Prepared in cooperation with the U.S. Fish and Wildlife Service

Abundance and Distribution of Sea Otters (*Enhydra lutris*) in the Southcentral Alaska Stock, 2014, 2017, and 2019

Open-File Report 2021–1122

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

Cover. Aerial photograph showing sea otters resting along the coast of Katmai National Park and Preserve, Alaska. Photograph by Daniel Monson, U.S. Geological Survey, July 11, 2018.

Inset. Sea otter (*Enhyra lutris*) resting near Homer, Alaska. Photograph by Nicole LaRoche, U.S. Geological Survey, May 7, 2021.

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Esslinger, G.G., Weitzman, B.P, and Robinson, B.H., 2021, Sea otter aerial survey data from northern and eastern Prince William Sound, Alaska, 2014: U.S. Geological Survey data release, https://doi.org/10.5066/p9OG6SR5.

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Speed	
meter per second (m/s)	3.281	foot per second (ft/s)

Abbreviations

ISU intensive search unit

SCAK southcentral Alaska

SE standard error

PWS Prince William Sound

Abundance and Distribution of Sea Otters (*Enhydra lutris*) in the Southcentral Alaska Stock, 2014, 2017, and 2019

By George G. Esslinger[1], Brian H. Robinson[1], Daniel H. Monson[1], Rebecca L. Taylor[1], Daniel Esler[1], Benjamin P. Weitzman[2], and Joel Garlich-Miller[2]

Abstract

The Southcentral Alaska (SCAK) sea otter (*Enhydra lutris*) stock is the northernmost stock of sea otters, a keystone predator known for structuring nearshore marine ecosystems. We conducted aerial surveys within the range of the SCAK sea otter stock to provide recent estimates of sea otter abundance and distribution. We defined three survey regions: (1) Eastern Cook Inlet (2017), (2) Outer Kenai Peninsula (2019), and (3) Prince William Sound (2014 and 2017). Combined, the three regional estimates yielded an overall abundance estimate of 21,617 sea otters (standard error [SE] = 2,190) with an average density of 1.96 sea otters per square kilometer (km^2; SE = 0.55). Sea otters were distributed unevenly across the survey regions and densities varied from 0.52 sea otters/km^2 (SE = 0.18) in the deep rock-walled glacial fjords along parts of the Outer Kenai Peninsula to nearly 20 sea otters/km^2 (SE = 6.70) in shallow soft-bottom communities such as those in Orca Inlet and Kachemak Bay. These survey results represent the best available contemporary information concerning the distri-bution, density, and abundance of sea otters across the range of the SCAK stock. Survey data files have been standardized and formatted in data releases associated with this report so that they can be queried and displayed with standard geographic information system and database management software. In addition to providing contemporary information on sea otter populations, this report details how an observer-based aerial survey method has been applied in Alaska over 2 decades.

Introduction

Southcentral Alaska (SCAK) is home to the northernmost stock (Gorbics and Bodkin, 2001) of the sea otter (*Enhydra lutris*), a keystone predator that serves an important role in structuring the nearshore marine ecosystem (Estes and Palmisano, 1974). Southcentral Alaska is also home to Alaska's largest concentration of humans, with a well-developed road and marine highway system linking multiple coastal communities. This co-location of sea otters and humans in SCAK has not only made sea otters an important resource for tour operators and subsistence hunters, but also has caused conflicts with local shellfisheries (Garshelis and Garshelis, 1984) and has made sea otters vulnerable to human-induced impacts such as oil spills (Esler and others, 2018). Given their role as keystone predators and susceptibility to marine pollutants, sea otters also are considered indicators of nearshore ecosystem health (Jessup and others, 2004; Goertz and others, 2013).

Measures of abundance and distribution that can be compared over time to establish trends are central to assessing the status of wildlife populations. As managing and research partners, the U.S. Fish and Wildlife Service and U.S. Geological Survey share a mutual interest in monitoring and assessing the status of sea otter populations. The purpose of this report is to provide estimates of contemporary sea otter abundance and distribution within the boundaries of the SCAK stock, using the most recent surveys for each sub-region. Here, we summarize results from aerial surveys conducted in 2014, 2017, and 2019 within the boundaries of the SCAK sea otter stock in the following three survey regions and, through compilation, most of the SCAK area (fig. 1): (1) Eastern Cook Inlet, (2) Outer Kenai Peninsula, and (3) Prince William Sound (PWS). These survey results have been standardized and formatted and are available for use by management agencies and other interested parties (Esslinger, Monson, and Robinson, 2021a, 2021b; Esslinger, Weitzman, and Robinson, 2021a, 2021b).

[1]U.S. Geological Survey

[2]U.S. Fish and Wildlife Service

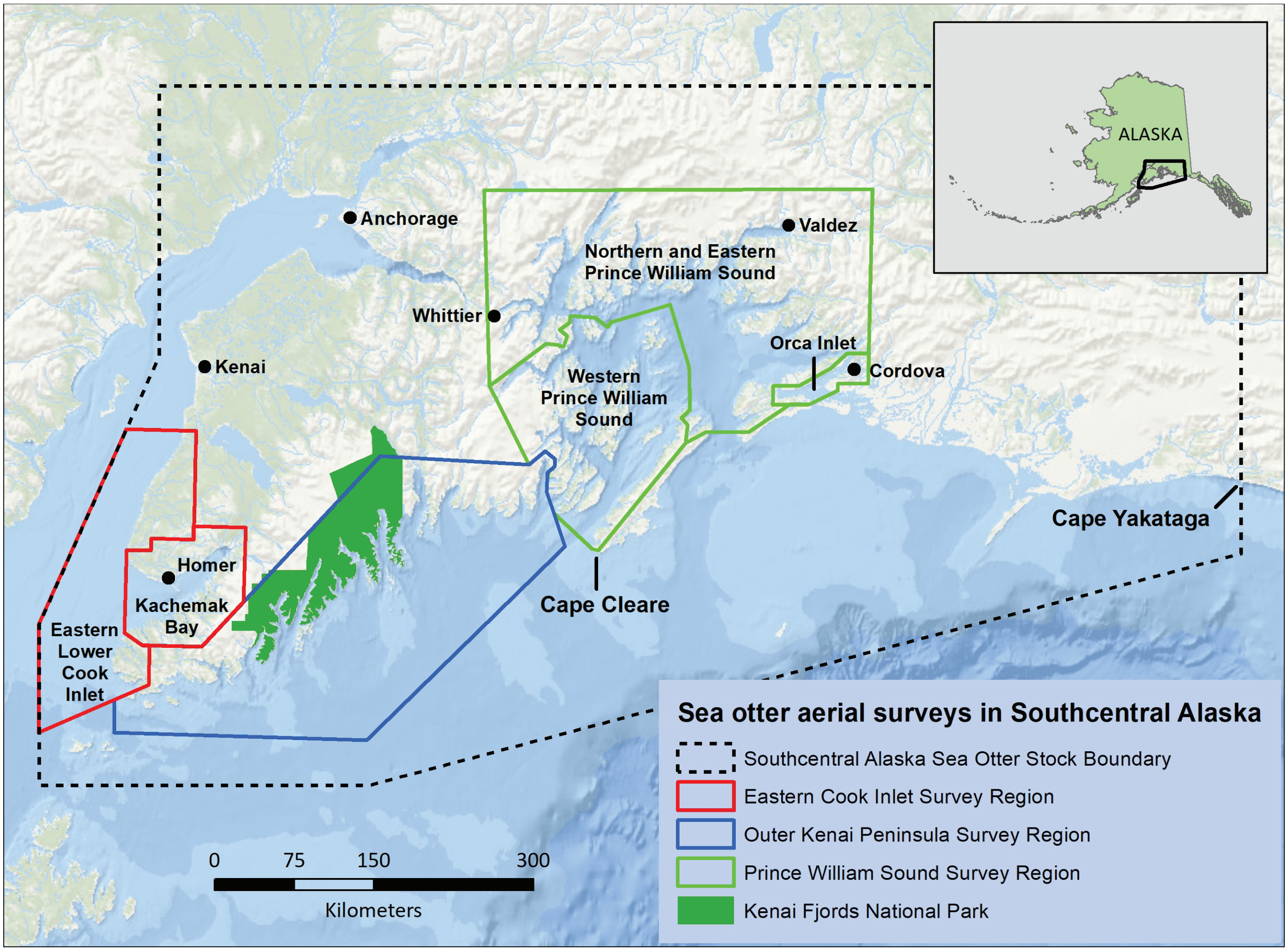

Figure 1. Image of southcentral Alaska showing sub-regional sea otter aerial survey boundaries. Ocean background image source: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors.

Methods

Standard Population Size Survey Methods

Here we describe an aerial survey method for estimating sea otter abundance in Alaska as it is currently conducted and has been conducted for many years. Most survey standardization occurred by 1999, although complete standardization of the "large group" definition did not occur until 2008. We conduct aerial surveys based on systematically placed strip transects within a stratified sampling design. These surveys are designed and field tested specifically for estimating sea otter abundance and account for sightability and availability bias (Bodkin and Udevitz, 1999). All surveys are conducted by a trained, experienced observer seated behind a pilot in a single-engine high-wing floatplane. The pilot flies transects at an altitude of 91 meters (m) and an airspeed of 29 meters per second while the observer counts sea otters within a 400-m strip of water, delineated by marks on the wing struts on one side of the plane.

Consistent with prior aerial surveys, we divide the surveyed area into two strata, high otter density habitat and low otter density habitat, based on water depth and distance from shore (Bodkin and Udevitz, 1999; Esslinger and others, 2014). Sea otters forage by diving for benthic prey in water as deep as 100 m, but most foraging occurs in depths less than (<) 30 m (Bodkin and others, 2004). Sea otters rest on the surface and sometimes drift over water deeper than 100 m, particularly in bays and glacial fjords. To reflect these behaviors, we define the high-density stratum as water 40 m deep or less out to 400 m from shore, whichever was greater. We also designate high-density habitat in areas where large groups of sea otters are known to rest offshore, such as bays and inlets with entrances narrower than 6 kilometers (km) and glacial fjords (for example, College Fjord, Prince William Sound [PWS]). The low-density stratum encompasses waters between the high-density stratum and 100 m depth contour or 2 km from

shore, whichever is greater. We place transects systematically throughout each stratum by randomizing the lower-left corner of the transect grid and, depending on the size of the survey area, adjusting the spacing between transects from 3 to 12 km apart until roughly 80 percent of the total transect length falls within the high-density stratum and 20 percent falls within the low-density stratum.

The surveyed area of each stratum j is defined as the sum of the areas of all n_j transects in the stratum $\left(a_{\bullet j} = \sum_{i=1}^{n_j} a_{i,j}\right)$, where each transect area $\left(a_{i,j}\right)$ is the length of that transect multiplied by the strip width (400 m). The number of otters estimated to occupy the surveyed area of stratum j is given by adding the number of otters seen in large groups over all n_j transects $\left(y^L_{\bullet j} = \sum_{i=1}^{n_j} y^L_{i,j}\right)$, with the detection-adjusted number of otters seen in small groups over all n_j transects $\left(\hat{p}y^s_{\bullet j} = \hat{p}\sum_{i=1}^{n_j} y^S_{i,j}\right)$. Thus, $y^L_{i,j}$ represents the number of otters seen in large groups on transect i of stratum j, and $y^S_{i,j}$ represents the number of otters seen in small groups on transect i of stratum j. A group is defined as one or more sea otters spaced less than three otter lengths apart. Large groups were initially defined as ≥30 otters (Bodkin and Udevitz, 1999), but later as ≥20 otters. This change was mostly implemented by 1999, but did not become completely consistent until 2008. The survey-wide correction factor for otters in small groups $\left(\hat{p}\right)$ is the reciprocal of the detection probability obtained through the intensive search units described below.

The estimated number of otters $\left(\hat{Y}_j\right)$ in all of stratum j (surveyed area plus unsurveyed area), is the number of otters estimated to occupy the surveyed area of stratum j multiplied by the ratio of the total stratum area (A_j) to the surveyed stratum area $\left(a_{\bullet j}\right)$. Thus,

$$\hat{Y}_j = \left(\frac{A_j}{a_{\bullet j}}\right)\left(y^L_{\bullet j}\right) + \left(\frac{A_j}{a_{\bullet j}}\right)\left(y^s_{\bullet j}\right)\left(\hat{p}\right) = \hat{Y}^L_j + \hat{Y}^S_j\left(\hat{p}\right), \quad (1)$$

where

$\hat{Y}^L_j$ includes the area adjustment for the number of otters in large groups, and

$\hat{Y}^S_j$ includes the area adjustment for the number of otters in small groups, but it does not include the correction factor for incomplete detection.

The population size estimate for the survey $\left(\hat{Y}\right)$ is the sum of the population size estimates for the two strata; that is, $\hat{Y} = \sum_{j=1}^{2} \hat{Y}_j$

Otters that form large groups generally are resting on the surface, making them easy to photograph or to fully enumerate by circling with the aircraft and then returning to the transect (complete count). Thus, these individuals are detected with probability 1. Although the definition of a large group varied over time, data sheets were always annotated to indicate which groups were considered large and therefore completely counted. The detection probability for otters in small groups is based on intensive search units (ISUs) conducted throughout the survey.

An ISU is a 400-m length of transect that initially is flown as part of the strip transect and searched intensively immediately thereafter to give the observer a chance to detect additional sea otters (for example, camouflaged by kelp or returning to the surface from diving). An ISU can only be initiated when a small group of otters is seen on the transect. This group is termed the initiating group, and the ISU type is termed "conditional" (Bodkin and Udevitz, 1999). Observers try to obtain approximately 20 "usable" ISUs (see below) per survey, which usually results in ISUs being conducted about every 15 minutes, depending on otter density and total time dedicated to the survey effort. Each ISU consists of five concentric circles that begin when the on-transect airplane is perpendicular to the initiating group of otters. For each group in each ISU, the observer records the number of sea otters observed during the strip count (strip otters) and the circle counts (circle otters) separately. The number of strip otters in a group may be positive or zero. The statistical method assumes that the number of circle otters in a group is positive and includes the number of strip otters in that group. Rarely, in the case of observer error, the number of strip otters in a group may be slightly greater than the number of circle otters, but the effect of this is negligible after the ISU data are summed (see eq. 2 below.) Otters that swim into an ISU after-the-fact are not included.

Numbers of strip otters and circle otters seen in ISUs in both strata are used to calculate the correction factor $\left(\hat{p}\right)$, which is the inverse of the detection probability. Because each ISU is conditioned on the presence of an initiating group, the initiating group is, by definition, seen with probability 1. Thus, it cannot be used to calculate the correction factor. In particular, the correction factor is defined as a function of the number of strip otters in each ISU (s^*_i), the number of strip otters in each ISU's initiating group (s^1_i), the number of circle otters in each ISU (c^*_i) and the number of circle otters in each ISU's initiating group (c^1_i). Defining $c_i = c^*_i - c^1_i$ and $s_i = s^*_i - s^1_i$, the survey-wide correction factor is then

$$\hat{p} = \frac{\sum_{i=1}^{t} c_i}{\sum_{i=1}^{t} s_i}, \quad (2)$$

where

t is the number of usable ISUs; that is, the number of ISUs where more than one otter group (the initiating group) was seen.

Just as the survey's population size estimate is summed over both strata and both group sizes, so is its variance. In particular,

$$var\left(\hat{Y}\right)=\sum_{j=1}^{2}\left[var\left(\hat{Y}_j^L\right)+\ var\left(\ \hat{Y}_j^S\left(\hat{p}\right)\right)\right], \qquad (3)$$

where

$$var\left(\ \hat{Y}_j^S\left(\hat{p}\right)\right)=\left(\ \hat{Y}_j^S\right)^2 var\left(\hat{p}\right)$$
$$+\left(\hat{p}\right)^2 var\left(\ \hat{Y}_j^S\right)-var\left(\ \hat{Y}_j^S\right)var\left(\hat{p}\right), \text{ and} \qquad (4)$$

$$var\left(\hat{p}\right)=\frac{t_j\sum_{i=1}^{t_j}\left(c_{i,j}-\hat{p}s_{i,j}\right)^2}{\left(t_j-1\right)s_{\bullet j}^2}. \qquad (5)$$

Because the same variance formula applies to $\hat{Y}_j^L$ and $\hat{Y}_j^S$, we use $\hat{Y}_j$ in the formula below to denote either one. Thus,

$$var\left(\hat{Y}_j\right)=\frac{n_j A_j^2\left(1-\frac{a_{\bullet j}}{A_j}\right)}{a_{\bullet j}^2\left(n_j-1\right)}\sum_{i=1}^{n_j}\left(y_{i,j}-\frac{a_{i,j}y_{\bullet j}}{a_{\bullet j}}\right)^2. \qquad (6)$$

When funding and logistics permit, we sometimes survey an area multiple times to increase precision of our estimates. In this case, each survey is a transect grid with the same spacing, but the lower left corner is located at a random distance between 1 m and the specified spacing between transects. We obtain the final abundance estimate for the area as the mean of the survey-specific abundance estimates, and the variance of this mean is given by summing the variances of all the surveys and dividing by the square of the number of surveys conducted.

Site-Specific Survey Details

In this section we detail methods specific to the surveys in this report.

Eastern Cook Inlet

To estimate abundance and distribution in Eastern Cook Inlet, we used a float-equipped American Champion® 8GCBC Scout to survey two sub-regions, Eastern Lower Cook Inlet and Kachemak Bay, during May 4–19, 2017. For the Eastern Lower Cook Inlet sub-region (fig. 1), we flew three surveys, each using a different transect layout, over the high-density stratum (Garlich-Miller and others, 2018). Unlike a similar aerial survey in 2002, we did not survey the low-density stratum because of safety concerns associated with flying a single engine airplane at low altitude, far from shore. Based on a prior distribution survey and anecdotal reports, we did not conduct abundance surveys north of Clam Gulch (upper Cook Inlet) because few sea otters were present in this region. For the Kachemak Bay sub-region (fig. 1), we classified the entire bay as high-density stratum and surveyed four different sets of transects (Garlich-Miller and others, 2018).

Outer Kenai Peninsula

To estimate sea otter abundance and distribution in the waters adjacent to Kenai Fjords National Park, we conduct aerial surveys regularly as part of the Gulf Watch Alaska long-term monitoring program (Coletti and others, 2016). In 2019, we expanded the survey area to include gaps between Kenai Fjords National Park and Cook Inlet to the west and PWS to the east (fig. 1) and surveyed the whole outer coast of the Kenai Peninsula with a Piper PA-18 Super Cub on floats from June 12 to 18.

Prince William Sound

To estimate sea otter abundance and distribution in PWS, we combined the results of two separate survey efforts, both done from an American Champion 8GCBC Scout on floats. From June 19 to 24, 2014, we surveyed one set of transects in the Northern and Eastern PWS sub-region (fig. 1). Consistent with our prior aerial surveys (Bodkin and Dean, 2000), we identified Orca Inlet (fig. 1) as a sub-region within PWS owing to unique shallow soft-bottom habitat and high sea otter densities and provide a separate sea otter abundance estimate for that sub-region. Western PWS (fig. 1), where substantial sea otter mortality occurred during the 1989 Exxon Valdez oil spill (Ballachey and others, 1994), has been surveyed regularly as part of Gulf Watch Alaska long-term monitoring program and, therefore, was treated as a separate sub-region. The most recent survey occurred during May 25–30, 2017, when we surveyed two sets of transects in Western PWS.

Spatial Distribution of Otters—Spot Maps and Heat Maps

Spot Maps

Spot maps show the distribution of sea otter sightings as spots scaled relative to group size. Where multiple surveys were flown (Eastern Cook Inlet and Western PWS), we show only the first replicate to standardize the number of surveys across the SCAK sea otter stock.

Heat Maps

We created heat maps to show variation in relative densities of sea otters within each region and for SCAK overall. The heat maps depicting kernel density estimation provide a

means to visualize relative spatial density of sea otters and are not intended to depict true density. We only included sea otters observed on transect because otter sightings off-transect were made opportunistically and documentation was not standardized. When an area was surveyed multiple times, we combined observations from all surveys unless transects overlapped, which only occurred in Kachemak Bay. When two transects overlapped, we only included sea otter sightings from the first transect. Given the difference in transect spacing between the high and low-density strata in the Outer Kenai Peninsula and PWS regions, we performed a cross-validation analysis and noted no perceivable difference in how well the model predicted sea otter densities in the two strata. Nonetheless, the kernel smoothing method used to create heat maps can produce higher densities in areas immediately adjacent to sea otter hot spots, regardless of habitat quality. Sea otter density heat maps were created using Program R (R Core Team, 2020) with ggplot2 (Wickham, 2016). Two-dimensional kernel density was estimated with an axis-aligned bivariate normal kernel. The bandwidth used in the kernel density estimator was selected using a normal reference distribution with a multiplicative bandwidth adjustment to each heat map to account for differing spatial scales (Venables and Ripley, 2002). Base maps used in these heat maps were created with R package Ptolemy (London, 2018), using data obtained from the Global, Self-consistent, Hierarchical, High-resolution Geography Database (Wessel and Smith, 1996).

Summary of Aerial Survey Results by Region

Standardized survey data for the three survey regions are available (Esslinger, Monson, and Robinson, 2021a, 2021b; Esslinger, Weitzman, and Robinson, 2021a, 2021b). Each survey region has three comma-separated value (CSV) data files and two metadata files that contain the following information:

- Strip transect counts with sea otter group location coordinates,
- ISU counts,
- Transect starting and end point coordinates, and
- Metadata in html and xml format that describes each data field.

Eastern Cook Inlet

In Eastern Lower Cook Inlet, sea otters were broadly distributed over the shelf defining the high-density stratum north and south of Anchor Point (figs. 2–3) at a mean density of 1.89 sea otters/km^2 (SE = 0.41; table 1). During the surveys, several sea otters were observed just beyond the offshore boundary of the high-density stratum and were recorded as off-transect but were not included in our analyses. We also observed small numbers of sea otters north of the survey area during a distribution survey (see Garlich-Miller and others, 2018). In Kachemak Bay, we observed sea otters distributed throughout the bay (fig. 2) at a mean density of 6.37 sea otters/km^2 (SE = 0.80; table 1) with higher densities on the north side (fig. 3). We estimated a total of 9,152 sea otters (SE = 1,020) for all of Eastern Cook Inlet at an average density of 3.50 sea otters/km^2 (SE = 0.39; table 1). A more detailed summary of these surveys is available in Garlich-Miller and others (2018).

Outer Kenai Peninsula

In the Outer Kenai Peninsula region, most sea otter sightings were loosely spread along the western half of the survey area with clusters near Port Dick, Nuka Island, and McCarty Fjord (figs. 4–5). We observed 148 sea otters in the high-density stratum and no sea otters in the low density stratum (table 2). A large group of more than 200 sea otters was sighted off-transect just offshore of the northwest corner of East Chugach Island (fig. 4), which was at least six times greater than any other sea otter group sighted in the Outer Kenai Peninsula region. We estimated that 1,620 sea otters (SE = 557) were living along the Outer Kenai Peninsula with an average density of 0.52 sea otter/km^2 (SE = 0.18; table 2).

Prince William Sound

In PWS, we observed large concentrations of sea otters at the confluence of Barry Arm and College Fjord, Green Island, and Orca Inlet (figs. 6–7). At nearly 20 sea otters/km ^{2}, Orca Inlet contains the highest known density of sea otters in SCAK (table 3). Combining the 2 survey years, we estimated a total of 10,845 (SE = 1,856) sea otters for PWS with an average density of 2.03 sea otters/km^2 (SE = 0.35; table 3).

Abundance Estimate for Southcentral Alaska

At the scale of SCAK, sea otters were unevenly distributed across all three regions (fig. 8) with the greatest relative densities in Kachemak Bay and Orca Inlet (fig. 9). Combined, the three regional estimates yielded an abundance estimate of 21,617 (SE = 2,190) sea otters and an average density of 1.96 sea otters/km^2 (SE = 0.20; table 4). We were unable to survey all areas of sea otter habitat across SCAK because of safety and logistical concerns. This abundance estimate for the SCAK stock of Northern sea otters does not include information from offshore areas (low density stratum) of Lower Cook Inlet, the Barren Islands, or along the outer coast from Cape Cleare to Cape Yakataga (fig. 1).

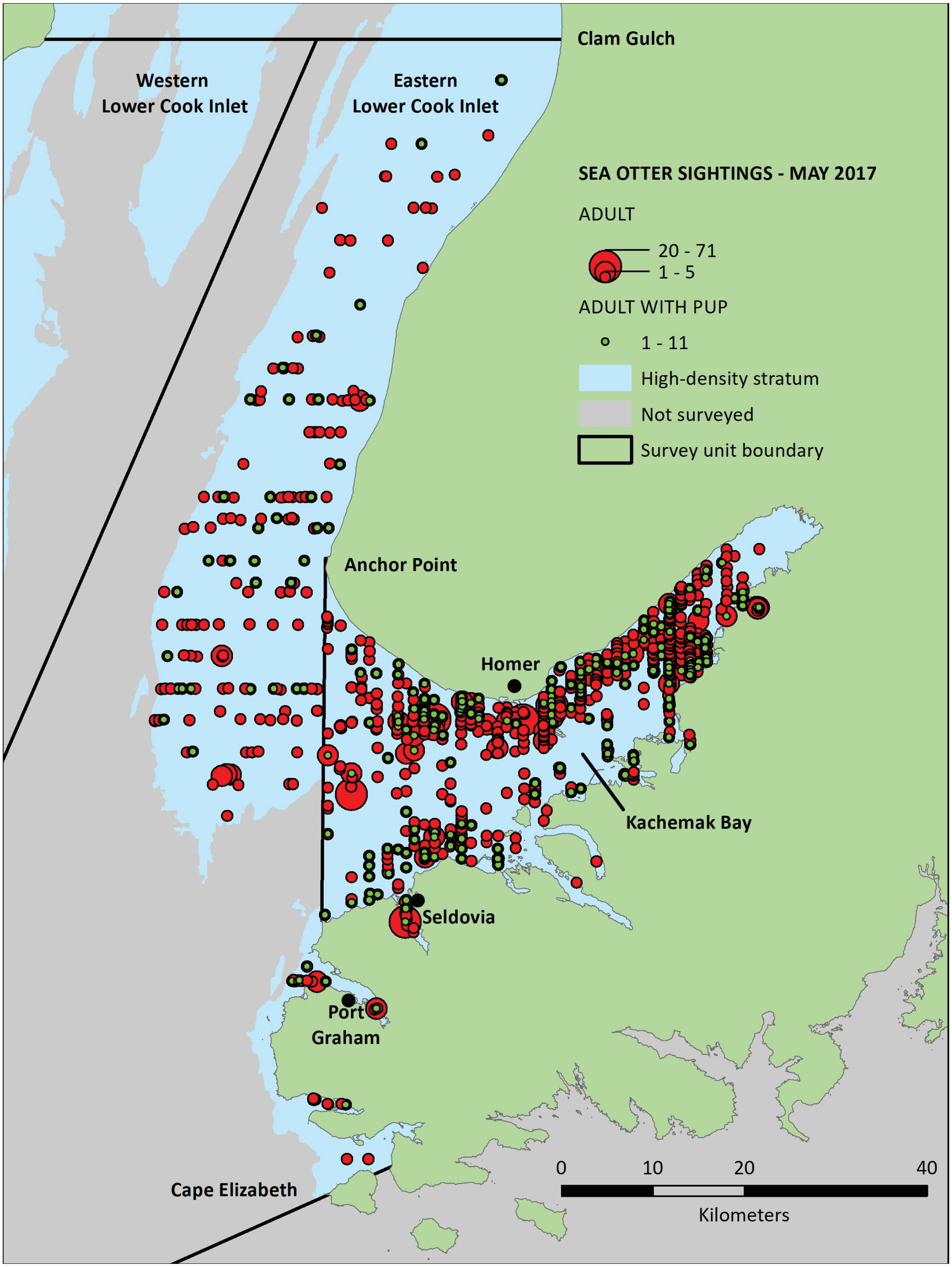

Figure 2. Distribution of sea otters sighted on transects during three aerial surveys in eastern lower Cook Inlet and four aerial surveys in Kachemak Bay, Alaska, May 2017.

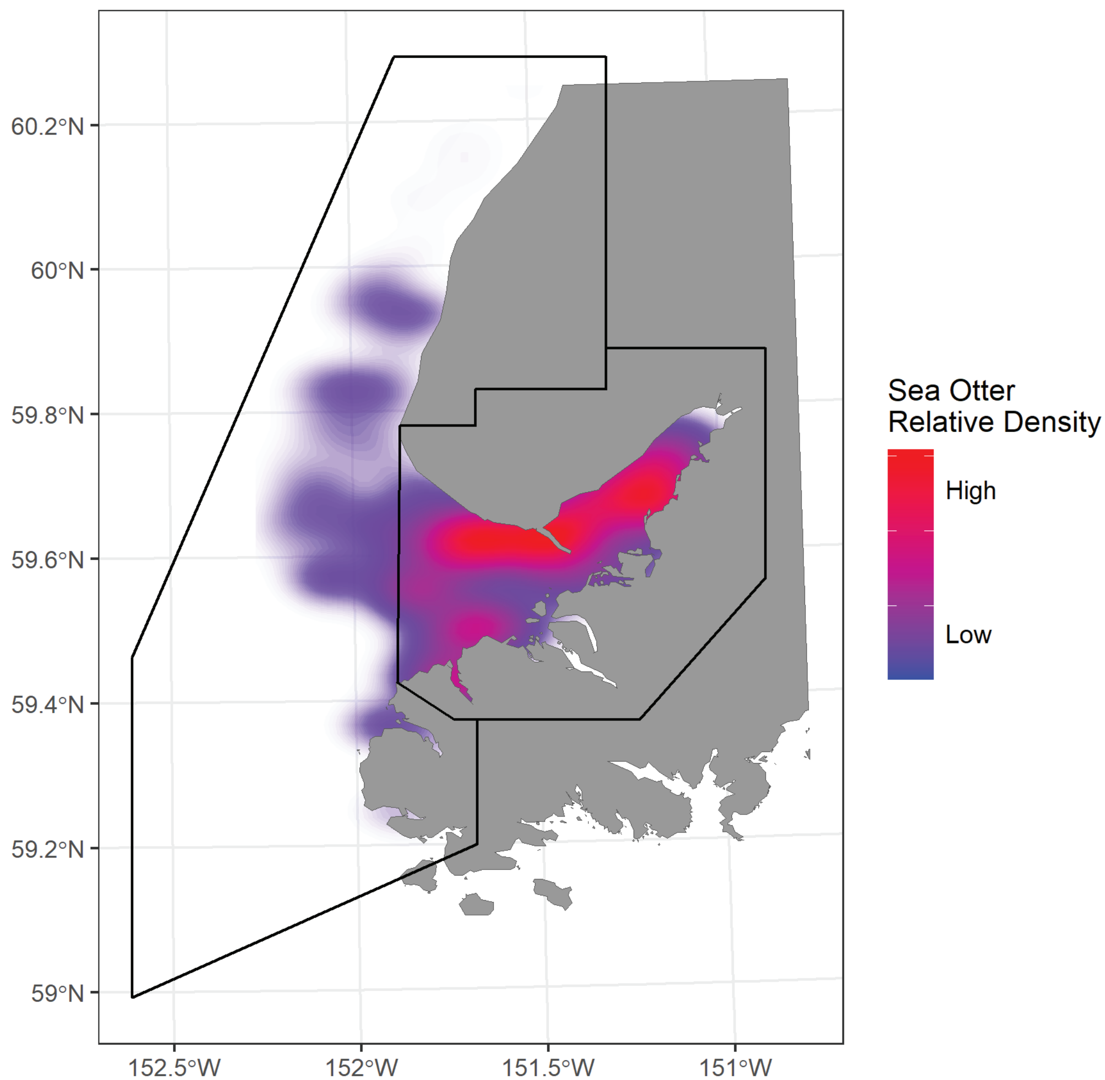

Figure 3. Kernel density estimation of sea otters in eastern lower Cook Inlet and Kachemak Bay, Alaska, from aerial surveys flown in May 2017.

Table 1. Sea otter abundance estimates based on aerial surveys in eastern Cook Inlet, May 2017.

[Means and totals are in bold text. **Proportional standard error:** Standard error of population size estimate divided by population size estimate. **Abbreviations:** ISU, intensive search unit; km, kilometer; km^2, square kilometer, NA = not applicable]

Replicate	Stratum	Group size	Sea otters counted	Transect spacing (km)	Area sampled (km^2)	Stratum area (km^2)	Number of ISUs	Correction factor	Population size estimate	Standard error of population size	Proportional standard error	Density (otters per km^2)	Standard error of density (otters per km^2)
						Eastern Lower Cook Inlet survey unit							
1	High	Small	65	7	96	1,677	[1]1	1.25	1,417	NA	NA	0.84	NA
2	High	Small	130	7	89	1,677	9	1.55	3,800	1,189	0.31	2.27	0.71
3	High	Small	134	7	94	1,677	6	1.05	2,528	679	0.27	1.51	0.40
Mean									**3,164**	**685**	**0.22**	**1.89**	**0.41**
						Kachemak Bay survey unit							
1	High	Small	232	4	95	940	8	1.60	3,684	878	0.24	3.92	0.93
1	High	Large	135	4	95	940	NA	NA	1,340	842	0.63	1.43	0.90
	Total	All	367	NA	NA	NA	NA	NA	**5,024**	**1,217**	**0.24**	**5.34**	**1.29**
2	High	Small	340	4	89	940	12	1.27	4,530	1,253	0.28	4.82	1.33
2	High	Large	31	4	89	940	NA	NA	326	315	0.97	0.35	0.34
	Total	All	371	NA	NA	NA	NA	NA	**4,856**	**1,292**	**0.27**	**5.17**	**1.37**
3	High	Small	313	4	83	940	10	1.93	6,791	1,625	0.24	7.22	1.73
3	High	Large	56	4	83	940	NA	NA	631	551	0.87	0.67	0.59
	Total	All	369	NA	NA	NA	NA	NA	**7,422**	**1,716**	**0.23**	**7.90**	**1.83**
4	High	Small	413	4	89	940	10	1.45	6,343	1,727	0.27	6.75	1.84
4	High	Large	29	4	89	940	NA	NA	307	283	0.92	0.33	0.30
	Total	All	442	NA	NA	NA	NA	NA	**6,650**	**1,750**	**0.26**	**7.07**	**1.86**
Mean									**5,988**	**756**	**0.13**	**6.37**	**0.80**
Eastern Lower Cook Inlet and Kachemak Bay combined						**2,617**	NA	NA	**9,152**	**1,020**	**0.11**	**3.50**	**0.39**

[1]This replicate was not used in calculating mean sea otter population size for eastern Lower Cook Inlet because there was only one usable intensive search unit.

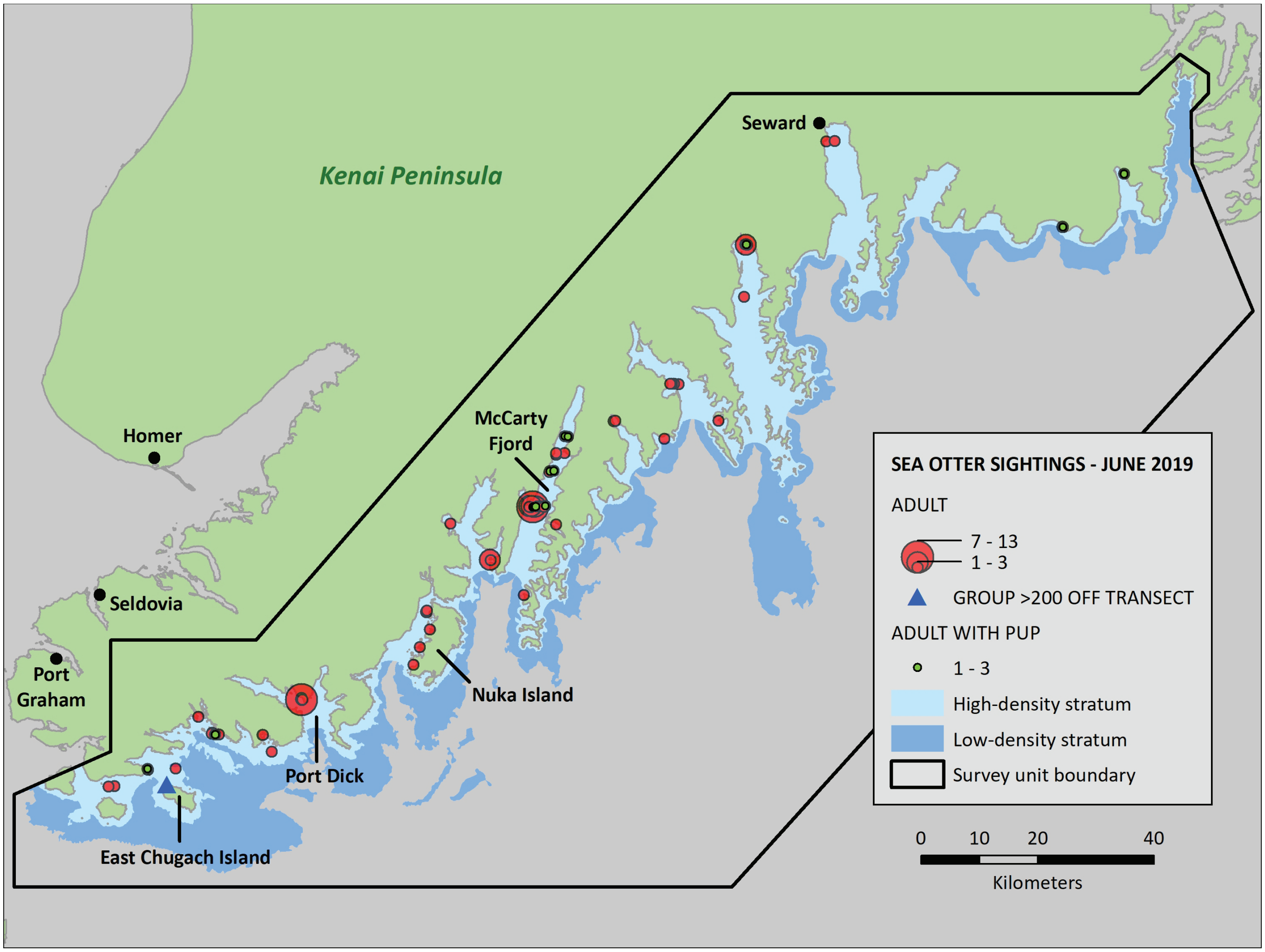

Figure 4. Distribution of sea otters sighted on transects during an aerial survey of the outer Kenai Peninsula, Alaska, June 2019, including location of a group of more than 200 sea otters sighted off-transect (triangle).

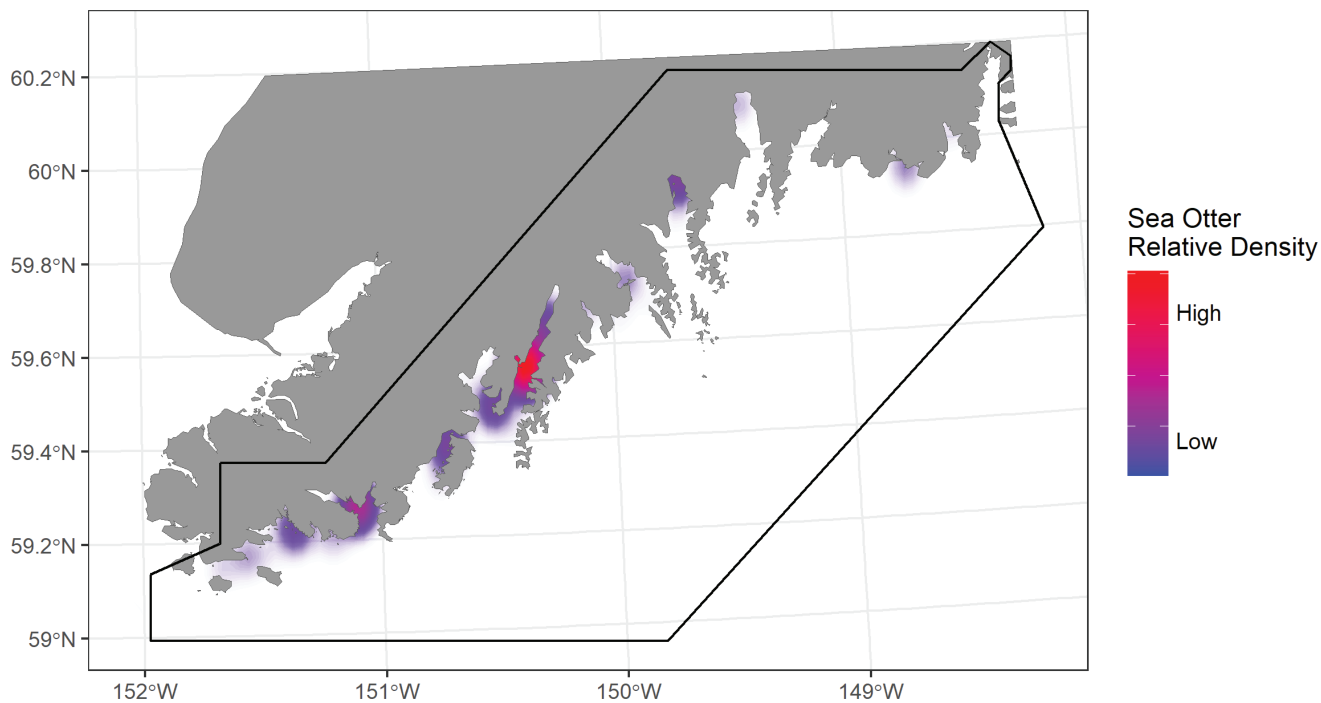

Figure 5. Kernel density estimation of sea otters along the outer Kenai Peninsula, Alaska, from an aerial survey flown in June 2019.

Table 2. Sea otter abundance estimates based on an aerial survey of the outer Kenai Peninsula, June 2019.

[Totals are in bold text. **Proportional standard error:** Standard error of population size estimate divided by population size estimate. **Abbreviations:** ISU, intensive search unit; km, kilometer; km^2, square kilometer, NA = not applicable]

Survey unit	Stratum	Group size	Sea otters counted	Transect spacing (km)	Area sampled (km^2)	Stratum area (km^2)	Number of ISUs	Correction factor	Population size estimate	Standard error of popular-tion size	Propor-tional standard error	Density (otters per km^2)	Standard error of density (otters per km^2)
Outer Kenai	High	Small	148	3	197	1,509	14	1.57	1,620	557	0.34	1.07	0.37
Peninsula	Low	Small	0	12	74	1,579	14	1.57	0	0	NA	0.00	0.00
Total	NA	NA	NA	NA	NA	**3,088**	NA	NA	**1,620**	**557**	**0.34**	**0.52**	**0.18**

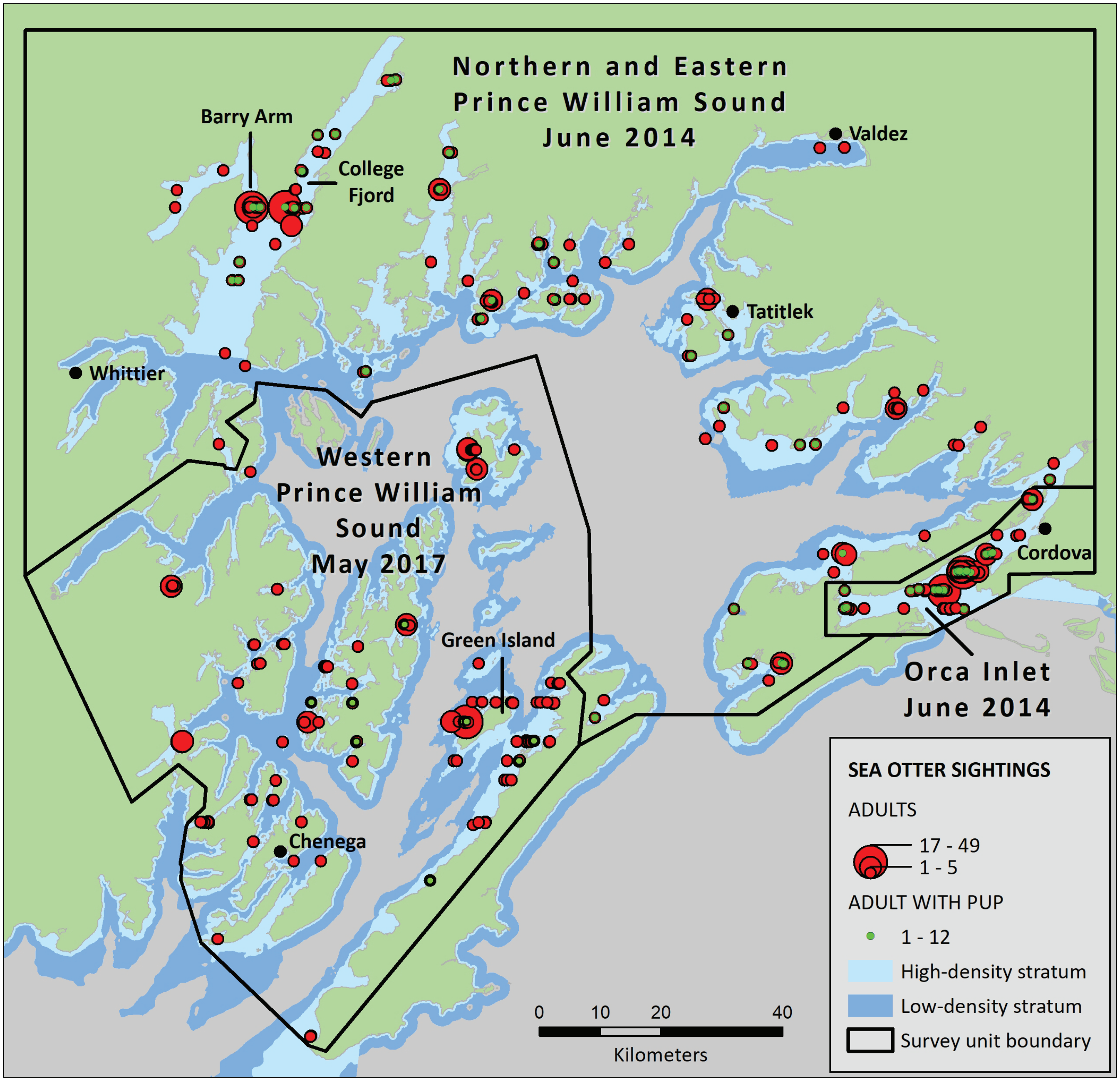

Figure 6. Distribution of sea otters sighted on transects during aerial surveys in Prince William Sound (PWS), Alaska, June 2014 and May 2017. Western PWS was surveyed twice in May 2017, but only sea otter sightings from the first survey are shown.

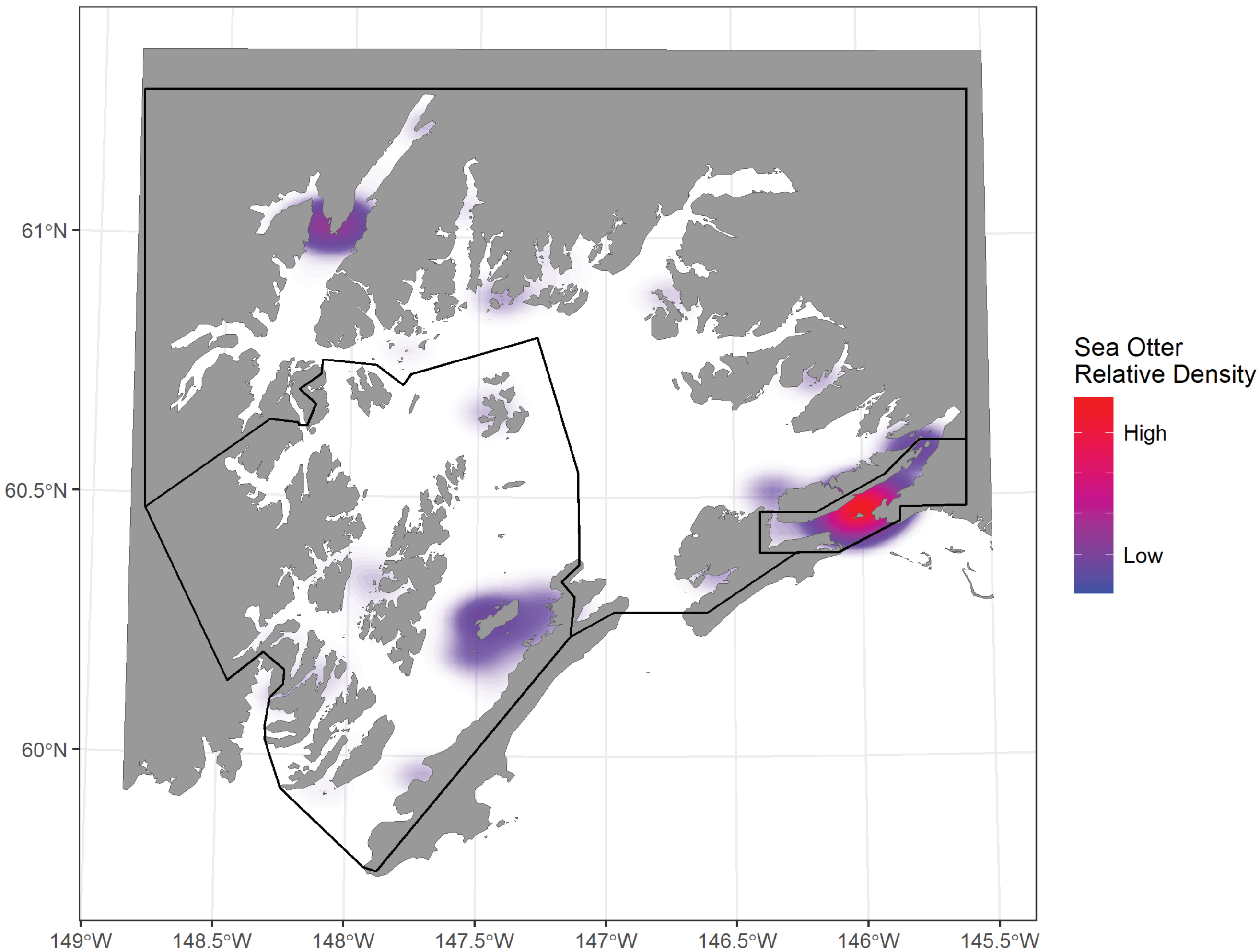

Figure 7. Kernel density estimation of sea otters in Prince William Sound, Alaska, from aerial surveys flown in June 2014 and May 2017.

Table 3. Sea otter abundance estimates based on aerial surveys in Prince William Sound, June 2014–June 2017.

[Means and totals are in bold text. **Proportional standard error:** Standard error of population size estimate divided by population size estimate. **Abbreviations:** ISU, intensive search unit; km, kilometer; km^2, square kilometer, NA = not applicable]

Replicate	Stratum	Group size	Sea otters counted	Transect spacing (km)	Area sampled (km^2)	Stratum area (km^2)	Number of ISUs	Correction factor	Population size estimate	Standard error of population size	Proportional standard error	Density (otters/km^2)	Standard error of density (otters per km^2)
Northern and Eastern Prince William Sound survey unit (including Orca Inlet), June 2014													
1	High	Small	525	3.0	242	1,857	25	1.50	6,073	1,515	0.25	3.27	0.82
1	Low	Small	6	12.0	38	1,133	25	1.50	270	101	0.38	0.24	0.09
1	High	Large	265	3.0	242	1,857	NA	NA	2,038	1,005	0.49	1.10	0.54
1	Low	Large	0	12.0	38	1,133	NA	NA	0	0	NA	0.00	0.00
		All	**796**	NA	NA	**2,991**	NA	NA	**8,380**	**1,821**	**0.22**	**2.80**	**0.61**
Orca Inlet survey unit, June 2014													
1	High	Small	248	3.0	27	230	7	1.39	2,945	1,262	0.43	12.78	5.48
1	High	Large	192	3.0	27	230	NA	NA	1,645	888	0.54	7.14	3.85
		All	**440**			**230**			**4,590**	**1,543**	**0.34**	**19.93**	**6.70**
Western Prince William Sound survey unit, June 2017													
1	High	Small	149	3.2	119	1,003	19	1.67	2100	418	0.20	2.09	0.42
1	Low	Small	2	16.0	32	1,355	19	1.67	142	144	1.01	0.11	0.11
1	High	Large	34	3.2	119	1,003	NA	NA	287	269	0.94	0.29	0.27
1	Low	Large	0	16.0	32	1,355	NA	NA	0	0	NA	0.00	0.00
		All	**185**	NA	NA	**2,358**	NA	NA	**2,530**	**517**	**0.20**	**1.07**	**0.22**
2	High	Small	126	3.2	121	1,003	18	1.73	1802	422	0.23	1.80	0.42
2	Low	Small	7	16.0	35	1,355	18	1.73	474	240	0.51	0.35	0.18
2	High	Large	15	3.2	121	1,003	NA	NA	124	117	0.94	0.12	0.12
2	Low	Large	0	16.0	35	1,355	NA	NA	0	0	NA	0.00	0.00
		All	**148**	NA	NA	**2,358**	NA	NA	**2,400**	**499**	**0.21**	**1.02**	**0.21**
Mean						**2,358**	NA	NA	**2,465**	**359**	**0.15**	**1.05**	**0.15**
Prince William Sound						**5,348**	NA	NA	**10,845**	**1,856**	**0.17**	**2.03**	**0.35**

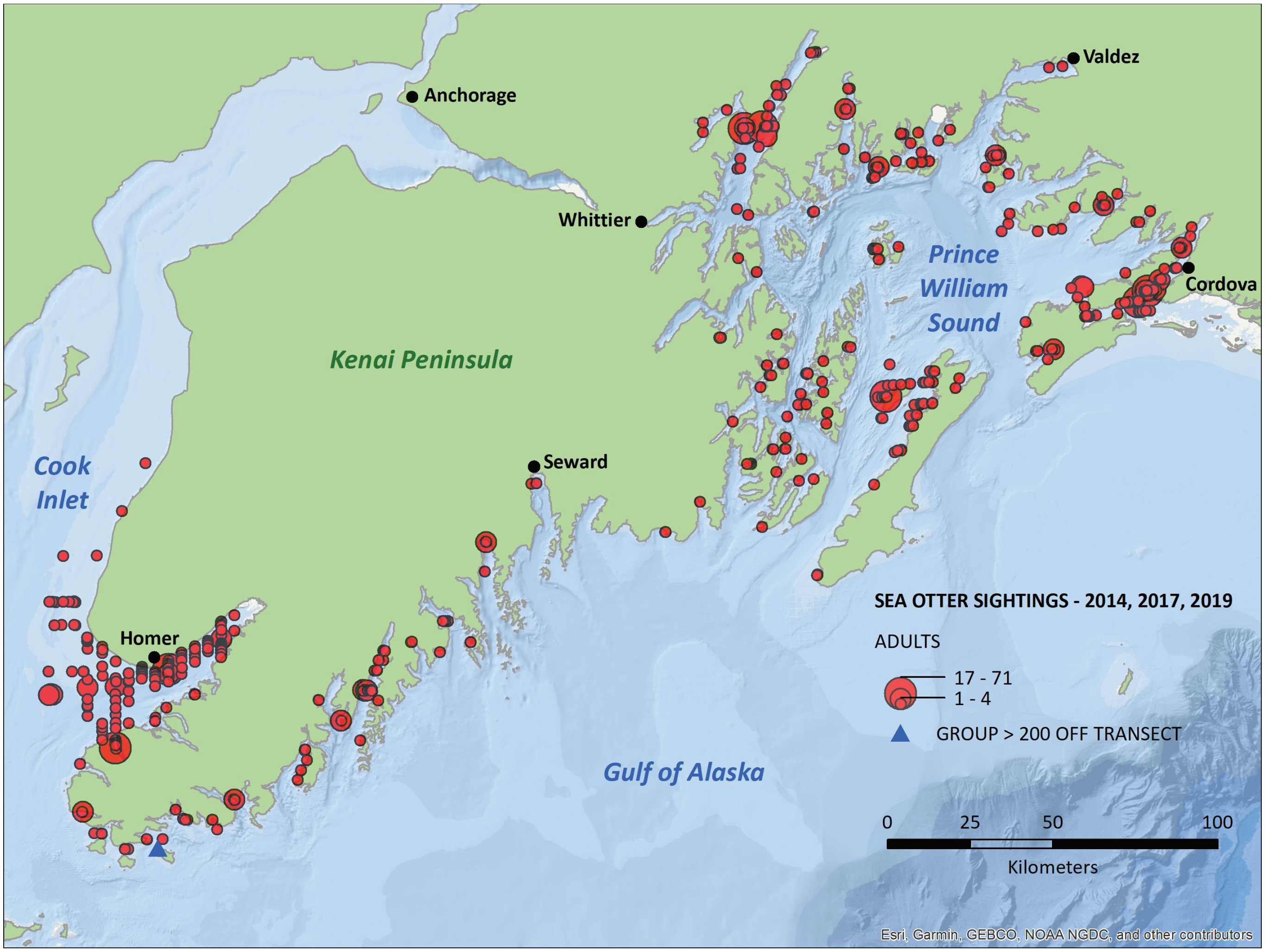

Figure 8. Distribution of sea otters sighted on transects during aerial surveys in southcentral Alaska, 2014, 2017, and 2019. For areas where more than one aerial survey was flown in a given year, only sea otter sightings from the first survey are shown. Also shown is the location of a group of more than 200 sea otters sighted off-transect (triangle). Ocean background image source: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors.

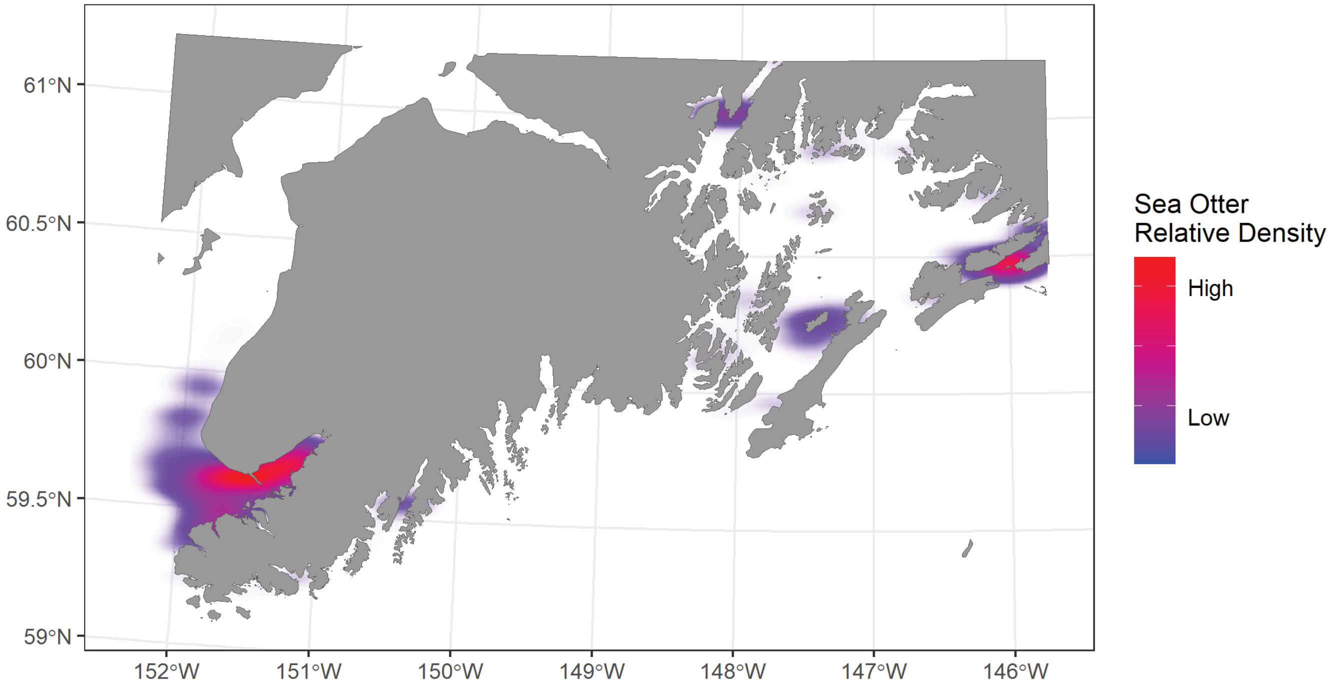

Figure 9. Kernel density estimation of sea otters in southcentral Alaska from aerial surveys flown in 2014, 2017, and 2019.

Table 4. Sea otter abundance estimates based on aerial surveys in Southcentral Alaska, 2014–19.

[Totals are in bold text. **Proportional standard error:** Standard error of population size estimate divided by population size estimate. **Abbreviations:** km^2, square kilometer]

Survey unit	Year	Stratum area (km^2)	Population size estimate	Standard error of population size	Proportional standard error	Density (otters per km^2)	Standard error of density (otters per km^2)
Eastern Cook Inlet	2017	2,617	9,152	1,020	0.11	3.50	0.39
Outer Kenai Peninsula	2019	3,088	1,620	557	0.34	0.52	0.18
Prince William Sound	2014 and 2017	5,348	10,845	1,856	0.17	2.03	0.35
Total estimate from aerial surveys within SCAK boundaries[1]		**11,054**	**21,617**	**2,190**	**0.10**	**1.96**	**0.20**

[1]Not including outer coast from Cape Cleare to Cape Yakataga.

Discussion

Our survey results show how an estimated 21,617 sea otters were distributed across SCAK during 2014–19. Southcentral Alaska encompasses a wide range of sea otter habitats and this variation is reflected in our estimates of abundance and density. Shallow soft-bottom habitats, such as those present in Orca Inlet (PWS) and Kachemak Bay (Eastern Cook Inlet), support some of the highest known sea otter densities at 20 otters/km^2, whereas deep rock-walled glacial fjords along parts of the Kenai Peninsula and PWS contain sea otter densities of <1 otter/km^2. The largest sea otter hotspots in SCAK, Kachemak Bay and Orca Inlet, are located just outside the communities of Homer and Cordova, respectively, and suggest concentrations of high productivity in these local ecosystems. These large co-habitations of sea otters and humans also suggest that high densities of these two species can be compatible and highlight the importance of monitoring local sea otter populations for managing direct effects (for example, hunting, fisheries conflicts, resource development, contaminants) and detecting ecosystem change (Coletti and others, 2016).

Although our results provide contemporary estimates of sea otter abundance and distribution in SCAK, they do not indicate trends or the current status of these populations relative to carrying capacity. To provide a longer-term perspective, summarization of historical surveys of SCAK would be a useful follow-up to this current effort describing contemporary sea otter numbers and could detect trends in abundance over time. Additionally, an analysis of foraging observations, specifically energy intake rates over time, would provide another metric that has proven valuable for assessing population status relative to a food-dictated carrying capacity (Dean and others, 2002; Coletti and others, 2016). Data from multiple recent (Esslinger, Monson, and Robinson, 2021a, 2021b; Esslinger, Weitzman, and Robinson, 2021a, 2021b) and historic aerial surveys (Esslinger and others, 2014; Esslinger, 2017; Garlich-Miller and others, 2018) are available for trend analyses, and Gulf Watch Alaska foraging observation data (Coletti and others 2016) are available to assess current population status.

The aerial survey method used in this report has been effective and safe for estimating sea otter abundance in many parts of SCAK because numerous sheltered landing areas for float planes exist, especially given that we conduct surveys only during calm sea conditions. However, even in the absence of windy sea conditions, it is generally not safe to fly small single-engine float planes low and slow over waters regularly exposed to ocean swell because of a lack of suitable landing areas. Consequently, the outer coast from Cape Cleare to Cape Yakataga, a long stretch of predominately sand beaches subjected to ocean waves, has not been surveyed for decades even though sea otters are known to occur there. Given the habitat in this region, we expect densities and overall abundance to be relatively low, but abundance and distribution are unknown. To fill this knowledge gap in a safe and efficient manner, this area could be surveyed using aerial methods involving twin-engine airplanes or imagery acquired by drone aircraft systems.

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References Cited

Ballachey, B.E., Bodkin, J.L., and DeGange, A.R., 1994, An overview of sea otter studies, *in* Loughlin, T.R., ed., Marine mammals and the *Exxon Valdez*: San Diego, Academic Press, p. 47–59.

Bodkin, J.L., and Dean, T.A., 2000, Patterns and processes of population change in sea otters: *Exxon Valdez* Oil Spill Restoration Project 99423 Annual Report, 24 p.

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, no. 2, p. 305–321.

Bodkin, J.L., and Udevitz, M.S., 1999, An aerial survey method to estimate sea otter abundance, *in* Garner, G.W., and others, eds., Marine Mammal Survey and Assessment Methods: Rotterdam, The Netherlands, Balkema Press, p. 13–26.

Coletti, H.A., Bodkin, J.L., Monson, D.H., Ballachey, B.E., and Dean, T.A., 2016, Detecting and inferring cause of change in an Alaska nearshore marine ecosystem: Ecosphere, v. 7, no. 10, p. 1–20.

Dean, T.A., Bodkin, J.L., Fukuyama, A.K., 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.

Esler, D., Ballachey, B.E., Matkin, C.O., Cushing, D., Kaler, R., Bodkin, J., Monson, D., Esslinger, G.G., and Kloecker, K., 2018, Timelines and mechanisms of wildlife population recovery following the Exxon Valdez oil spill: Deep-Sea Research. Part II—Topical Studies in Oceanography, v. 147, p. 36–42.

Esslinger, G.G., 2017, Gulf Watch Alaska nearshore component—Sea otter aerial survey data from Kenai Fjords National Park, 2002–2016. U.S. Geological Survey data release, https://doi.org/10.5066/F7CJ8BN7.

Esslinger, G.G., Ballachey, B.E., and Bodkin, J.L., 2014, Sea otter abundance in Western Prince William Sound through 2013, chap. 1 *of* Ballachey, B.E., Monson, D.H., Esslinger, G.G., Kloecker, K.A., Bodkin, J.L., 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. 5–10.

Esslinger, G.G., Monson, D.H., and Robinson, B.H., 2021a, Sea otter aerial survey data from the outer Kenai Peninsula, Alaska, 2019: U.S. Geological Survey data release, https://doi.org/10.5066/P9TTJVBC.

Esslinger, G.G., Monson, D.H., and Robinson, B.H., 2021b, Sea otter aerial survey data from western Prince William Sound, Alaska, 2017: U.S. Geological Survey data release, https://doi.org/10.5066/P9KNKOG1.

Esslinger, G.G., Weitzman, B.P., and Robinson, B.H., 2021a, Sea otter aerial survey data from lower Cook Inlet, Alaska, 2017: U.S. Geological Survey data release, https://doi.org/10.5066/P9Q4DA3T.

Esslinger, G.G., Weitzman, B.P, and Robinson, B.H., 2021b, Sea otter aerial survey data from northern and eastern Prince William Sound, Alaska, 2014: U.S. Geological Survey data release, https://doi.org/10.5066/p9OG6SR5.

Estes, J.A., and Palmisano, J.F., 1974, Sea otters—Their role in structuring nearshore communities: Science, v. 185, no. 4156, p. 1058–1060.

Garlich-Miller, J.L., Esslinger, G.G., and Weitzman, B.P., 2018, Aerial surveys of sea otters (*Enhydra lutris*) in Lower Cook Inlet, Alaska, May 2017: U.S. Fish and Wildlife Service Technical Report MMM 2018-01, 22 p.

Garshelis, D.L., and Garshelis, J.A., 1984, Movements and management of sea otters in Alaska: The Journal of Wildlife Management, v. 48, no. 3, p. 665–678.

Goertz, C.E.C., Walton, R., Rouse, N., Belovarac, J., Burek-Huntington, K., Gill, V., Hobbs, R., Xavier, C., Garrett, N., and Tuomi, P., 2013, *Vibrio parahaemolyticus*, a climate change indicator in Alaska marine mammals, *in* Mueter, F.J., Dickson, D.M.S., Huntington, H.P. Irvine, J.R., Logerwell, E.A., MacLean, S.A., Quakenbush, L.T., and Rosa, C., eds., Responses of Arctic marine ecosystems to climate change: Alaska Sea Grant, University of Alaska Fairbanks, p. 41–52.

Gorbics, C.S., and Bodkin, J.L., 2001, Stock structure of sea otters (*Enhydra lutris kenyoni*) in Alaska: Marine Mammal Science, v. 17, no. 3, p. 632–647.

Jessup, D.A., Miller, M., Ames, J., Harris, M., Kreuder, C., Conrad, P.A., and Mazet, J.A.K., 2004, Southern sea otter as a sentinel of marine ecosystem health: EcoHealth, v. 1, p. 239–245.

London, J.M., 2018, Ptolemy—An R package for accessing global high-resolution geography, Version 1.0.0: San Francisco, GitHub web page, accessed January 26, 2021, at https://github.com/jmlondon/ptolemy.

R Core Team, 2020, R—A language and environment for statistical computing: Vienna, Austria, R Foundation for Statistical Computing web page, accessed January 26, 2021, at https://www.r-project.org.

Venables, W.N., and Ripley, B.D., 2002, Modern applied statistics with S (4th ed.): New York, Springer, 510 p.

Wessel, P., and Smith, W.H.F., 1996, A global, self-consistent, hierarchical, high-resolution shoreline database: Journal of Geophysical Research, v. 101, p. 8741–8743.

Wickham, H., 2016, ggplot2—Elegant graphics for data analysis: New York, Springer-Verlag, 276 p.

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