
					3	97	4,058	1,626	0.40
					4	100	1,277	312	0.24
2006	1,600	3,200	229	251	1	92	3,117	1,141	0.37
					2	93	3,535	1,348	0.38
					3	95	2,633	767	0.29
					4	85	1,854	504	0.27
2012	2,000	4,000	336	512	1	109	6,765	1,405	0.21
					2	117	12,960	3,046	0.24
					3	121	5,800	1,251	0.22

Simulations

We evaluated data collected in 1999–2004, 2006, and 2012 to assess efficiency of the sampling design. Specifically, the number of replicates within a year and the number of transects within each replicate were evaluated in a simulation to determine the most efficient use of sampling effort within a year. Additionally, replicate estimates of abundance were used in a trend analysis to examine the power to detect trend as a function of the number of replicate surveys.

Note that the efficacy of intensive searches to estimate detectability was not evaluated in this simulation. The searches contribute to the replicate-level estimates by adjusting small groups for undercounts. However, the methodology of detection probability adjustment was not the focus of this analysis and therefore not evaluated as part of this simulation exercise.

Assessing Effort Within a Year

Effort within a year affects precision and accuracy of the estimate of abundance for a given year. A Monte Carlo simulation was used to assess influences of the number of transects and survey replicates on the standard error (SE) of the estimate of sea otter abundance in Glacier Bay. Only 2012 data were used in the simulation because it reflected the updated sampling frame that extended into more recently occupied areas in the northern part of Glacier Bay.

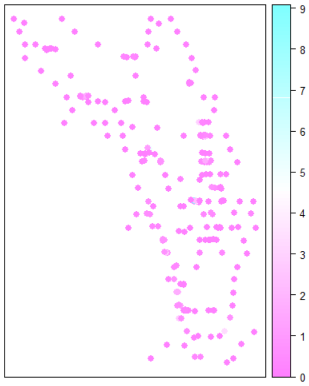
To simulate systematic sample draws across the sampling frame, the distribution of sea otter groups in Glacier Bay was approximated with inverse distance weighting (IDW), an empirical interpolation approach (Bivand and others, 2013). IDW approximates values of the outcome of interest, $\hat{Z}$, at a location s_0, as a weighted mean of the sample points with weights calculated as a function of distance. Therefore, an interpolated point at location s_0 is given by:

$$\hat{Z}(s_0) = \frac{\sum_{i=1}^{n} w(s_i) Z(s_i)}{\sum_{i=1}^{n} w(s_i)}, \tag{1}$$

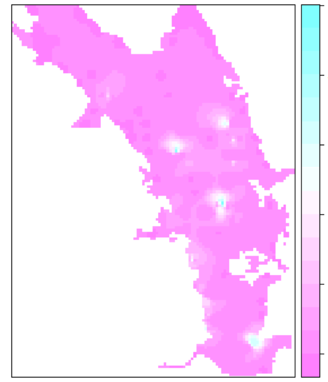
where the s_i represents the locations of the n points in the sample and $w(s_i)$ is given by:

$$w(s_i) = \left\| s_i - s_0 \right\|^{-p} \tag{2}$$

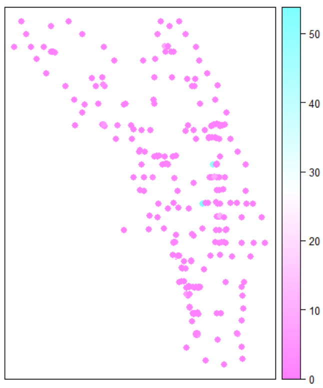
for an IDW power, p. The IDW power parameter was tuned with cross validation (Bivand and others, 2013). In this process, the 2012 data were split in half for each stratum into a modeling data set and a validation data set. IDW was used for the modeling data set, and the IDW interpolations were compared to the observed values in the validation data set. When interpolation performs well, the residuals are small with no apparent structure. Assessment in a simulation of 100 iterations evaluated with the coefficient of determination, R^2, indicated that the interpolation performed best with an IDW power parameter value of 2.75. However, the transect-level interpolation totals tended to be higher than observed for the three 2012 replicate surveys. Using the proportion of zeros observed in each transect as a metric for IDW power tuning provided a more realistic data set for interpolation and resulted in a IDW power parameter value of 3.75. Observed and IDW-interpolated (evaluated at IDW power values of 3.75) surfaces of sea otter distributions are shown in figure 1-3.



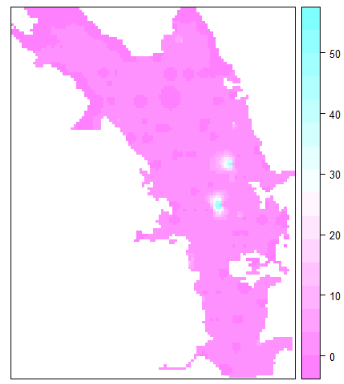
A. Observed sea otter density per 400×400 m area from the 2012 replicate 1 survey



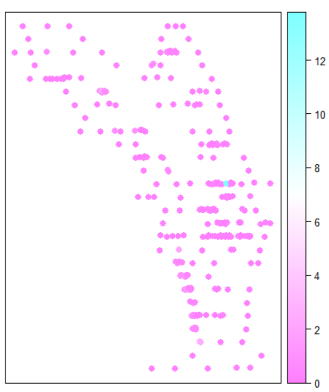
B. IDW interpolation of sea otter density per 400×400 m grid cell based on 2012 replicate 1 survey



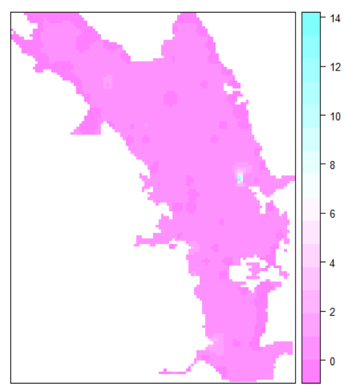
C. Observed sea otter density per 400×400 m area from the 2012 replicate 2 survey



D. IDW interpolation of sea otter density per 400×400 m grid cell based on 2012 replicate 2 survey



E. Observed sea otter density per 400×400 m area from the 2012 replicate 3 survey



F. IDW interpolation of sea otter density per 400×400 m grid cell based on 2012 replicate 3 survey

Figure 1-3. Spatial distributions of the 2012 observed groups by replicate survey and the resulting inverse distance weighted (IDW) interpolation calculated for an inverse distance weighting power of 3.75, Glacier Bay, Alaska. Note the varying color scale among plots.

For each of 500 iterations of the sample size simulation, IDW was used to interpolate a sea otter distribution across the extent of Glacier Bay. Variation in the population was attained by randomizing which of the 2012 replicate surveys was used for each iteration of the simulation and then randomizing observed group sizes within each stratum to observed locations within that replicate survey. This approach accounts for the variation in the distribution of group sizes while preserving preference for particular habitat within the sampling frame. The correction factor estimated from that replicate survey was used to adjust small groups for detection error.

A 400×400 m prediction grid was established to reflect the transect width. Group totals were transformed to densities per grid cell area, and group locations from the 2012 surveys were used to create the prediction grid for each iteration of the simulation. Systematic random samples of transects within each density stratum were selected from the sampling frame of transects. The 2012 allocation of 24 percent low-density stratum transects and 76 percent high-density stratum transects was used in the simulation. Random starting transects for each stratum and replicate survey were obtained from a "without-replacement" simple random sample of possible starting transects. This approach ensured that the same starting transect was not used more than once among a set of replicate surveys. Summing across grid cells that intersected the sample of transects provided an approximation of the number of sea otters that would be observed in that transect based on the IDW interpolation. The interpolated points were formatted for analysis with the methods outlined by Bodkin and Udevitz (1999).

The variance estimate was calculated in two ways. The first variance estimator is the variance of the mean of the replicate surveys, which incorporates variance components due to detection error, extrapolation to unsurveyed areas (sampling error), and estimation of the mean of the estimated replicate population sizes. For the purposes of this simulation, this variance-components estimator is useful for assessing the impact of varying the numbers of replicates and transects. The second variance estimator is an empirical variance calculated as the sample variance among the replicate estimates of the population total.

The Monte Carlo simulation to assess appropriate sample sizes of replicates and transects incorporated 500 iterations each for up to 5 replicate surveys of 40–168 transects. Means of SEs for the estimates of the population total are reported as well as boxplots to illustrate the range of values each might take under different simulation scenarios.

Assessing Effort Across Years

Monte Carlo simulation was used to assess power to detect trend in a two-sided hypothesis test with the Wald statistic of the trend coefficient. Each simulation accounted for a unique combination of the number of replicates (2 through 5), revisit design, and trend effect. For each of 1,000 iterations in a given simulation, a set of replicate abundance estimates were generated for each year of the 20-year monitoring period. The estimate of the logged 2012 abundance served as the baseline status for the monitoring period, and subsequent annual estimates were obtained by applying the specified trend each year. Effects were randomly generated from their assumed distributions, with $b_j \sim N(0, \sigma_b)$ and $e_{ij} \sim N(0, \sigma_e)$ and added to the simulated logged abundance estimate. Note that, because the logged abundance was simulated, the linear trend of the logged outcome translates to an exponential trend on the original scale.

Therefore, the assumed levels of annual multiplicative trend examined in this power simulation (table 1-2) translate to linear trends on the logged scale. For example, a 3.75 percent annual multiplicative trend in abundance is equivalent to an annual additive increase of log(1.0375) = 0.0368 in the logged abundance. After the replicate sets of abundance estimates were simulated over time, one of five revisit designs was imposed on the time series, the linear mixed model was applied to the data set, and the test of trend was obtained from the linear mixed model. This process was conducted a total of 1,000 times, resulting in 1,000 trend tests for a single simulation scenario defined by the number of replications, the revisit design, and the trend level. The power of the trend test was approximated as the proportion of the 1,000 iterations for which the trend test was significant, indicating that a trend had been accurately detected. The Welch (1947) approximation to Satterthwaite's (1946) degrees of freedom was used to maintain nominal test size when data were unbalanced (that is, when a revisit design other than [1-0] was used).

Four levels of increasing annual trend were assessed over a 20-year period (table 1-2). Power simulations were based on 2012 estimates of abundance, which reflect a large and robust population. Trends were conservatively modeled as increases because population declines have slightly higher power of detection (Gerrodette, 1987). Note that the net change in abundance over time is very different for a 5-year monitoring period than for a 20-year monitoring period. A 1 percent annual trend results in a 5 percent increase in abundance over 5 years, but after 20 years corresponds to a 22 percent increase in the sea otter population total. Note that an 8.5 percent annual trend results in a 50 percent increase in abundance over 5 years, but is more than 5 times larger than the original abundance after 20 years.

Table 1-2. Annual and corresponding net trends as a function of time.

Annual trend, in percent	Years	Net increase, in percent
1	5	5
1	20	22
2	5	10
2	20	49
3.75	5	20
3.75	20	109
8.5	5	50
8.5	20	411

Results

Between 1999 and 2012, we conducted 33 aerial surveys in Glacier Bay (table 1-1) and generated 8 annual abundance estimates (fig. 1-4).

Assessing Effort Within a Year

For each variance estimator, once a minimum number of transects is visited within a replicate survey, sampling more transects provides little benefit in precision. For the variance-components estimator of variance, changes in the mean coefficient of variation (CV) are slight after 80–100 transects are surveyed within a replicate (fig. 1-5). However, the number of replicate surveys greatly reduces the mean SE, with considerable benefit obtained with two or three replicates over a single survey. For the more conservative empirical variance estimator, a minimum of about 120 transects are needed within a survey to obtain a stable mean CV in the simulations (fig. 1-6). Note that the empirical variance estimator requires at least two surveys to compute the variance. Further note that the empirical CV is consistently smaller for surveys with two replicates. This result does not indicate more precision for fewer replicates but instead a tendency for the sample standard deviation to underestimate the population standard deviation for small sample sizes (Brugger, 1969). More than three replicate surveys of at least 120 transects do not substantially improve precision as measured by the empirical CV. Additional simulation results are provided in appendix A (figs. A1–A10). Mean estimates of the population total are similar for all sample sizes of transects and replicates (fig. A7).

Comparing the recommended effort of 120 transects per replicate to the sampling effort expended in past years (table 1-1), effort was determined to be sufficient for precise estimation with the empirical variance estimator for all years except 2004 (three of four replicate surveys) and 2006. All surveys were adequate to calculate the variance components SE with the recommended 80–100 transects per replicate survey. Confidence intervals constructed for a Type-I error level of 0.05 from both variance components and empirical variance estimators demonstrated low coverage (figs. A9 and A10, respectively).

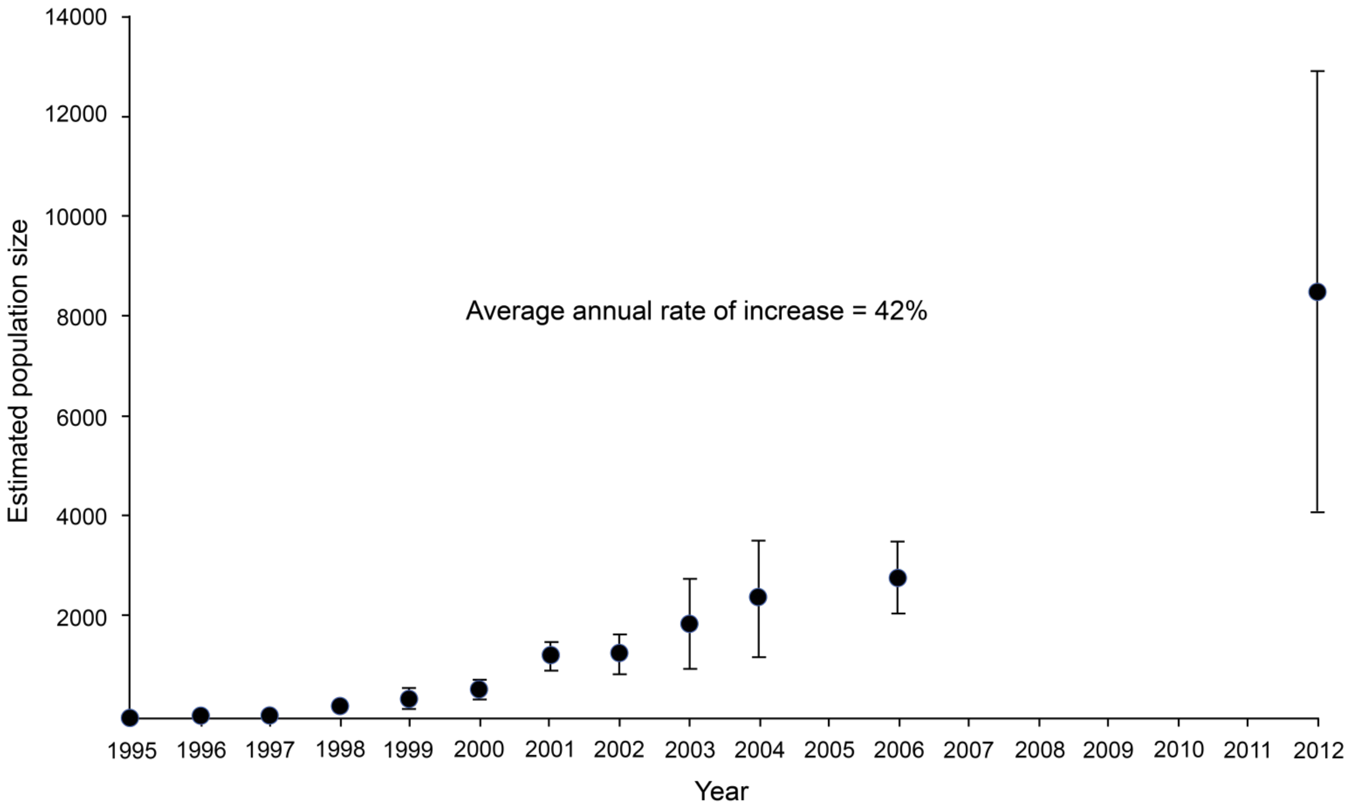


Figure 1-4. Graph showing sea otter population growth based on counts (1995–1998) and population size estimates from aerial surveys (1999–2012), Glacier Bay, Alaska. Error bars are 95 percent confidence intervals.

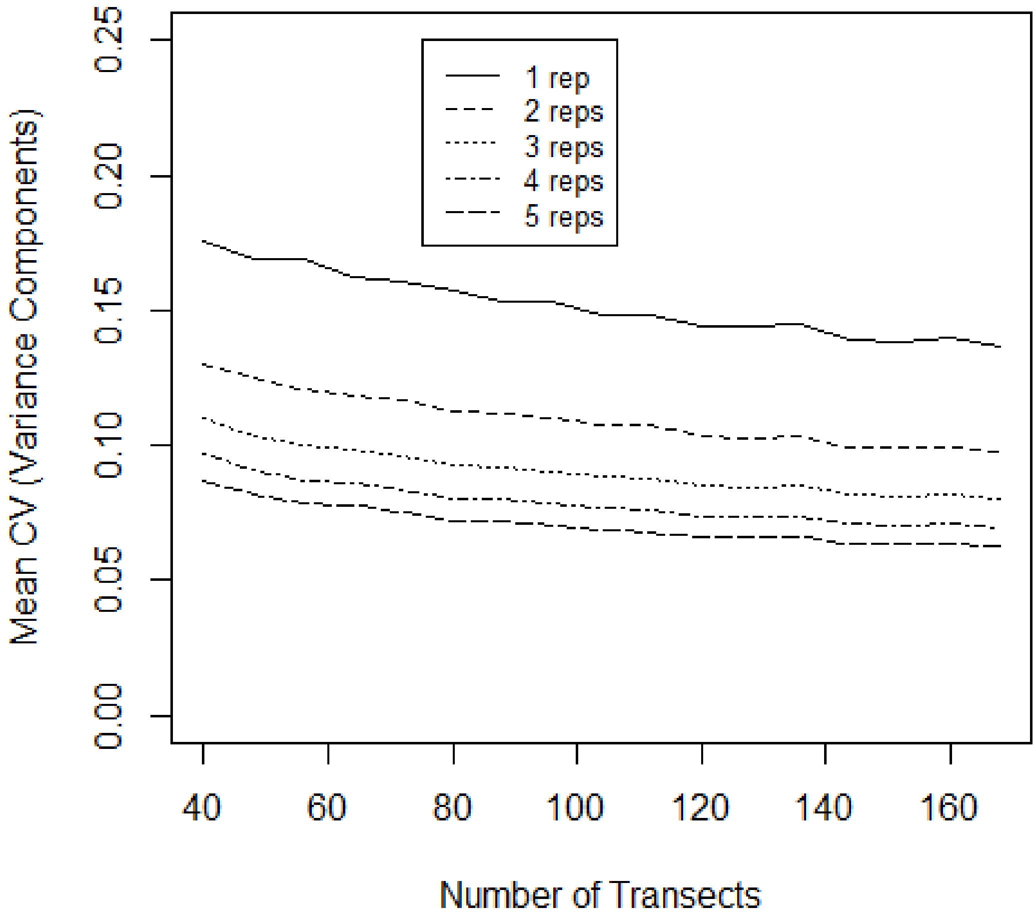


Figure 1-5. Graph showing mean of variance components coefficient of variation (CV) for 5 levels of replications and 40–168 transects per replicate survey.

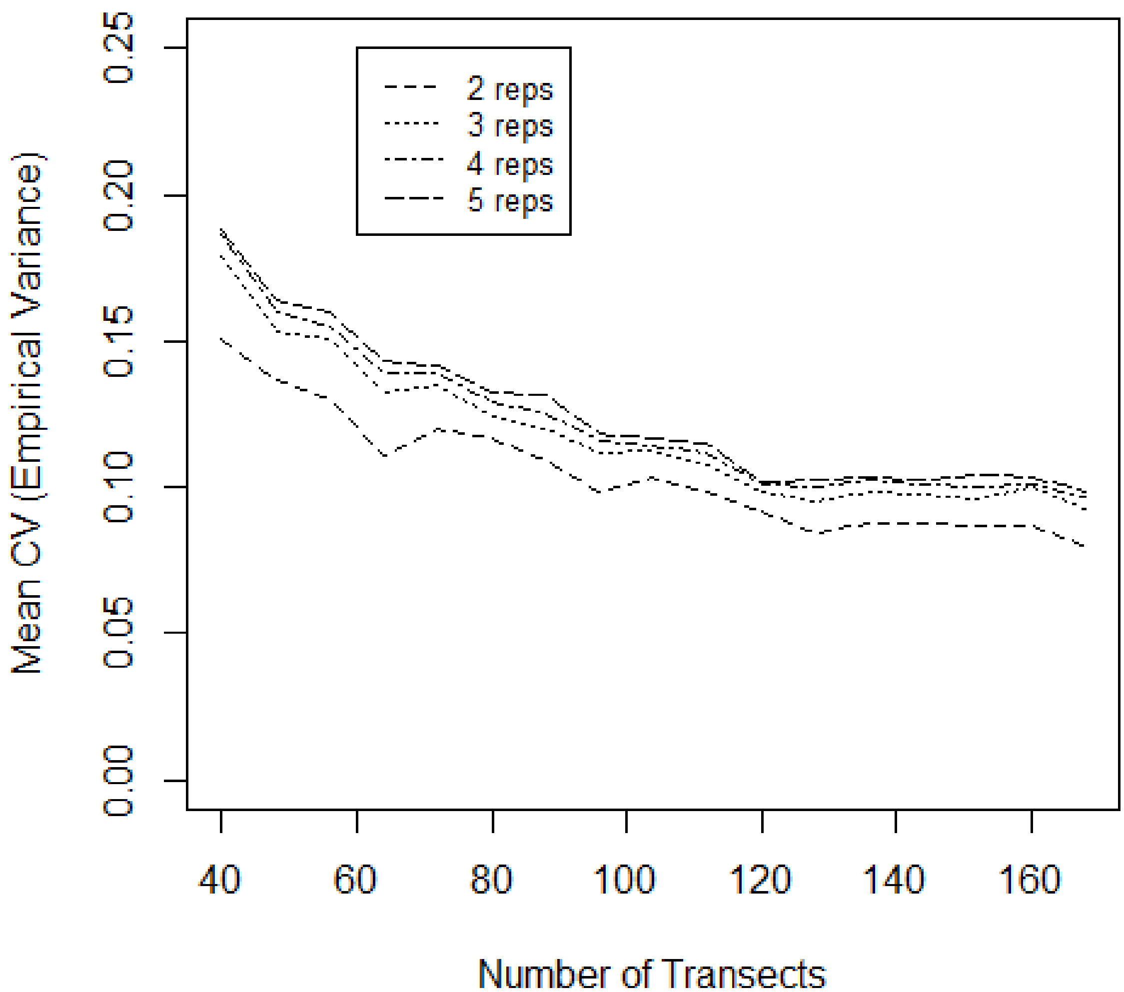


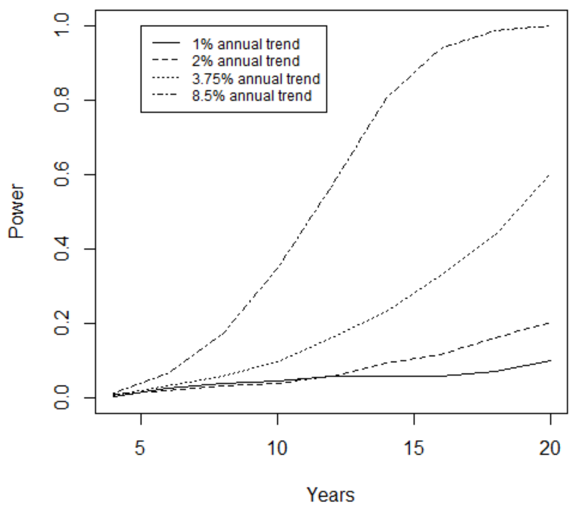
Figure 1-6. Graph showing mean of empirical coefficient of variation (CV) for 4 levels of replications and 40–168 transects per replicate survey.

Assessing Effort Across Years

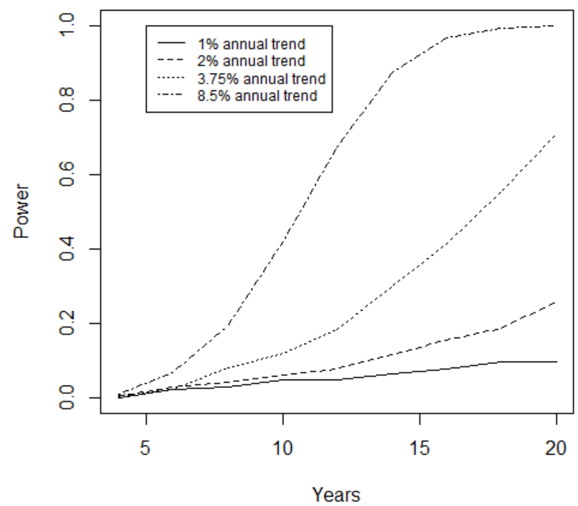
Results of power analysis for trend detection are provided in figures 1-7–1-11. Figure 1-7 provides power approximations for annual ([1-0]) surveys exhibiting four levels of trend for two to five replicates each year. Similarly, power approximations are given for surveys conducted every other year ([1-1], fig. 1-8), every third year ([1-2], fig. 1-9), every fourth year ([1-3], fig. 1-10), and every fifth year ([1-4], fig. 1-11). Therefore, each successive set of plots represents a longer interval between sampling.

As expected, the highest power is obtained by the [1-0] design for which aerial surveys are conducted annually (fig. 1-7). However, annual trends of 1 and 2 percent cannot be detected with 80 percent power even over 20 years for the [1-0] revisit design, indicating consistently low power to detect small trends. The 3.75 percent annual trend attains 80 percent power with the [1-0] revisit design but only with 5 replicates surveys conducted annually over a 20-year monitoring period.

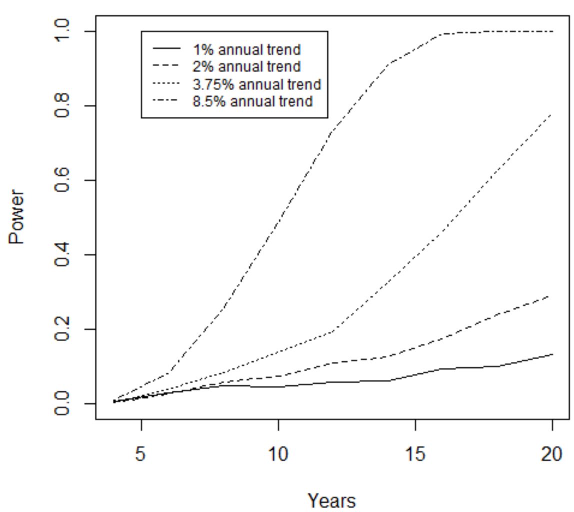
Sampling every other year with the [1-1] design (fig. 1-8) provides enough power to detect a large annual trend of 8.75 percent after 15 years or so, but power to detect moderate and small trends is much lower. The pattern of decreasing power as the period between revisits increases continues as the revisit design goes to every third year (fig. 1-9), every fourth year (fig. 1-10), and every fifth year (fig. 1-11). The only scenario in which 80 percent power is reached among the [1-2], [1-3], and [1-4] designs is the combination of the [1-2] revisit design, a large annual trend of 8.75 percent, at least 4 replications per year, and at least 18 years in the monitoring program (fig. 1-9C).



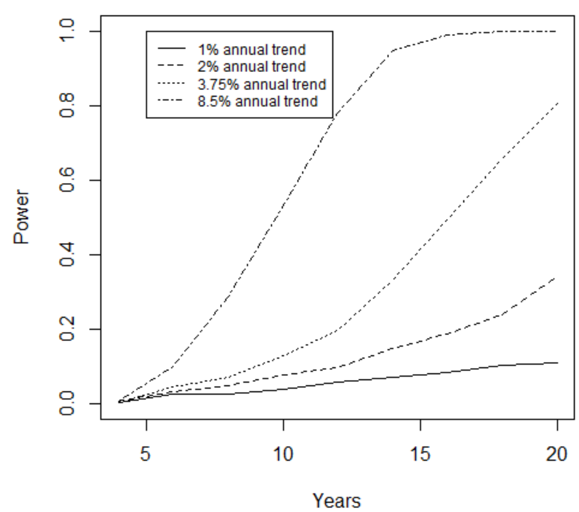
A. Power to detect a trend in either direction with a [1-0] revisit design and 2 replicate surveys.



B. Power to detect a trend in either direction with a [1-0] revisit design and 3 replicate surveys.

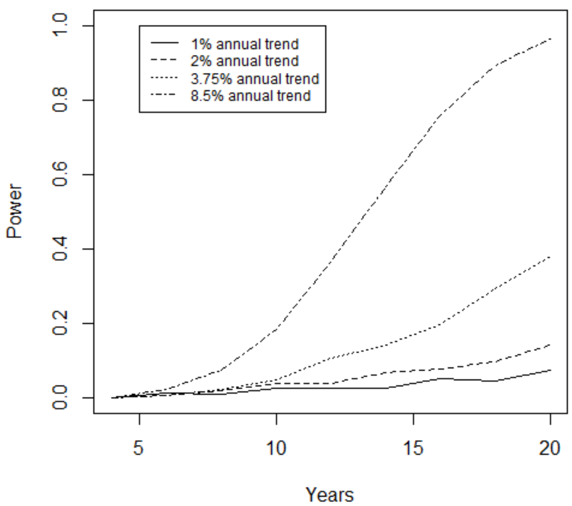


C. Power to detect a trend in either direction with a [1-0] revisit design and 4 replicate surveys.

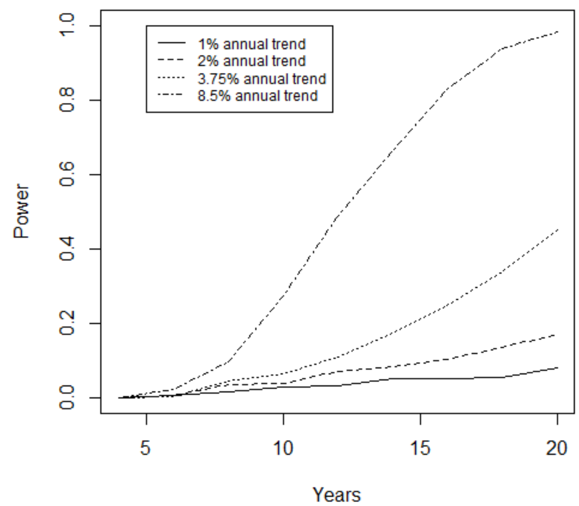


D. Power to detect a trend in either direction with a [1-0] revisit design and 5 replicate surveys.

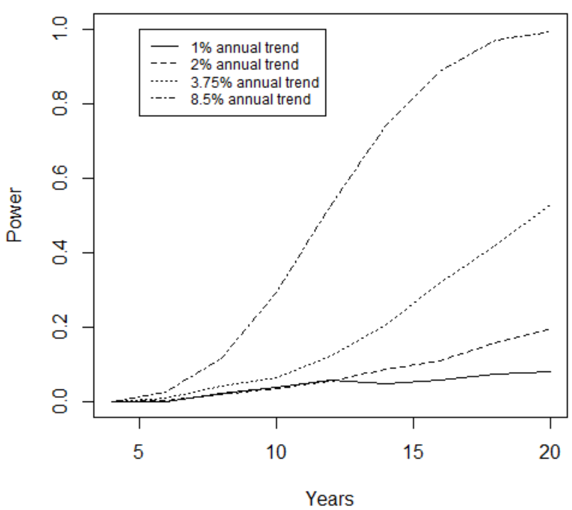
Figure 1-7. Graphs showing power to detect a trend in either direction with a [1-0] revisit design and 2 (a), 3 (b), 4 (c), or 5 (d) surveys.



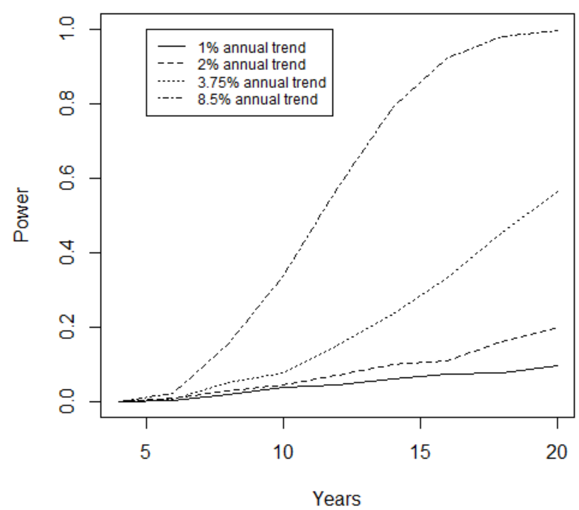
A. Power to detect a trend in either direction with a [1-1] revisit design and 2 replicate surveys.



B. Power to detect a trend in either direction with a [1-1] revisit design and 3 replicate surveys.

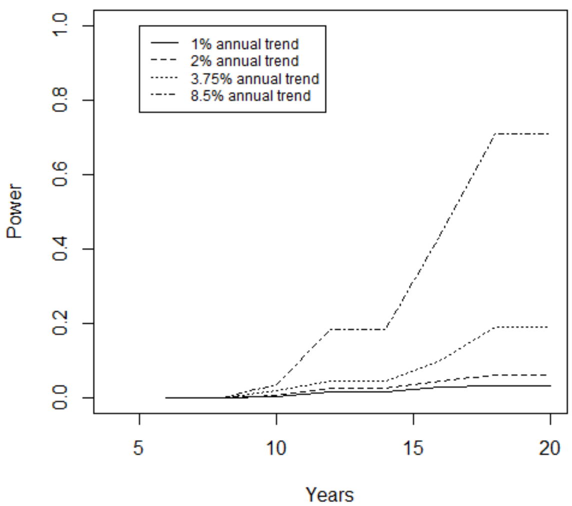


C. Power to detect a trend in either direction with a [1-1] revisit design and 4 replicate surveys.

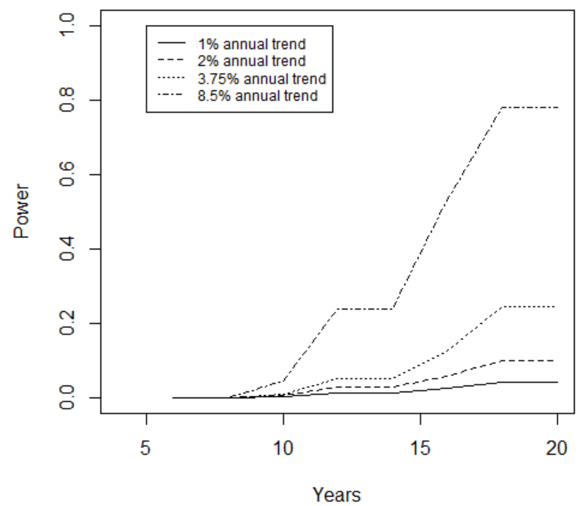


D. Power to detect a trend in either direction with a [1-1] revisit design and 5 replicate surveys.

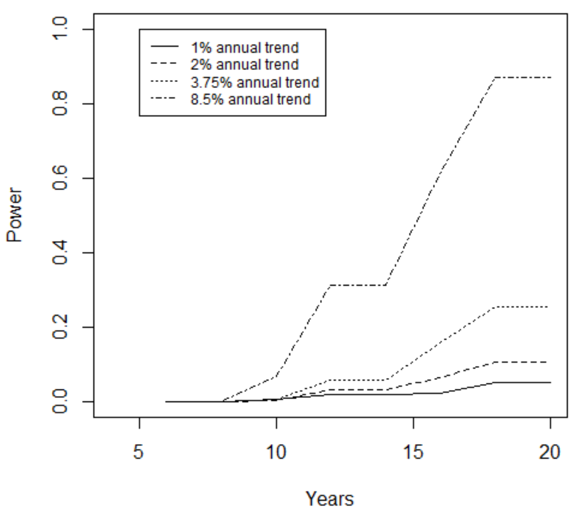
Figure 1-8. Graphs showing power to detect a trend in either direction with a [1-1] revisit design and 2 (a), 3 (b), 4 (c), or 5 (d) surveys.



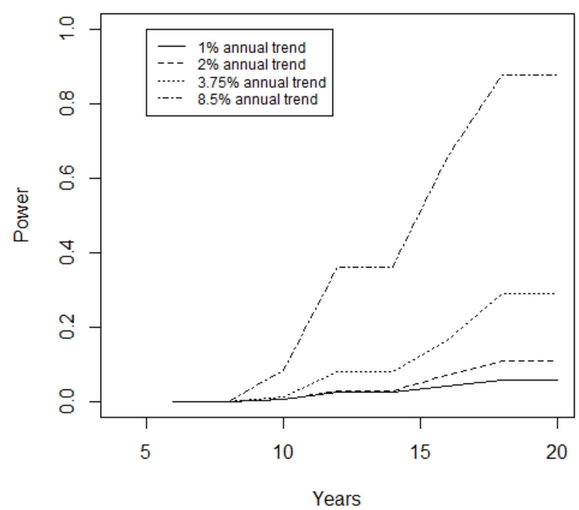
A. Power to detect a trend in either direction with a [1-2] revisit design and 2 replicate surveys.



B. Power to detect a trend in either direction with a [1-2] revisit design and 3 replicate surveys.

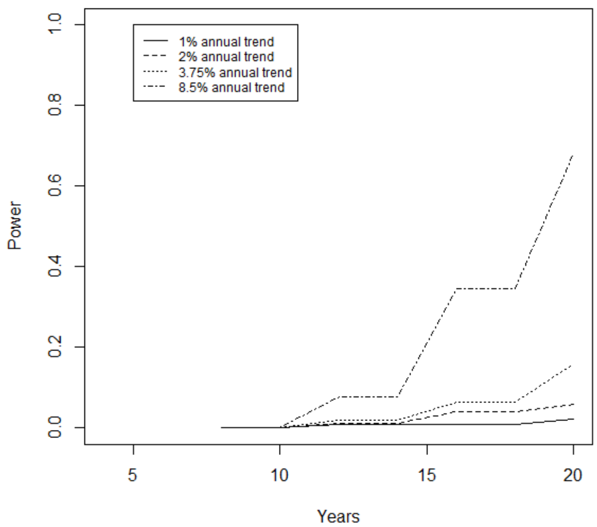


C. Power to detect a trend in either direction with a [1-2] revisit design and 4 replicate surveys.

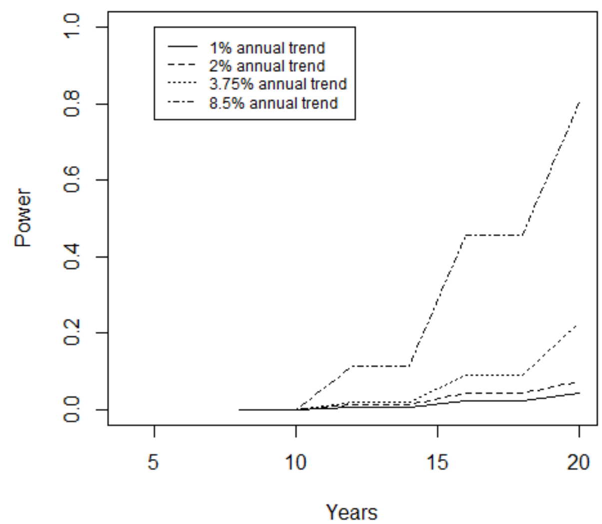


D. Power to detect a trend in either direction with a [1-2] revisit design and 5 replicate surveys.

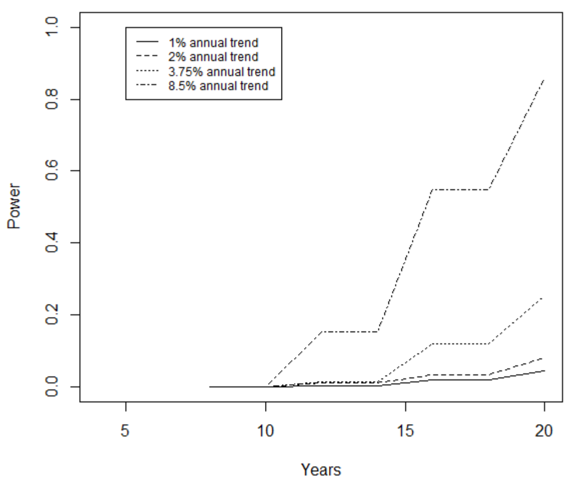
Figure 1-9. Graphs showing power to detect a trend in either direction with a [1-2] revisit design and 2 (a), 3 (b), 4 (c), or 5 (d) surveys.



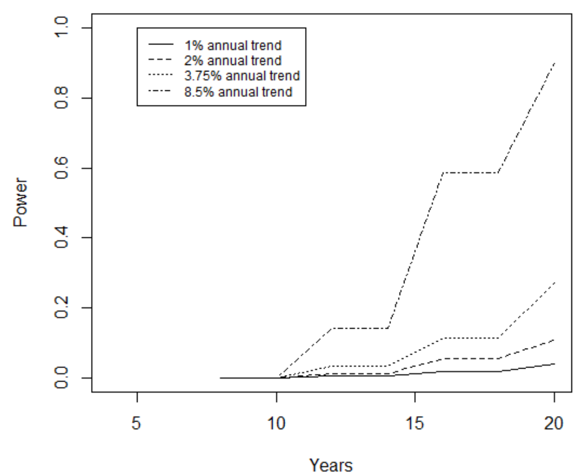
A. Power to detect a trend in either direction with a [1-3] revisit design and 2 replicate surveys.



B. Power to detect a trend in either direction with a [1-3] revisit design and 3 replicate surveys.

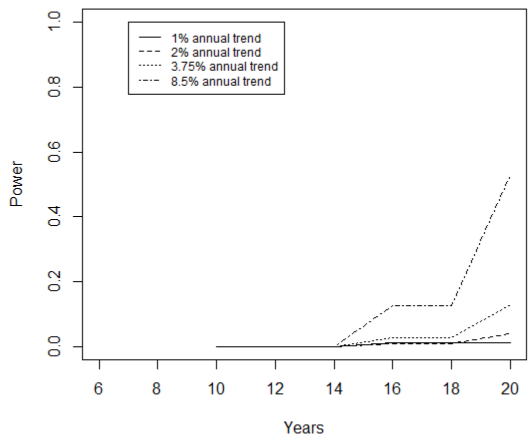


C. Power to detect a trend in either direction with a [1-3] revisit design and 4 replicate surveys.

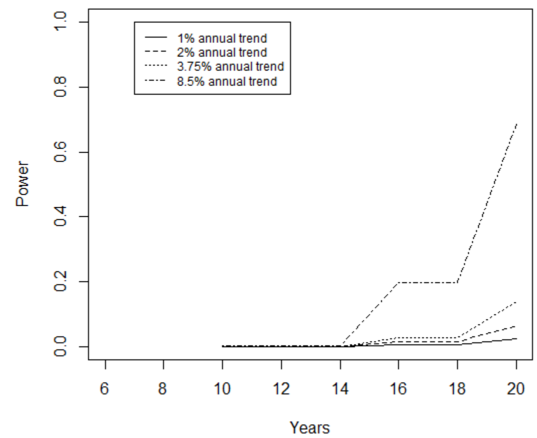


D. Power to detect a trend in either direction with a [1-3] revisit design and 5 replicate surveys.

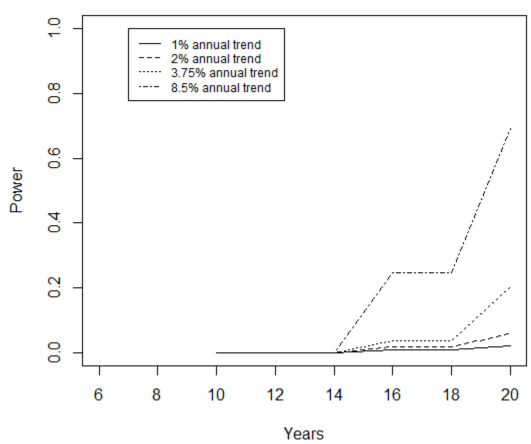
Figure 1-10. Graphs showing power to detect a trend in either direction with a [1-3] revisit design and 2 (a), 3 (b), 4 (c), or 5 (d) surveys.



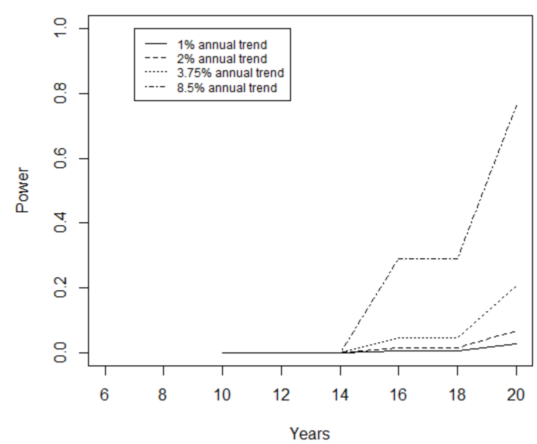
A. Power to detect a trend in either direction with a [1-4] revisit design and 2 replicate surveys.



B. Power to detect a trend in either direction with a [1-4] revisit design and 3 replicate surveys.



C. Power to detect a trend in either direction with a [1-4] revisit design and 4 replicate surveys.



D. Power to detect a trend in either direction with a [1-4] revisit design and 5 replicate surveys.

Figure 1-11. Graphs showing power to detect a trend in either direction with a [1-4] revisit design and 2 (a), 3 (b), 4 (c), or 5 (d) surveys.

Discussion

Evaluation of effects of varying within-year effort indicates that three replicates provide reasonable precision. Assessing effort with the variance-component variance suggests that 80–100 transects per replicate is sufficient, but at least 120 transects are needed for efficient estimation with the empirical variance estimator, which may provide better confidence interval coverage. Although the results of our trend analysis indicate low power for trend detection, we believe the aerial survey technique described herein currently provides the most unbiased abundance estimates of any viable sea otter survey technique in Glacier Bay. Here, we describe a design for the continuation of aerial abundance surveys and suggest ways to improve estimate precision.

The highest power to detect trends in sea otter abundance is obtained when the trend is large (8.5 percent annually) and when aerial surveys are conducted annually (fig. 1-7). With the exception of the 3.75 percent annual trend for five annual replicates and the [1-0] revisit design (fig. 1-7D), 80 percent power is only attained for the most extreme trend of 8.5 percent. Otherwise, the power to detect more modest trends is consistently low. The number of replicates influences power to a small degree, but any additional replication over three replicates would need to be consistent over the 20-year monitoring period to see any benefit. For the [1-4] design, power attains a level of nearly 80 percent only for the largest trend with the most replicates and the longest monitoring period (fig. 1-11D). The power to detect a trend after 5 years of monitoring is uniformly low for all scenarios.

The results of the trend analysis indicate that power to detect small to moderate trends is low even after 20 years of consistent monitoring. Detection of even the largest trend effect requires consistent annual monitoring to overcome the effect of year-to-year variation. Obtaining precise and accurate replicate-level estimates will help in accurately estimating the year-to-year variation. Future survey estimate precision and power to detect trend may be improved through further analyses of existing sea otter survey data from Glacier Bay by (1) redefining strata based on previous otter sightings relative to depth and distance from shore, (2) estimating the optimum allocation of sampling effort among strata (Thompson, 2002), or (3) accounting for spatial correlation among transects.

A variety of other survey methods have been used to estimate sea otter abundance. Although aerial and boat-based surveys have been used extensively (Lensink, 1960; Boolootian, 1961; Kenyon, 1969; Burn, 1994), counts are known to be biased low because they do not account for undetected otters. For example, when boat-based counts were compared against shore-based counts in Prince William Sound, it was estimated that 30 percent of the otters were not detected by boat observers (Udevitz and others, 1995). In contrast, shore-based observers using binoculars and telescopes to census sea otters in California have an estimated sighting probability of 0.945 (Estes and Jameson, 1988). The shore-based method also has been used effectively in the Aleutian Islands where observers can view sea otters from elevated positions with unobstructed views of the coastline (Estes, 1977), but is inappropriate for large areas with greater shoreline complexity and offshore reefs such as Glacier Bay.

Based on the large amount of unoccupied sea otter habitat and lack of mortality from hunting in Glacier Bay, sea otter abundance likely will continue to increase (Esslinger and others, 2013). However, recent sea otter diet and prey sampling data suggest decreases in prey availability in areas of long-term occupation in the lower bay (Weitzman, 2013). As prey resources become limiting, we can expect reduced survival and increased emigration to slow sea otter population growth in Glacier Bay. Because sea otters are known for structuring nearshore ecosystems, we also can expect to see community-level changes such as increased kelp abundance and changes in the size and number of other consumers (Estes and Palmisano, 1974; Kvitek and others, 1992). Monitoring sea otter abundance and distribution in Glacier Bay will help park researchers and managers understand the population status of sea otters, and aid in the interpretation of sea otter-induced ecosystem changes relative to other sources of variation, including potential human-induced impacts such as ocean acidification, vessel disturbance, and oil spills.

Given the sample size and cost (in U.S. dollars; table 1-3) considerations involved in sea otter abundance surveys, it appears most practical to focus on acquiring a time series of relatively precise abundance estimates rather than trend detection. A reasonable monitoring plan might be conducting abundance surveys every 1–3 years using 3 replicates consisting of at least 120 transects each. Because the Federal government imposes a daily flight time limit of 8 hours for each pilot to avoid fatigue, sampling intensity can be adjusted through transect spacing so a replicate can be completed within 8 hours or less. For example, during the 2012 survey, the survey team flew approximately 37 km of transect per hour or 296 km per 8 hour day, including ISUs.

Table 1-3. Estimated annual cost of sea otter aerial surveys in Glacier Bay, Alaska.

Item	Number	Unit	Unit cost (U.S. dollars)	Item cost (U.S. dollars)
Survey design and logistics, 1 biologist GS-11	0.5	Pay period	2,460	1,230
Aerial observer, 1 biologist GS-11	0.5	Pay period	2,460	1,230
Airplane and pilot survey time	24	Hours	350	8,400
Avgas for survey	168	Gallons	5	840
Pilot per diem	5	Days	83	415
Airplane and pilot transit time (round trip)[1]	12	Hours	350	4,200
Avgas for transit (round trip)	84	Gallons	5	420
Data management, 1 technician GS-7	0.5	Pay period	1,662	831
Data analysis, 1 biologist GS-11	0.5	Pay period	2,460	1,230
TOTAL				18,796

[1]Based on estimated 1,111 kilometer commute from Nikiski, Alaska to Bartlett Cove.

Chapter 2. Estimating Sea Otter Diets and Energy Intake Rates

Sea otter foraging observations provide another method for assessing population status. Sea otters dive for prey in water less than100 m in depth, but the majority of their foraging occurs in water less than 60 m (Bodkin and others, 2004). Sea otters are unique among marine mammals in that they consistently bring their prey to the surface for consumption. This characteristic of sea otter behavior provides a window into nearshore community structure through which we are able to observe the relative availability of various prey types and estimate sea otter energy intake rates. As sea otter density increases, prey availability decreases and sea otters must spend more time foraging to meet their energy requirements (Estes and others, 1986; Garshelis and others, 1986; Bodkin and others, 2007b). Comparing energy intake rates of sea otters from Glacier Bay with other intake rates of sea otters in other regions can inform us about sea otter population status relative to carrying capacity. Over time, these data not only reflect changes in sea otter diets and benthic communities, but also identify areas of critical foraging habitat.

To collect data used to estimate diet composition and energy recovery rates, observers use telescopes with 50–80× magnification (Questar® Corporation, New Hope, Pennsylvania) and follow an established protocol (Bodkin and others, 2001) to observe foraging sea otters. The goal is to obtain a balanced sample of foraging observations from newly and previously occupied areas to accurately describe dietary changes in space and time. To avoid biasing results toward individual sea otters with more observations, sampling effort is determined by the number of foraging bouts, a series of 1–20 foraging dives made by a randomly selected focal otter. Hence, observation sites are selected based on the distribution of sea otters and the number of foraging bouts already collected in a given area. Most observations are shore-based and thus limited to less than1 km from shore, but ship-based observations greater than 1 km from shore also can be collected during calm sea conditions. After each foraging dive, the observer records dive duration, post-dive surface interval, whether the otter successfully acquired prey, and an estimated location of the foraging otter. For successful dives, observers identify prey to the lowest possible taxon, estimate prey size relative to the otter's paw width, and record the number of prey per type and size. Following data collection, an algorithm called Sea Otter Foraging Analysis (SOFA) is used to quantify diet composition, estimate energy intake rates, and account for uncertainty in the observational data (Dean and others, 2002; Tinker and others, 2008, 2012).

Between 1993 and 2011, the USGS collected foraging observations from 12,908 foraging dives (1,907 bouts) throughout lower Glacier Bay. Based on previous sea otter foraging studies in Glacier Bay, at least 50 foraging bouts per area should be collected to obtain enough data to adequately characterize diet. Because Glacier Bay is still being colonized by sea otters, areas can be defined based on distribution and length of occupancy to provide a spatiotemporal metric for expected changes in the diet. Previous foraging studies in Glacier Bay have used sea otter distribution data to categorize the length of occupation in each area as early (<5 years), middle (5–10 years), or late (>10 years) (Weitzman, 2013). A team of 2–3 observers can collect 8–12 bouts per day, thus it will likely take about 2–3 weeks of sampling effort to gather 150 bouts of foraging data per year (see table 2-1 for estimated costs, in U.S. dollars). Given the rapid rates of range expansion within Glacier Bay thus far, foraging observations would need to be collected every year or every other year to appropriately document sea otter recolonization process and anticipated effects on associated prey communities. The amount of time and cost of obtaining these observations also will depend upon the capabilities of the vessel used to access foraging areas and whether the observers are commuting from Bartlett Cove on a daily basis or staying near the work sites (for example, camping on shore, staying aboard a larger vessel or floating cabin). Because sea otter foraging observations are collected in California and other parts of Alaska on an annual basis, a pool of trained observers is available to support the collection of Glacier Bay data. New observers can be trained by working alongside experienced observers and are usually ready to operate independently after 1 week if they have familiarity with marine invertebrates.

Table 2-1. Annual cost of estimating sea otter diet and energy intake rates in Glacier Bay, Alaska.

Item	Number	Unit	Unit cost, (U.S. dollars)	Item cost (U.S. dollars)
Field salary, 1 supervisor GS-11	1	Pay period	2,460	2,460
Field salary, 2 technicians GS-7	2	Pay period	1,662	3,324
Transportation (fuel for 25-foot skiff)[1]	14	Day	250	3,500
Data management, 1 technician GS-7	1	Pay period	1,662	1,662
Data analysis, 1 supervisor GS-11	0.5	Pay period	2,460	1,230
TOTAL				12,176

[1]Assumes commuting from Bartlett Cove on a daily basis.

Chapter 3. Detecting Change in Population Status by Monitoring Ages at Death

Another way to monitor population status of sea otters is to annually obtain the age distribution from beach-cast sea otter carcasses (Bodkin and others, 2000; Monson and others, 2000a). The relative distributions of dying otters within juvenile, prime-age, and old-age classes can provide insights into sea otter population status, mechanisms underlying observed changes in abundance, and predictions about future changes. For example, juvenile survival in expanding sea otter populations, where food resources are not limiting, can be much higher than in food-limited situations and has the potential to drive population growth rates (Kenyon, 1969; Monson and DeGange, 1995; Monson and others, 2000b). Thus, the proportion of juveniles within carcass collections can be considered an indication of whether a population, or a portion of a population, is approaching food limitation, and thus whether numbers in that area are likely to increase. Based on previous surveys and energy intake rates estimated from recently collected foraging observations, Glacier Bay may contain a mix of areas with abundant food resources and areas approaching food limitation (Weitzman, 2013); age distributions of dying otters within those areas would add to our understanding of whether food limitation is occurring, the scale over which it is occurring, and the demographic consequences of food limitation. Mortality data also are useful in the event of human-caused perturbations such as the *Exxon Valdez* oil spill (EVOS) in Prince William Sound (Monson and others, 2000a, 2011; Monson, 2014). Because sea otter carcass data had been obtained prior to the EVOS, post-spill carcass surveys were conducted to evaluate when sea otter mortality patterns had recovered to a pre-spill age distribution (fig. 3-1).

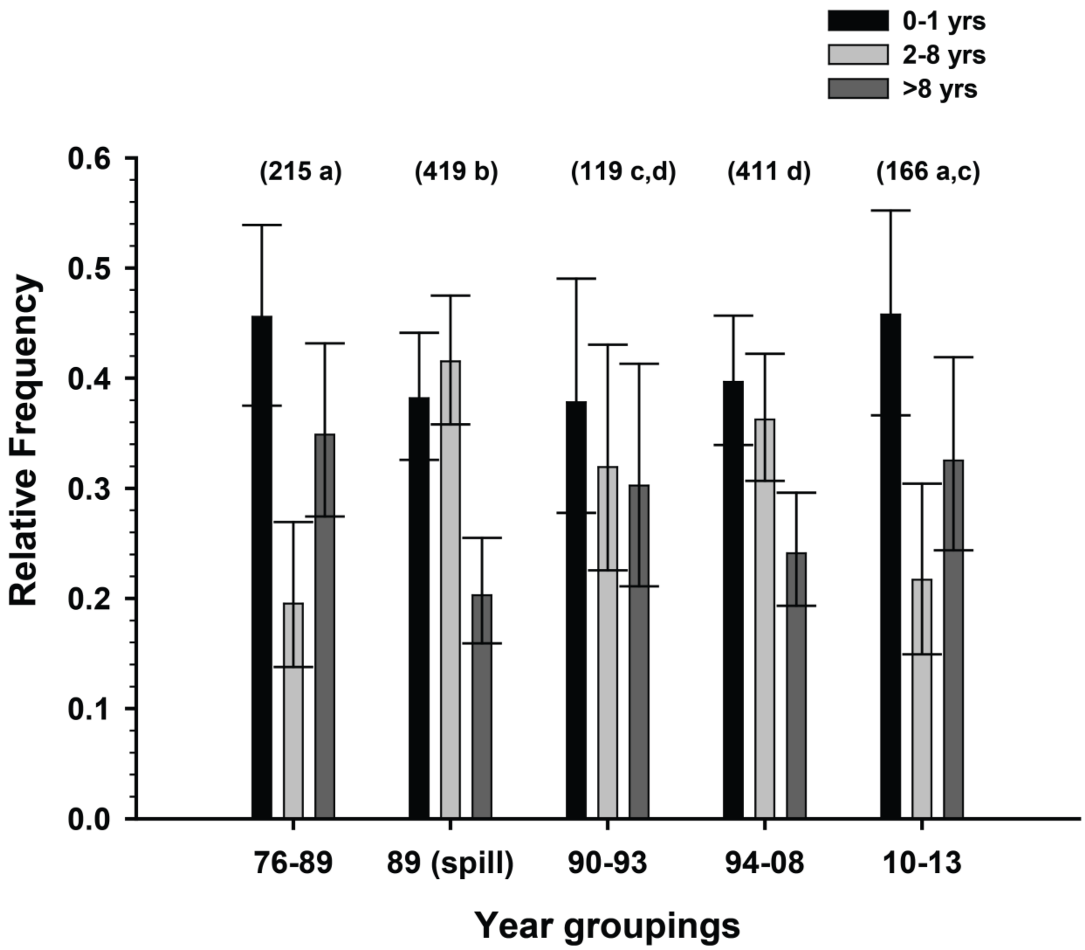


Figure 3-1. Graph showing relative age distributions of sea otter carcasses collected on western Prince William Sound beaches, Alaska, 1976–2013 (from Monson, 2014). All non-pup ages were estimated by tooth cementum analysis (Matson's Laboratory, Milltown, Montana). Total numbers of carcasses collected are in parentheses above each grouping and distributions with the same letter do not differ significantly from each other. Error bars are 95 percent confidence intervals.

Sea otter carcass collection efforts in Alaska typically occur in the latter part of April, after snow has melted away from the upper beach zone and before beach vegetation has grown thick enough to obscure carcasses. The suitability of beaches for carcass collections depends on a variety of factors including slope, substrate type, exposure to wave energy, shoreline proximity to otter activity, and orientation relative to prevailing winds and currents. After potential beaches have been located and deemed likely to receive deposition of sea otter carcasses, beaches are typically surveyed by a pair of observers walking parallel along the shoreline with one observer searching above the wrack zone and the other searching below. A tooth is extracted from each carcass and sent to a laboratory (Matson's Laboratory, Milltown, Montana) where they are sectioned and stained so the cementum annuli can be counted to estimate age (Bodkin and others, 1997). Sea otter mortality data are typically summarized by age class: (1) juveniles (0-age pups and 1 year-old juveniles), (2) prime-age (2–8 year-olds), and (3) old-age (>8 years). Based on the number of sea otters living in Glacier Bay and our experiences conducting sea otter carcass surveys in Prince William Sound, Alaska, 4-6 people should be able to collect 30–50 carcasses over a 5–7 day period. The amount of time and cost of obtaining carcasses also will depend upon the capabilities of the vessel used to access beaches and whether the surveyors are commuting from Bartlett Cove on a daily basis or staying near the beaches (for example, camping on shore, staying aboard a larger vessel or floating cabin). Surveys should occur on an annual basis to maximize the probability that carcasses or parts (for example, skulls) being collected accurately represent mortality from the prior year and minimize losses to scavengers such as bears. Table 3-1 summarizes the estimated costs, in U.S. dollars, of conducting annual sea otter carcass surveys in Glacier Bay.

Table 3-1. Estimated annual cost of sea otter carcass surveys in Glacier Bay, Alaska.

Item	Number	Unit	Unit cost (in U.S. dollars)	Item cost (in U.S. dollars)
Field salary, 1 supervisor GS-11	0.5	Pay period	2,460	1,230
Field salary, 3 technicians GS-7	1.5	Pay period	1,662	2,493
Transportation (fuel for 25-foot skiff)[1]	7	Day	250	1,750
Supplies (knives, bags, latex gloves, data sheets)	4	Kit	20	80
Matson's Laboratory	50	Tooth	5	250
Data management, 1 technician GS-7	1.0	Pay period	1,662	1,662
Data analysis, 1 supervisor GS-11	0.5	Pay period	2,460	1,230
TOTAL				8,695

[1]Assumes commuting from Bartlett Cove on a daily basis.

Directed Research

Here we describe three directed research studies that could provide additional insight into sea otter population dynamics and community effects and complement any monitoring that is conducted. These include (1) sea otter movement ecology, (2) Dungeness crab (*Metacarcinus magister*) population status, and (3) sea otter effects on shallow benthic communities.

Because sea otter abundance in Glacier Bay has grown more quickly than the maximum reproductive rates recorded for the species, increases in numbers are a function of both reproduction and immigration from areas outside Glacier Bay National Park and Preserve. As sea otters in Glacier Bay approach carrying capacity, movements may switch to emigration out of the bay. This dynamic likely will be influenced by lack of sea otter hunting within the park. A study evaluating the movement ecology of sea otters would help elucidate the degree to which the park functions as a source or sink for neighboring regions in southeast Alaska, and how that changes over time as numbers increase (as documented by surveys) and the otter population approaches carrying capacity (as indicated by foraging observation and carcass age distributions). A movement study would require capturing, marking, and tracking a subset of the population through time using radiotelemetry. Morphometric data collected from captured sea otters would provide an additional means of assessing population status (Monson, 2009).

Prior to arrival of sea otters in Glacier Bay, two key studies documented abundance and size structure of subtidal epifauna in the nearshore zone (O'Clair and others, 1993; Donnellan and others, 2002). The Multi-Agency Dungeness Study (MADS) was designed to assess effects of the commercial Dungeness crab fishery by using pots and divers to estimate crab size and abundance before and after a phased-in closure of the fishery in Glacier Bay beginning in 1999 (O'Clair and others, 1993; Taggart and others, 2004). During the MADS sampling from 1992 to 2000, sea otters were in the early stages of colonizing Glacier Bay so their effects on crab size and abundance were likely minimal. However, since completion of MADS, sea otters have been present at all sites for at least a decade or more and anecdotal observations suggest the Dungeness crab population has declined even though crabs appear to be a relatively minor portion of the diet (Weitzman, 2013). Resampling the MADS sites would clarify our understanding of crab population structure in the presence of sea otters, with implications for how crab populations will change as otter abundance increases elsewhere, both in and outside of Glacier Bay.

The goal of the second study was to provide a detailed inventory of the nearshore marine communities of lower/mid Glacier Bay to assess the impacts of sea otters (Donnellan and others, 2002). From 2000 to 2002, 30 subtidal sites were established, surveyed, and resampled using divers to quantify the density of primary producers (macroalgae), primary consumers (for example, sea urchins), and secondary/tertiary consumers (for example, sea stars, crabs). Sea otters have now occupied most of these sites for well over a decade and likely have substantially reduced consumer biomass, thereby releasing the macroalgae from grazing pressure, and encouraging the growth of an entirely different community. Because the initial sampling was well documented and the approximate timing of sea otter occupation is known, these sites could be resampled to provide an accurate representation of how subtidal communities have changed in the presence of sea otters and serve as a benchmark for future change.

Synthesis

In this report, we have reviewed three well-established techniques that can be used to monitor population status of sea otters in Glacier Bay. Although each technique, by itself, provides insight on the status of sea otters in Glacier Bay, a clearer picture will emerge when more than one technique is used. We provide a brief summary of the costs, and pros and cons of each technique to assist in development of a long-term strategy for monitoring sea otters in Glacier Bay.

Method	Objective	Annual cost (in U.S. dollars)	Pros	Cons
Aerial surveys	Abundance and distribution	18,796	An abundance of pre-existing data; relatively small time investment; does not have to be done every year	Requires trained observer and pilot, specific type of aircraft
Foraging observations	Diet composition and energy intake rates	12,176	An abundance of pre-existing data; does not have to be done every year	Requires trained observers, relatively large time investment
Carcass surveys	Ages at death	8,695	Requires minimal training and equipment	Should be conducted every spring

Acknowledgments

Support for this work was provided by the U.S. Geological Survey and National Park Service. Mark Udevitz, Karen Oakley, Dan Monson, and Patrick Lemons provided valuable comments on earlier versions of this report.

References Cited

Bivand, R.S., Pebesma, E., and Gómez-Rubio, V., 2013, Applied spatial data analysis with R (2d ed.): Heidelberg/New York, Springer, UseR! Series, 405 p.

Bodkin, J.L., Ames, J.A., Jameson, R.J., Johnson, A.M., and Matson, G.M., 1997, Estimating age of sea otters with cementum layers in the first premolar: Journal Wildlife Management, v. 61, p. 967–973.

Bodkin, J.L., Ballachey, B.E., Cronin, M.A., and Scribner, K.T., 1999, Population demographics and genetic diversity in remnant and translocated populations of sea otters: Conservation Biology, v. 13, p. 1378–1385.

Bodkin, J.L., Ballachey, B.E., Esslinger, G.G., Kloecker, K.A., Monson, D.H., and Coletti, H.A., 2007a, Perspectives on an invading predator—Sea otters in Glacier Bay, *in* Piatt, J.F., and Gende, S.M., eds., Proceedings of the Fourth Glacier Bay Science Symposium, October 26–28, 2004: U.S. Geological Survey Scientific Investigations Report 2007-5047, p. 133–136.

Bodkin, J.L., Burdin, A.M., and Ryazanov, D.A., 2000, Age- and sex-specific mortality and population structure in sea otters: Marine Mammal Science, v. 16, no. 1, p. 201–219.

Bodkin, J.L., Esslinger, G.G., and Monson, D.H., 2004, Foraging depths of sea otters and implications to coastal marine communities: Marine Mammal Science v. 20, p. 305–321.

Bodkin, J.L,. Kloecker, K.A., Esslinger, G.G., Monson, D.H., and DeGroot, J.D., 2001, Sea Otter studies in Glacier Bay National Park and Preserve—Aerial surveys, foraging observations, and intertidal clam sampling, 2000 Annual Report: Anchorage, Alaska, U.S. Geological Survey, 78 p.

Bodkin, J.L., Monson, D.H., and Esslinger, G.G., 2007b, Activity budgets derived from time-depth recorders in a diving mammal: Journal of Wildlife Management v. 71, p. 2,034–2,044.

Bodkin, J.L., and Udevitz, M.S., 1999, An aerial survey method to estimate sea otter abundance, *in* Garner, G.W., Amstrup, S.C., Laake, J.L., Manly, B.J.F., McDonald, L.L., and Robertson, D.G., eds., Marine mammal survey and assessment methods: A Balkema, Rotterdam, Netherlands, p. 13–26.

Boolootian, R. A., 1961, The distribution of the California sea otter: California Fish and Game, v. 47, no. 3, p. 287–292.

Brugger, R. M., 1969, A note on unbiased estimation of the standard deviation: American Statistician, v. 23, no. 4, p. 32.

Burris, O.E., and McKnight, D.E., 1973, Game transplants in Alaska: Alaska Department of Fish and Game, Wildlife Technical Bulletin 4, 57 p.

Burn, D.M., 1994, Boat-based population surveys of sea otters in Prince William Sound, *in* Loughlin, T.R., ed., Marine mammals and the *Exxon Valdez*: San Diego, California, Academic Press, Inc., p. 61–80.

Dean, T.A., Bodkin, J.L., Fukuyama, A.F., Jewett, S.C., Monson, D.H., O'Clair, C.E., and VanBlaricom, G.R., 2002, Food limitation and the recovery of sea otters following the *Exxon Valdez* oil spill: Marine Ecology Progress Series v. 241, p. 255–270.

Donnellan, M., Bodkin, J.L., Fisher, J., and Barber, J., 2002, The ecological effects of sea otters on shallow benthic communities in Glacier Bay National Park and Inventory and monitoring of shallow subtidal communities in lower/mid-Glacier Bay, Annual Report 2002 Gustavus, Alaska,: U.S. National Park Service, 219 p.

Esslinger, G.G., and Bodkin, J.L., 2009, Status and trends of sea otter populations in Southeast Alaska, 1969–2003: U.S. Geological Survey Scientific Investigations Report 2009–5045, 18 p.

Esslinger, G.G., Bodkin, J.L., and Weitzman, B.P., 2013, Sea otter population abundance, distribution, and growth in Glacier Bay, Southeast Alaska, May 2012: U.S. Geological Survey Administrative Report, 9 p.

Estes, J.A., 1977, Population estimates and feeding behavior of sea otters, in Merritt, M.L., and Fuller, R.G., eds., The environment of Amchitka Island, Alaska: Springfield, Virginia, U.S. Department of Commerce National Technical Information Service TID-26712, p. 511–526.

Estes, J.A., and Jameson, R.J., 1988, A double-survey estimate for sighting probability of sea otters in California: Journal of Wildlife Management v. 52, p. 70–76.

Estes, J.A., and Palmisano, J.F., 1974, Sea otters—their role in structuring nearshore communities: Science v. 185, no. 4,156, p. 1,058–1,060.

Estes, J.A., Underwood, K.E., and Karmann, M.J., 1986, Activity-time budgets of sea otters in California: Journal of Wildlife Management v. 50, p. 626–636.

Garshelis, D.L., Garshelis, J.A., and Kimker, A.T., 1986, Sea otter time budgets and prey relationships in Alaska: Journal of Wildlife Management, v. 50, p. 637–647.

Gerrodette, T., 1987, A power analysis for detecting trends: Ecology, v. 68, no. 5, p. 1,364–1,372.

Kenyon, K.W., 1969, The sea otter in the eastern Pacific Ocean: Washington, D.C.,U.S. Fish and Wildlife Service, North American Fauna 68, 352 p.

Kvitek, R.G., Oliver, J.S., DeGange, A.R., and Anderson, B.S., 1992, Changes in Alaskan soft-bottom prey communities along a gradient in sea otter predation, Ecology, v. 73, p. 413–428.

Lensink, C.J., 1960, Status and distribution of sea otters in Alaska: Journal of Mammalogy, v. 41, no. 2, p. 172–182.

Monson, D.H., and DeGange, A.R., 1995, Reproduction, preweaning survival, and survival of adult sea otters at Kodiak Island, Alaska: Canadian Journal of Zoology, v. 73, p. 1,161–1,169.

Monson, D.H., Doak, D.F., Ballachey, B.E., Johnson, A., and Bodkin, J.L., 2000a, Long-term impacts of the *Exxon Valdez* oil spill on sea otters, assessed through age-dependent mortality patterns: Proceedings of the National Academy of Sciences, v. 97, p. 6,562–6,567.

Monson, D.H., Estes, J.A., Bodkin, J.L., and Siniff, D.B., 2000b, Life history plasticity and population regulation in sea otters: Oikos, v. 90, p. 457–468.

Monson, D.H., 2009, Sea otters (*Enhydra lutris*) and Steller sea lions (*Eumetopias jubatus*) in the north Pacific—evaluating mortality patterns and assessing population status at multiple time scales: Santa Cruz, California, University of California, Dissertation, 207 p.

Monson, D.H., Doak, D.F., Ballachey, B.E., and Bodkin, J.L., 2011, Could residual oil from the *Exxon Valdez* spill create a long-term population “sink” for sea otters in Alaska?: Ecological Applications, v. 21, p. 2,917–2,932.

Monson, D.H., 2014, Age distributions of sea otters found dead in western Prince William Sound, Alaska, through 2013, *in* Ballachey, B.E., Monson, D.H., Esslinger, G.G., Kloecker, K., Bodkin, J., Bowen, L., and Miles, A.K., eds., 2013 Update on sea otter studies to assess recovery from the 1989 *Exxon Valdez* oil spill, Prince William Sound, Alaska: U.S. Geological Survey Open-File Report 2014-1030, p. 11–16, http://dx.doi.org/10.3133/ofr20141030.

O’Clair, C.E., Freese, J.L., and Stone, R.P., 1993, Nearshore distribution and abundance of Dungeness crabs in Glacier Bay National Park, Alaska, *in* Engstrom, D.R., ed., Proceedings of the third Glacier Bay Science Symposium: National Park Service, p. 196–202.

Pitcher, K.W., 1989, Potential conflicts between sea otters and the human utilization of shellfish in southeastern Alaska: Anchorage, Alaska, Alaska Department of Fish and Game, 24 p.

Satterthwaite, F.E., 1946, An approximate distribution of estimates of variance components: Biometrics Bulletin, v. 2, p. 110–114.

Taggart, S.J., O’Clair, C.E., Shirley, T.C., and Mondragon, J., 2004, Estimating Dungeness crab (Cancer magister) abundance: crab pots and dive transects compared: Fishery Bulletin, v. 102, p. 488–497.

Thompson, S.K., 2002, Sampling: New York, Wiley, 367 p.

Tinker, M.T., Bentall, G., and Estes, J.A., 2008, Food limitation leads to behavioral diversification and dietary specialization in sea otters: Proceedings of the National Academy of Sciences, v. 105, p. 560–565.

Tinker, M.T., Guimarães Jr, P.R., Novak, M., Marquitti, F.M.D., Bodkin, J.L., Staedler, M., Bentall, G., and Estes, J.A., 2012, Structure and mechanism of diet specialization–Testing models of individual variation in resource use with sea otters: Ecology Letters, v. 15, p. 475–483.

Udevitz, M.S., Bodkin, J.L., and Costa, D.P., 1995, Detection of sea otters in boat-based surveys of Prince William Sound, Alaska: Marine Mammal Science, v. 11, p. 59–71.

Weitzman, B.P., 2013, Effects of sea otter colonization on soft-sediment intertidal prey assemblages in Glacier Bay, Alaska: Santa Cruz, University of California, Thesis, 68 p.

Welch, B. L., 1947, The generalization of "student's" problem when several different population variances are involved: Biometrika, v. 34, p. 28–35.

Appendix A. Simulation Plots

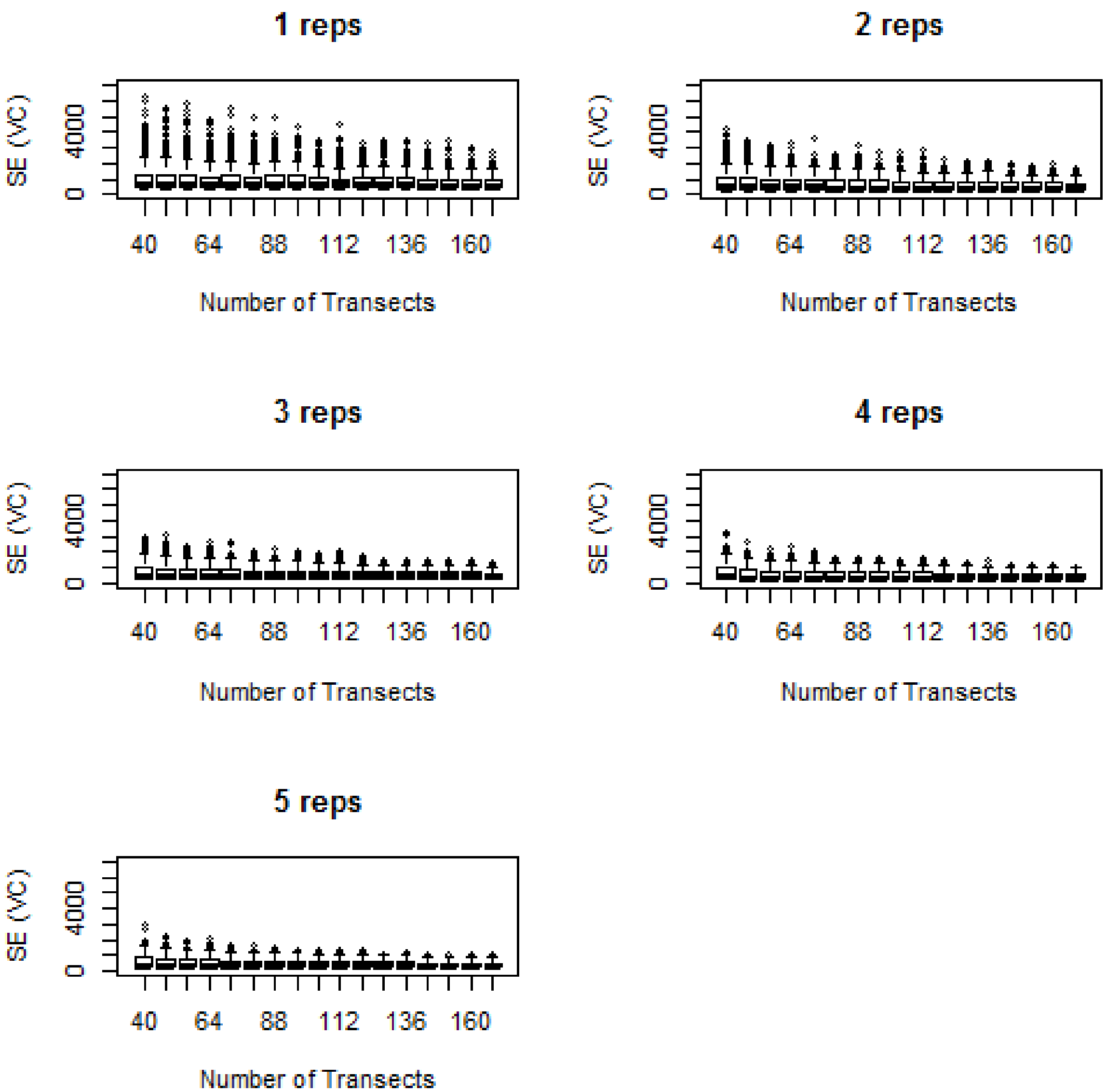


Figure A1. Boxplots of variance components (VC) standard error (SE) for 5 levels of replications and 40–168 transects per replicate survey. Boxes represent the interquartile range (IQR, the difference between the 25th and 75th percentiles) and whiskers represent 1.5*IQR and 3*IQR.

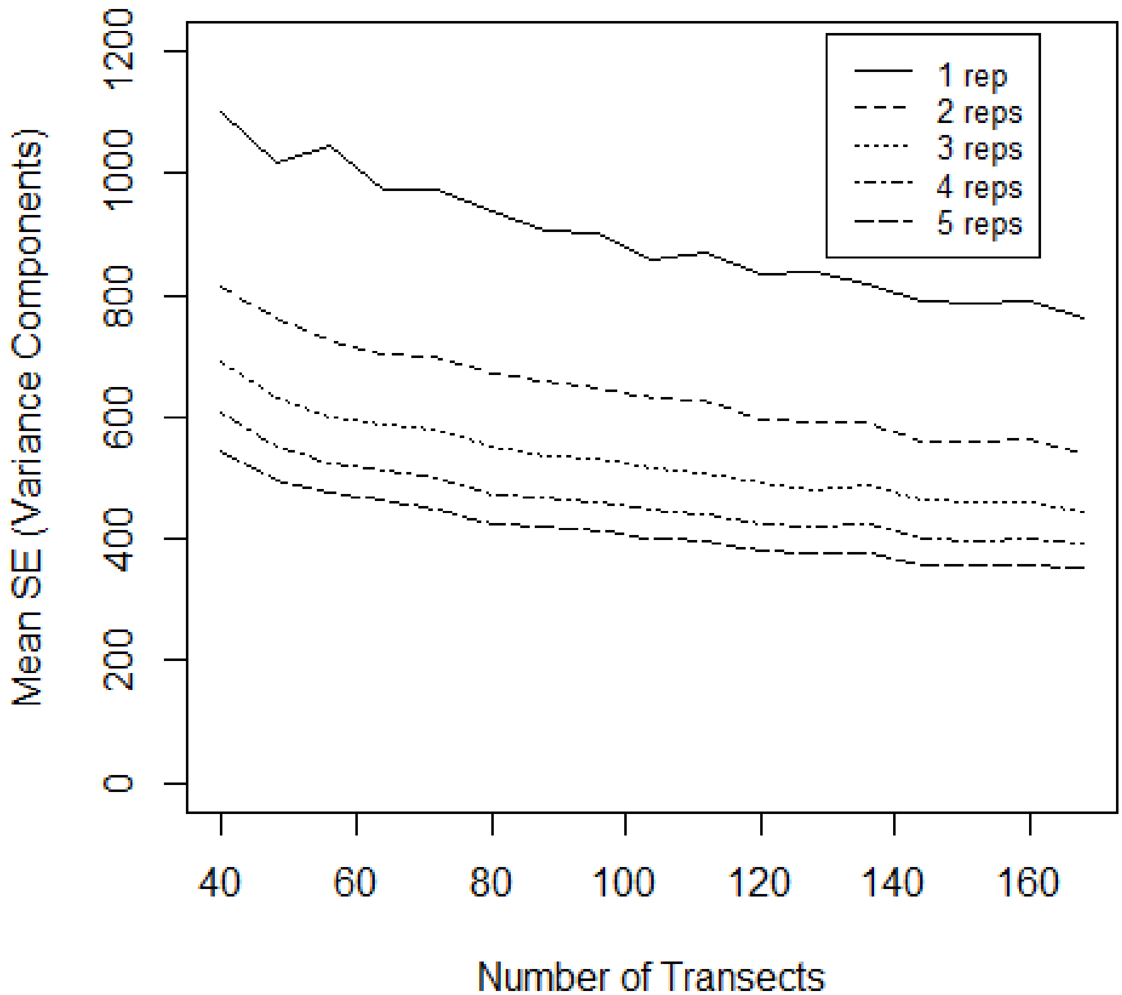


Figure A2. Graph showing mean of variance components standard error (SE) for 5 levels of replications and 40–168 transects per replicate survey.

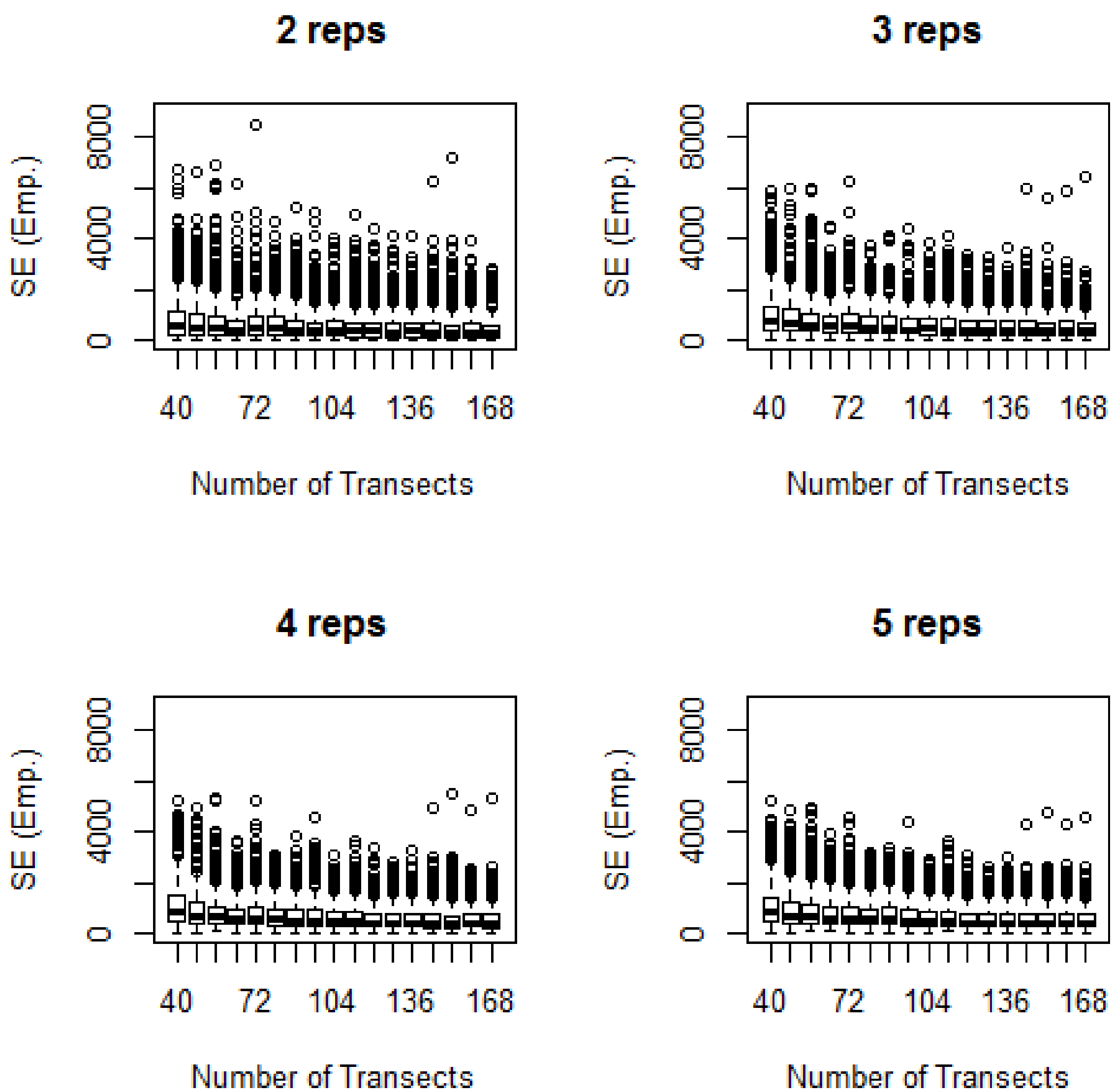


Figure A3. Boxplots of empirical variance (Emp.) standard error (SE) for 5 levels of replications and 40–168 transects per replicate survey. Boxes represent the interquartile range (IQR, the difference between the 25th and 75th percentiles) and whiskers represent 1.5*IQR and 3*IQR.

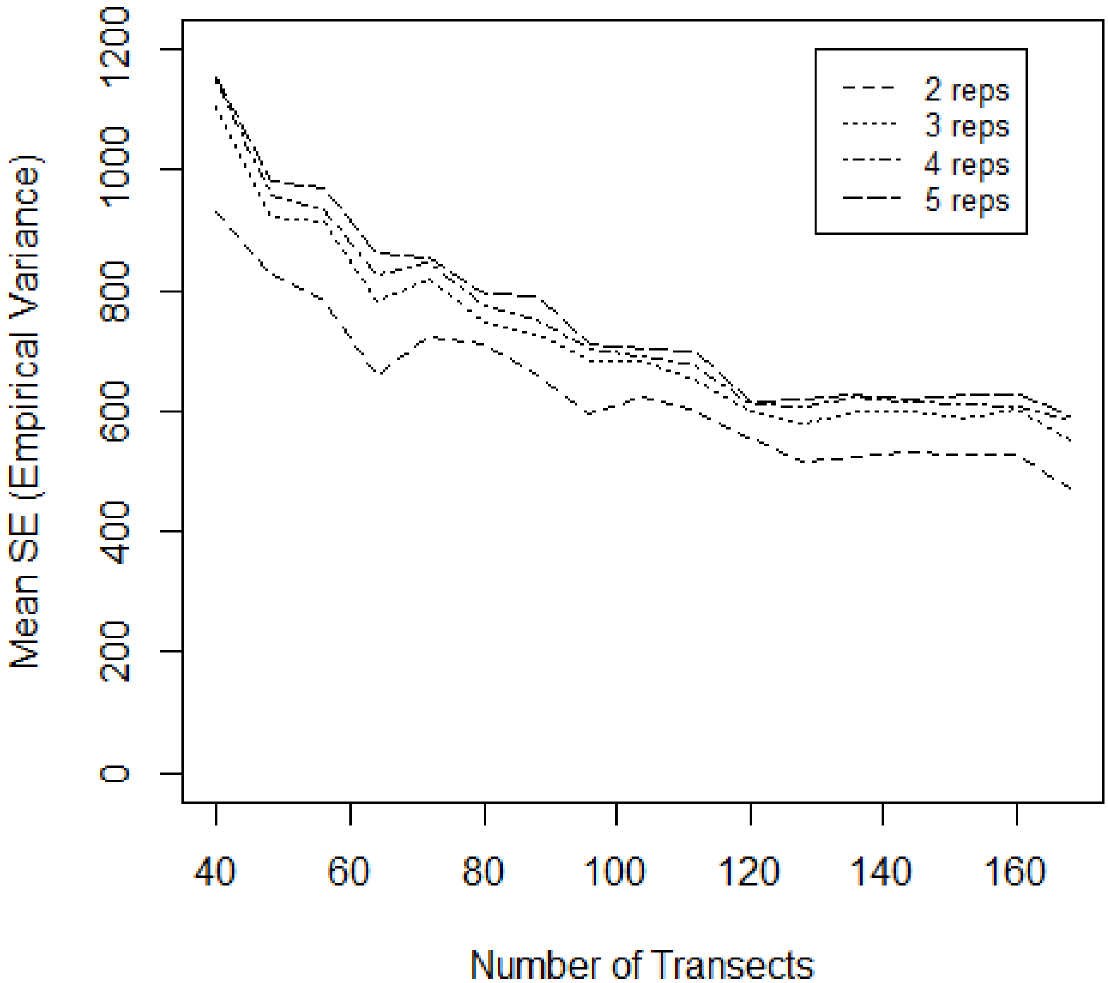


Figure A4. Graph showing mean of the empirical variance standard error (SE) for 5 levels of replications and 40–168 transects per replicate survey.

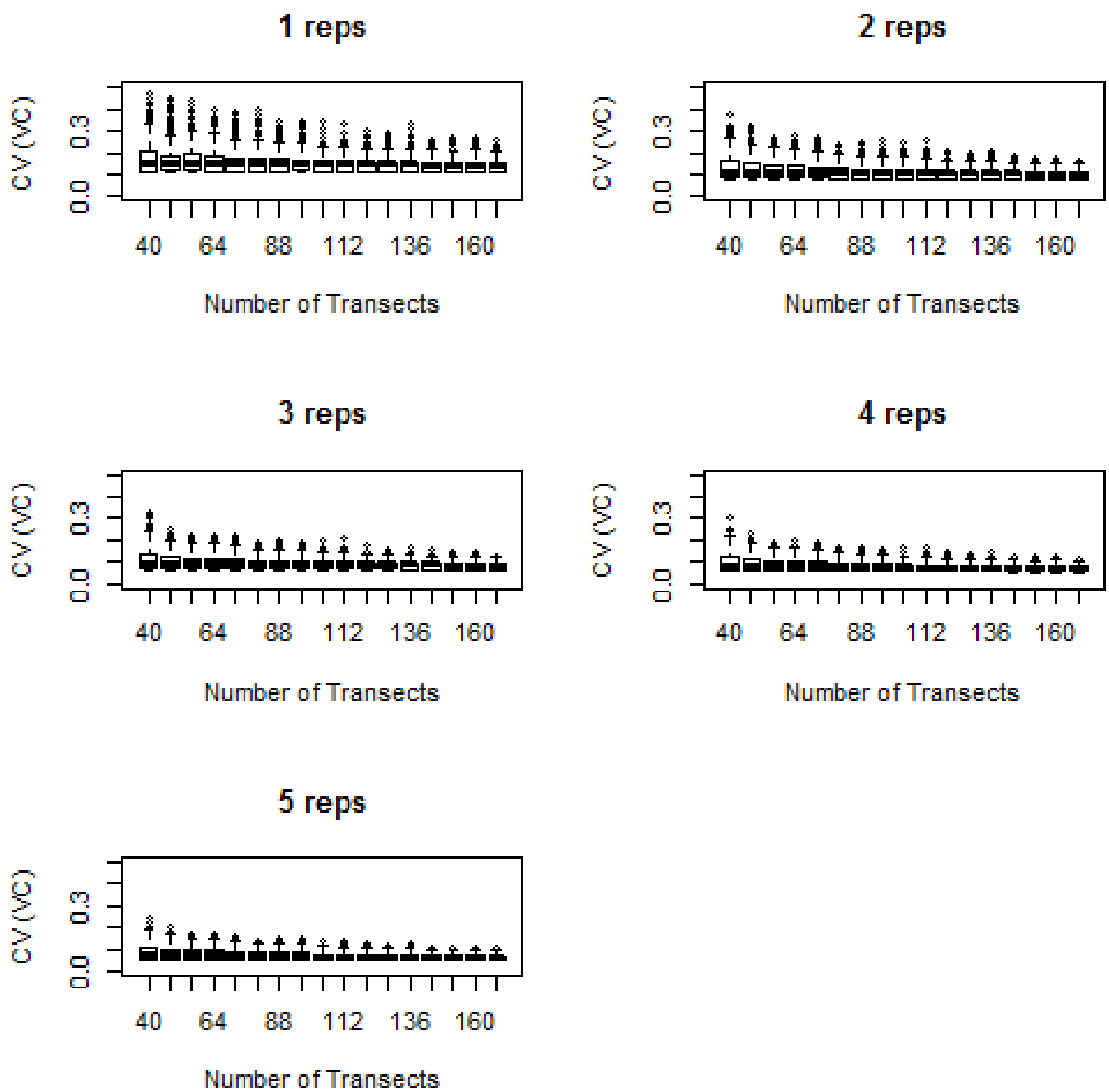


Figure A5. Boxplots of variance components (VC) coefficient of variation (CV) for 5 levels of replications and 40–168 transects per replicate survey. Boxes represent the interquartile range (IQR, the difference between the 25th and 75th percentiles) and whiskers represent 1.5*IQR and 3*IQR.

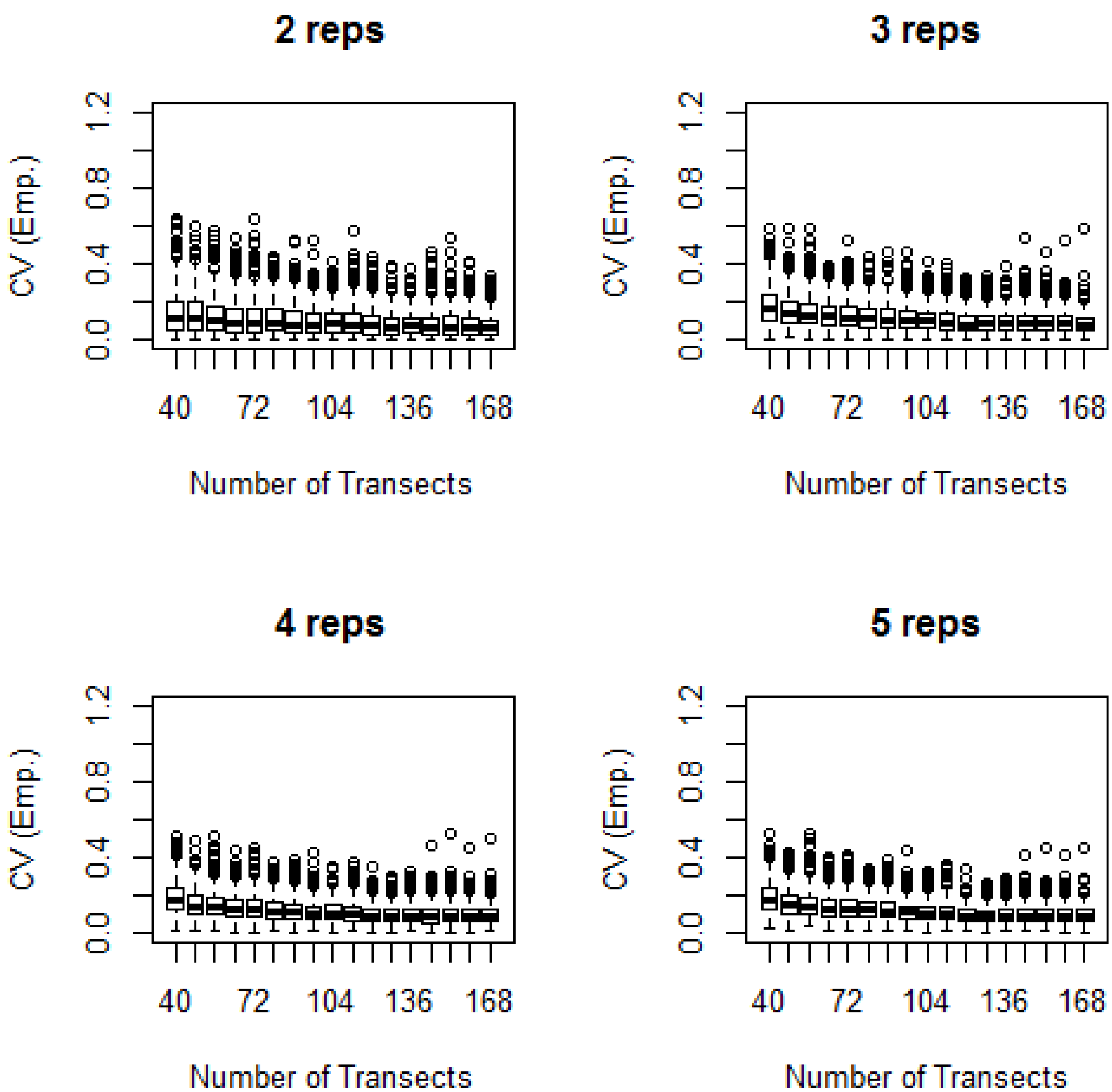


Figure A6. Boxplots of empirical (Emp.) variance coefficient of variation (CV) for 5 levels of replications and 40–168 transects per replicate survey. Boxes represent the interquartile range (IQR, the difference between the 25th and 75th percentiles) and whiskers represent 1.5*IQR and 3*IQR.

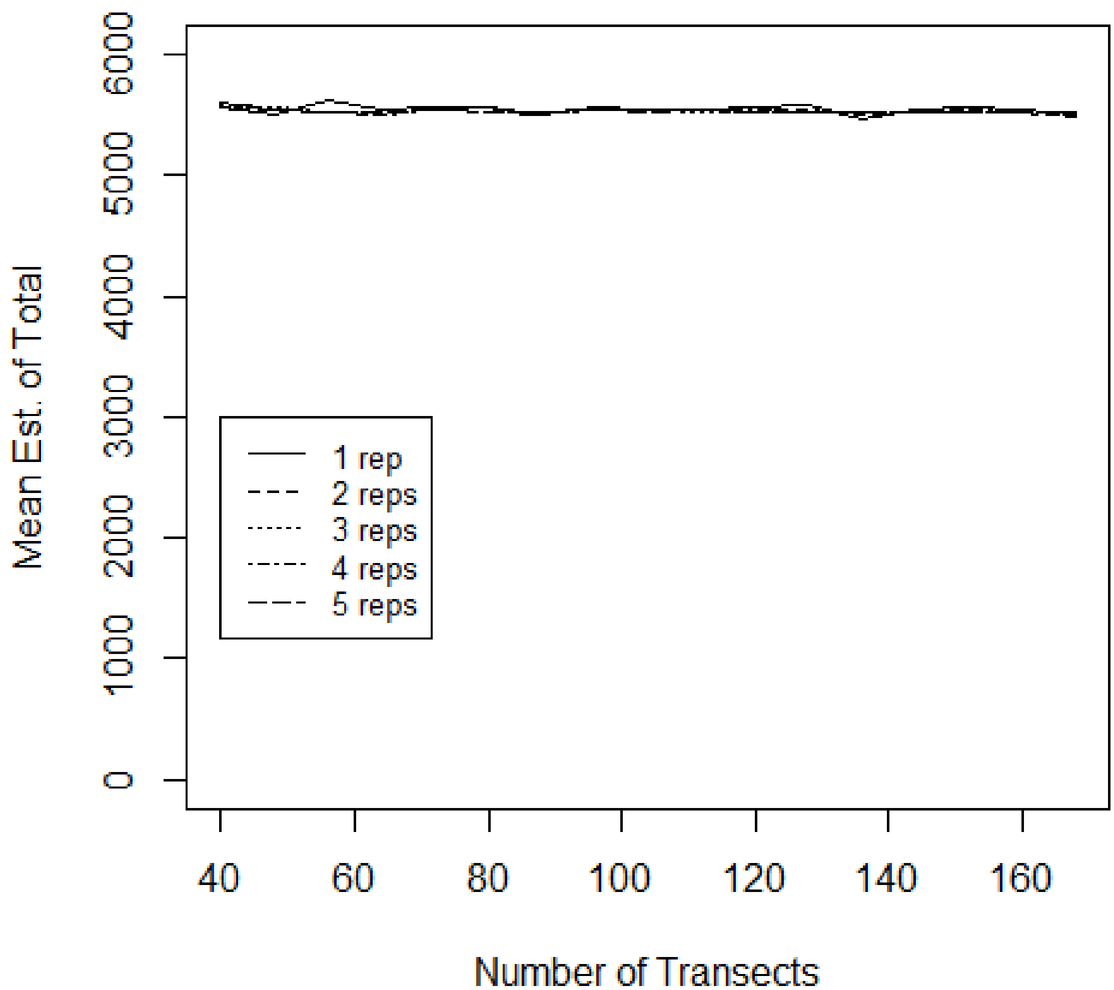


Figure A7. Graph showing mean of total population size estimates for 5 levels of replications and 40–168 transects per replicate survey.

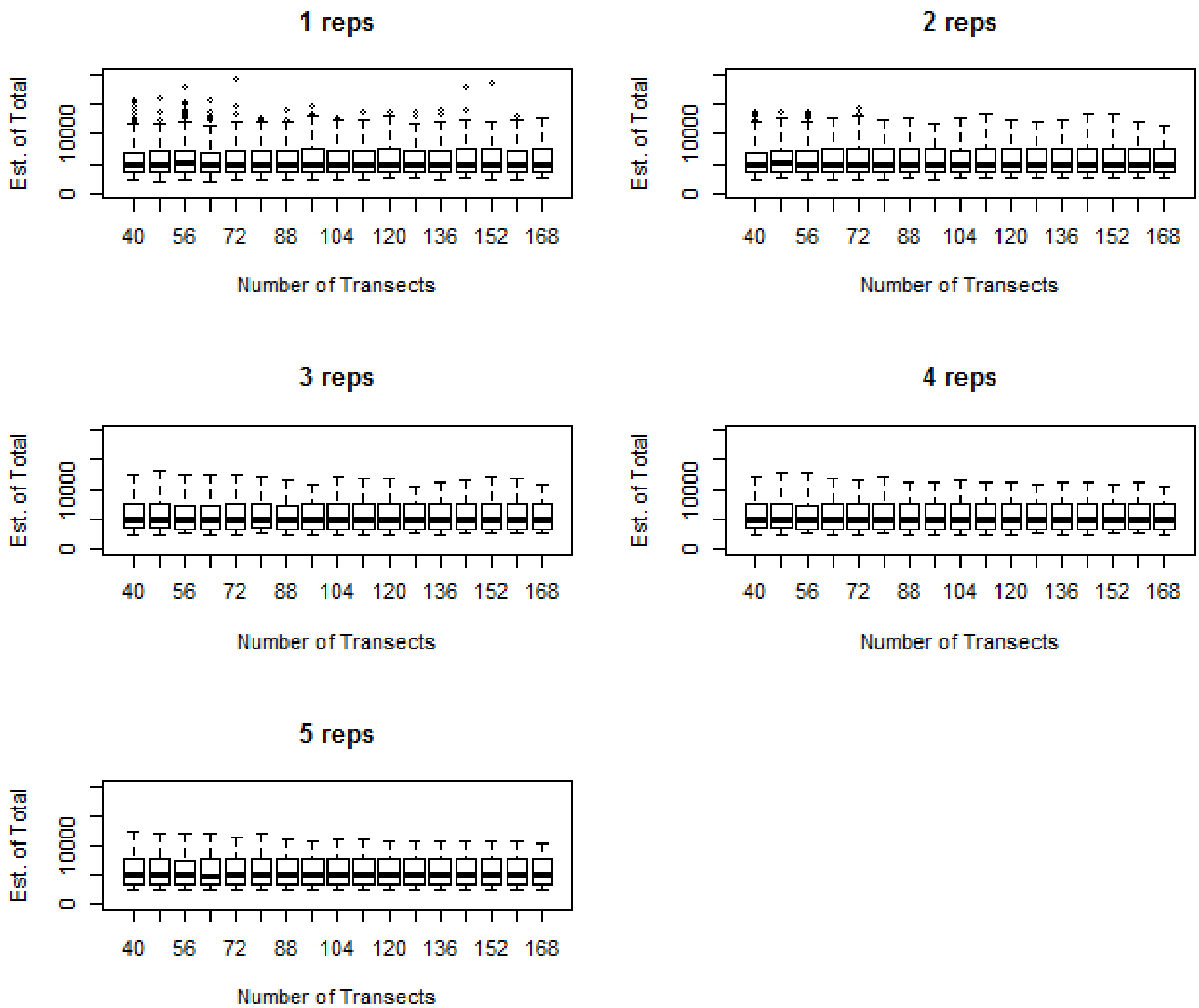


Figure A8. Boxplots of total population size estimates for 5 levels of replications and 40–168 transects per replicate survey. Boxes represent the interquartile range (IQR, the difference between the 25th and 75th percentiles) and whiskers represent 1.5*IQR and 3*IQR.

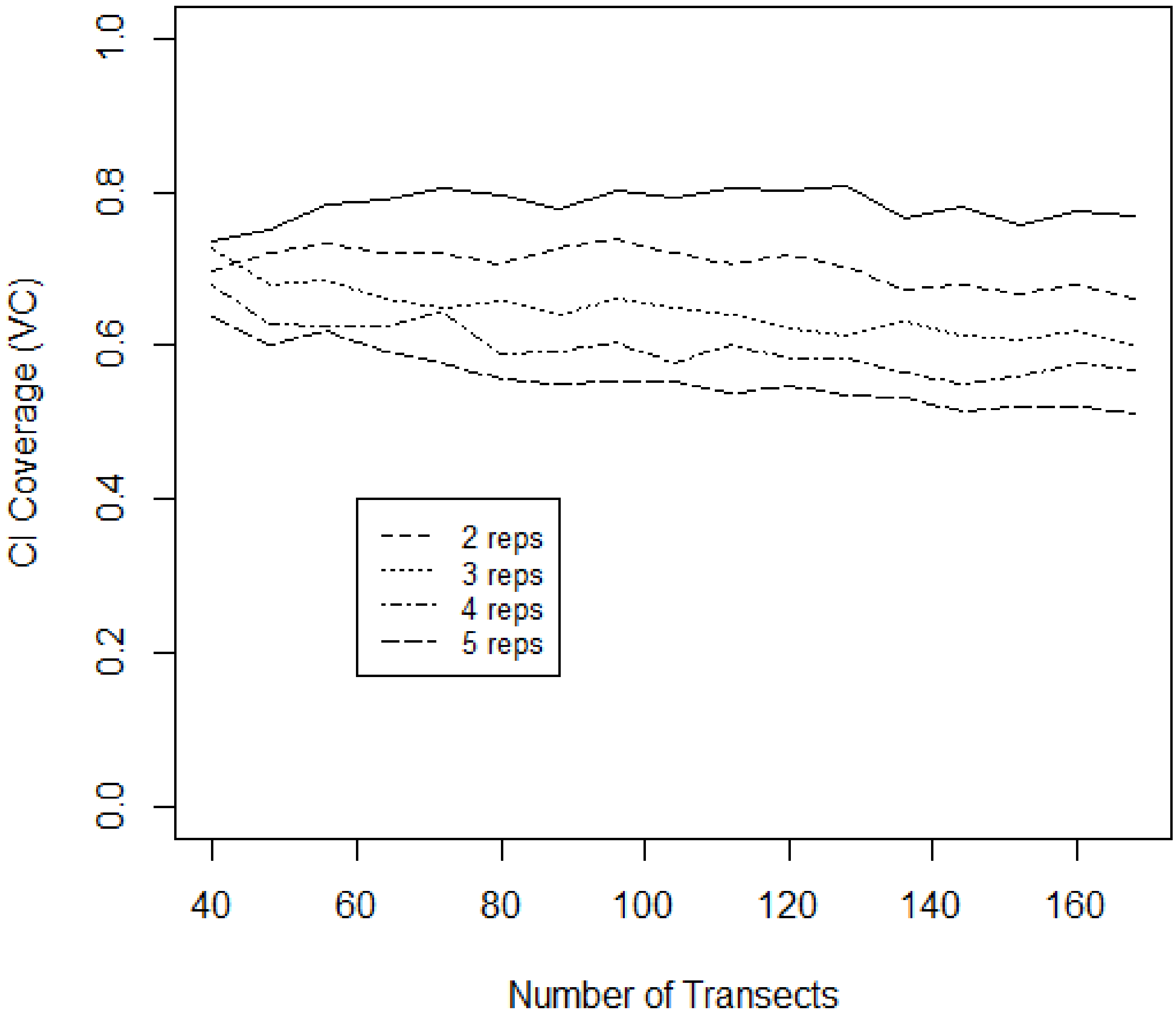


Figure A9. Graph showing 95-percent confidence interval (CI) coverage for the variance components (VC) estimate of standard error (SE) for 5 levels of replications and 40–168 transects per replicate survey.

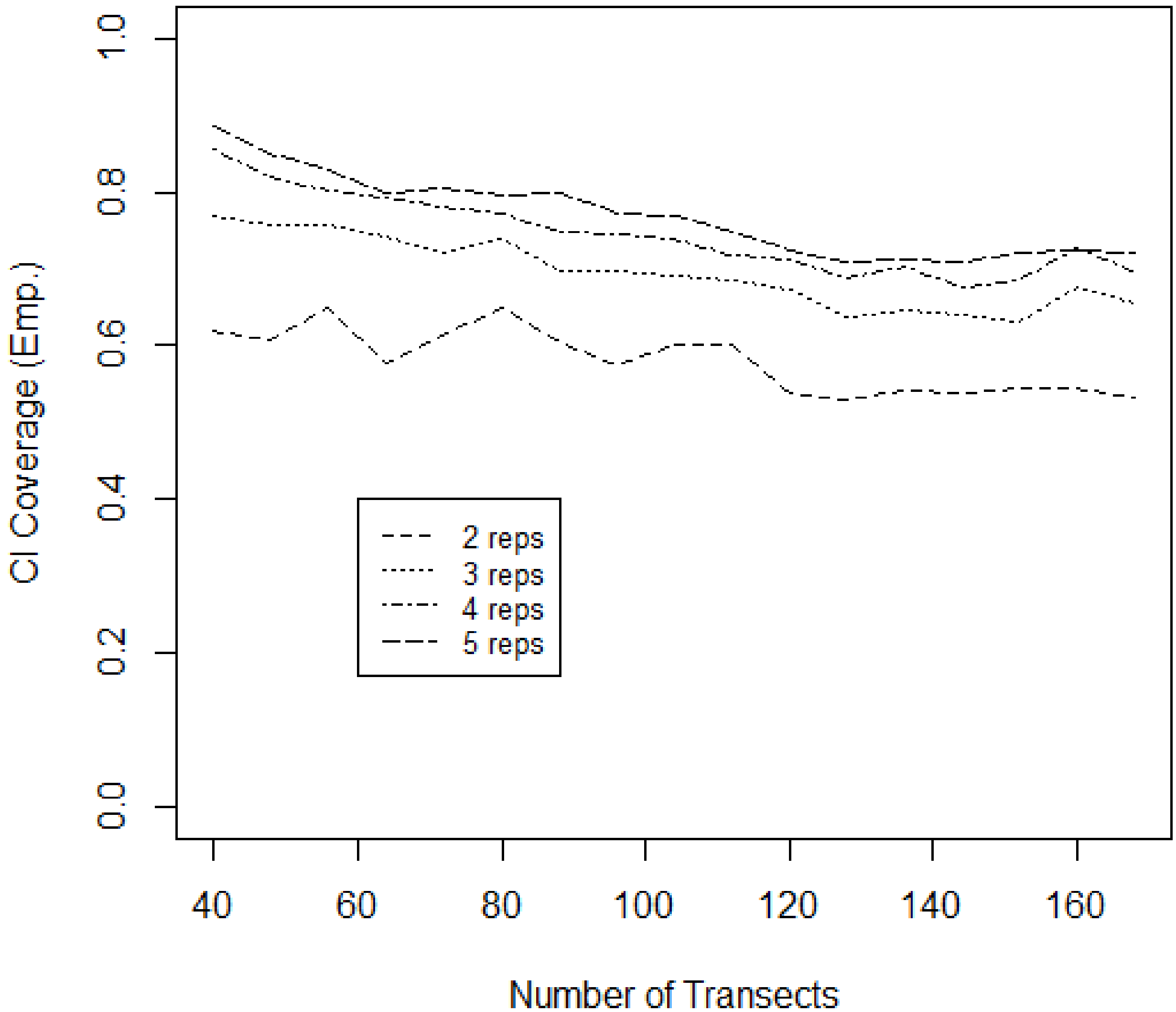


Figure A10. Graph showing 95-percent confidence interval (CI) coverage for the empirical variance estimate (Emp.) of standard error (SE) for 5 levels of replications and 40–168 transects per replicate survey.

Publishing support provided by the U.S. Geological Survey
Publishing Network, Tacoma Publishing Service Center

For more information concerning the research in this report, contact the
Director, Alaska Science Center
U.S. Geological Survey
4210 University Dr
Anchorage, Alaska 99508-4560
http://alaska.usgs.gov

USGS

Esslinger and others—**Monitoring Population Status of Sea Otters in Glacier Bay National Park and Preserve, Alaska**—Open-File Report 2015–1119

ISSN 2331-1258 (online)
http://dx.doi.org/10.3133/ofr20151119