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QUANTIFYING SEA OTTER ABUNDANCE, DISTRIBUTION, HABITAT USE, AND FORAGING INTAKE IN LOWER COOK INLET, ALASKA

Photo by Nicole LaRoche

U.S. Department of the Interior
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Alaska OCS Region

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Final Report

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DISCLAIMER

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REPORT AVAILABILITY

This report will be available at: https://espis.boem.gov/Final%20Reports/BOEM_2025-19.pdf.

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ABOUT THE COVER

A sea otter in lower Cook Inlet, Alaska. Credit: Nicole LaRoche. U.S. Geological Survey. Public domain.

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Quantifying Sea Otter Abundance, Distribution, Habitat Use, and Foraging Intake in Lower Cook Inlet

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List of Abbreviations and Acronyms

AI	Artificial Intelligence
ANOVA	Analysis of Variance
AUGI	Augustine Island
BOEM	Bureau of Ocean Energy Management
CBAY	Chinitna Bay
CMI	Coastal Marine Institute
CR	consumption rate
CTD	conductivity-temperature-depth probe
DPS	Distinct Population Segment
ECOI	eastern Cook Inlet
EDF	estimated degrees of freedom
EIR	energy intake rate
ESA	Endangered Species Act
GAM	generalized additive model
ICC	interaclass correlation coefficient
IRA	Inflation Reduction Act
KBAY	Kachemak Bay
LACL	Lake Clark National Park & Preserve
LCI	lower Cook Inlet
MAE	mean absolute error
MIZ	mixed ice zone
MMPA	Marine Mammal Protection Act
MSE	mean square error
NEPA	National Environmental Policy Act
nm	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NPPSD	North Pacific Pelagic Seabird Database
NPS	National Park Service
OCS	Outer Continental Shelf
ROV	Remotely Operated Vehicle
SEAK	southeast Alaska
UCI	upper Cook Inlet
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WCOI	Western Cook Inlet

1 Abstract

Following near extirpation from the fur trade, sea otters (*Enhydra lutris*) have returned to occupy lower Cook Inlet since the 1950s, or earlier, with numbers increasing to ~11,000 and ~9,000 on the west and east side, respectively, by 2017. Northward range expansion on the west side has been negligible for decades with few animals found north of Kamishak Bay, while northward expansion on the east side has been more pronounced in recent decades. The reasons for these contrasting distribution patterns are not certain. Possible explanations for lack of expansion on the west side included 1) poor sea otter habitat north of Kamishak Bay; 2) adequate habitat north of Kamishak Bay but no incentive for sea otters to move north because of abundant food in Kamishak Bay, and/or sea otters discouraged from moving north of Kamishak Bay; 3) seasonal ice formation; or 4) seasonal presence of killer whales. This project was designed to document current sea otter abundance and distribution in lower Cook Inlet, including seasonal variation, and evaluate drivers of habitat use and foraging conditions, including how these overlap with Bureau of Ocean Energy Management (BOEM) Lease Sale blocks.

We found that the probability of sea otter presence in lower Cook Inlet was significantly related to depth and distance from shore with the highest probabilities of sea otter presence in areas ~7–8 kilometers (km) from shore in water ~20–30 meters (m) deep. Historical survey data suggest sea otter distribution has not changed dramatically since 2002, and while we detected significant seasonal changes including due to presence of heavy sea ice, the seasonal changes were modest and primarily related to locations with consistent winter ice formation on the west side of lower Cook Inlet. Overall, throughout the year, sea otters appeared to be utilizing most of the habitat within the 40-m depth contour on the east side of lower Cook Inlet, including Kachemak Bay. Sea otters on the west side reside largely within Kamishak Bay. Because of the shallow bathymetry of lower Cook Inlet, sea otters consistently occurred farther offshore than in many other areas of Alaska. The presence of sea otters, including females with pups, in these offshore waters indicates that sea otters can forage productively in these open water areas. Importantly, we documented that sea otters, including females with pups, occurred in most of the eastern BOEM lease blocks including the original Lease Sale 244 blocks 7064, 7114, 6162, 6310, 6360, 6410, 6458 and 6457. The relinquishments for these 7 leases were effective September 17, 2024: OCS-Y-02434 (block # 7064), OCS-Y-02435 (7114), OCS-Y-02436 (6162), OCS-Y-02438 (6357), OCS-Y-02442 (6407), OCS-Y-02446 (6457), OCS-Y-02447 (6458)
https://www.boem.gov/sites/default/files/documents/environment/Map%20of%20Active%20Leases%20Cook%20Inlet%20OCS_0.pdf

Regarding differential northward expansion on the east and west side of lower Cook Inlet, we found that wind and water circulation patterns make winter sea ice more prominent on the west side, but this had minimal effects on sea otter distribution. In addition, although there have been observations of killer whale (*Orcinus orca*) predation on sea otters in Cook Inlet, we did not see behavioral or distributional evidence that it was prevalent enough to have strong effects on sea otter habitat use. Benthic surveys using a remotely operated vehicle (ROV) indicated that epibenthic substrate and biological community heterogeneity differed between areas with and without otters, suggesting that these factors may explain the current distribution of otters within lower Cook Inlet. However, ROV surveys cannot assess infaunal prey abundance, making assessments of the role of prey availability difficult. The existence of a healthy Pacific razor clam (*Siliqua patula*) fishery along western lower Cook Inlet along the Lake Clark coast north of Kamishak Bay suggests there may still be a resource base for eventual expansion of sea otters into this area.

Our shore-based forage observations indicated that sea otters exist near carrying capacity densities relative to nearshore prey resources. However, our distribution model suggests the bulk of the population lives offshore beyond our ability to observe their feeding activity. The fact that sea otters are a consistent

presence in offshore areas suggests that prey resources in these areas were relatively abundant in comparison to nearshore prey resources, making foraging in offshore areas, with water depths of 0–40 m, energetically profitable. Prey types in these offshore areas of lower Cook Inlet likely included epifauna such as crabs and large urchins, in addition to infaunal clams based on the soft substrate habitat types that characterize lower Cook Inlet.

Collectively, our results suggest that sea otters occupy most areas of lower Cook Inlet with appropriate benthic habitat types and prey resources, which includes areas within BOEM Lease Sale blocks. With the exception of the Lake Clark coast, sea otters may be approaching a food- and habitat-limited distribution and carrying capacity, suggesting that the current status of sea otters in lower Cook Inlet is likely to remain similar in the absence of significant changes to prey, habitat, predation, or anthropogenic disturbance.

2 Introduction

Resource managers need to understand potential conflicts between oil and gas activities and sea otters (*Enhydra lutris*) to minimize impacts. To that end, we evaluated sea otter abundance, distribution, habitat use, and foraging behavior in lower Cook Inlet (LCI), Alaska, which has both large numbers of sea otters and active oil and gas lease sale blocks. Lower Cook Inlet is distinct from upper Cook Inlet (UCI) with the boundary defined by the narrowing of Cook Inlet (~16 km wide) west of Nikiski on the Kenai Peninsula (Figure 1). In addition, Alaska state jurisdiction is out to 3 nautical miles (nm) from the coastline while BOEM Outer Continental Shelf (OCS) lease blocks occur outside state waters. Understanding how many sea otters are in LCI, how they are spatially and seasonally distributed, what factors drive habitat use, and what sea otters are eating throughout their range will all contribute to greater understanding of overlap and potential conflict with oil and gas development activities.

The Southwest stock of sea otters, which was listed as a threatened distinct population segment (DPS) under the Endangered Species Act (ESA) in 2005 (Burn 2005), extends from Attu at the west end of the Aleutian Islands to Kodiak Island, Cape Douglas and Kamishak Bay on the west side of LCI. The southcentral sea otter stock, which is not ESA listed, extends from eastern LCI to the Kenai Peninsula, Prince William Sound, and down to Cape Yakataga. Thus, the boundary between ESA listed, southwest and non-listed, southcentral stocks is designated by a line down the center of LCI (Figure 1). Both the southwest and southcentral sea otter stocks, like all marine mammals in Alaska, are protected under the Marine Mammal Protection Act (MMPA; 16 U.S.C. 1361-1407). Despite occupying the same body of water, sea otters in eastern and western LCI are considered independent population segments (Gorbics and Bodkin 2001). However, eastern and western populations share a similar set of anthropogenic risks in LCI, particularly from shipping vessels, natural resource extraction and infrastructure, and contaminant leaks. Potential natural resource extraction projects include the development of offshore oil and gas wells in LCI. We currently have limited information to determine how proposed natural resource extraction projects might affect sea otters in this transition zone between two sea otter stocks managed under the ESA and MMPA.

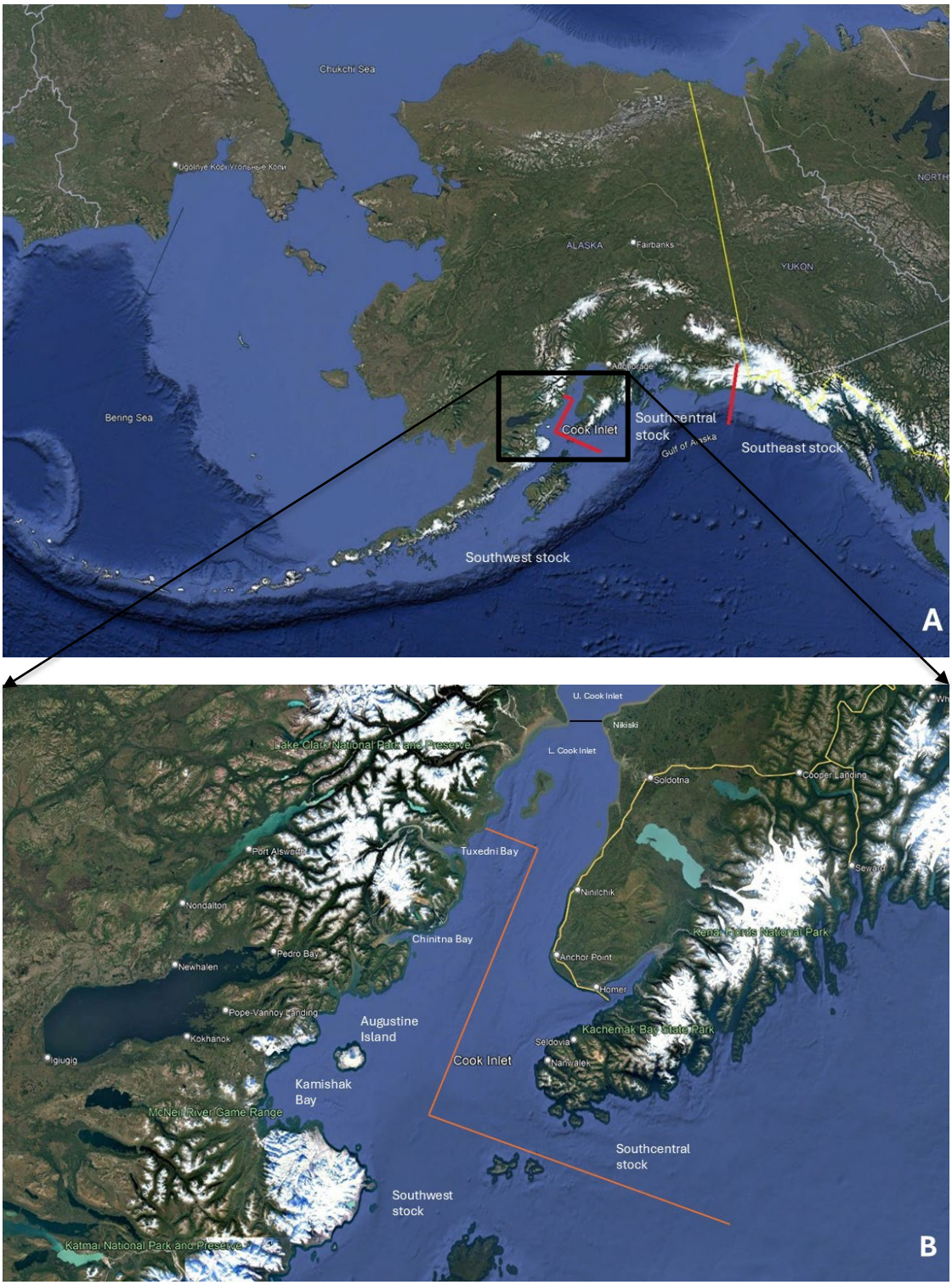


Figure 1. A: The spatial distribution of the three recognized northern sea otter (*Enhydra lutris kenyoni*) stocks in Alaska. Red lines denote the boundaries between the southwest, southcentral, and southeast stocks. All three stocks are protected by the Marine Mammal Protections Act. The southwest stock is listed as 'Threatened' under the Endangered Species Act. B: Detailed map of lower Cook Inlet highlighted in the box of Figure A.

Oil and gas extraction platforms have existed in UCI, north and west of Nikiski on the Kenai Peninsula, including in Alaska state waters since the 1960s (Figure 2). However, declining oil and gas production has spurred interest in additional development. OCS Lease Sale 244 was held in June of 2017, and 14 lease blocks were leased (BOEM 2025c). On September 19, 2024, BOEM accepted relinquishment of seven of those leases (BOEM 2025b). In addition, BOEM conducted a Cook Inlet OCS oil and gas Lease Sale in December 2022 when 193 Lease Sale blocks were offered (Figure 3). One Lease Sale block (block #6255) was leased by Hilcorp Alaska LLC, which was awarded in March 2023 (BOEM 2025a; 2025d).

The 11 active platforms in UCI do not occur within currently occupied sea otter habitat. However, sea otter populations within western LCI are directly down current of active oil and gas extraction infrastructure.

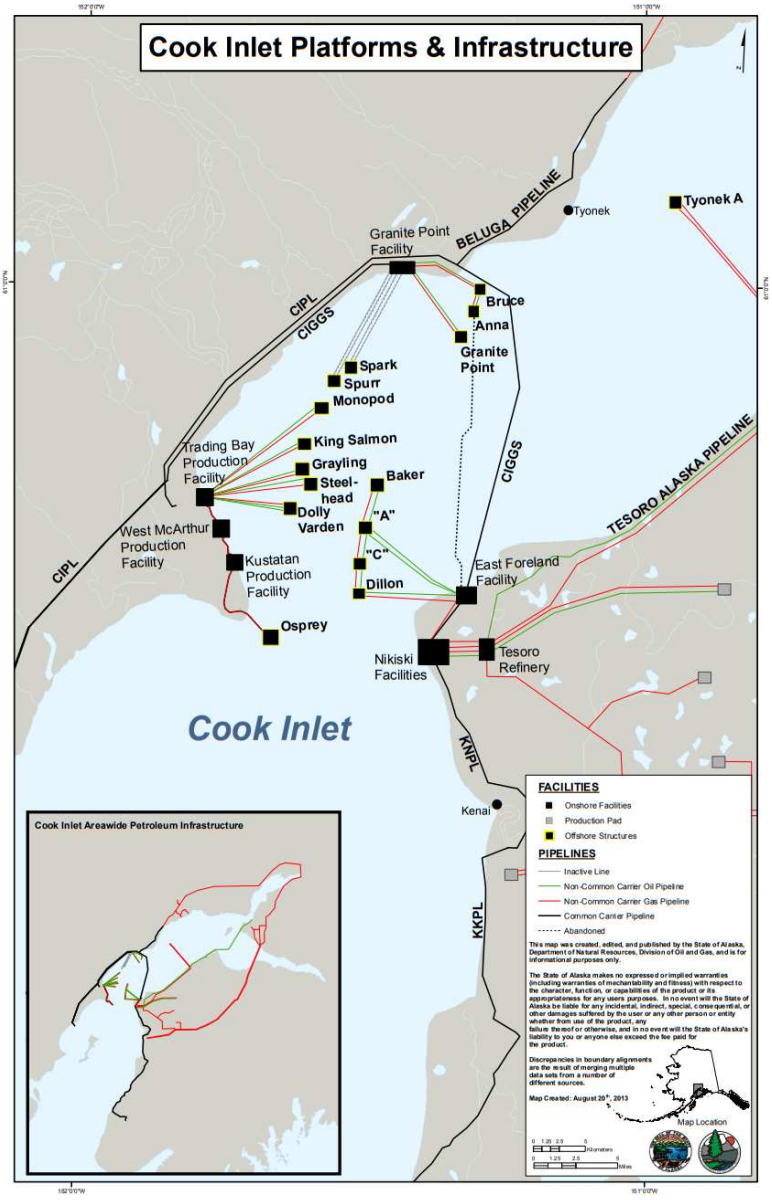


Figure 2. Oil and gas platforms in upper Cook Inlet Alaska. Figure taken from Cook Inlet Regional Citizens Advisory Council (2025). Not all platforms are currently active.

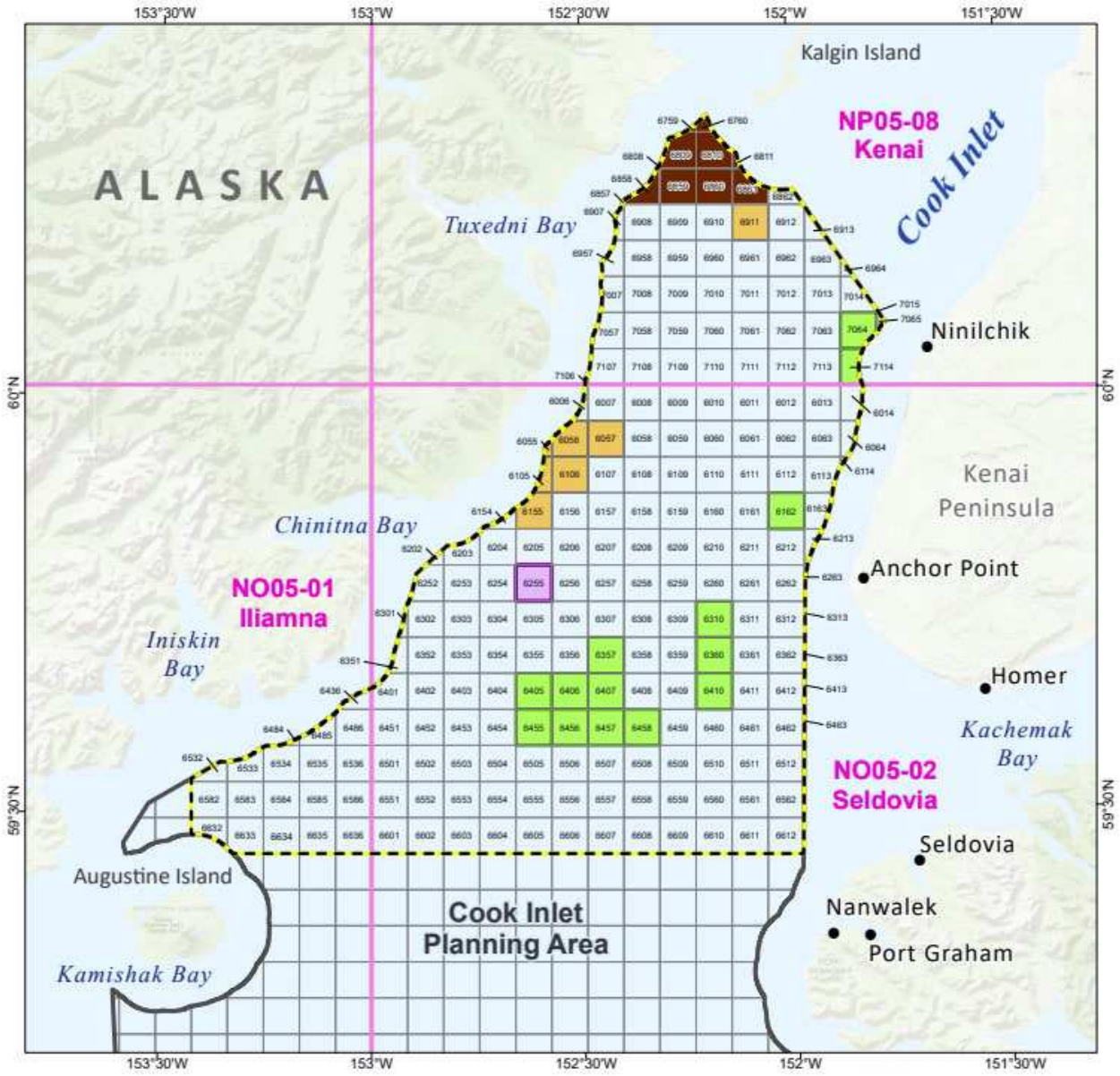


Figure 3. Map of BOEM lower Cook Inlet Outer Continental Shelf Oil and Gas Lease Sale 244 on June 21, 2017 (BOEM 2025c) and Lease Sale 258 on Dec. 30, 2022 (BOEM 2025a; 2025d). Original Lease Sale 244 lease blocks are colored light green, and Lease Sale 258 is colored magenta. Beluga (*Delphinapterus leucas*) critical habitat excluded blocks are colored brown, and northern sea otter critical habitat excluded blocks (colored orange) are designated because they intersect with the line identifying critical sea otter habitat along the entire west coast of lower Cook Inlet, which follows the 20-meter depth contour shown in Figure 4.

2.1 History of Research and Available Datasets

Sea otters are the world's smallest marine mammal (Yeates et al. 2007). In addition, they rely on fur instead of blubber for warmth (Liwanag et al. 2012). These factors necessitate an exceedingly high metabolic rate that requires sea otters to feed several times per day (Yeates et al. 2007), which means they do not travel long distances to feeding areas. This leads to generally small home-ranges where they rest

and feed in relatively small areas (Garshelis and Garshelis 1984) except when making longer range movements into new habitats (Bodkin et al. 2007; Garshelis et al. 1984). When sea otters first reoccupy habitat that has been without sea otters for long periods, their preferred prey are often large and abundant, allowing individual otters to easily fulfill their daily energetic needs. However, as prey resources become more limited, their energy intake rates decline as the size and density of prey decline, which leads to more time spent foraging (Bodkin et al. 2007; Dean et al. 2002; Garshelis et al. 1986). Thus, estimates of energy intake rates have become an important index of the status of sea otter populations relative to available food resources (Coletti et al. 2016; Monson and Bowen 2015).

Sea otters primarily consume benthic invertebrate prey species (Kenyon 1969; Kvitek and Oliver 1988; Riedman and Estes 1990). In Alaska, their preferred prey include clams, crabs, mussels, and sea urchins (Dean et al. 2002; Dean et al. 2000; Doroff et al. 2012; Doroff and DeGange 1994; Garshelis et al. 1986; Kvitek et al. 1991; Kvitek et al. 1992; Leach et al. 2024; Leach et al. 2023; Watt et al. 2000). Within LCI, Dungeness crab (*Metacarcinus magister*) and Pacific razor (*Siliqua patula*) are, or have been, important for both commercial and sport fisheries. Pacific razor in particular have been an important commercial and personal use fishery on both the east and west side of LCI (Booz et al. 2019). In addition, LCI had a small commercial and personal use fishery to for two species of hard-shell clams (*Saxidomus gigantea* and *Leukoma staminea*) primarily located in Kachemak Bay that is not currently operational (Booz et al. 2019; Rumble et al. 2016). All these species are important sea otter prey and provide a good indication of what the prey base in LCI may be.

Sea otters can have large impacts on their prey populations. They are considered a "keystone species" in rocky habitats where they limit herbivorous sea urchins, which in turn encourages growth of kelps that provide habitat for a diverse array of other species (Estes and Duggins 1995; Estes and Palmisano 1974). Sea otters can also affect the density and size of their prey. However, prey in soft sediment habitats, such as clams, are more resilient to overexploitation and can therefore provide a more sustainable prey base than epifauna, such a crabs and urchins (Kvitek and Oliver 1988; Kvitek et al. 1992; Leach et al. 2024; Leach et al. 2023).

Presumably, sea otters inhabited LCI prior to their near extirpation by the fur trade of the 18th and 19th centuries. Since cessation of the fur trade and subsequent protections, sea otters are reoccupying much of their former range, including LCI. Sea otter reoccupation of LCI, initially evident around Augustine Island (AUGI), was underway by the 1950s (Lensink 1960) with the earliest qualitive sea otter distribution information available from an aerial survey conducted in 1976 (Figure 4; Schneider 1976a). The two nearest remnant populations to LCI after the fur trade included one located at the northern tip of the Kodiak archipelago and one within western Prince William Sound (Kenyon 1969). Kodiak Island was the most likely source population for the AUGI reoccupation because in the 1950s, expansion from the western Prince William Sound population had not yet reached Kachemak Bay on the eastern side of LCI. Sea otters did not appear on the east side of LCI until the 1970s after the western Prince William Sound population had expanded westward across the Kenai Peninsula (Schneider 1976a).

While the southwest and southcentral sea otter stocks are separated by a boundary down the middle of LCI (Gorbics and Bodkin 2001), and the western and eastern LCI populations were initially reoccupied by sea otters from different remnant populations, genetic-based models of population structure indicate more recent genetic exchange has occurred between the southwest and southcentral sea otter stocks (Figure 5; Flannery et al. 2022). Specifically, the Kachemak Bay sea otter population (location 4 in Table 1, Figure 5) appears to be comprised of individuals with genetic heritages from both the southcentral stock (locations 1–3) and the nearest southwest stocks (locations 5–6). This would indicate that the distance between western and eastern LCI is not a significant deterrent to exchange of individuals between the southcentral and southwest stocks.

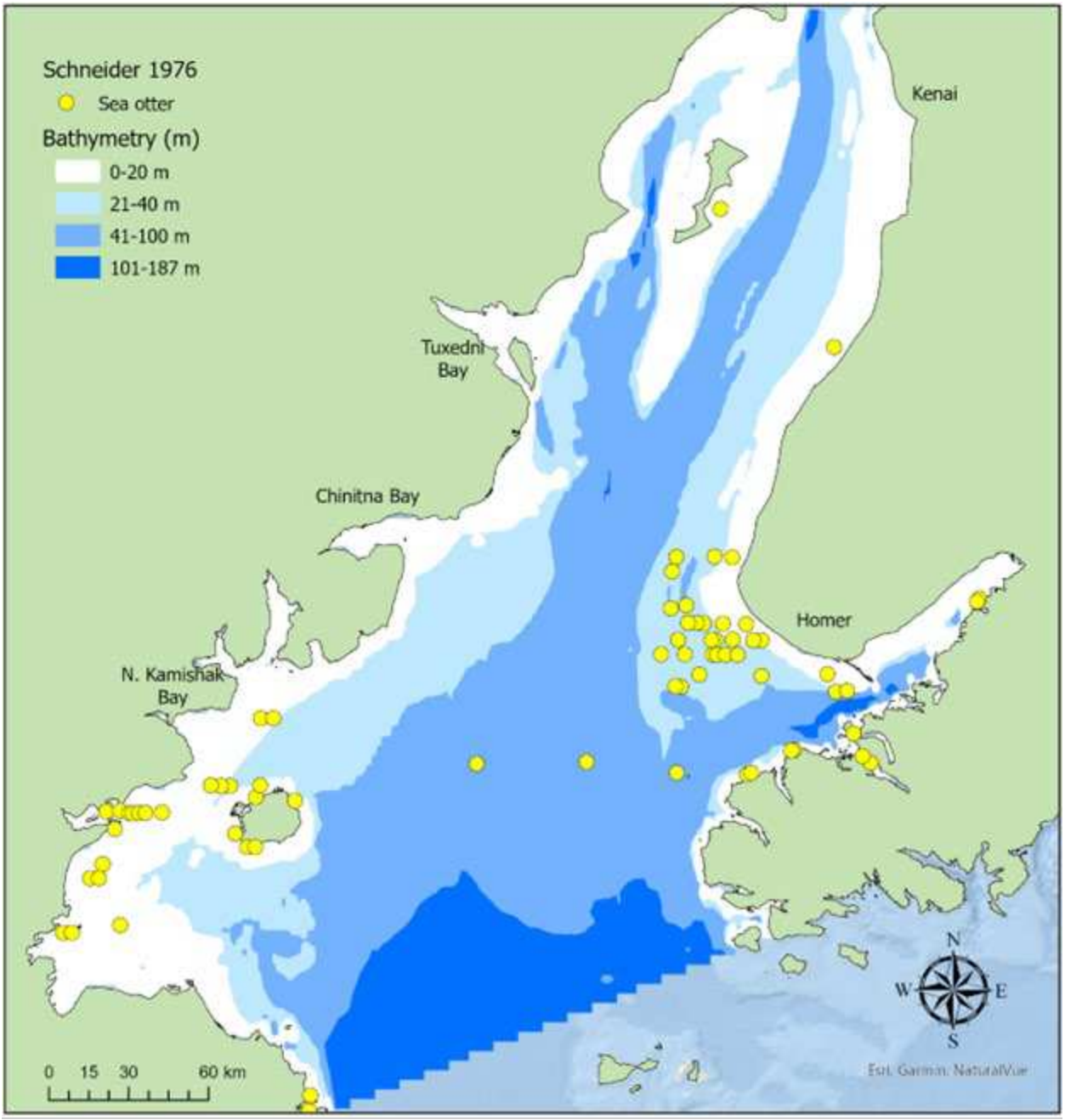


Figure 4. Sea otter sightings (yellow dots) in lower Cook Inlet, Alaska, from U.S. Fish and Wildlife bird and mammal survey (Schneider 1976a).

Table 1. From Flannery et al. (2022) listing sampling location, stock, management unit, location label, number (*n*) of sea otter tissue samples, and year collected for reference to Figure 5.

Location	Stock	Management unit	Label	*n*
Prince William Sound East	Alaska-southcentral	Prince William Sound	1	47
Prince William Sound West	Alaska-southcentral	Prince William Sound	2	67
Kenai Peninsula	Alaska-southcentral	Kenai Peninsula	3	42
Kachemak Bay	Alaska-southcentral	Cook Inlet	4	47
Kodiak	Alaska-southwest	Kodiak - North Alaska Peninsula	5	50
North Alaska Peninsula	Alaska-southwest	Kodiak - North Alaska Peninsula	6	32
Bristol Bay	Alaska-southwest	Bristol Bay	7	18
South Alaska Peninsula	Alaska-southwest	South Alaska Peninsula	8	36
Unalaska	Alaska-southwest	Eastern Aleutian	9	12
Adak	Alaska-southwest	Western Aleutian	10	44
Amchitka	Alaska-southwest	Western Aleutian	11	17
Attu	Alaska-southwest	Western Aleutian	12	19
Medny	Russia	Commander Islands	13	14
Bering	Russia	Commander Islands	14	56

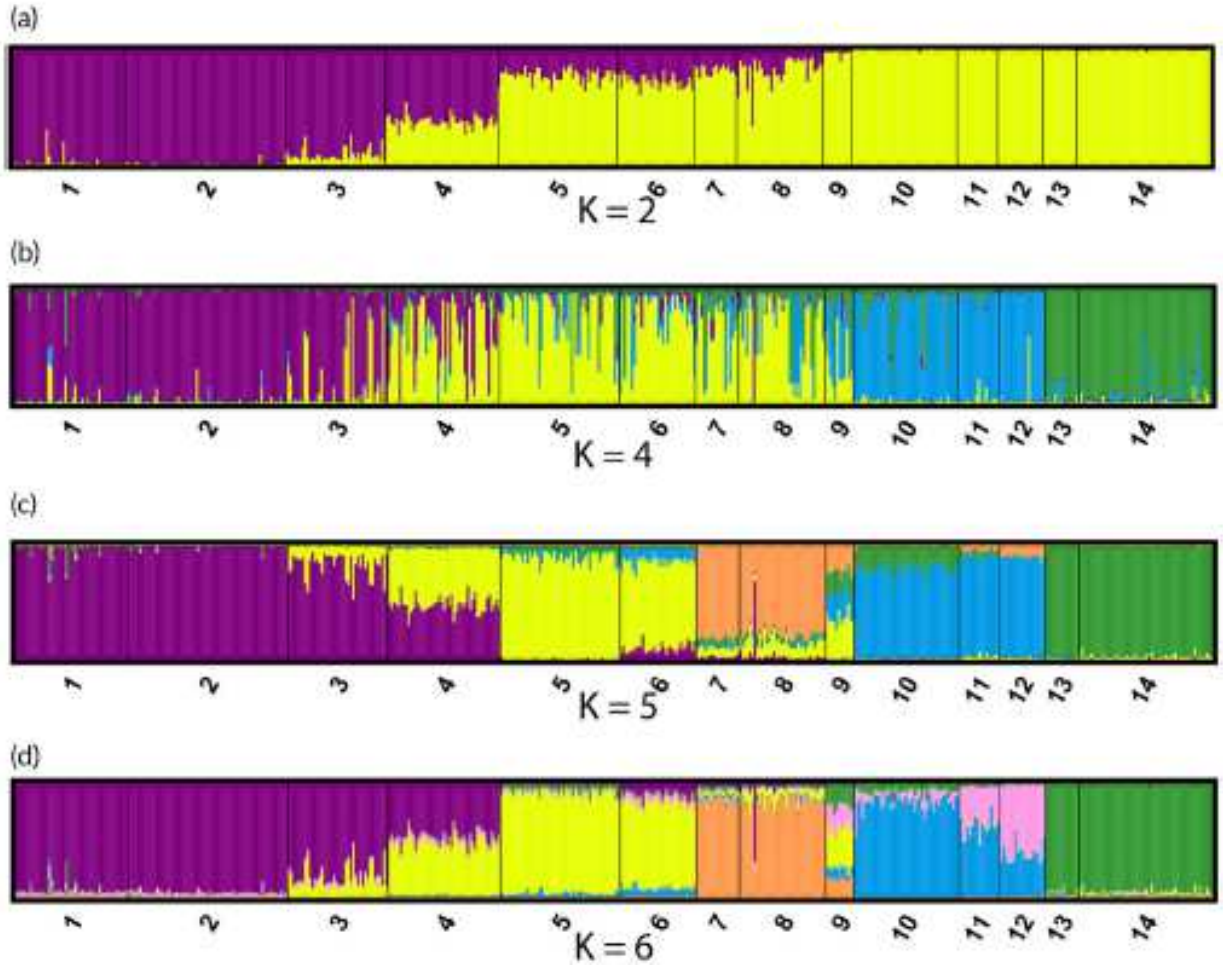


Figure 5. From Flannery et al. (2022). Proportional membership plots testing support for different genetic clusters based on nuclear microsatellite loci from sea otters captured in 14 locations (x-axis) from Russia (location 14) to Prince William Sound (location 1). Each vertical line is an individual sea otter, and genetic clusters are indicated by color for groupings (panels a-d) of 2, 4, 5, and 6 genetic subpopulations (K). Black lines separate locations, and location identifiers are listed below the graphs. Kachemak Bay (location 4) located on the eastern side of LCI is part of the southcentral stock (locations 1–4) while Kodiak and north Alaska Peninsula (locations 5 and 6) are the populations adjacent to LCI within the southwest stock (locations 5–12). Within location 4, yellow indicates genetic mixing with southwest stock. Refer to Table 1 for all location names.

Additional sea otter distribution information is available from two sources extending back to the 1970s. First, sea otters are noted during near-annual aerial Beluga summer surveys flown by the National Oceanic and Atmospheric Administration (NOAA) since 1993 (Figure 6). Similarly, sea otters were identified during many years of vessel-based sea bird surveys available in the North Pacific Pelagic Seabird Database (NPPSD; Drew et al. 2005; Figure 7). Development of a quantitative aerial survey method that accounts for availability and detection of sea otters (Bodkin and Udevitz 1999) allowed collection of systematic distribution and abundance data in LCI. The first surveys using this aerial survey method were flown in 2002 (Esslinger and Monson 2024) followed by a second in 2017 (Garlich-Miller et al. 2018).

In 2002, the total estimated number of sea otters in LCI (excluding Kachemak Bay) and the eastern Kenai Peninsula was 9,591 (SE = 2,413). An estimated 6,918 sea otters (SE = 2,290) (72%) occurred in western LCI, primarily in Kamishak Bay. The remaining 1,761 sea otters (SE = 394) (28%) occurred in eastern LCI along the coast of the Kenai Peninsula (excluding Kachemak Bay) (Esslinger and Monson 2024). By 2017, the total estimated for LCI was ~20,000 including a 55% increase in western LCI to 10,737 sea otters (SE = 2,323), with most sea otters again concentrated in Kamishak Bay. The estimated number of sea otters in eastern LCI in 2017 was 9,152 split between those outside Kachemak Bay (3,164, SE = 685) and within Kachemak Bay (5,988, SE = 756), which was nearly double the 2002 population estimate for eastern LCI despite surveying a smaller total area in 2017 than in 2002 (Garlich-Miller et al. 2018).

The 2002 and 2017 aerial sea otter surveys were designed to provide an estimate of both population distribution (Figure 8 and 9) and abundance in LCI. Both surveys were conducted in the spring/early summer (April–May 2002, May 2017) when the weather was clear. Thus, we had limited information on how sea otters were distributed during other seasons, which complicates efforts to identify important sea otter hotspots and associated habitats in LCI. Garlich-Miller et al. (2018) suggested sea otters along eastern LCI may move into Kachemak Bay in winter but had no winter survey information to test that idea. Without this information, we cannot assess potential effects of proposed oil and gas development, shipping lanes, and contaminant leak scenarios on sea otters. This information would support BOEM analysts and decision-makers who will need this information for National Environmental Policy Act (NEPA) related analyses of Lease Sales, exploration plans, and development and production plans.

2.2 Current Study

This study was designed to assess spatial and temporal patterns of sea otter use of LCI, including the OCS Lease Sale area, primarily through aerial surveys. Although previous surveys used an observer-based method (Bodkin and Udevitz 1999), we used this project to further develop protocols to collect and process imagery for aerial photo-based surveys (Williams et al. 2017). The change to photo-based aerial surveys was initiated to decrease risks associated with low-level flights required for observer-based surveys, while increasing survey efficiency and producing a permanent photo record of survey data (Williams et al. 2017). However, photo-based surveys result in the collection of tens of thousands of images that need to be reviewed for identification of sea otters. Traditional methods, such as manual counting, are labor-intensive and prone to observer variability. In contrast, Artificial Intelligence (AI) models offer promising alternatives that can efficiently process large datasets with greater consistency (Kellenberger et al. 2020). In collaboration with the U.S. Fish and Wildlife Service (USFWS) and the National Park Service (NPS), this study assisted in development of an AI model for identification of sea otters from aerial images. Surveys provide critical information on distribution and abundance, as well as identification of specific habitat attributes that could influence sea otter densities, such as substrate type, prey availability, and ice concentration.

We also conducted detailed foraging observations throughout LCI. These data provide information on sea otter prey species and size classes of retrieved benthic invertebrates, which in turn, offers insights on variation in habitat quality across LCI. Foraging observations also allows us to assess the status of the LCI sea otter population relative to available food resources as indexed by foraging energy intake rates (Coletti et al. 2016; Dean et al. 2002; Monson and Bowen 2015). In addition, in collaboration with National Park Service (NPS) partners, we assessed benthic habitat quality via Remotely Operated Vehicle (ROV) benthic surveys (Hasan 2022). Finally, we examined recently collected bottom trawl data from another U.S. Geological Survey (USGS) BOEM-funded project (BOEM 2025e) to identify some of the sea otter prey species available across offshore areas of LCI.

Figure 6. Historical sightings of sea otters (yellow dots) identified during NOAA aerial Beluga surveys conducted mainly in June from 1993–2018 (Shelden et al. 2015; Alaska Fisheries Science Center 2025).

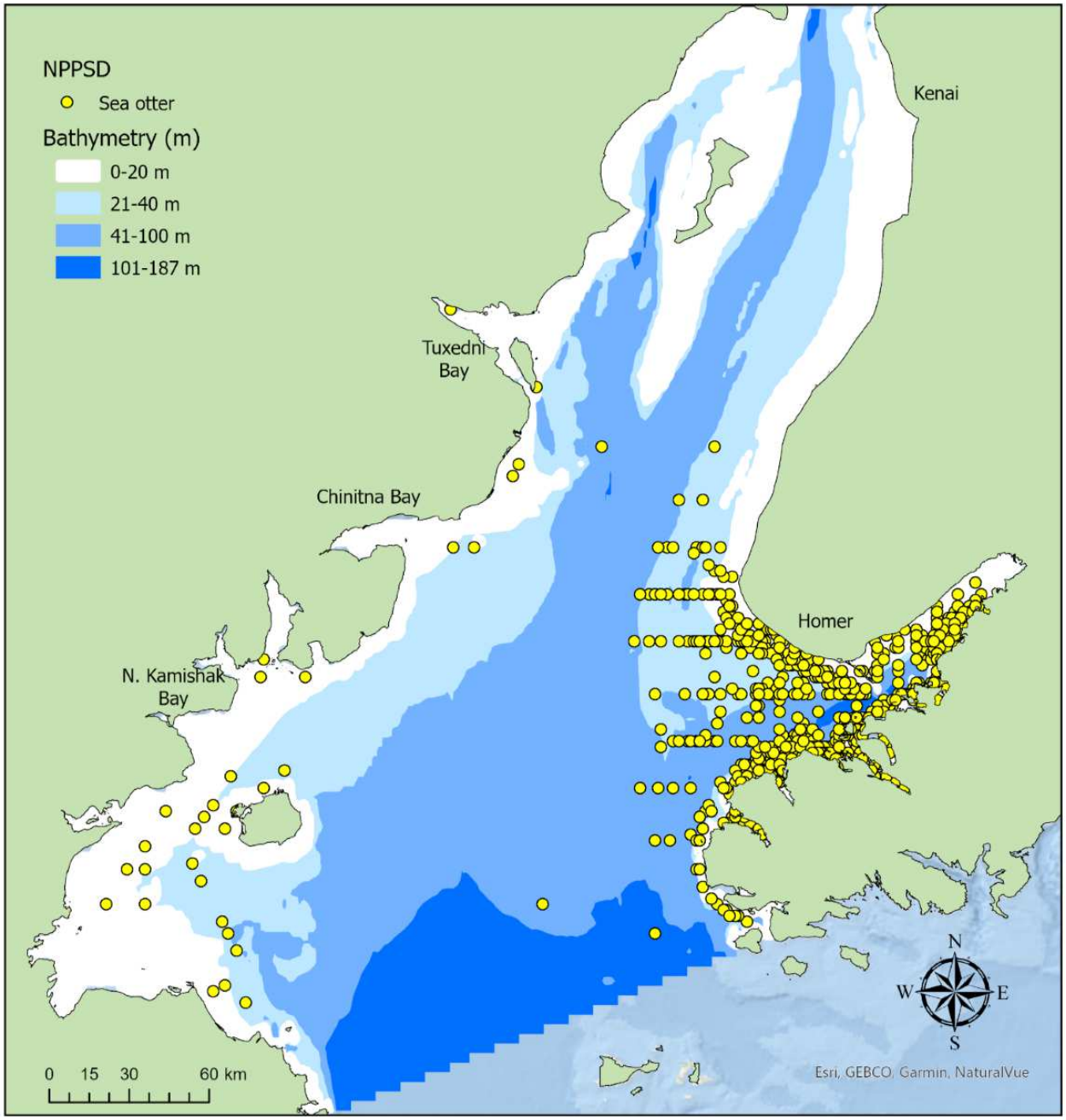


Figure 7. Historical sightings (yellow dots) of sea otters identified from 1973 to 2022 during vessel-based surveys in lower Cook Inlet, Alaska, and archived in the North Pacific Pelagic Seabird Database (NPPSD; Drew et al. 2005).

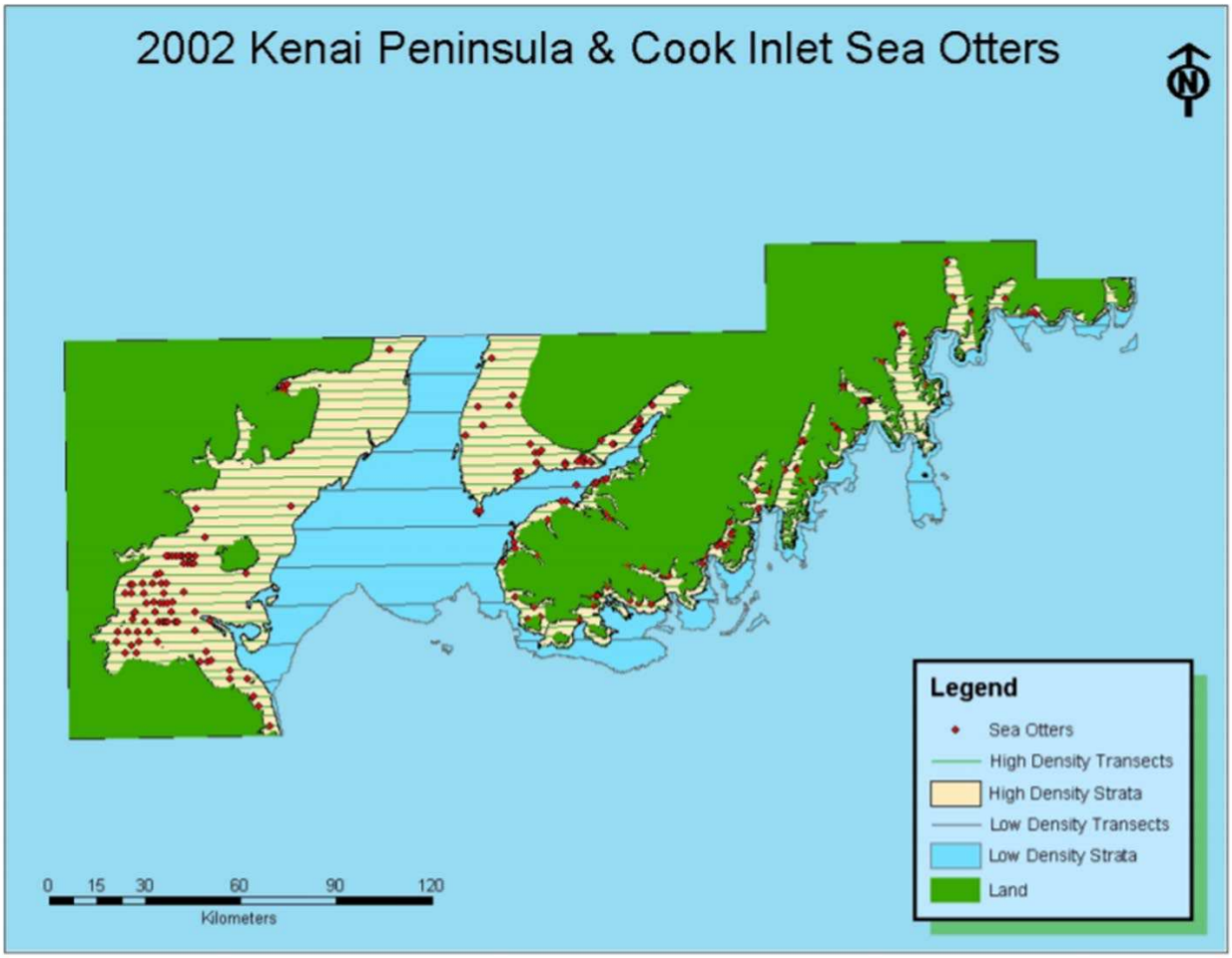


Figure 8. Distribution of sea otters (red dots) sighted during replicate aerial surveys in lower Cook Inlet, Alaska, during summer of 2002. From Esslinger and Monson (2024).

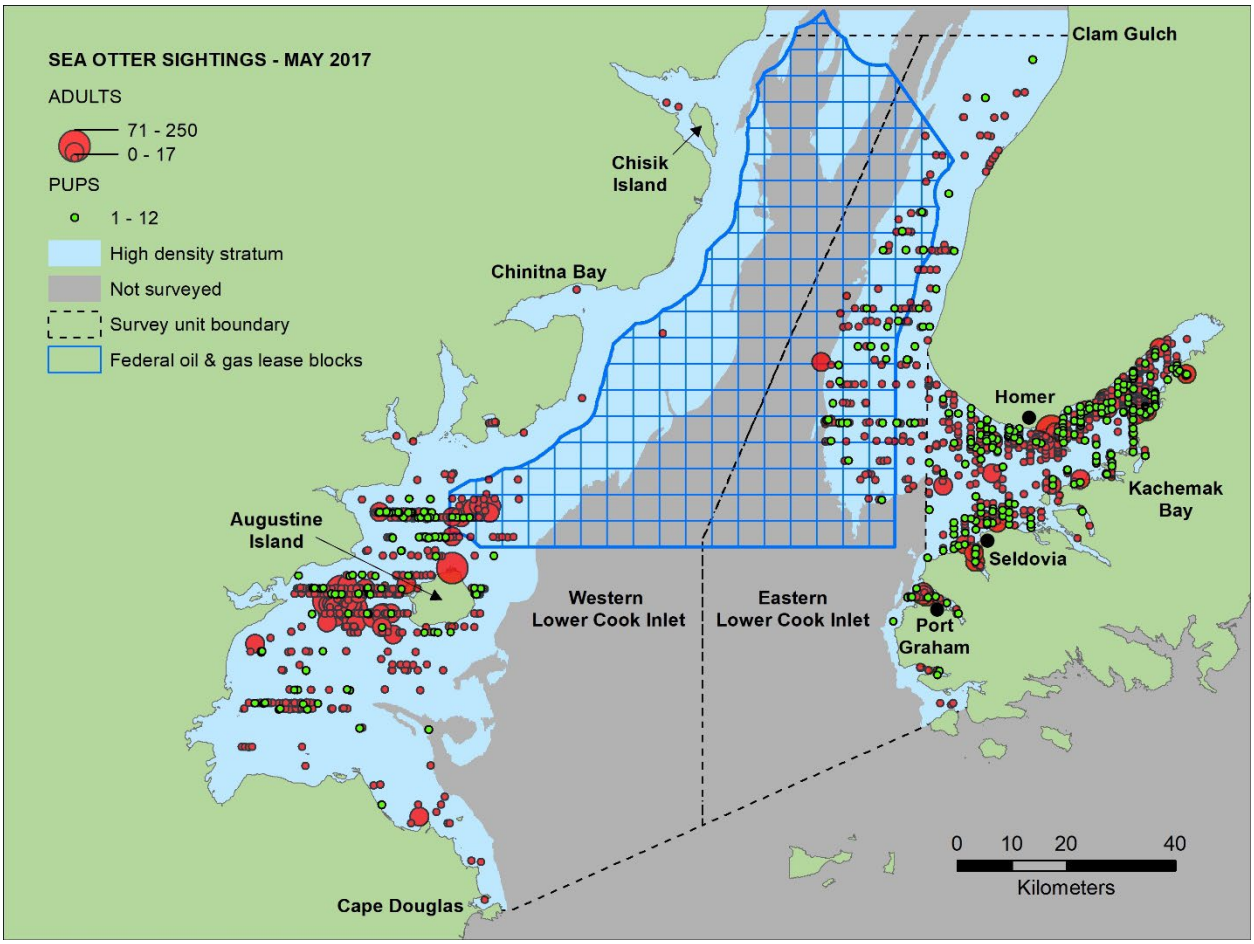


Figure 9. Distribution of sea otters sighted during replicate aerial surveys in lower Cook Inlet, Alaska, in May 2017. From Garlich-Miller et al. (2018).

3 Project Objectives

Objectives of this study included providing data on seasonal sea otter distribution, abundance, and habitat use patterns, (i.e., feeding and resting habitats) within LCI from 2021 to 2023, including identifying spatial and temporal patterns of use by females with pups. Specific objectives were as follows:

1. Use crewed aircraft aerial surveys to document sea otter abundance, distribution and habitat use patterns (e.g., identify resting, foraging and female areas) relative to habitat attributes and oil and gas Lease Sale blocks and development activities within LCI as identified by BOEM Alaska Region.
2. Identify steps for a full transition of sea otter aerial survey work from observer-based to photo-based methods.
3. Use boat-based surveys to document offshore sea otter foraging habitats in LCI.
4. Use submersible remotely operated vehicle (ROV) to assess and describe subtidal habitats identified as sea otter foraging habitat.
5. Use shore-based sea otter foraging observations to document prey composition and energy intake rates in LCI and generate an index of habitat quality and sea otter population status at appropriate spatial scales.

4 Methods

4.1 Study Area

Cook Inlet is a large subarctic estuary, with LCI measuring approximately 215 km long and approximately 120 km wide at the mouth to 15 km wide at the northern restriction that forms the boundary with UCI. Within LCI, depths are relatively shallow ranging from < 50 to 100 m, which are generally within the feeding dive capabilities of sea otters (Bodkin et al. 2004). Cook Inlet waters are influenced by many glacial-fed streams and four major rivers. LCI is bordered on the east by the Kenai Peninsula with its most prominent features including Kachemak Bay in the southeast corner near the entrance opposite Kamishak Bay and AUGI on the south-west corner (Figure 1). Oceanographically, Cook Inlet is characterized by the fourth largest tidal range in the world (max >7.7 m) that are influenced by the shape and orientation of the inlet, which results in strong tidal flows of up to 6 knots and predominantly counterclockwise flows that exit out the western third of LCI (Figure 10). The northly flow of relatively warm, saline ocean-derived water along the eastern half of LCI contrasts with the outgoing flow of colder, fresher water moving down the western half of Cook Inlet (Fissel and Lin 2022; Renner et al. 2017; Figure 11).

Eastern LCI includes several large towns, fishing ports, and oil and gas facilities, while the western side has a much lower human population density, a higher proportion of protected coastline, and no towns or villages. The east side had a recreational Pacific razor clam fishery with nearly one million clams harvested each year from 1977–2006 (Szarzi et al. 2010). From 2009 to 2012, the annual harvest of Pacific razor clams drastically declined, and the fishery bag limit was reduced in 2013. The fishery then closed in 2015, aside from one short period of limited sport and personal use fishery, from July 1–4, 2023, which was opened from 3 miles north of the Ninilchik River to the Homer Spit (Alaska Department of Fish and Game 2023). Pacific razor clams are also harvested both recreationally and commercially on the west side of LCI, although no restrictions have been applied in this area.

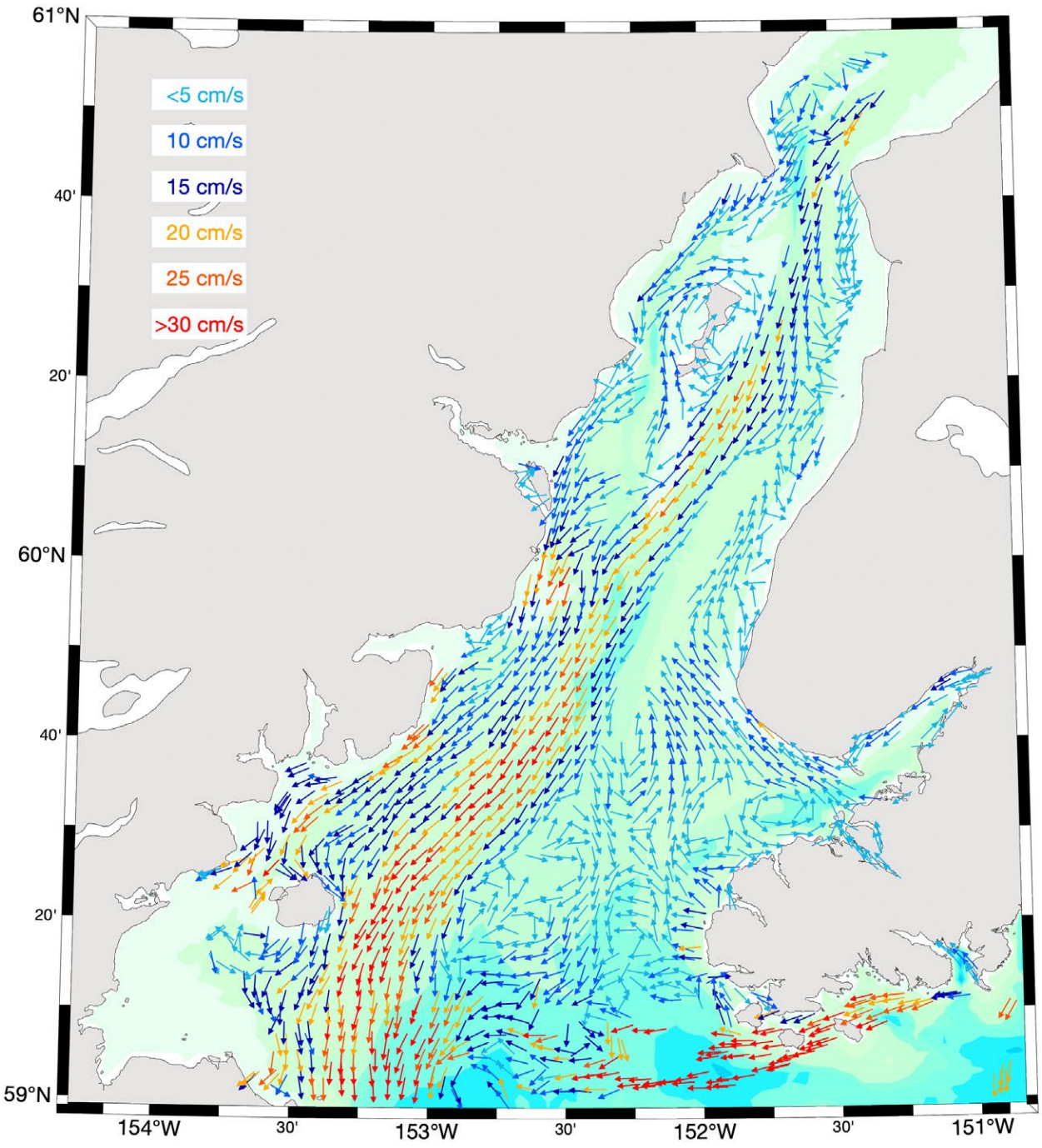


Figure 10. Velocity vectors colored according to speed (centimeters per second) for lower Cook Inlet, Alaska (from Johnson, 2021). Southward flow occupies the western half of lower Cook Inlet with northward, meandering flow in the east. Kalgin Island is surrounded by clockwise flow. A single, cyclonic gyre is in outer Kachemak Bay.

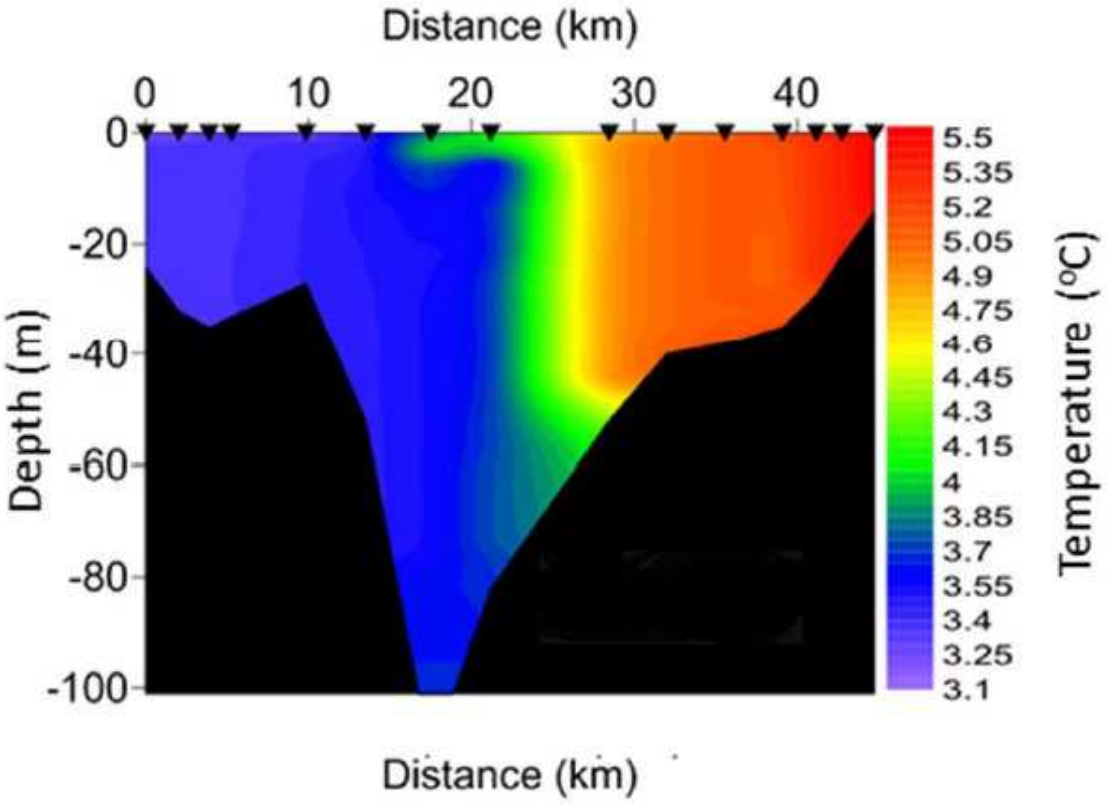


Figure 11. Interpolation of conductivity, temperature, and depth (CTD) casts along the Anchor Point line, across lower Cook Inlet, Alaska, on 2 May 2012, going west (left) to east (right). Warm, oceanic water (reds) entering the Inlet is visible on the right and cold inlet water (blues) flowing south can be seen on the left. No stratification is apparent, indicating that the water column is well mixed. From Renner et al. (2017).

4.2 Photo-based Aerial Surveys

We flew two spring photo-based aerial surveys (2022 and 2023), one summer survey (2022), and one winter survey (2023) along a set of systematic transect lines (Figure 12) with the same lines flown at each survey. Orientation of the survey lines matched that from previous surveys and were spaced so that the survey could be conducted in approximately 3–4 days of flying. Repeating the same lines allowed a more direct comparison of seasonal differences in distribution. Flight altitudes varied from survey to survey as we were still determining the optimal altitude that balanced the trade-off between image quality and survey coverage. Lower altitudes provide higher image quality, but at the expense of a smaller survey footprint, which reduces overall survey coverage when only a limited amount of flight time is available. We evaluated altitudes ranging from 152 to 244 m, which equates to a footprint width of 218 to 349 m (Table 2).

Table 2. Month and altitude of photo-based sea otter surveys flown in lower Cook Inlet, Alaska between spring 2022 and spring 2023.

Survey	Month	Altitude	Survey complete?
Spring 2022	April	229 m	No (equipment failure)
Summer 2022	June	152 m	Yes
Winter 2023	March	244 m	Yes
Spring 2023	April	213 m	No (weather conditions)

Aerial imagery was collected using manned aircraft equipped with a dual DSLR camera system (Waldo Air XCAM ULTRA50, Waldo Air, Franklin, Tennessee) positioned for nadir (down-facing) photography, capturing high-resolution images (Figure 13) approximately every 1.5 seconds while following predefined transects to sample the study area. The imagery was captured using Canon EOS 5DS R cameras with 50 mm lens, chosen for their ability to capture high-resolution images (8688 x 5792 pixels). As much as possible, flights were only flown when wind and light conditions were adequate to allow collection of the highest possible quality images.

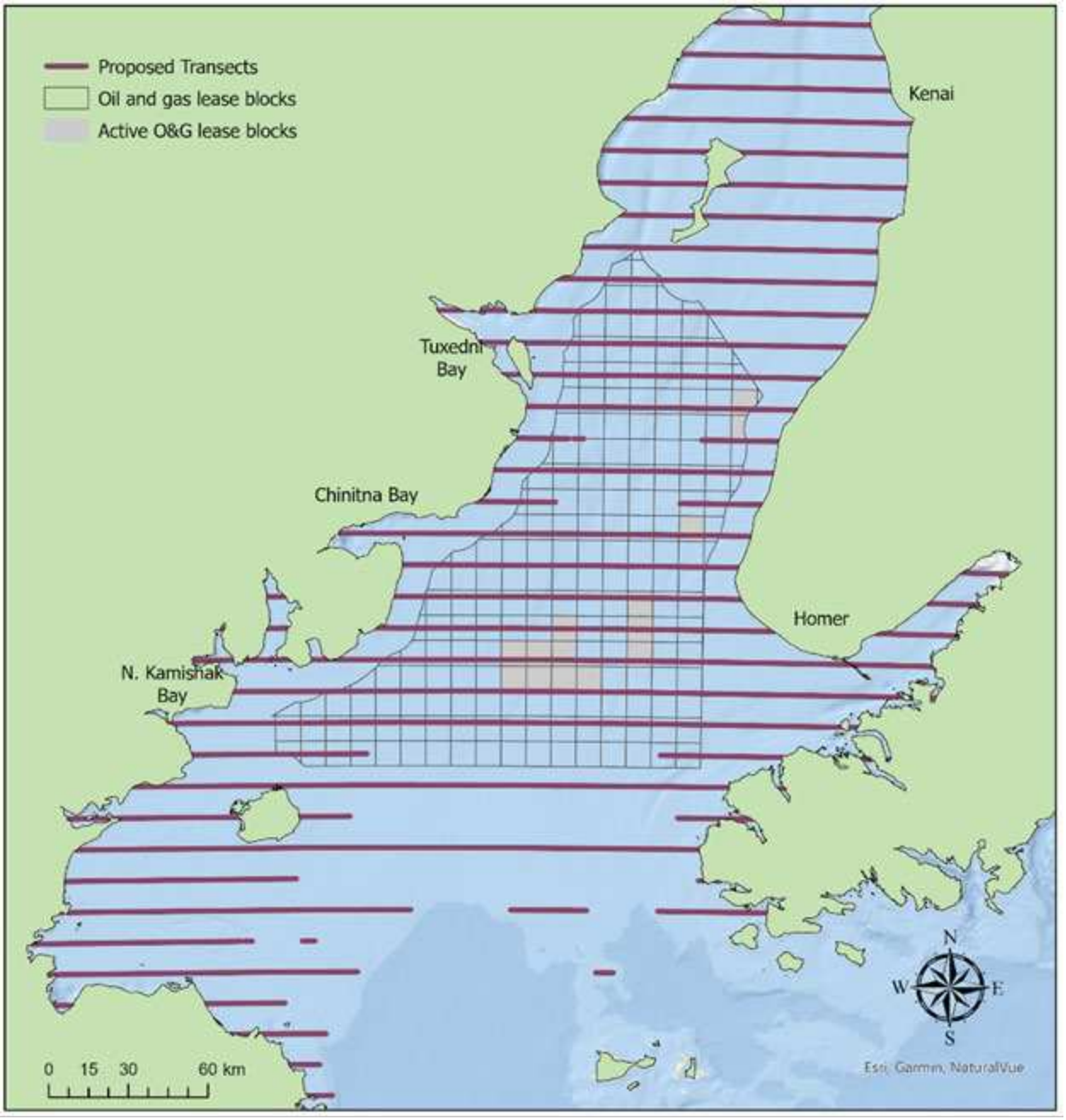


Figure 12. Map of repeat transect lines flown by the crewed photo survey aircraft in lower Cook Inlet, Alaska. However, not all lines were flown for each survey because of factors such as poor survey conditions or equipment failure (refer to Table 2). Active BOEM lease blocks, as of Lease Sale 244, are highlighted in pink. Tracklines from LaRoche et al. (2025a).

Figure 13. Cropped aerial photo of a group of 35 sea otters in Cook Inlet, Alaska taken during the June 2022 survey (this study). USGS photo.

4.2.1 AI-assisted Photo Processing

We used all aerial photos from two regions to test performance of AI-assisted sea otter counts under different environmental conditions. Pilot studies were conducted in Cook Inlet (this study) and southeast Alaska (SEAK). These regions display a wide range of distinct habitat types, sea states, lighting conditions, and additional environmental variability, offering a broad range of conditions for testing the AI model's accuracy. From all the survey images collected by USFWS, USGS, and NPS for sea otters in Alaska from 2021–2023, a random subset of 1,488 photos was selected and organized into observer folders. Photos used to train the object detection model were taken from earlier test flights in Glacier Bay National Park and Cook Inlet and were not included in our experimental sample.

A team of experienced wildlife biologists from the USGS, USFWS, and NPS conducted manual sea otter counts using specialized image analysis software (Schuette et al. 2023), adhering to a standardized protocol. Observers zoomed into grid cells of each image to scan for sea otters, marking detected individuals with bounding boxes and labeling them as either 'p' for pups or 'a' for adults. Each image was tagged with relevant environmental conditions, such as water contrast, kelp presence, and ice conditions, which could influence count accuracy. To ensure consistency, observers underwent training and calibration sessions to align their counting techniques, and a subset of images was reviewed by multiple observers to evaluate inter-observer variability.

We trained a custom AI model using the object detection algorithm YOLOv5 (Jocher 2020) to detect sea otters in aerial photos. We refined the model's performance through multiple training cycles, adjusting key parameters and incorporating new data to enhance its ability to detect sea otters in varying sea states, lighting conditions, and habitat types.

We tested different settings for the AI model to find the best balance between speed and accuracy. This included adjusting how fast the model learns (learning rate), how much data it processes at once (batch size), and how long it trains (epochs). The model was trained on photos from pilot studies conducted by the NPS, USFWS, and USGS. Images were manually processed and annotated, and then split into training (80%), testing (10%), and validation (10%) datasets of annotated aerial images. To improve training efficiency and detection accuracy, full-size images were split into 1024 x 1024 pixel tiles. This tiling process reduces computational load, allowing the model to train faster while fitting within graphics processing unit (GPU) memory limits. Smaller tiles allow for increased computational efficiency, allowing us to train models and perform predictions more rapidly. At the same time, larger tiles retain enough environmental context, such as kelp beds, ice, and water contrast, so the model can learn how habitat influences otter presence. Therefore, at 1024 pixels, these tiles balance computational efficiency with the inclusion of larger-scale habitat characteristics to achieve high accuracy with lower computational input. Additionally, this approach balances the dataset by ensuring otters appear more frequently in training samples and allows for data augmentation techniques like rotation and brightness adjustments to improve generalization across different conditions.

As the model progressed, active learning techniques were incorporated to iteratively improve performance. This involved a cycle where the model made predictions on new and previously unseen data. Predictions that were uncertain or incorrect were reviewed by experts, and the associated data points were re-annotated or corrected as needed. This process helped to refine the model by adding these challenging cases back into the training dataset, ensuring the model could learn from its mistakes and improve over time.

Hyperparameter optimization was a crucial aspect of model refinement. Through grid search and cross-validation, the optimal configurations for hyperparameters such as learning rate, batch size, and the number of epochs were identified. Grid search systematically evaluated different combinations of these parameters to determine which settings provided the best balance between training time and model accuracy. Cross-validation was used to ensure that the model's performance generalized well to new, unseen data. The model underwent a process of iterative evolutions, each time training on the previous iteration until performance plateaued regardless of increased training size.

Post-processing steps were also implemented to refine detection results. This included setting confidence thresholds to filter out low-confidence detections, which helps to reduce false positives. A confidence threshold of 0.4 was selected due to its location on the curve minimizing false negatives and reducing the rate of false positives (Schuette et al. 2023).

To further enhance accuracy of predictions, a manual validation process was implemented to remove false positives. All correct predictions above 0.4 confidence were viewed by a human observer and marked correct, incorrect, or ambiguous. Ambiguous predictions would then undergo further validation by a team of experts to generate the final data. This approach helped in refine the output by ensuring that only validated targets are considered and reducing the manual labor typically associated with photo processing. By utilizing automated identification of targets, the process allowed humans to perform the final review and make decisions based on their expertise.

Data from the AI-assisted and manual counts were merged into a unified dataset for analysis. Each entry was matched based on image timestamps, geographic coordinates, and bounding box annotations. The dataset included fields such as image ID, location, date, observer type, count details, and environmental conditions.

We utilized several statistical analyses to compare the accuracy and consistency between AI-assisted and manual sea otter counts. Intraclass Correlation Coefficient (ICC) was used to evaluate reliability across

multiple raters on a per-photo basis. Cohen's Kappa was employed to measure inter-rater reliability beyond chance on a pairwise observer basis. Mean Squared Error (MSE) and Mean Absolute Error (MAE) were computed to quantify the accuracy of each method, with MSE focusing on the average squared difference and MAE on the average absolute difference between counts. An Analysis of Variance (ANOVA) was conducted to evaluate if statistically significant differences existed between the two methods, examining variance within and between groups.

4.3 Aerial Survey Data Analysis

To assess the effect of habitat attributes in LCI on sea otter distributions, we first used a 400-meter grid coverage overlaying LCI in ArcGIS (Esri, Redlands, California) to define sample blocks. We then obtained daily marginal zone ice coverages from 2007 to 2022 (NOAA 2023) for all years where data were available for the entire year at the time of the analysis (2007 to 2022). Daily Marginal Ice Zones are a U.S. National Ice Center product with two ranges, 10%–80% coverage and > 80% coverage. We used the daily marginal ice in these images to determine the number of days each block contained >80% sea ice concentrations ("heavy ice" henceforth) each year. We also determined the distance to shore for each identified sea otter location and overlayed a bathymetry coverage (NOAA 2024) to determine depth at each location. When photo quality was adequate, small pups were identified in aerial photos although large pups of nearly adult size were more likely to be misclassified as adults.

Statistical analysis of sea otter distributions relative to distance from shore, depth, and cumulative presence of heavy sea ice was conducted using a generalized additive model (GAM). Sea otter sightings from summer (June 2022) and winter (March 2023) aerial surveys were fitted to latitude and longitude by season, daily ice presence, distance from shore, and water depth in the GAM. An additive model was used because there was a highly non-linear relationship with the response variables used. The GAM was fit using *mgcv* in R (Wood 2017, R Core Team 2021) using the equation:

$$y = s(\text{Latitude, Longitude, by season (summer vs. winter)}) + s(\text{Depth (m)}) + s(\text{Distance from Shore (km)}) + s(\text{ice concentration (heavy ice)}) + \text{season}$$

Where y was the dependent variable (presence-absence or abundance of sea otters) and s indicates a thin plate regression spline smoothing function (Wood 2003).

4.4 Vessel Surveys

We conducted vessel-based surveys as a complement to our aerial surveys to identify areas potentially important to females with pups and to document sea otter foraging patterns in offshore areas of LCI. To identify sea otter foraging areas, we conducted vessel-based surveys from the USGS *R/V Alaskan Gyre* and from smaller, 17-foot skiffs when in nearshore habitats. Vessel surveys consisted of following predominantly east-west or north-south transects with two observers recording sea otter sightings on each side of the vessel/skiff. Transects were not systematic. Instead, we haphazardly transited LCI either in route to conduct other work (e.g., ROV surveys) or in a pattern that would allow coverage of specific areas of LCI (Figure 14). Observers recorded the number of independent otters and females with pups sighted within 3 distance zones (≤0–200 m, 200—500 m, and >500 m) as they passed perpendicular to the vessel. However, sea otters were generally spotted, and their behavior assessed before the vessel reached this perpendicular position. We also recorded activity of the sea otters as 1) feeding, 2) active (swimming, diving, spy hopping, interacting with others), or 3) resting when they were first observed. We chose vessel tracks both inside and outside lease blocks with the goal of surveying as many lease blocks as possible that were active at the time of Lease Sale 244. We recorded boat survey data using the computer program SeaLog, which automatically ties the ship's GPS coordinates (latitude, longitude) to the

observation (Swingley et al. 2023). When conducting nearshore transects in shallow water, we used the same methodology but aboard a 17-foot ridged-hulled inflatable boat.

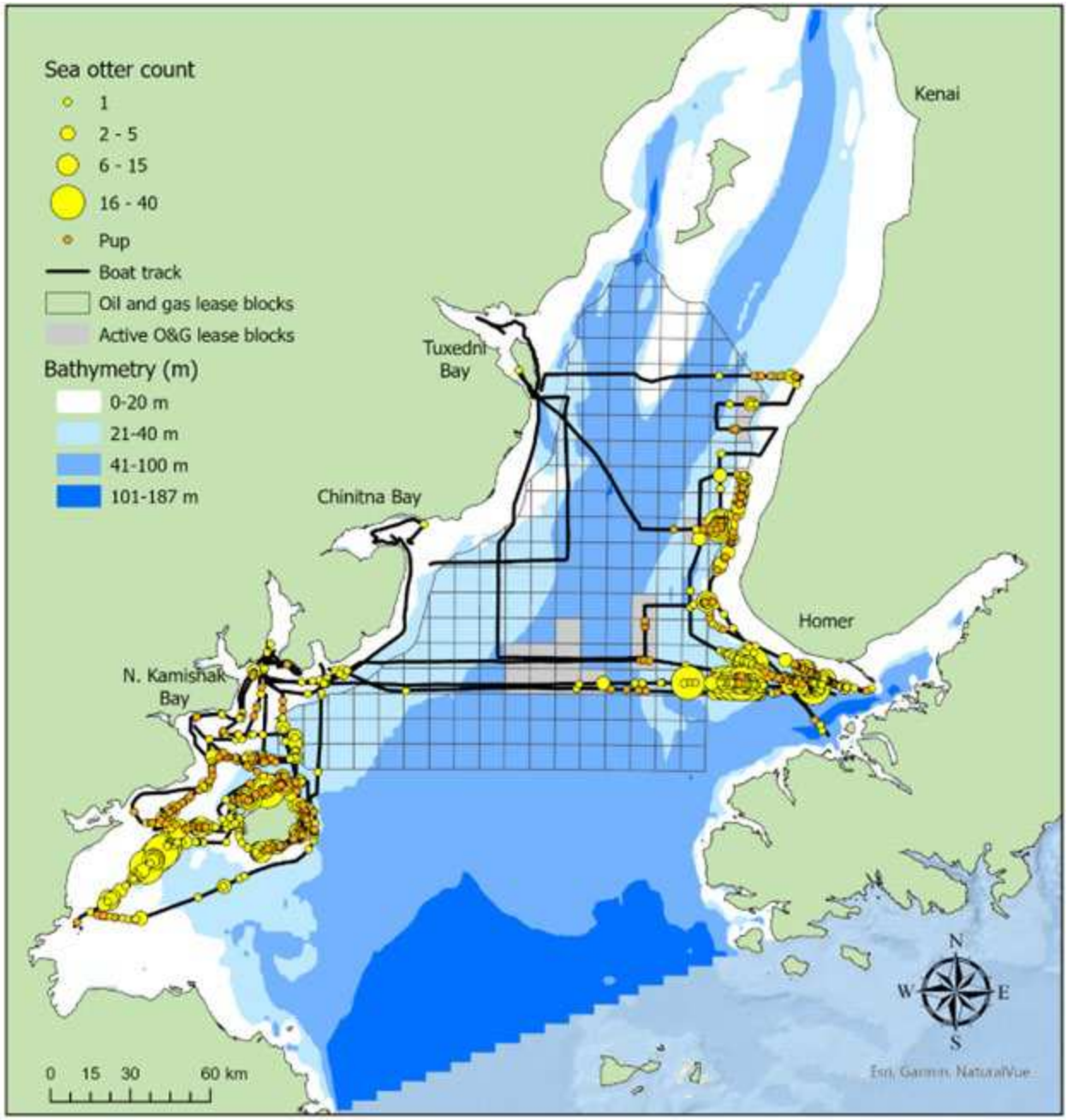


Figure 14. Vessel-based sea otter surveys in Cook Inlet, Alaska, June 2021 and May 2022. Gray lines define Outer Continental Shelf lease blocks grey filled blocks are active as of Lease Sale 244. Black lines are the vessel track, yellow circles represent sea otters without pups with size increasing with group size, orange circles represent females with pups. Vessel track line and sea otter sightings from LaRoche et al. (2025b).

We used a Fisher's Exact test to look for differences in independent:pup ratios inside and outside lease blocks (SAS Institute Inc, Cary, NC, USA). Independent sea otters are non-pups, which could be

juveniles no longer with their mothers, adult males, or adult females. A pup is dependent on and always associated with its mother. High independent:pup ratios indicate a “female area” while “male areas” will have few if any pups (Garshelis et al. 1984).

4.5 ROV Benthic Surveys

We conducted surveys of benthic substrate and epifaunal invertebrates in collaboration with a University of Alaska Fairbanks Coastal Marine Institute (CMI) graduate student award (AK-19-02-01; Hasan 2022) to characterize habitats with varying levels of sea otter density. If habitat types differed relative to sea otter densities, then habitat quality may be a factor contributing to differences in sea otter distribution. Benthic habitat surveys using a ROV were conducted in eastern Cook Inlet (ECOI), Kachemak Bay (KBAY), Lake Clark National Park and Preserve (LACL), western Cook Inlet (WCOI), and Chinitna Bay (CBAY). ROV surveys were completed across a gradient of sea otter population density and occupation (Table 3 from Hasan 2022). The methods for conducting ROV surveys can be found in Hasan (2022).

Table 3. Locations and sea otter density categories where ROV Surveys were conducted in lower Cook Inlet, Alaska (from Hasan 2022).

Survey region	Sea otter density categories surveyed	Funding source/supporting agency
Eastern Cook Inlet	Low, mid, high	Coastal Marine Institute
Kachemak Bay	High	Coastal Marine Institute
Lake Clark National Park and Preserve	Uncolonized	National Park Service
Western Cook Inlet	Low, high	U.S. Geological Survey, Bureau of Ocean Energy Management
Chinitna Bay	Uncolonized	U.S. Geological Survey, Bureau of Ocean Energy Management

4.6 Benthic Trawl Surveys

During summer 2024, benthic trawl surveys were conducted by another USGS BOEM-funded project (lower Cook Inlet Fish and Invertebrate Community Composition, Distribution, and Density; BOEM 2025e) for the purpose of collecting benthic fish and invertebrate information in LCI. However, these trawls also collected epibenthic invertebrates that are potential prey for sea otters. These surveys were not conducted for the purpose of collecting sea otter prey and thus cannot be used to quantitatively assess epibenthic prey availability. Thus, we included them here simply to identify some of the potential prey types that are available to sea otters in LCI. A 3-meter plumb staff beam trawl, with 7 mm square mesh and a 4 mm mesh codend liner was dragged along the top of the benthos for a standard duration of 10 minutes. Previous work has shown the plumb staff beam trawl is highly effective for sampling demersal fauna, including commercial crab species and other invertebrates, flat fishes, and juvenile groundfish while sampling diverse benthic habitats (Abookire and Rose, 2005). When invertebrates were recovered from trawls, they were identified to species, measured, and weighed (Donnelly et al. 2025).

4.7 Sea Otter Forage Observations

Energy intake rates (EIR) are an informative metric of the status of sea otter populations relative to food resources (Coletti et al. 2016; Dean et al. 2002; Tinker 2015; Tinker et al. 2021). We can estimate energy intake because sea otters bring their prey to the surface to eat, allowing observers to identify prey species consumed, count numbers of prey collected per dive and estimate size of prey relative to otter paw size.

This information by itself is useful, but along with estimates of species-specific biomass curves and edible tissue energy densities, energy intake per minute of foraging effort can be estimated (Coletti et al. 2016; Dean et al. 2002; Tinker 2015). Thus, we conducted shore-based sea otter foraging observations on both eastern and western LCI, where possible. Some of these forage observations were collected as part of two graduate student projects led by Laura Geissinger (Geissinger 2024) and Emily Reynolds (Reynolds 2024). We observed foraging sea otters using a 40- to 80-power spotting scope (Questar, New Hope, Pennsylvania, USA) following established methods (Altmann 1974; Dean et al. 2002; Doroff and DeGange 1994).

We estimated rates of food consumption by sea otters based on (1) time of an average foraging dive; (2) time interval between dives; (3) proportion of dives that were successful in obtaining food; (4) type, number, and size of prey obtained on each successful dive; and (5) the average energy content of each prey consumed (Coletti et al. 2016; Dean et al. 2002). The average energy content of prey was estimated based on published information (Cummins and Wuycheck 1971; Dean et al. 2002; LaRoche et al. 2023; Wacasey and Atkinson 1987). We conducted all foraging work during daylight hours (generally between ~ 6 am and 8 pm) with the bulk of the observations made between late May and late July. For dives where prey type was not identified, we used maximum-likelihood methods to assign the most likely prey type based on the dive attributes associated with identified prey types, which removes potential biases that may occur if the known dive data are not representative of unidentified prey (Tinker 2015; Tinker et al. 2012). We estimated 95% confidence intervals for each recovery rate using Monte Carlo simulations (Dean et al. 2002; Manly 2018) within an R-based analytical approach that is currently referred to as Sea Otter Foraging Analysis (Tinker 2020). This analysis fits parameters related to prey recovery rates using likelihood analyses and Bayesian methods in the R interface CmdStanR ("CmdStan"; Gabry et al. 2025). The resulting parameter estimates account for all sources of uncertainty, including sampling error, measurement error, uncertainty in the functional relationship between prey size and edible biomass, error in energy density estimates, and various other sources of parameter uncertainty.

5 Results

5.1 Aerial Surveys

We flew four aerial surveys including a spring and summer survey in 2022 and a winter and spring survey in 2023 (Figure 15 through Figure 18; Table 2). The spring 2022 survey was not completed due to equipment malfunctions, and the spring 2023 survey was mostly completed except for a small number of transects missed because of persistent poor weather (i.e., high winds, low ceilings and/or fog). As expected, we found the highest image quality was obtained at the lowest survey altitude (152 m = 500 ft) and the lowest quality images, which resulted in more ambiguous sea otter IDs, were obtained at the highest survey altitude (244 m = 800 ft). The optimal altitude for data collection appeared to be approximately 213 m (700 ft), which optimized the survey footprint while still allowing image quality to be adequate to confidently identify most sea otters in images.

The temporal extent of heavy ice formation varied from year to year, but was most prominent in the winters of 2008 through 2012, with the most ice forming in January through March (Figure 19). Overall, heavy ice was most common in the northern end of LCI, the back of Tuxedni and Chinitna Bays, and the southwest corner of Kamishak Bay where some blocks had cumulative days with heavy ice coverage present for up to 1,200 days (average of 80 days per year), which equates to 21.9% of the 5,475-day (15-year) period (Figure 20). Moderate ice coverage levels (10%–80% coverage) did not deter sea otters because they were often observed surrounded by or hauled out on ice flows during the winter 2023 survey

and sea otters even occurred in areas with heavy ice concentrations when there were open water leads (Figure 21). Substantial ice rarely formed anywhere along eastern LCI (Figure 20).

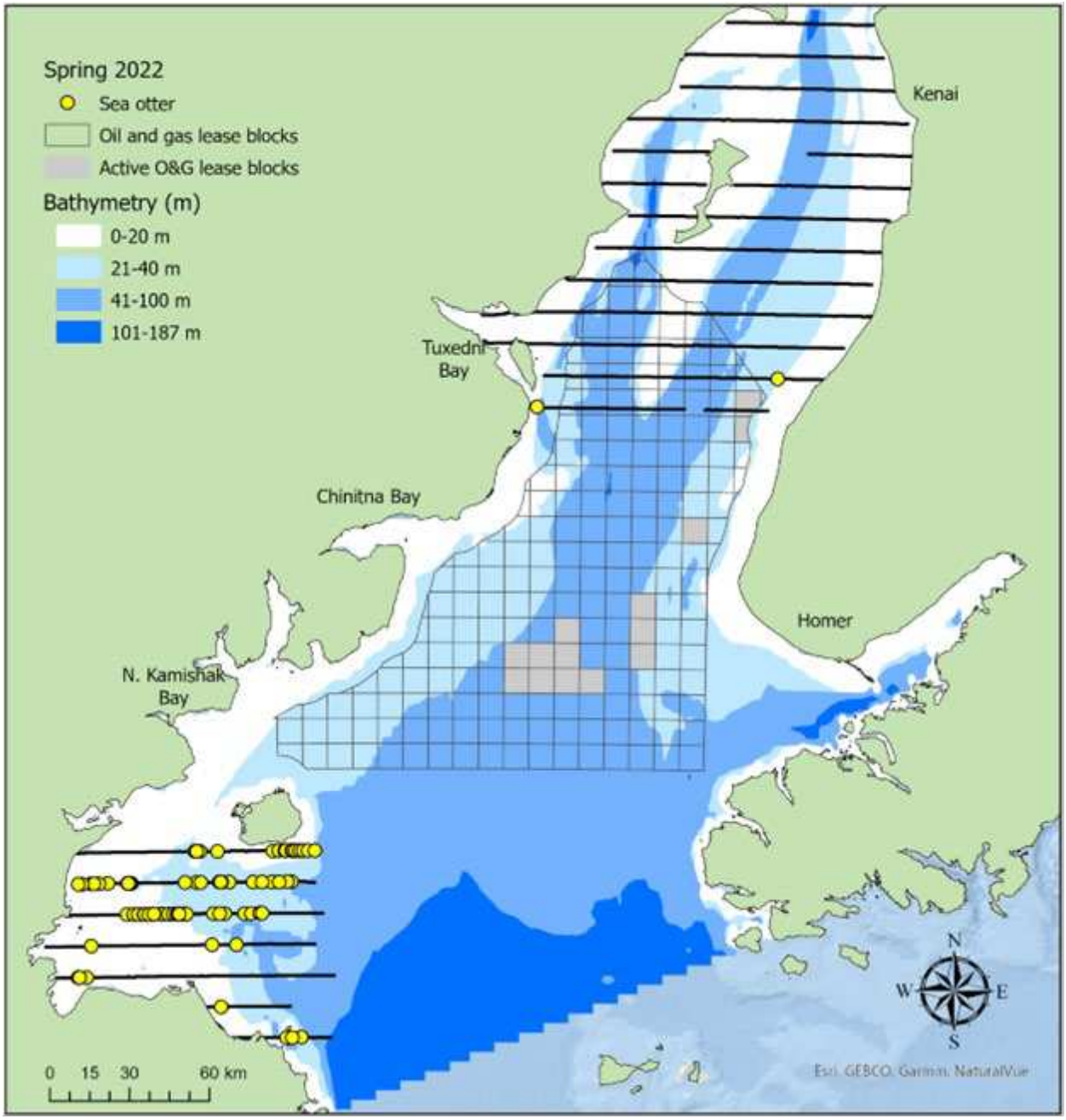


Figure 15. Spring 2022 aerial sea otter survey in Cook Inlet, Alaska. The survey was not completed due to equipment malfunction. Black lines indicate survey transects that were flown in this survey and yellow circles indicate individual sea otter sightings. Active BOEM lease blocks, as of Lease Sale 258, are highlighted in pink. Aerial survey track lines and sea otter sightings are from LaRoche et al. (2025a).

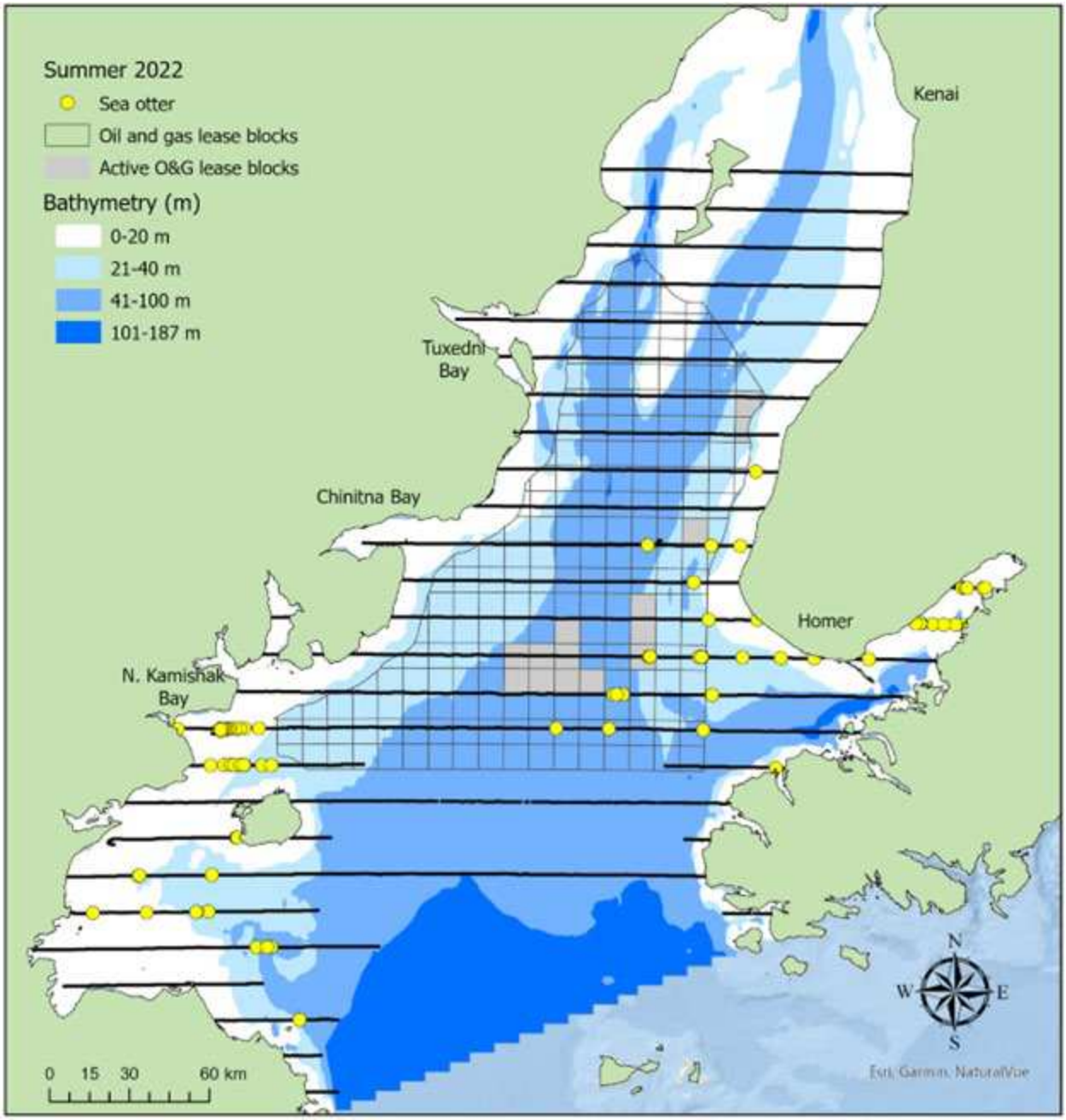


Figure 16. Summer 2022 aerial sea otter survey, in Cook Inlet, Alaska. Black lines indicate survey transects flown in this survey and yellow circles indicate individual sea otter sightings. Active BOEM lease blocks, as of Lease Sale 258, are highlighted in pink. Aerial survey track lines and sea otter sightings are from LaRoche et al. (2025a).

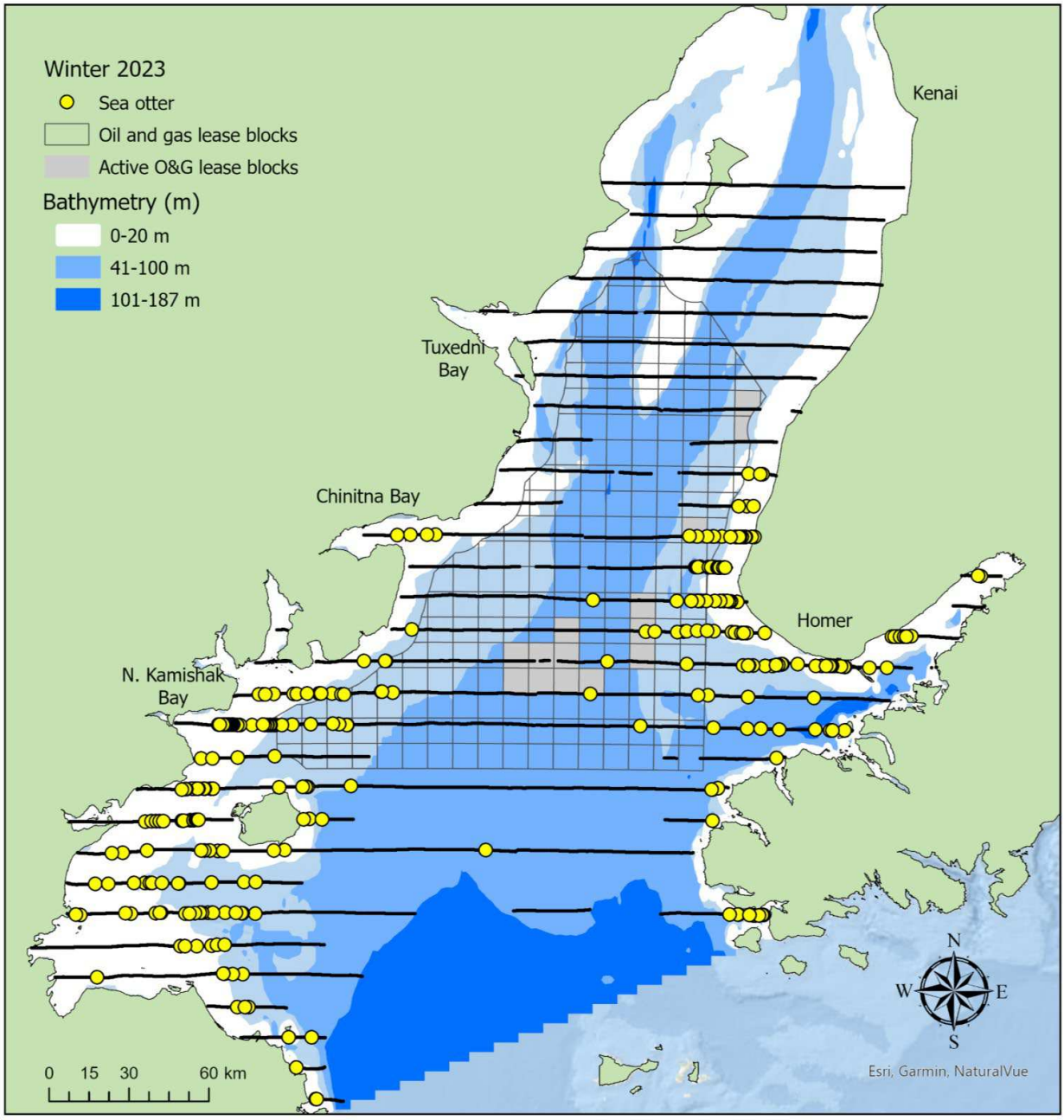


Figure 17. Winter 2023 aerial sea otter survey, in Cook Inlet, Alaska. Black lines indicate survey transects flown in this survey and yellow circles indicate individual sea otter sightings. Active BOEM lease blocks, as of Lease Sale 258, are highlighted in pink. Aerial survey track lines and sea otter sightings are from LaRoche et al. (2025a).

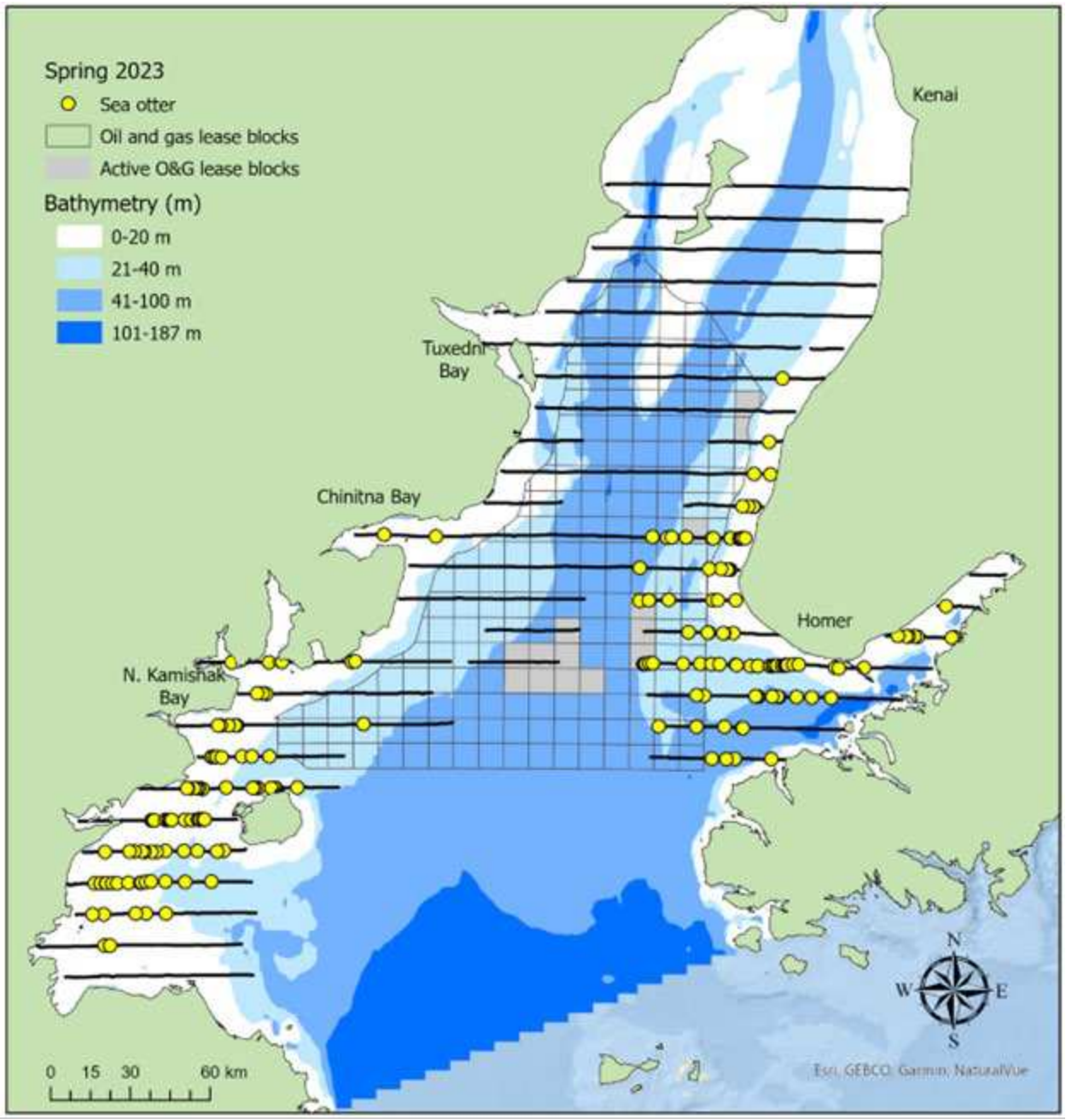


Figure 18. Spring 2023 aerial sea otter survey, in Cook Inlet, Alaska. The survey was not completed due to poor weather conditions. Black lines indicate survey transects flown in this survey and yellow circles indicate individual sea otter sightings. Active BOEM lease blocks, as of Lease Sale 258, are highlighted in pink. Aerial survey track lines and sea otter sightings are from LaRoche et al. (2025a).

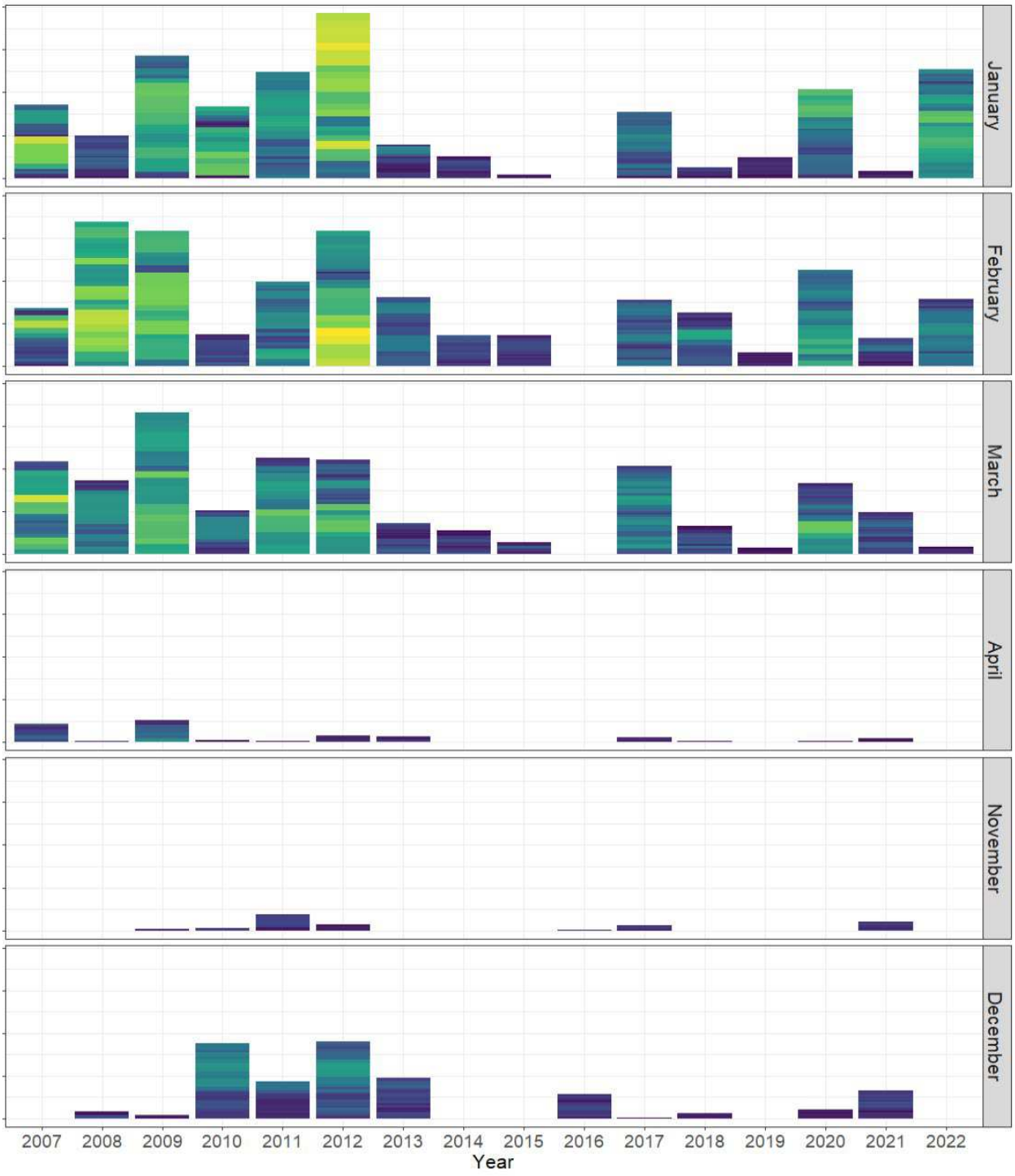


Figure 19. Number of 5-km blocks within lower Cook Inlet, Alaska (refer to map in Figure 20), where heavy ice was present. Data are split into month and year with days (y-axis) stacked for each day heavy ice was present in chronological order of occurrence. Any day without ice is excluded whereas days with ice are colored based on a yellow-to-blue gradient representing the number of blocks with heavy ice for that day. Bright yellow equals more blocks with heavy ice within a single day, and dark blue are days with the minimum of at least one block. Ice data from U.S. National Ice Center (2007–2022).

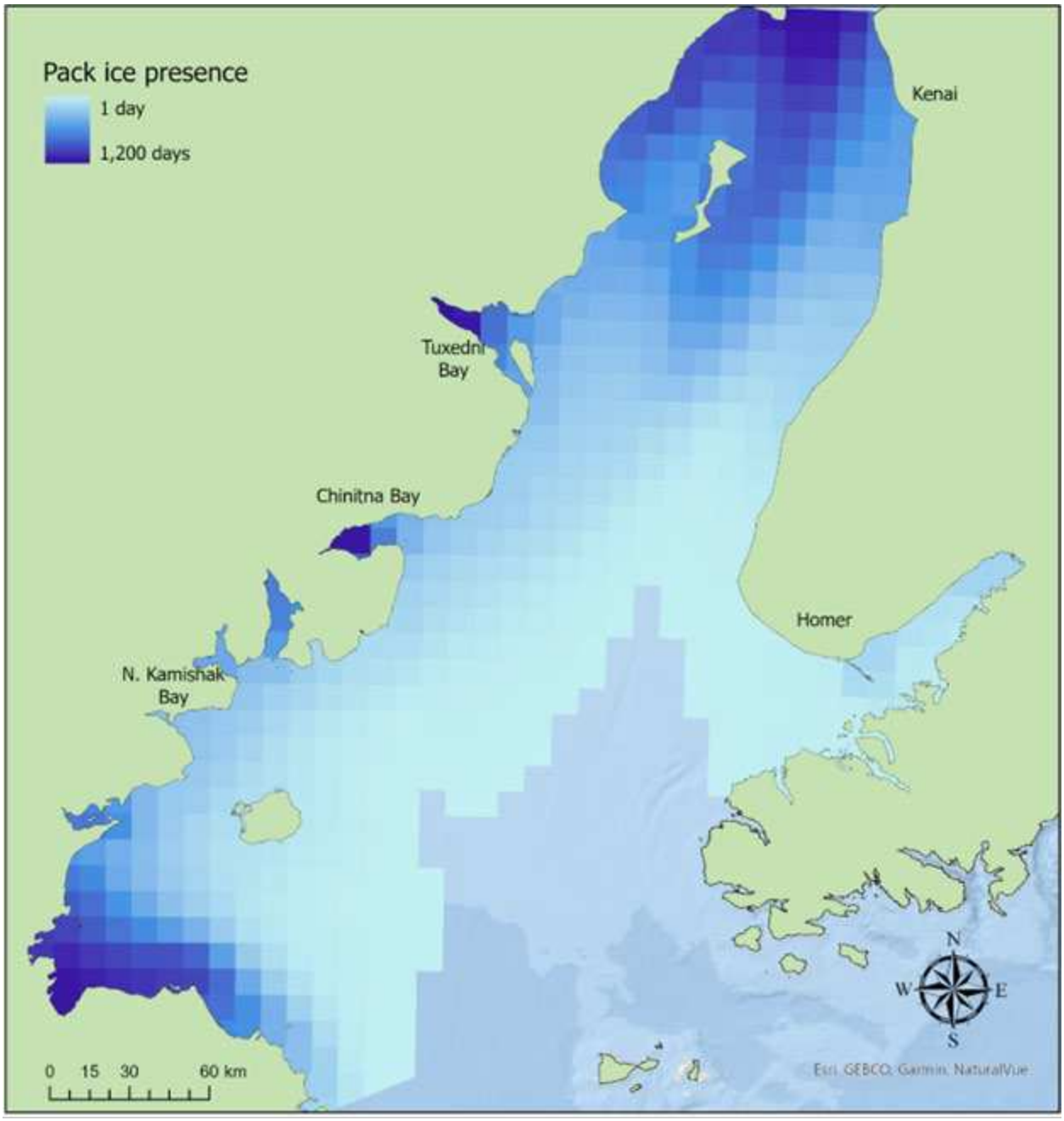


Figure 20. Total number of days with heavy ice concentrations in each 5X5 km block within lower Cook Inlet, Alaska from 2007 to 2022. Darker blue = more cumulative days of heavy ice presence and lighter blue = fewer days of heavy ice presence. Ice data from U.S. National Ice Center (2007-2022).

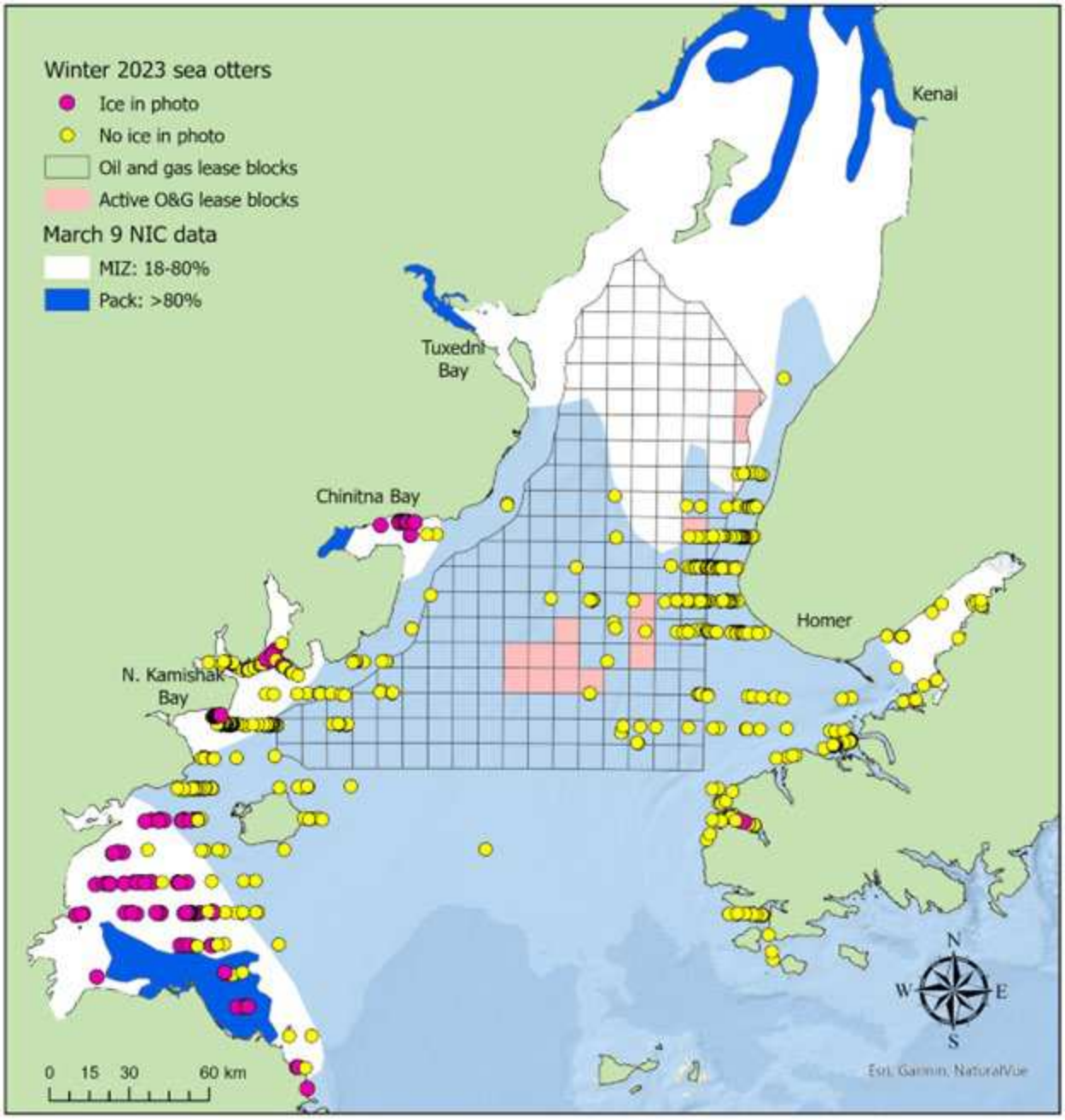


Figure 21. Comparison of sea otter sightings (including off transect sightings) from the Winter 2023 survey overlayed with the daily marginal ice coverage within lower Cook Inlet, Alaska during the winter sea otter survey. Dark blue denotes heavy ice concentration and white denotes Mixed Ice Zone (MIZ) with >10% but <80% ice concentration. Active BOEM lease blocks, as of Lease Sale 258, are highlighted in pink. Ice data from U.S. National Ice Center (2007-2022). Sea otter sightings are from LaRoche et al. (2025a).

We found that season, cumulative presence of heavy ice, distance to shore, and water depth were all statistically significant factors in determining probability of sea otter presence (Table 4). Sea otters were less likely in the northwest and southwest areas of LCI where heavy ice was present in winter 2023 compared to summer 2022 (Figure 22 and Figure 23) including OCS lease blocks numbered 6055–6057,

6105, 6106 and 6155 between the latitudes of 59.9° and 60.0° N in western LCI that had been identified as critical sea otter habitat (Figure 3). In addition, the highest probability of otters tended to occur approximately 8 km from shore (Figure 24) with water depths of 30 to 40 m (Figure 25). Relative to heavy ice, the probability of sea otter presence did not begin dropping off until an area had heavy ice concentration presence for greater than 300 cumulative days (average of ~20 days per year) between 2007 to 2022 (Figure 26).

Table 4. Results of a generalized additive model (GAM) of sea otter presence. Estimated degrees of freedom (EDF) and probability (*p*) values are listed for the covariates: season, cumulative days with heavy sea ice present, distance to shore, and water depth. The correlation coefficient (R^2) value for the model is 0.412.

Model covariate	EDF	*p* value
Season: summer	28.9	<0.001
Season: winter	28.6	<0.001
Cumulative heave ice presence	8.0	<0.001
Distance to shore	8.9	<0.001
Water depth	8.9	<0.001

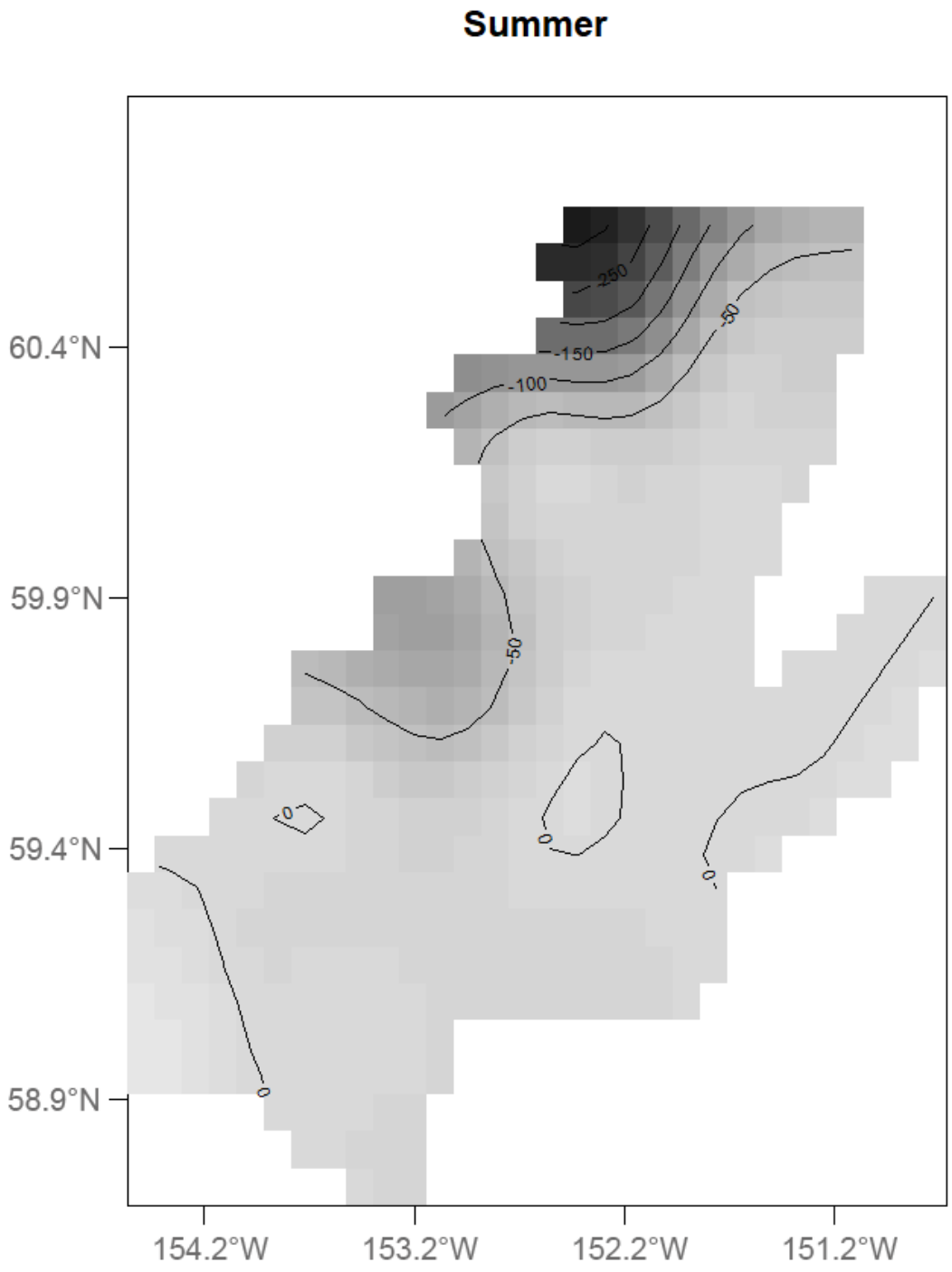


Figure 22. Probability of sea otter presence within lower Cook Inlet in Summer 2022 based on GAM model at 400-meter resolution. Zero is higher likelihood of sea otter presence, in light gray, whereas negative values (dark coloring) are less likely to have sea otters present. Latitude and Longitude are in m (Universal Transverse Mercator [UTM] coordinate system converted to decimal degrees). Sea otter sightings used in the GAM model from LaRoche et al. (2025a). Ice data from U.S. National Ice Center (2007-2022). Bathymetry data from NOAA 2024.

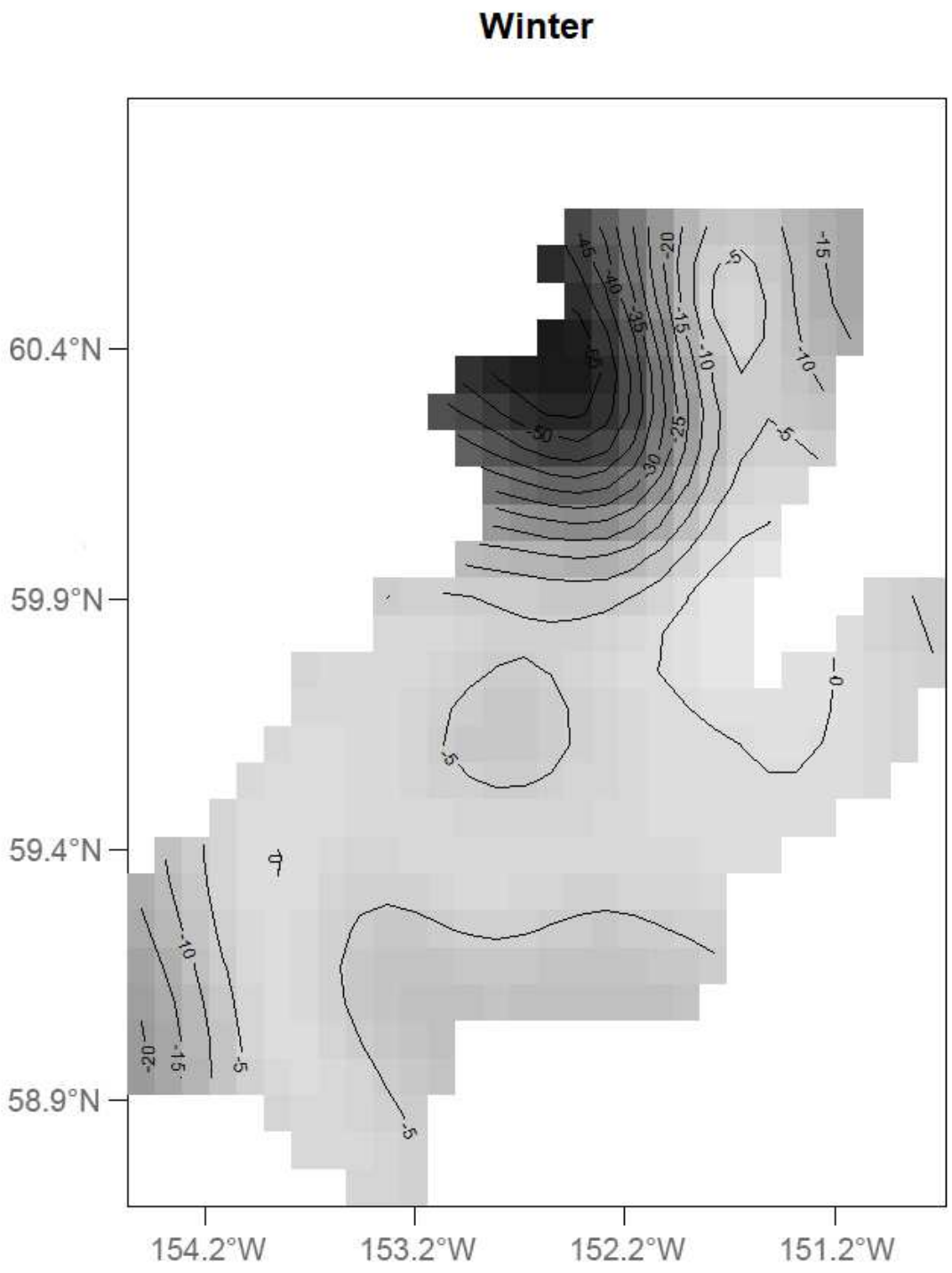


Figure 23. Probability of sea otter presence within lower Cook Inlet in winter 2023 based on GAM model at 400-m resolution. Zero is higher likelihood of sea otter presence, in light gray, negative values (dark coloring) are less likely to have sea otters present. Latitude and Longitude are in m (UTM converted to decimal degrees). Sea otter sightings used in the GAM model from LaRoche et al. (2025a). Ice data from U.S. National Ice Center (2007-2022). Bathymetry data from NOAA 2024.

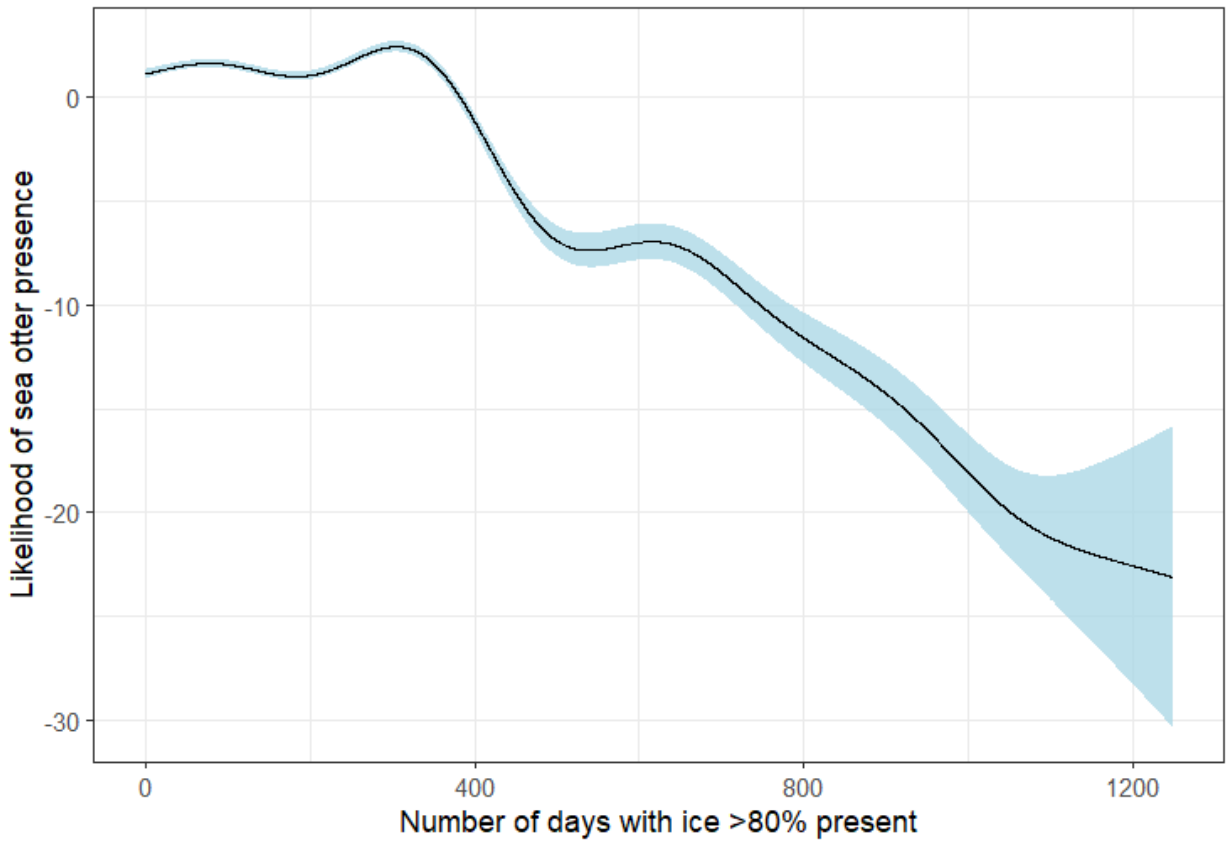


Figure 24. Output of a GAM model illustrating the likelihood of sea otter presence within 5X5 km blocks relative to the cumulative total number of days heavy sea ice was present within the same block from 2007 to 2022 in lower Cook Inlet. Light blue shading indicates 95% confidence intervals. Sea otter sightings used in the GAM model from LaRoche et al. (2025a). Ice data from U.S. National Ice Center (2007-2022). Bathymetry data from NOAA 2024.

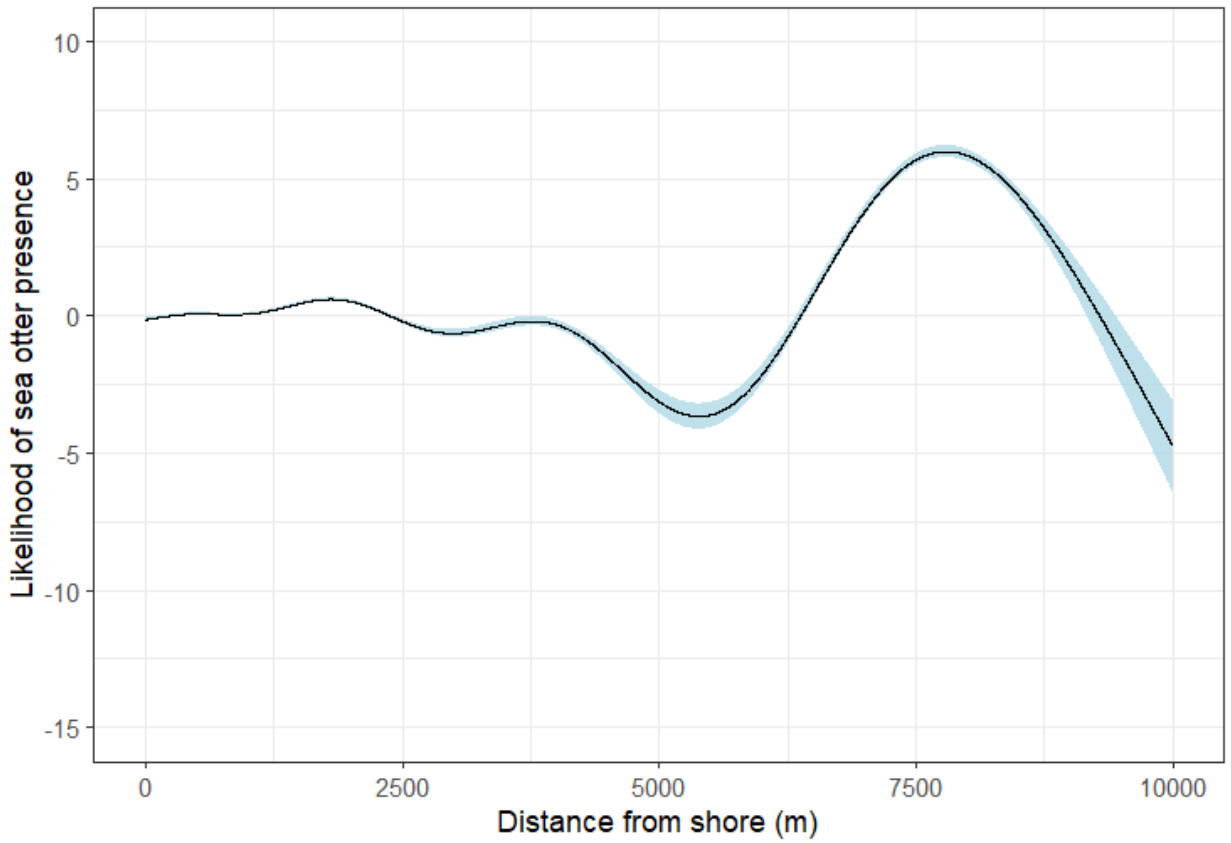


Figure 25. Sea otter distribution relative to distance to shore (m) within lower Cook Inlet, Alaska based on GAM model. Light blue shading indicates 95% confidence intervals. Sea otter sightings used in the GAM model from LaRoche et al. (2025a). Ice data from U.S. National Ice Center (2007–2022). Shoreline data from NOAA 2024.

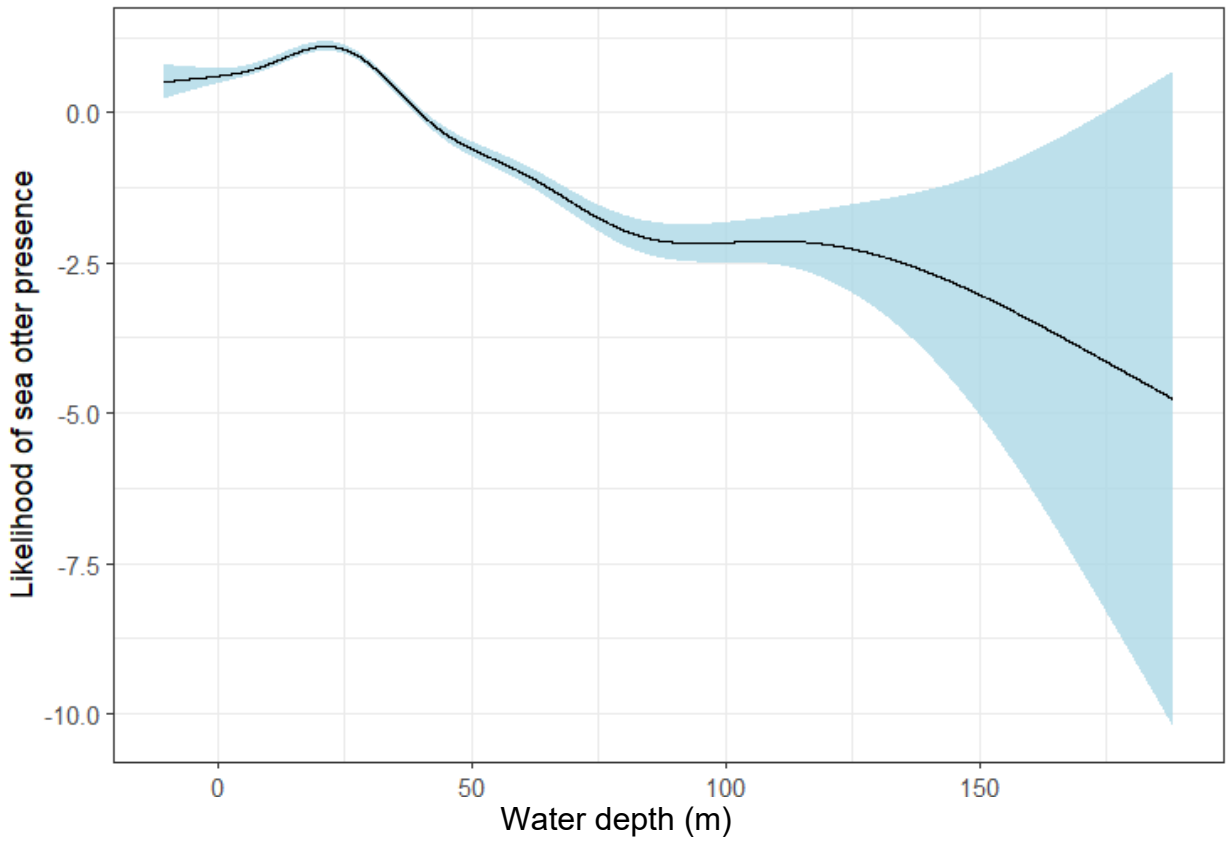


Figure 26. Sea otter distribution relative to water depth (m) within lower Cook Inlet, Alaska based on GAM model. Light blue shading indicates 95% confidence intervals. Sea otter sightings used in the GAM model from LaRoche et al. (2025a). Ice data from U.S. National Ice Center (2007–2022). Bathymetry data from NOAA 2024.

5.2 AI-assisted Photo Processing

During survey flights in LCI, we collected a total of 160,158 images with the number of photos collected per year ranging from approximately 19,000 to 54,000. During summer 2022 imagery collection, parameters included a mean F-Stop of 3.5 (range: 2.5–5.6), a mean exposure time of 0.000379 seconds (range: 0.000125–0.0005), a mean ISO speed of 503 (range: 100–1,250), and a mean altitude of 238 m (range: 43–2005 m). These settings optimized image clarity under both bright sunlight and low-light conditions.

The analysis revealed clear differences between AI-assisted and manual sea otter counts. The AI-assisted counts showed high consistency and accuracy, with an Intraclass Correlation Coefficient (ICC2K) of 0.991, meaning the AI-assisted counts produced nearly identical results when analyzing the same images multiple times. Manual observers also showed strong agreement, but with a slightly lower ICC of 0.908, indicating more variability in their counts. Cohen's Kappa, R^2, and Mean Absolute Error (MAE) values also demonstrated higher reliability and precision of AI-assisted counts compared to manual counting.

Despite these differences, the ANOVA test showed that the performance gap between AI-assisted and manual counting was not statistically significant ($p = 0.568$). This means that although the AI-assisted

process was more consistent, the overall variation in counts across methods is likely not large enough to impact final population estimates.

A linear regression analysis ($R^2 = 0.812$, $p < 0.001$) confirmed a strong relationship between AI-assisted and manual counts. The slope (m=1.071, 95% CI: 0.979 to 1.164) and intercept (b=0.076, 95% CI: -0.149 to 0.301) were close to the expected values (m=1, b=0), indicating that there was only a marginal bias between the manual counts and the AI-assisted counts. The confidence intervals suggest that while the estimates are nearly ideal (1:1), the slope slightly exceeds 1, indicating that the AI-assisted method tends to count slightly more otters than manual methods in some cases, though the bias remains minimal.

The Intraclass Correlation Coefficient (ICC) is used to measure consistency and agreement among methods, but different types of ICCs provide distinct insights into the reliability of AI-assisted versus manual sea otter counts. In this study, ICC(1), ICC(2), and ICC(3) were analyzed to compare how consistently the AI-assisted and human observers detected sea otters across different conditions.

ICC(1) measures single-rater consistency, evaluating whether the same observer (or AI) produces consistent results when counting sea otters in multiple images. A high ICC(1) means that an observer or AI-assisted model is internally reliable in its own counts. The AI-assisted had an ICC(1) of 0.964, indicating that when analyzing similar images, it provided nearly identical results each time. In contrast, human observers had a lower ICC(1) of 0.709, suggesting that individual manual counters showed more variation in their own assessments across different images.

ICC(2) assesses agreement between multiple observers, determining whether different individuals (or different validators for the AI-assisted) produce similar counts when analyzing the same images. The AI-assisted demonstrated a high ICC(2) of 0.964, meaning that different runs of the AI-assisted model remained consistent and would likely produce the same results if repeated. However, human observers had a lower ICC(2) of 0.712, indicating that different people counting the same images showed more variation in their results, likely due to differences in interpretation or experience.

ICC(3) evaluates absolute agreement, determining whether two methods (such as AI-assisted and human observers) produce nearly identical results and could be used interchangeably. The AI-assisted achieved a high ICC(3) of 0.966, showing that it produced stable and reliable counts across different conditions. In contrast, manual counting had a lower ICC(3) of 0.742, indicating that human observers were less interchangeable—one person might count slightly more or fewer sea otters than another, leading to inconsistencies.

High ICC scores across all three measures indicate that the AI-assisted model is highly consistent within itself, across different runs, and when compared to human methods. Manual observers showed greater variation, both within their own counts and between different people. This suggests that while manual counts remain suitable for estimating sea otter abundance, they are more prone to variability. The AI-assisted model provides repeatable, reliable, and standardized sea otter detections, indicating the model can be used for large-scale wildlife monitoring.

Furthermore, the AI-assisted model achieved a higher Cohen's Kappa of 0.829, which measures agreement beyond chance, compared to manual counting's Cohen's Kappa of 0.706. This suggests that the AI-assisted model’s counts are more reliable and less subject to random error. The AI-assisted model also had lower error rates, with a MSE of 0.620 and MAE of 0.235, compared to manual counting with a MSE of 1.316 and MAE of 0.379. These numbers indicate that the AI-assisted model detected sea otters more accurately and with greater precision, reducing variability and increasing reliability in population estimates.

5.3 Vessel Surveys

We surveyed approximately ~1,600 km during two vessel surveys in 2021 and 2022 (Figure 14). We transited 88 OCS lease blocks, and of those, 27 had sea otters present and 11 of the 27 had pups present (Figure 14). Overall, most animals were either resting or active when first observed, with few observed feeding (Figure 27). However, many of the sea otters observed from the vessel appeared to be aware of our presence; therefore, some feeding animals may have detected us as we approached and ceased feeding by the time we spotted them.

Over the entire survey area, we recorded a total of 3,551 sea otters on transects of which 7.6% (271) were pups. However, the ratio of independents to pups was higher inside OCS lease blocks compared with outside OCS lease blocks (Fisher's Exact $p<0.001$, Table 5). That is, inside of OCS lease blocks, we recorded a total of 120 sea otters, of which 22.5% (27) were pups. Outside OCS lease blocks, we recorded a total of 3,431 sea otters, of which 7.1 % (244) were pups.

Table 5. Comparison of sea otter independent:pup ratios inside 88 Lease Sale blocks vs. outside oil and gas Lease Sale blocks (see map of Lease Sale blocks in Figure 14) in lower Cook Inlet, Alaska. Observed numbers are listed with expected numbers based on Fisher's Exact test in parentheses.

Lease Blocks	Independent sea otters	pups
Inside	93 (111)	27 (9)
Outside	3,187 (3,169)	244 (262)

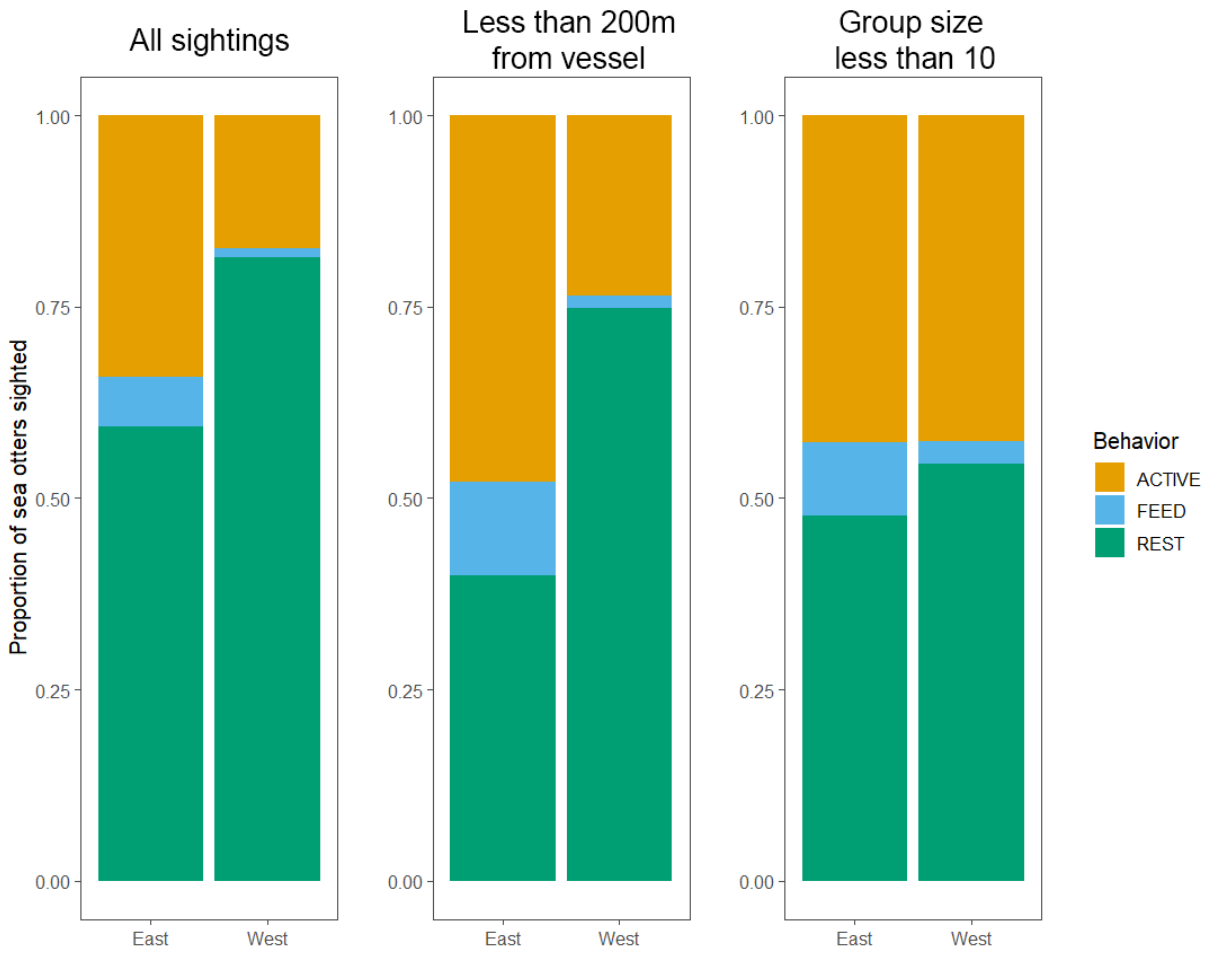


Figure 27. Sea otter behavior as recorded from boat-based surveys in Cook Inlet, Alaska, in 2021–2023. The left-most plot shows all sea otter sightings, the middle plot shows only sea otters that were within 200 m of the vessel, and is the right-most plot shows only sea otters that were in groups less than 10. Orange is active (non-feeding), blue is feeding, and green is resting. Data from LaRoche et al. (2025b).

5.4 ROV Benthic Surveys

In total, ~150 ROV surveys were conducted in LCI between May and October 2021 (Figure 28), and 3,210 images from 107 surveys were analyzed (Hasan 2022). Maps of substrate and algal habitat were produced to demonstrate the distribution of habitat across ROV survey sites (Figure 29 and Figure 30). Invertebrate cover was low across all regions, so a map was not produced for this habitat type. Invertebrates that were occasionally observed at the image-level include anemones, barnacles, bryozoans, crabs, hydroids, jellyfish, rock jingles, scallops, sea pens, sea stars, sea urchins, shrimp, snails, sponges, and tunicates (Hasan 2022). Substrate was primarily composed of mud, shell, and pebble (Figure 29). KBAY was dominated by mud with substantial shell cover (Figure 29).

Sea otters are rarely found along the LACL coastline, which stretches along the west side of LCI north of Kamishak Bay and includes Chinitna and Tuxedni Bays. The benthos in this area had significantly different biological communities than other areas of LCI where sea otters are common (Hasan 2022). In

addition, the substrates along LACL coast were more homogeneous than those along the eastern shore of LCI. Hasan (2022) suggests that these differences may indicate that few sea otters are moving into the LACL area because it is simply poor sea otter habitat with few resources to support sea otters.

Complete analysis of ROV survey results can be found in Hasan (2022).

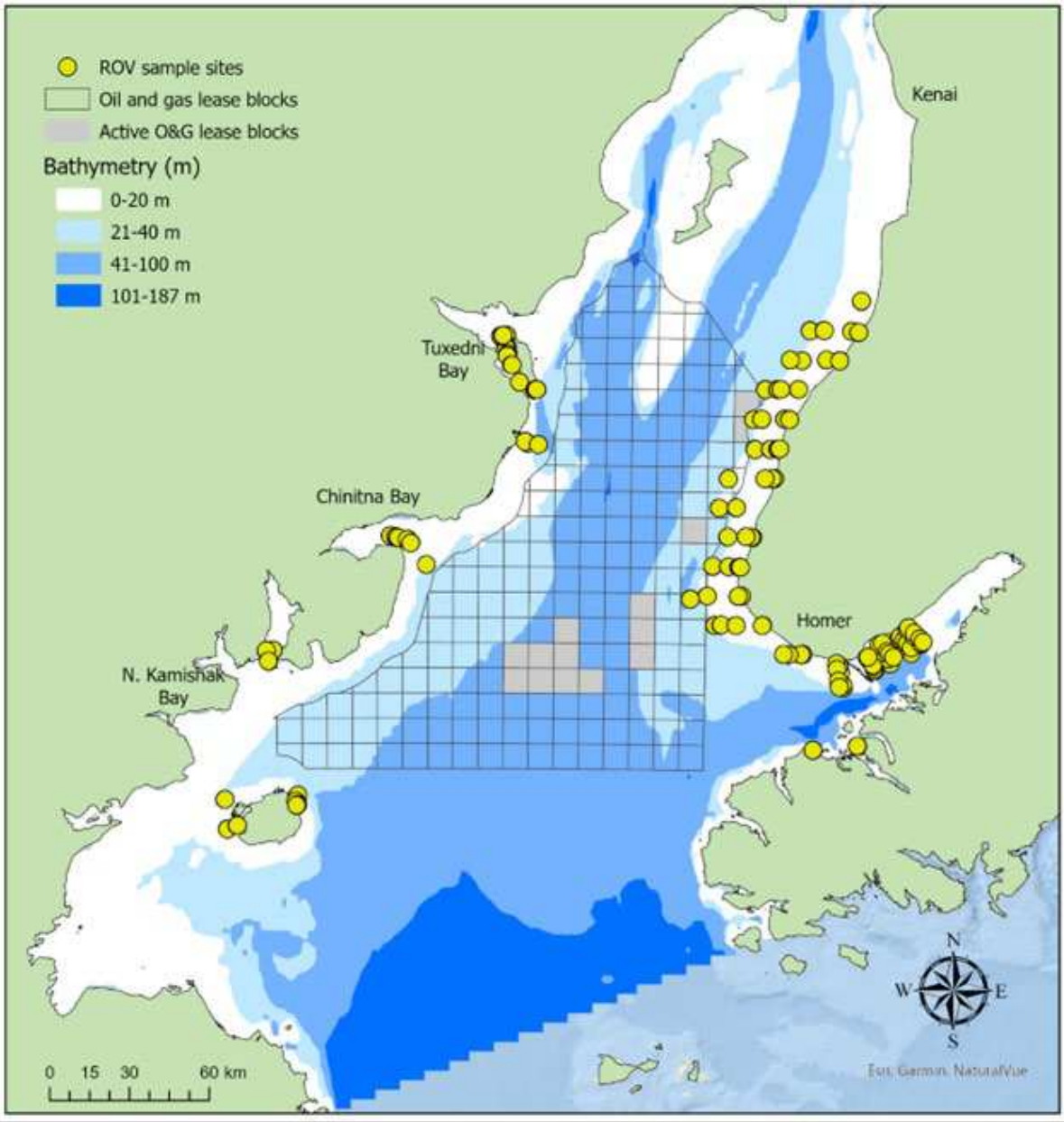


Figure 28. Sites within lower Cook Inlet, Alaska, where benthic ROV video footage was recorded. Active BOEM lease blocks, as of Lease Sale 244, are highlighted in grey. ROV sites from Hasan (2022).

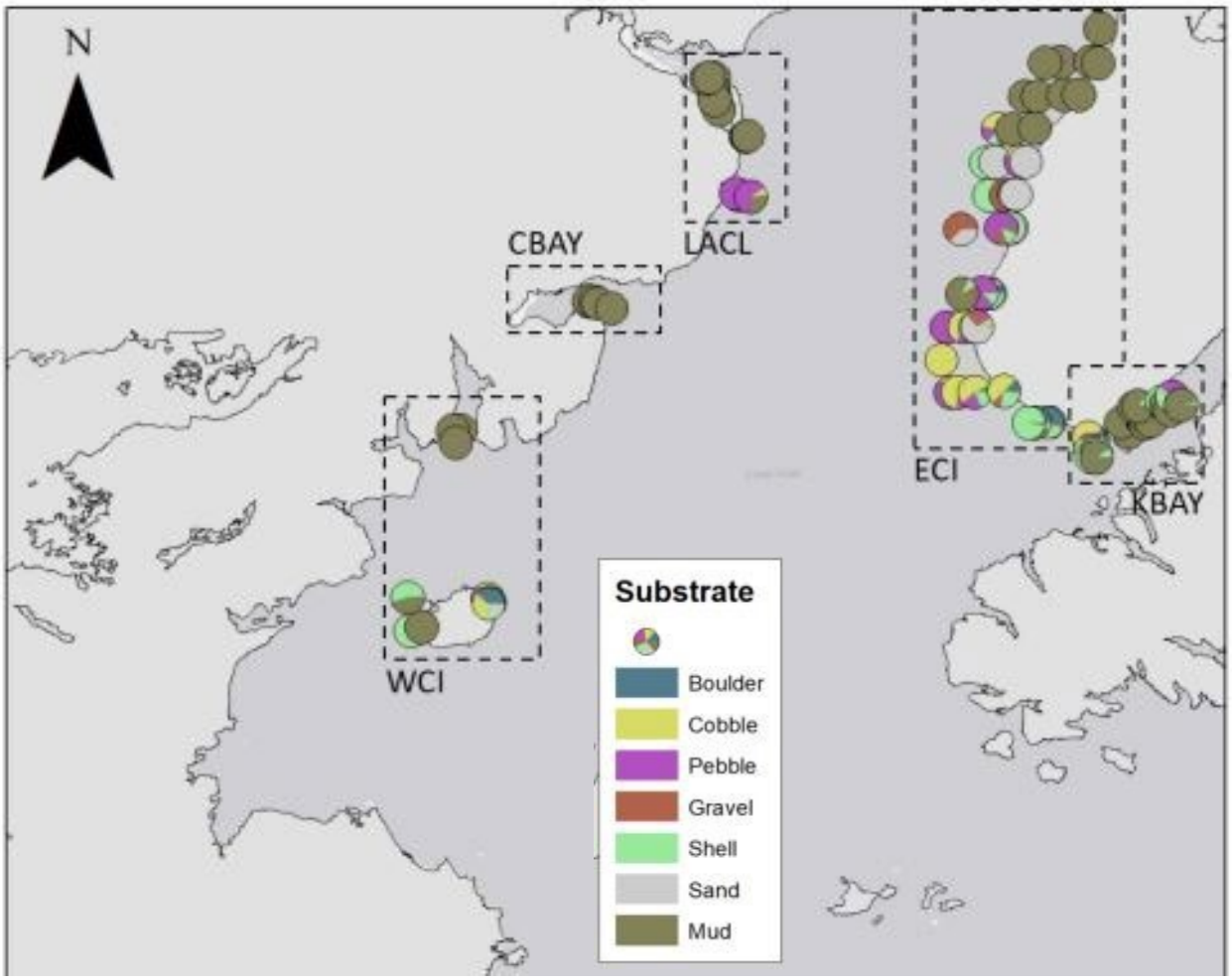


Figure 29. Map of substrate composition at ROV survey sites across the study region of lower Cook Inlet, Alaska (Western Cook Inlet [WCI], Chinitna Bay [CBAY], Lake Clark National Park and Preserve [LACL], Eastern Cook Inlet [ECI], and Kachemak Bay [KBAY]). Substrate composition is represented by pie charts where each pie is a survey and pie slivers represent the relative percent cover of substrate habitat attributes. Percent cover values are averages for each transect survey (from Hasan 2022).

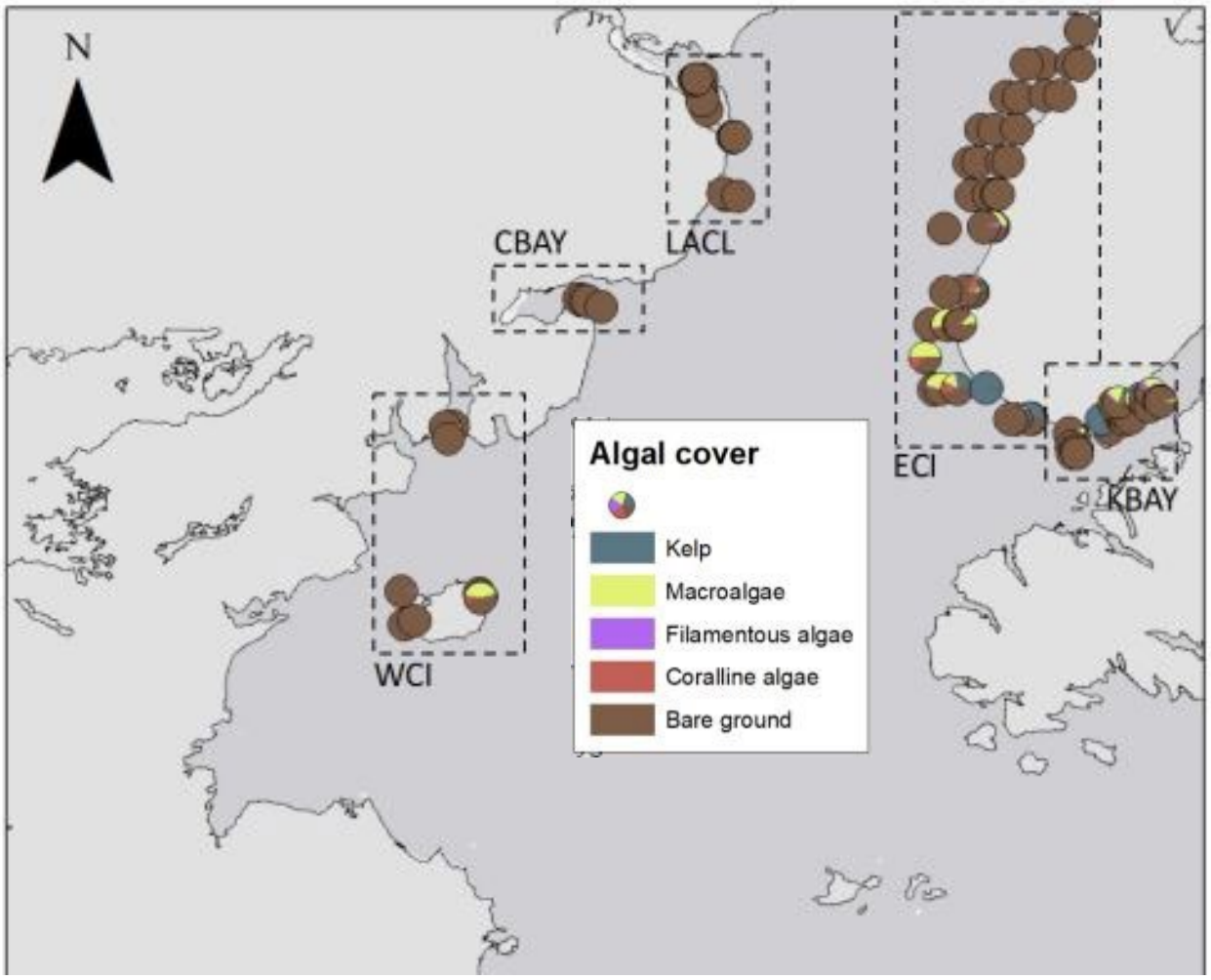


Figure 30. Map of algal cover at ROV survey sites across the study region of lower Cook Inlet, Alaska (western Cook Inlet [WCI], Chinitna Bay [CBAY], Lake Clark [LACL], eastern Cook Inlet [ECI], and Kachemak Bay [KBAY]). Algal composition is represented by pie charts where each pie is a survey and pie slivers equal the relative percent cover of algal habitat attributes. Percent cover values are averages for each transect survey (from Hasan 2022).

5.5 Benthic Trawl Surveys

Another USGS BOEM-funded project (BOEM 2025e) conducted 56 bottom trawl surveys in summer 2024 including 24 trawls that recovered epibenthic invertebrates that could be potential sea otter prey (Figure 31, Appendix A; Donnelly et. al. 2025). Primary epibenthic prey recovered included crabs, clams, scallops and sea urchins (Appendix B; Donnelly et al. 2025). Many of these were small (mean = 20 mm). However, one relatively large Tanner crab (*Chionoecetes bairdi*) was recovered (135 mm carapace width), and several transects had large (mean diameter = 63.5 mm) green sea urchins (*Strongylocentrotus droebachiensis*), which would be highly valuable sea otter prey. The Tanner crab was collected from a depth of 62 m, which is well within the limits of sea otter foraging depths. For the transects with large urchins, 3 of 4 trawls were in relatively shallow water (mean depth = 36 m) while one trawl was at the limit of sea otter diving ability (102 m) and potentially represents a depth refuge from sea otter predation. These data were not collected for the purpose of sampling epibenthic sea otter prey, so

quantitative analysis is not appropriate. However, the prey recovered by these surveys indicate some of the prey types available to sea otters in offshore areas of LCI.

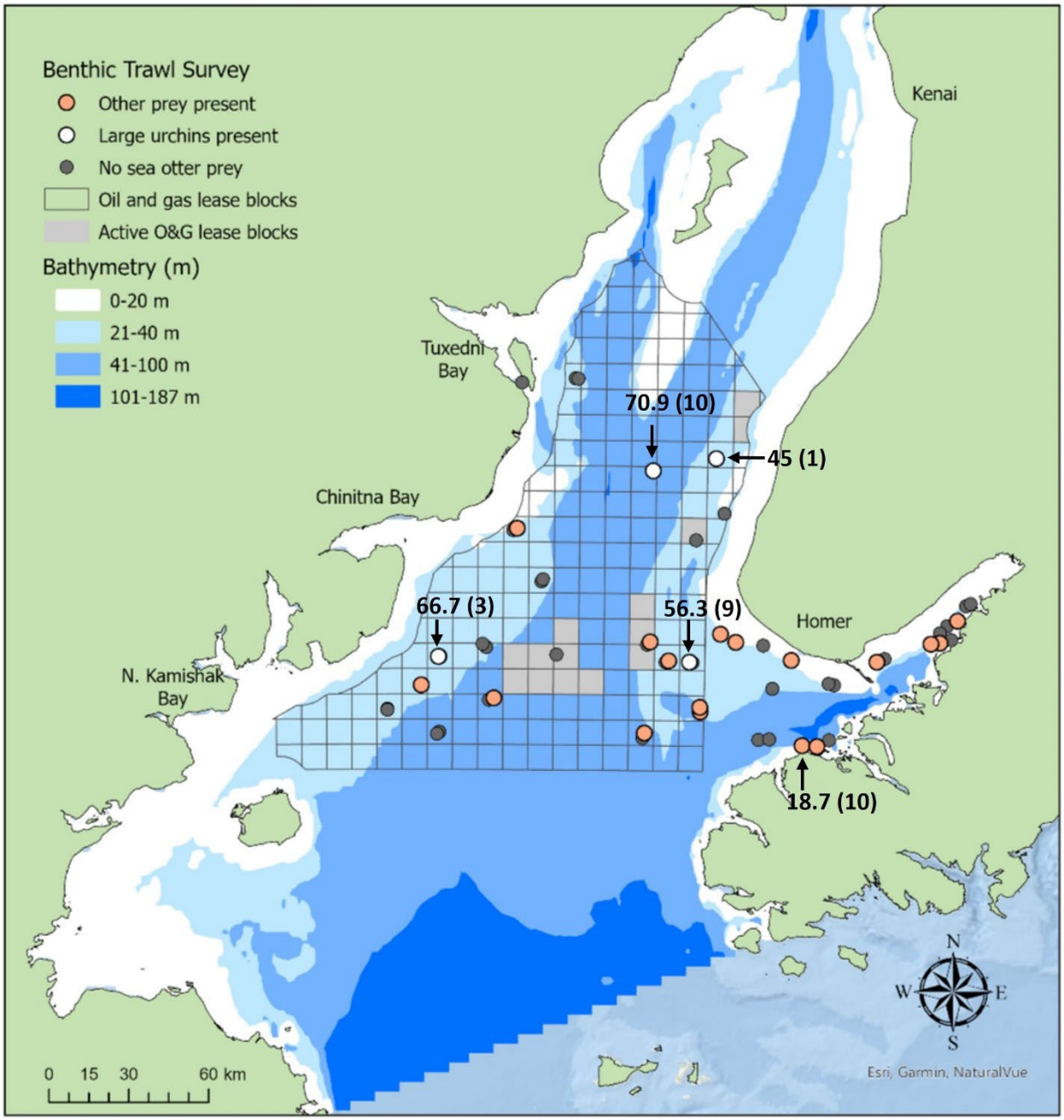


Figure 31. Trawl survey results from Donnelly et al. (2025), another USGS BOEM-funded project (BOEM 2025e) in lower Cook Inlet, Alaska. Gray symbols were trawls that brought up no epibenthic sea otter prey, orange symbols had epibenthic sea otter prey present (mainly crabs, clams, scallops and urchins), and white symbols had large (mean = 63.5 mm) green urchins present. For sites where urchins where found, mean size = diameter in mm and (N) is listed. Active BOEM lease blocks, as of Lease Sale 258, are highlighted in pink.

5.6 Sea Otter Forage Observations

We conducted shore-based sea otter foraging observations in three main areas: at AUGI within Kamishak Bay at the southwest corner of western LCI, along eastern LCI between Kachemak Bay and Ninilchik (ECOI), and within Kachemak Bay (KBAY; Figure 32). We observed 680 dives from 74 bouts at AUGI, 929 dives from 111 forage bouts along ECOI, and 2,940 dives from 398 bouts in KBAY (Table 6). All foraging locations appeared to be "female areas" (Garshelis et al. 1984) based on the presence of females with pups and the higher proportion of females than males in the sample (Table 6).

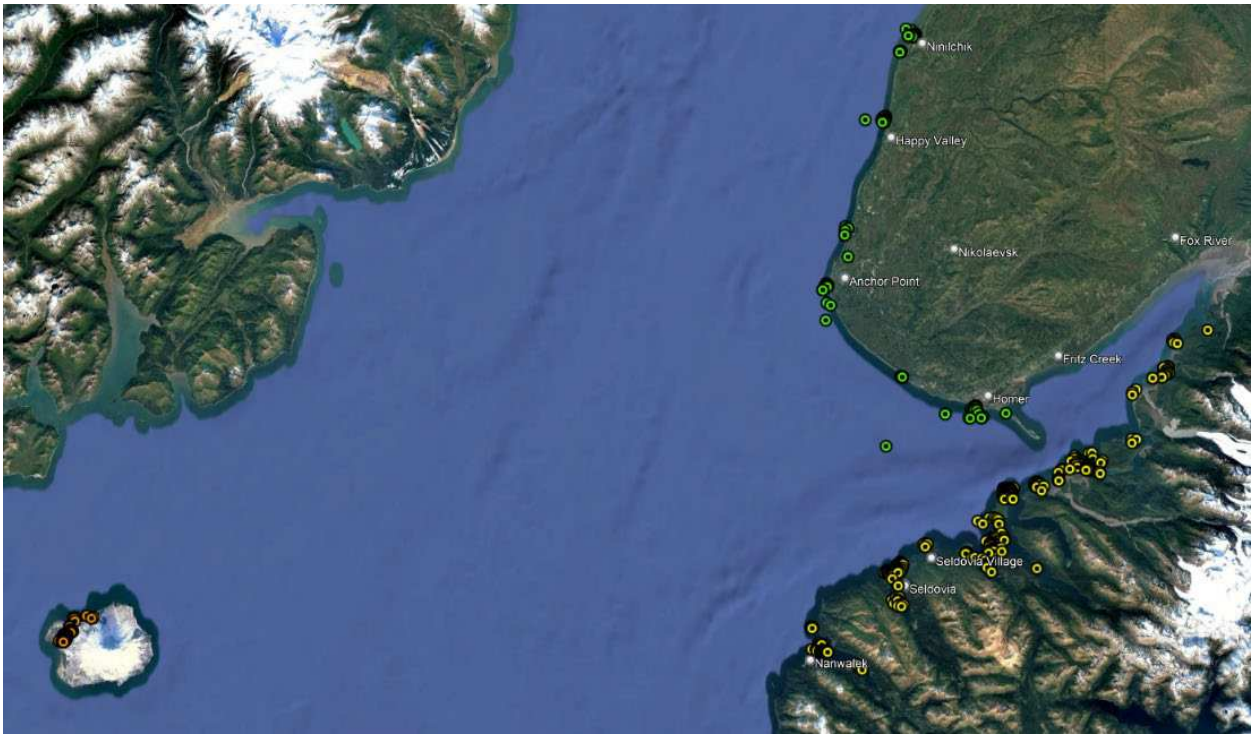


Figure 32. Locations of all foraging bouts observed conducted from 2017 to 2024 in lower Cook Inlet. Orange markers are Augustine Island bouts (this study), green are eastern Cook Inlet bouts, and yellow are Kachemak Bay. Data from Kloecker and Monson (2017).

Table 6. Summary of sea otter foraging bouts (a series of foraging dives observed on one otter usually up to 20 dives) and dives from Augustine Island (AUGI), eastern Cook Inlet (ECOI), and Kachemak Bay (KBAY) in lower Cook Inlet. Listed are proportion of bouts focused on females, males, otters of unknown sex, and females with a pup. The presence of females with pups females indicates foraging observations took place in female areas (Garshelis et al. 1984). Forage data are from Kloecker at al. (2017).

Location	Year(s)	Months	Bouts	Dives	Females	Males	Sex unk	Female w/ pup
AUGI	2021–2022	June, July	74	680	0.73	0.11	0.16	0.50
ECOI	2022	June, July, August	111	929	0.21	0.12	0.68	0.57
KBAY	2017–2024	April–August	389	2,863	0.50	0.19	0.31	0.45
KBAY	2017	April	18	175	0.56	0.28	0.17	0.28
KBAY	2018	May	71	511	0.56	0.17	0.27	0.60
KBAY	2019	May	57	330	0.39	0.14	0.47	0.27
KBAY	2021	August	64	389	0.56	0.25	0.25	0.44
KBAY	2022	May, July	57	358	0.42	0.28	0.30	0.46
KBAY	2023	June	48	424	0.46	0.25	0.29	0.36
KBAY	2024	June	74	676	0.54	0.11	0.35	0.45

Prey compositions (based on biomass of prey retrieved) were similar in all areas with most of the diet (~75%) comprised of clams for all areas combined (Figure 33). Sea otters in KBAY had the most diverse diet, with clams making up 67% of prey observations, while mussels, urchins and crabs contributed ~6%–7% each, scallops contributed 3% and the final 10% comprised of "other" prey items that included things like sea stars, chitons and fish (Figure 33). Clams comprised 80% of the diet for sea otters living along ECOI, while other items comprised 17% and mussels the final 3%. However, sea otters along ECOI also had the highest proportion of large clams (> 55 mm) in their diet (56%). Prey composition at AUGI included 84% clams with 10% crabs, and 5% other items, but in contrast to ECOI, AUGI had the highest percentage of smaller clams (57%, Figure 33).

Based on frequency of clams retrieved by sea otters, 43% to 60% were unidentified (Figure 34). The most commonly identified clams at AUGI were Nuttall cockle (*Clinocardium nuttalli*) along with various soft-shelled clams (*Mya spp*.). Along ECOI, 53% of all clams retrieved were identified as Pacific razor (*Siliqua patula*) while Washington butterclams (*Saxidomus gigantea*) and truncate softshelled clams (*Mya truncata*) were the most often identified clams within KBAY (Figure 34).

Mean prey size by prey type was fairly similar among areas (Figure 35) although the larger size of "large clams" along ECOI reflects presence of Pacific razor (*Siliqua patula*) in the diet of otters in that area. Mussel size was larger and more variable at AUGI because sea otters there retrieved several large *Modiolus* mussels, which are significantly larger than *Mytilus trossulus* that were the only mussels collected in the other areas (Figure 35). Similarly, "other" prey captured by sea otters at AUGI were on average larger and more varied in size because several sea otters that fed on large *Nereididae* worms in that area that were not found in other areas (Figure 35). Crabs tended to be larger in KBAY because several otters were observed retrieving relatively large Dungeness crab in that area.

Mean handling time by prey type was again similar among areas (Figure 36). However, it appears sea otters consumed Pacific razor relatively quickly because the average handling time for large clams was shorter at ECOI than at other locations. This is likely because Pacific razor, while generally larger than clams retrieved in other areas, have relatively fragile, easy-to-open shells compared to the hard-shelled clams retrieved by otters in KBAY in particular. Handling times for crabs was longer than for other prey

types with the longest times occurring in KBAY likely because of the large Dungeness crabs consumed by sea otters there.

Prey specific consumption rate (CR = grams of prey tissue consumed per minute of foraging) and energy intake rate (EIR = kcal consumed per minute of foraging) are highly correlated (Figure 37 and Figure 38) with the relative differences determined by the energy density of the various prey types. In general, both CR and EIR were highest for large clams. CR and EIR were essentially the same for small clams in all three areas, while values for mussels at AUGI were more variable again because of the inclusion of *Modiolus* mussels in their diet (Figure 37 and Figure 38). Crabs had intermediate CR and EIR rates while "other" prey had highly variable values due to the diverse species lumped into this category including small items such as chitons to larger prey such as sea stars and octopus (species not recorded). Overall, CR and EIR values estimated for all data combined and for the three areas separately where consistent with CR values = ~8 to 9 grams per minute and EIR ~5 to 6 kcal per minute (Figure 39a and 39b).

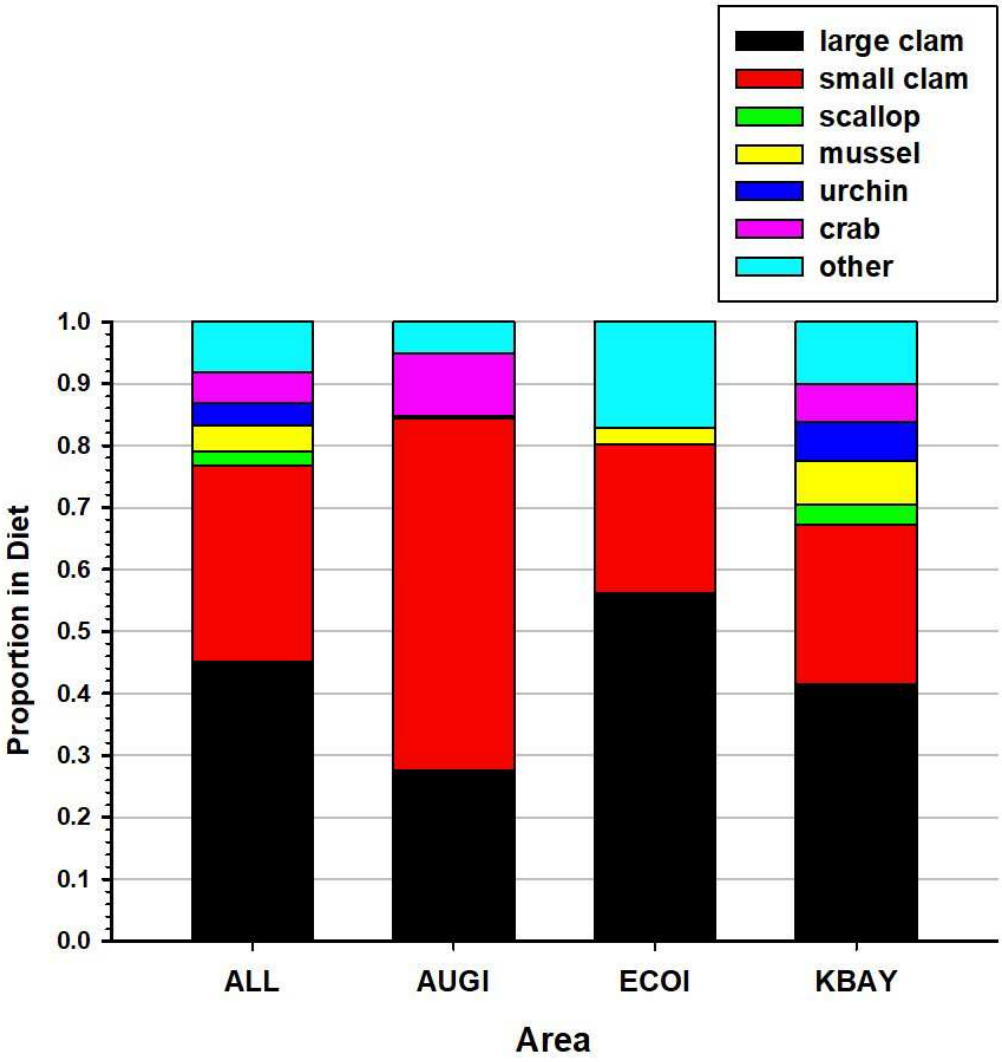


Figure 33. Proportion of prey types in sea otter diets based on consumed biomass for all forage data combined (ALL), and foraging data from Augustine Island (AUGI), along eastern Cook Inlet (ECOI) and within Kachemak Bay (KBAY). Data from Kloecker et al. (2017).

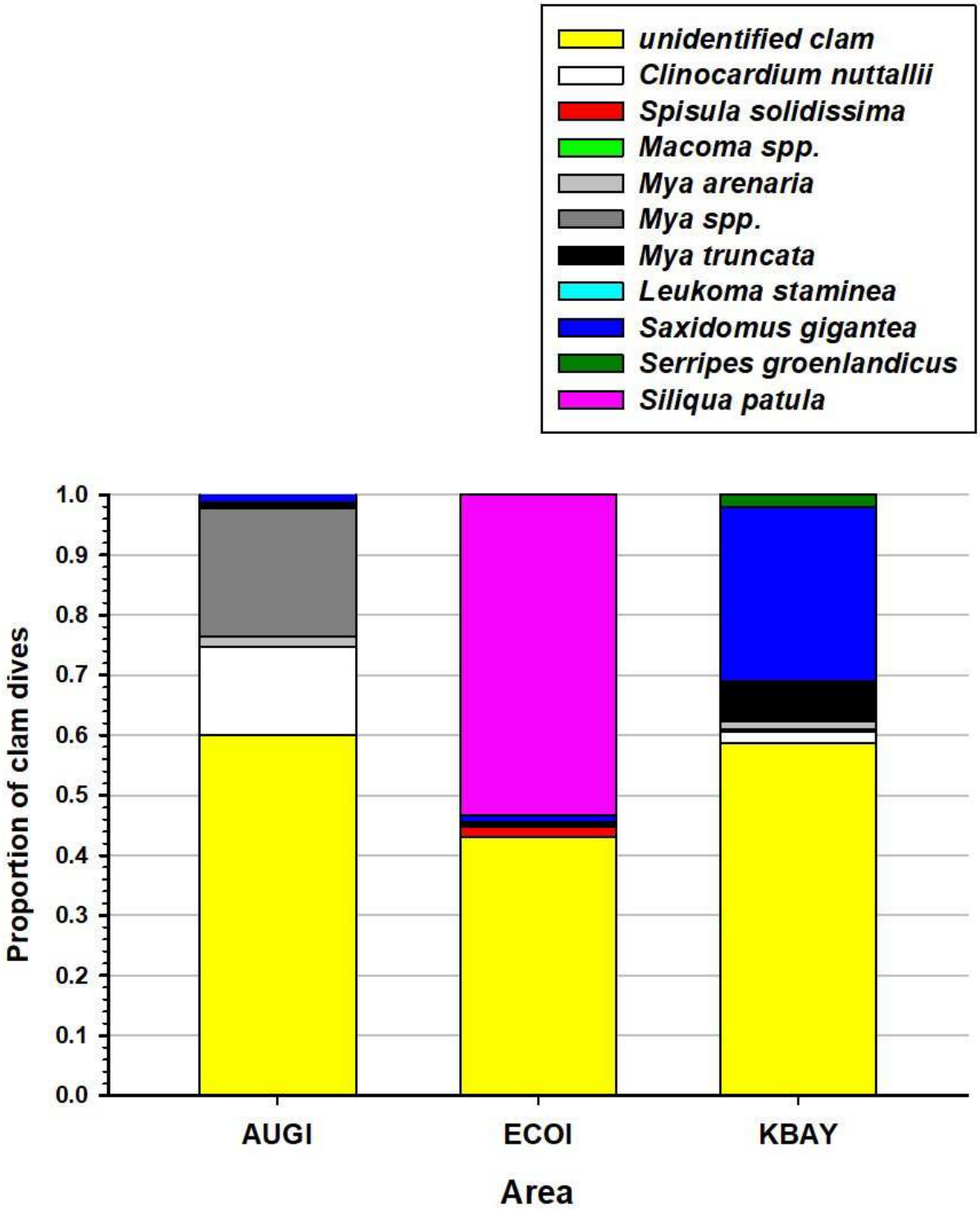


Figure 34. Proportion of clam species within "clam dives" based on frequency of clams retrieved by sea otters forage at Augustine Island (AUGI), along eastern Cook Inlet (ECOI) and within Kachemak Bay (KBAY). Data from Kloecker et al. (2017).

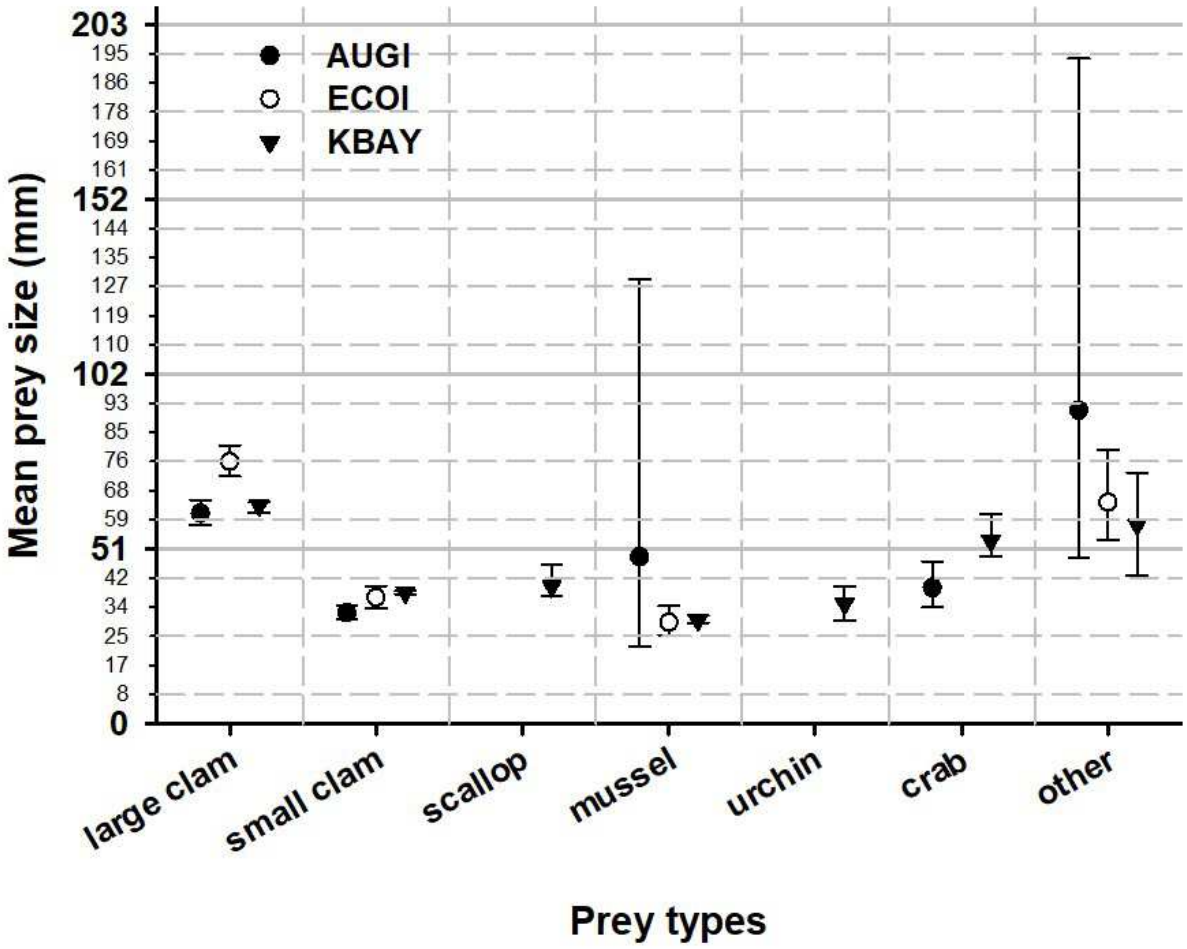


Figure 35. Mean (error bars = 95% CL) prey-specific prey sizes for sea otters foraging at Augustine Island (AUGI), along eastern Cook Inlet (ECOI) and in Kachemak Bay (KBAY). Data from Kloecker et al. (2017).

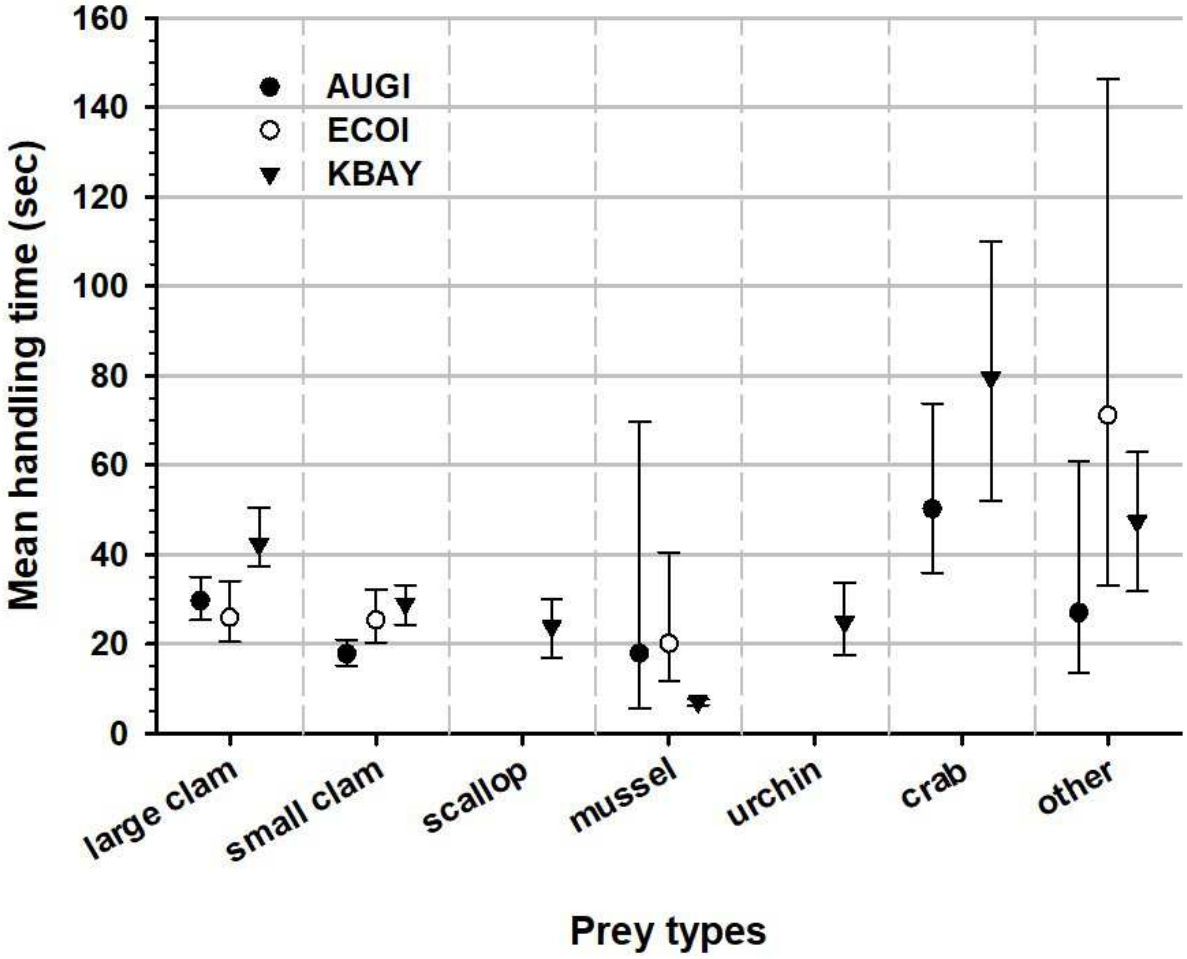


Figure 36. Mean (error bars = 95% CL) prey-specific handling times for sea otters foraging at Augustine Island (AUGI), along eastern Cook Inlet (ECOI) and in Kachemak Bay (KBAY). Data from Kloecker et al. (2017).

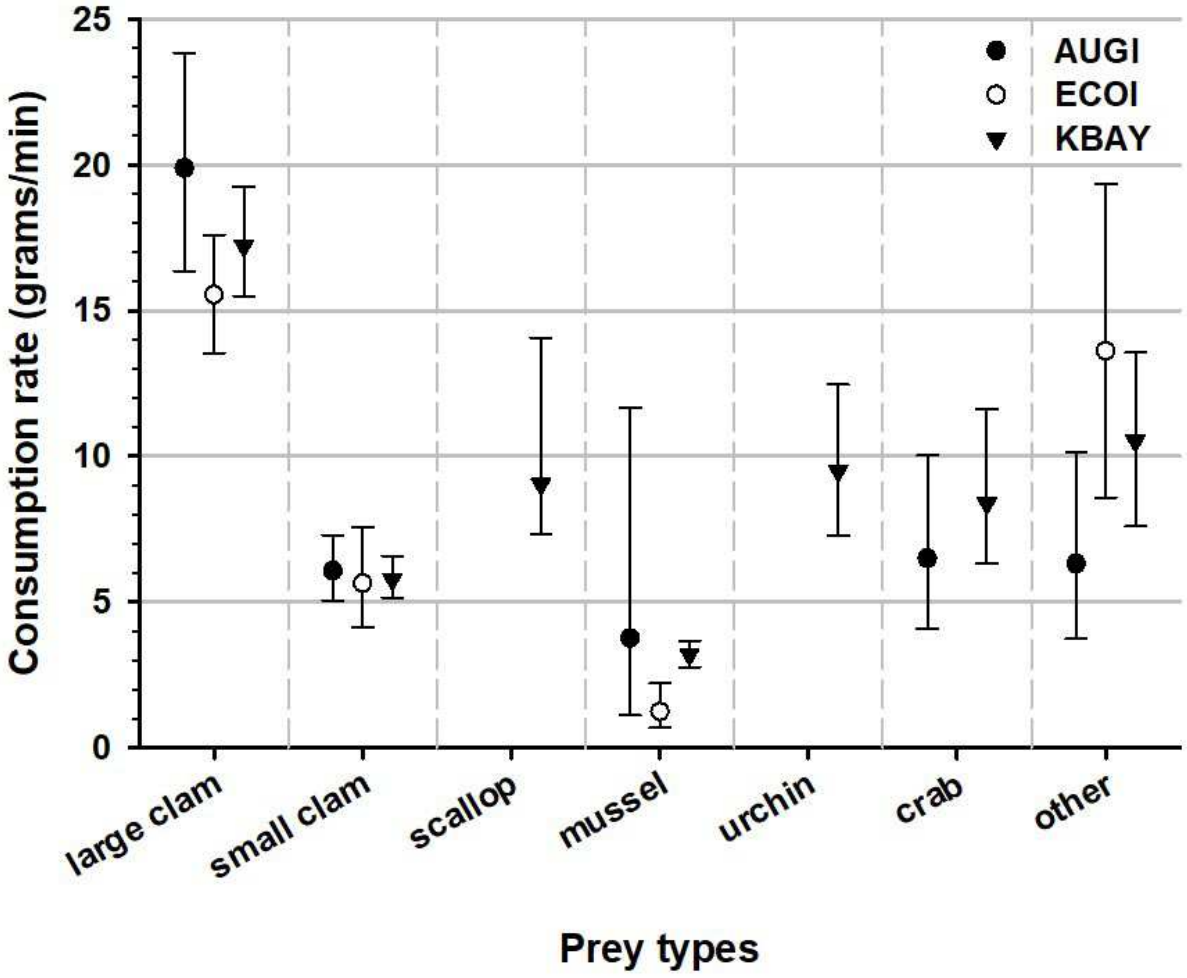


Figure 37. Mean (error bars = 95% CL) prey-specific consumption rates for sea otters foraging at Augustine Island (AUGI), along eastern Cook Inlet (ECOI) and in Kachemak Bay (KBAY). Data from Kloecker et al. (2017).

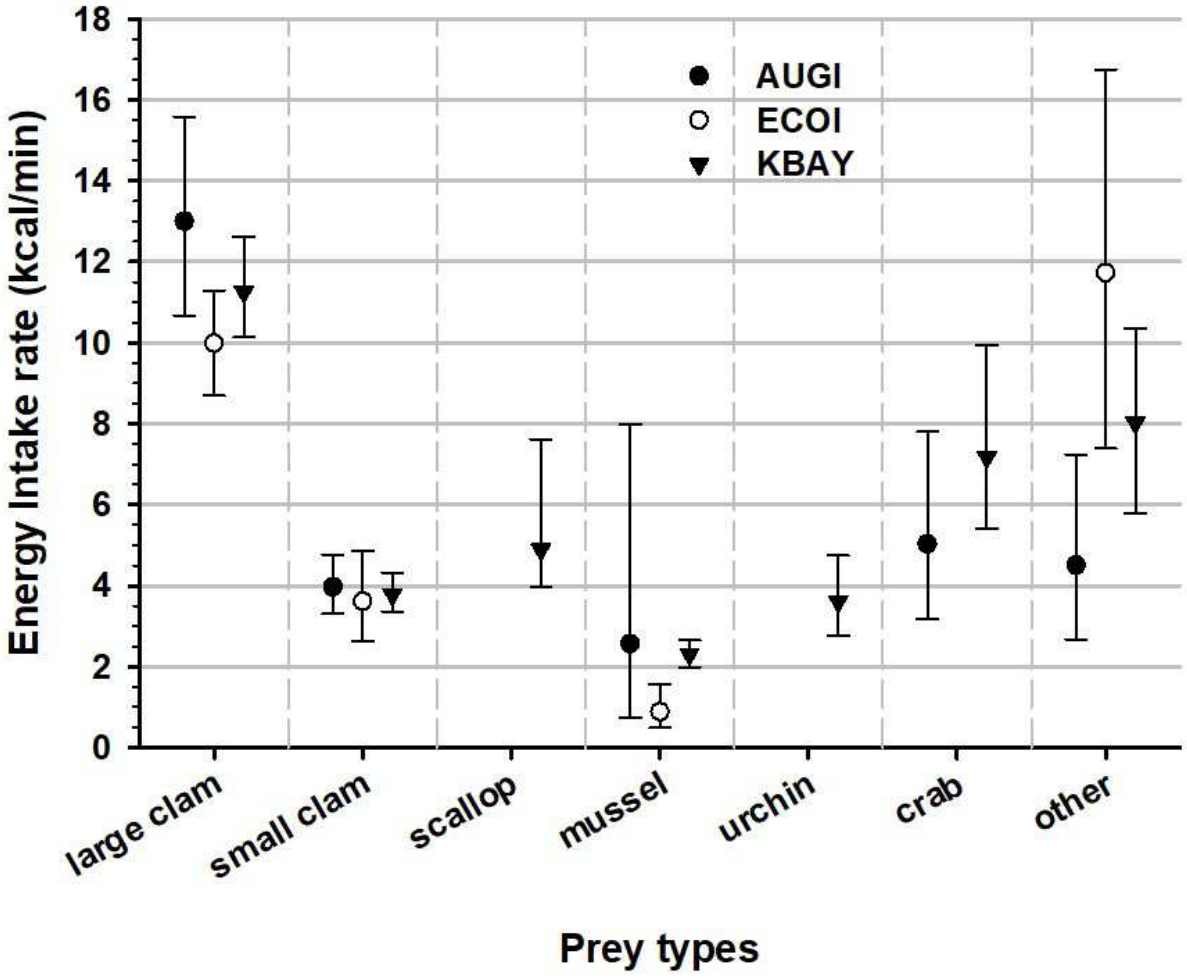


Figure 38. Mean (error bars = 95% CL) prey-specific energy intake rates for sea otters foraging at Augustine Island (AUGI), along eastern Cook Inlet (ECOI) and in Kachemak Bay (KBAY). Data from Kloecker et al. (2017).

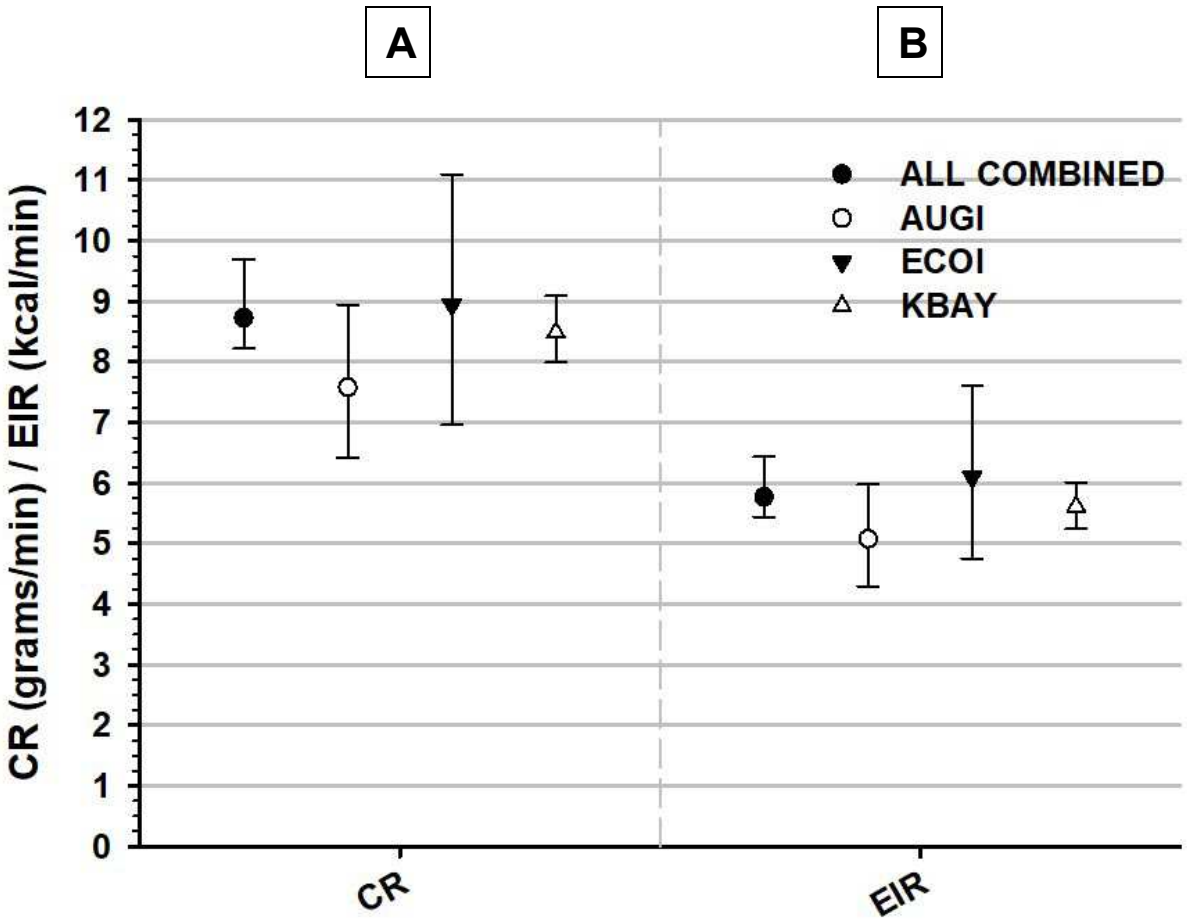


Figure 39. A: Overall mean (error bars = 95% CL) consumption rates (CR = grams/min prey tissue obtained while feeding) for all forage data combined, and for each area separately including at Augustine Island (AUGI), along eastern Cook Inlet (ECOI) and in Kachemak Bay (KBAY). B: Overall mean (error bars = 95% CL) energy intake rates (EIR = kcal/min of foraging time) separated into the same geographic groupings as A. Data from Kloecker et al. (2017).

6 Discussion

6.1 Aerial Surveys

Our aerial surveys found sea otter distributions in LCI have not changed dramatically since the 2002 survey, and the distribution from the winter 2023 survey (Figure 17) did not indicate any large-scale seasonal movements of otters. Our sea otter distribution model indicates that sea otters in LCI are most likely to occur from ~6 to 9 km offshore in water depths of ~20 to 30 m (Table 4, Figure 25 and Figure 26). Sea otters occurred offshore within Kamishak Bay and along the east side of LCI where sea otters are regularly seen out to 20 km from shore yet generally within the 40 m bathymetric contour. This area includes several OCS lease blocks including ~9 to 12 blocks located just to the north of AUGI and >50 blocks on the east side of LCI. Sea otters were consistently present in the lease blocks 7064, 7114, 6162, 6310, 6360, 6410, 6457 and 6458, which were leased prior to the period of study.

We identified females with pups in aerial images (for example, Figure 40) throughout LCI including within the lease blocks indicating most areas occupied by sea otters in LCI can be considered "female areas" (Garshelis et al. 1984; Kenyon 1969). However, pups are likely under-counted in aerial photo surveys because large pups may not always be distinguishable from an independent otter, and small pups may sometimes not be identifiable when image quality is poor.

We hypothesized sea ice formation in winter may influence sea otter distributions particularly relative to movements north on both sides of LCI. That is, heavy ice is more prevalent along western LCI, especially at the northern end, while heavy ice rarely forms anywhere along eastern LCI. Thus, it was reasonable to examine the potential effect sea ice may be having on the northern range expansion of sea otters because the sea ice differed between the west and east sides. Year-to-year sea ice formation in LCI is variable; little ice formed during the winters of 2013–2014 and 2014–2015, and heavy ice formation did not occur at all in the warm winter of 2015–2016 (also know as the Pacific Marine Heatwave; Walsh et al. 2018) and very little formed during a second warm winter of 2018–2019 (Figure 19). However, sea otters did not avoid areas with heavy ice concentrations during our winter 2022-2023 survey (Figure 21). In fact, sea otters often hauled out on ice when available (for example, Figure 41a–c). While the presence of heavy ice concentration explained some variability in distributions (Table 4), the likelihood of sea otter presence did not decrease until cumulative heavy ice presence over the 15 years of ice data reached ~400 days (average of ~27 days per year, Figure 24). That is, the only locations where heavy ice cover may be having an effect were locations where consistent ice cover forms year-after-year, which mainly only occurs at the head of bays along the west coast of LCI and along the southern shore of Kamishak Bay where prevailing northerly winds keep moving ice into shore (Figure 20). In general, as long as there are leads in the ice allowing sea otters to dive to obtain food and reach the surface, they can tolerate heavy ice concentrations and weather conditions (Schneider and Faro 1975). Ice can temporarily displace sea otters, and heavy ice that forms quickly can be dangerous for sea otters; however, sea otters have been known to return to areas after the ice retreats (Schneider and Faro 1975).

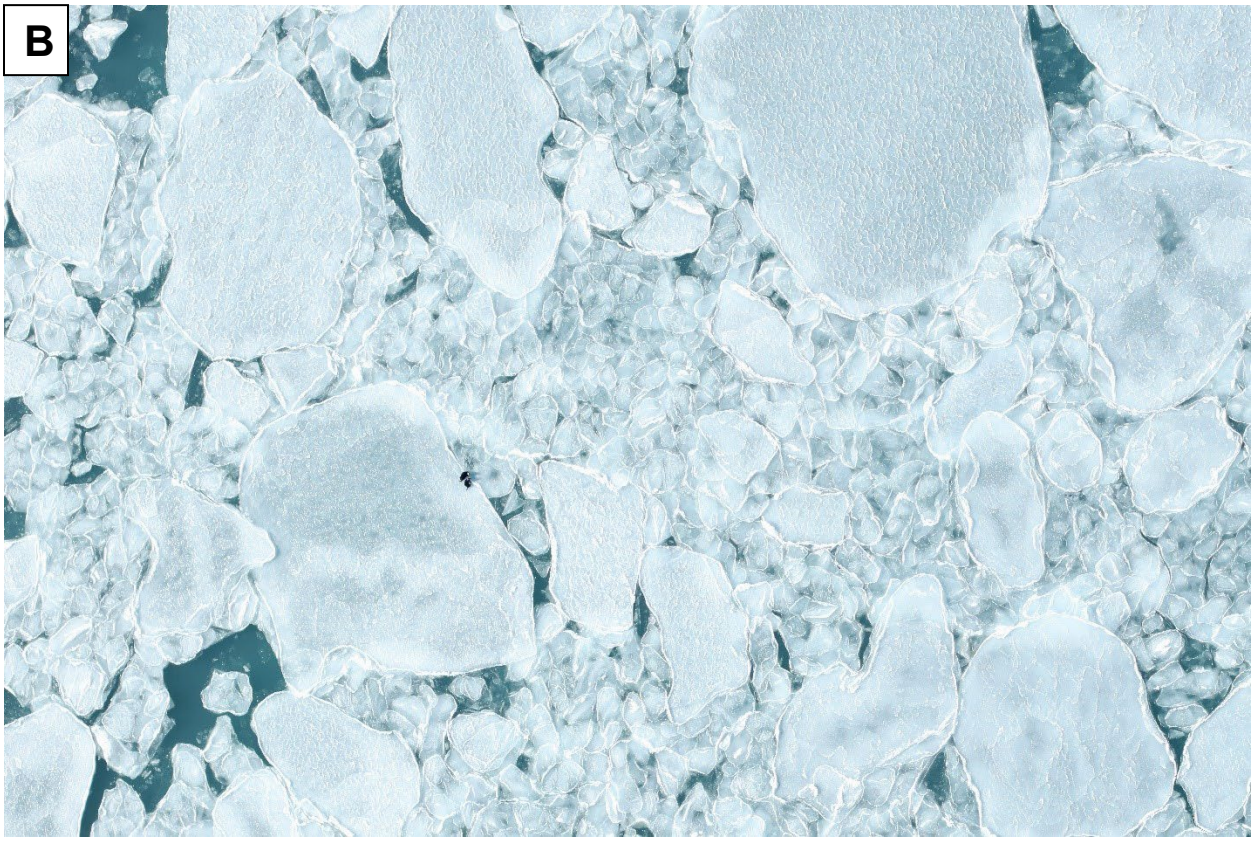
Consistent with previous surveys, few sea otters were observed on the west side of LCI north of Kamishak Bay, especially along the LACL coast, including the OCS lease blocks overlapping designated critical sea otter habitat by virtue of being shallow (Figure 3). It is possible this area is simply poor sea otter habitat, as suggested by Hasan (2022) based on ROV surveys. However, the ROV surveys can only observe the benthic surface and cannot determine infaunal prey densities. Alternatively, the heterogeneity of benthic habitats and biological communities in areas with higher sea otter densities may be created by foraging sea otters whose digging turns over the benthic substrates and litters it with shell debris (Kvitek and Oliver 1988; Kvitek et al. 1992). If sea otters eventually move into the LACL area, they may alter the appearance of the benthic habitat to something more similar to those observed in other areas of LCI. If true, it is possible that LACL is simply not yet occupied by a significant number of otters because the food resources within Kamishak Bay are still plentiful even after ~7 decades of occupation.

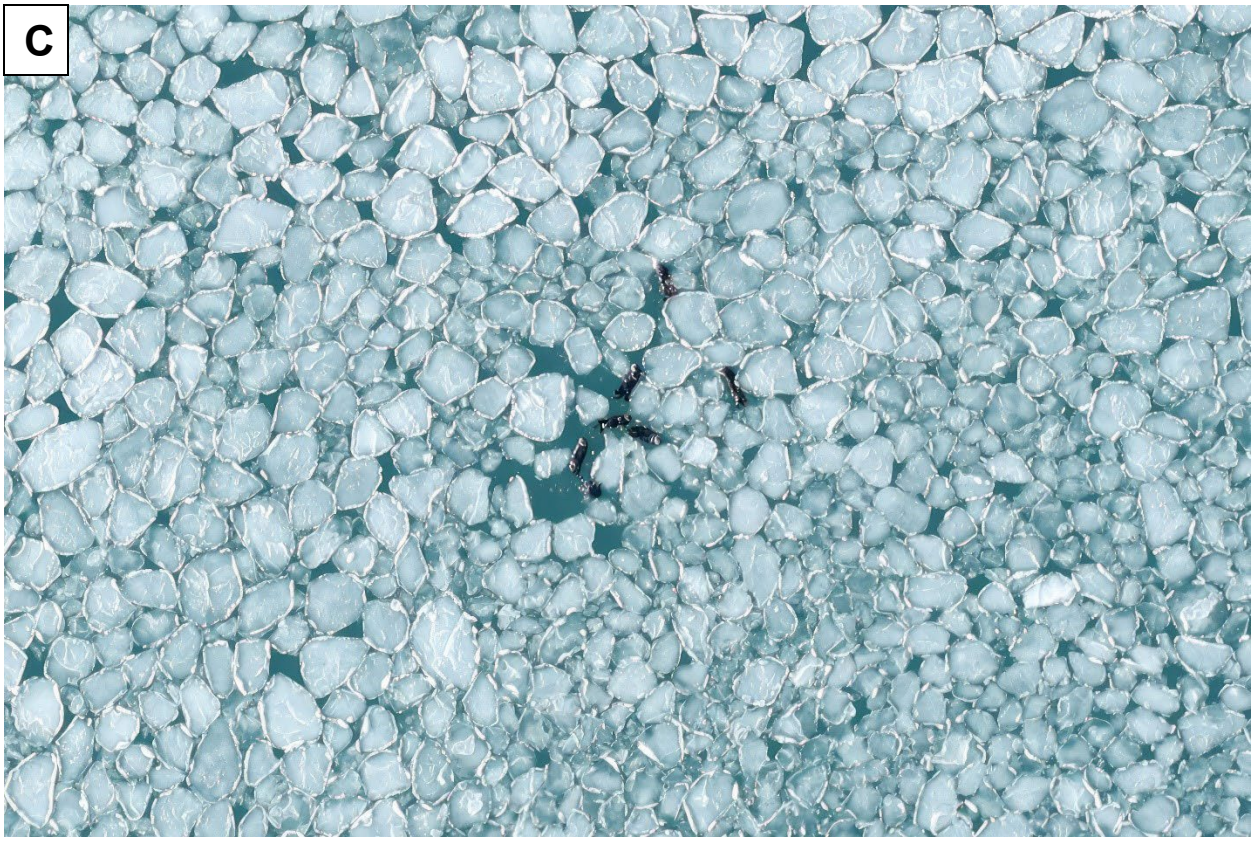
Another alternative explanation is that the periodic presence of orcas in the area north of Kamishak Bay (Castellote et al. 2023; Castellote et al. 2024) may discourage sea otters from long-term occupation. Orcas are the most likely cause of large sea otter population declines in the western Aleutian Islands that began in the early 1990s. In addition, sea otter population declines in the Aleutian Islands coincided with a shift in their distribution and habitat use to shallow, complex habitats very close to shore because of the protection from orca predation it provided (Doroff et al. 2003; Estes et al. 2004; Estes et al. 2005; Estes et al. 1998; Springer et al. 2003; Tinker et al. 2021; Williams et al. 2004). However, we have no direct evidence that orcas are currently playing any role in limiting sea otter population size or distribution in LCI, with the exception of noting the high number of sea otters that were observed occupying the shallow shelf habitat around AUGI (Section 5.3, Vessel Surveys). That is, the shallow bench habitat surrounding AUGI would be a place that would likely restrict access by orcas and where we might expect sea otters to concentrate if orca-related predation became prevalent.

Critical sea otter habitat along western LCI was designated to include all habitat within the 20-m depth contour (74 FR 51988, October 8, 2009). Thus, Kamishak Bay contains most of the critical habitat for sea otters in western LCI. However, our results suggest sea otters are using most of the habitat out to the 40-m depth contour in LCI, so the definition of critical habitat within LCI may need to be reexamined. All Kamishak Bay (an area of ~3,000 sq km) is shallow (<40 m). Because infaunal prey tends to be more resilient to over exploitation (Kvitek and Oliver 1992; Kvitek et al. 1992), Kamishak Bay may support large densities of sea otters essentially indefinitely, similar to Orca Inlet in eastern Prince William Sound, which has supported some of the highest reported densities of sea otters for the past 30 years (Esslinger et al. 2021). In addition, sea otters occur offshore in other places as long as feeding depths are reachable. Sea otters north of the Alaska Peninsula have historically occurred out to 50 km from shore, and during the early population recovery phase, the highest densities of otters occurred in water 20-40 m deep (Schneider 1976b).

Figure 40. Female sea otter with pup in typical "T" position in aerial survey image from lower Cook Inlet. USGS photo.


A


B



Figures 41 A, B, and C. Sea otters floating within sea ice in lower Cook Inlet during March of 2023. USGS photo.

6.2 AI-assisted Photo Processing

Results indicate that AI-assisted counts outperform manual methods in precision and consistency, though environmental factors affect both methods. Overall, the iterative training, active learning, hyperparameter optimization, and post-processing techniques ensured that the custom YOLO v5 model effectively detects sea otters. These advancements contributed to a robust and accurate tool capable of handling the complexities and variations present in aerial imagery.

The findings of this study align closely with previous research demonstrating the potential of AI to enhance wildlife monitoring. Earlier studies consistently report that AI models, especially those employing object detection frameworks like YOLO, achieve high levels of accuracy in identifying and counting wildlife. For example, research on marine mammals such as whales and dolphins has shown that AI models can significantly reduce the time required for manual counting while maintaining accuracy rates often exceeding 90%. This performance is comparable to or even better than human observers. Similarly, studies on birds and other wildlife have demonstrated AI's capability to process large volumes of imagery rapidly, achieving high precision in identifying species and counting individuals. For instance, AI-assisted methods used in bird monitoring have shown high correlation with manual counts and provided data used to inform conservation efforts (Hodgson et al. 2018).

6.3 Vessel Surveys

Sea otters spatially segregate by sex with most suitable habitats occupied by females and their pups along with smaller numbers of territorial males (Garshelis et al. 1984; Kenyon 1969). Non-territorial males occupy "male areas" that, within established populations, may be less protected or have fewer resources than "female areas" (Kenyon 1969). Thus, the simple presence of females and pups indicate sea otter habitats with adequate food resources. We documented the presence of females with pups in essentially all the offshore areas along eastern LCI, including several of the active lease blocks listed in Section 5.1 (Figure 14). Many of the identified pups were small and could only be present because the females chose to ferry them offshore. Even large pups that can swim independently stay close to their mothers and are there because their mother leads them. Interestingly, based on a comparison of independent:pup ratios outside the BOEM Lease Sale blocks, independent:pup ratios were significantly higher than expected inside these offshore Lease Sale blocks (Table 5),) indicating the offshore regions of the sea otter's range in LCI can be considered female areas. In contrast, the area to the southwest of AUGI within Kamishak Bay had large numbers of animals without pups (Figure 14) and may be a "male area" (Garshelis et al. 1984; Kenyon 1969).

Unfortunately, we were not able to document what sea otters were eating in these offshore areas because most otters appeared wary of the approaching vessel, and stopped feeding, dove or swam away before we could identify what they were eating, thus they were simply recorded as "active" (Figure 27). The water depths in all these offshore areas are <100 m and generally < 40 m, which is within the range of foraging depths of sea otters (Bodkin et al. 2004). In addition, sea otters need to feed several times per day (Bodkin et al. 2007; Esslinger et al. 2014; Yeates et al. 2007), thus swimming back and forth several kilometers to nearshore areas multiple times per day would be energetically costly. While we do not have specific observations of what types of prey sea otters may be retrieving in these offshore locations, the most likely prey items would be crabs and sea urchins (refer to Section 5.5, BOEM trawl surveys) or potentially *Modiolus* mussels and other bivalves. If large clams do occur offshore, they would likely be targeted (Bodkin et al. 2007).

Skiff surveys near AUGI documented large numbers of sea otters (~1,000) were at times occupying the shallow shelf waters that ring the island (Figure 14). Previous surveys have not documented such large numbers so closely associated with AUGI including seasonal surveys of Kamishak Bay (Gall et al. 2020). At this time, we do not know if this was an ephemeral event or a relatively recent change in sea otter behavior. Sea otters in the Aleutian Islands have shifted their distributions to very nearshore (<100 m), shallow complex habitats similar to the shelf habitat around AUGI in response to orca (*Orcinus orca*) predation pressure (Tinker et al. 2021), and we would expect the shallow bench habitat surrounding AUGI would be critical habitat that could protect sea otters from orca predation if orca predation were to became prevalent in LCI. However, we have not documented a dramatic decline in sea otter numbers in LCI and have no evidence that orcas are currently affecting sea otter numbers or distributions in LCI.

6.4 ROV Benthic Surveys

ROV surveys indicated the dominant substrate composition of in the nearshore areas of LCI (within ~ 5 km from shore) is soft sediments, (Figure 29, Hasan 2022). Sea otters are known to be soft-sediment ecosystem engineers because their feeding activity brings small cobble and pebbles to the surface, overturns larger rocks, and deposits shell litter (Kvitek and Oliver 1992; 1988). Consistent with our foraging observations that found clams were a major part of sea otter diets in LCI (refer to Section 5.5, Sea otter foraging observations), shell litter was prominent in areas occupied by sea otters (Figure 29). Pacific razor clam (*Siliqua patula*) shell litter was common along eastern LCI, again consistent with the importance of the razor clams to sea otter diets in that area (Geissinger 2024). Hasan (2022) also found

the areas occupied by sea otters were more likely to have kelp and macroalgae cover (Figure 30). Shell litter deposited by foraging otters is known to provide settlement and attachment substrate for kelps and sessile invertebrates, thus encouraging algal cover growth leading to increased biological community complexity (Kvitek and Oliver 1988; Kvitek et al. 1992). Consistent with this idea, Hasan (2022) found that eastern LCI and Kachemak Bay, where mid to high-densities of sea otter occur, had more heterogeneous substrates and biological communities compared to western LCI north of Kamishak Bay along the coast of LACL where few otters occur. As a result, Hasan (2022) hypothesized that habitat composition may play a role in the lack of sea otter presence along the LACL coast. However, epibenthic surveys cannot measure infaunal prey densities. Thus, the question remains, does the LACL coast have more homogeneous substrates and epibenthic communities because it is poor sea otter habitat? Or has the area just not yet experienced the changes that occur once sea otters move into the area and begin turning over the benthos thus increasing its heterogeneity and epifaunal community complexity? The healthy Pacific razor clam fishery that still exists in the LACL area (Booz et al. 2019) suggests that poor quality habitat may not be the primary reason sea otters still do not occur there. Ultimately, infaunal sampling may be required to determine which hypothesis is correct.

6.5 Benthic Trawl Surveys

The USGS BOEM-funded project titled "Lower Cook Inlet Fish and Invertebrate Community Composition, Distribution, and Density" (AK-22-01) included benthic trawl sampling in LCI (BOEM 2025e). Donnelly et al. (2025) provides a summary of the invertebrates collected during trawl samples, which we present here to identify some of the potential prey types available to sea otters in the offshore areas of LCI (Appendix B). Several epibenthic invertebrate species they collected, including Pacific pink scallops (*Chlamys rubida*), several species of clams and crabs, and green sea urchins are preferred sea otter prey. Because some of the sampling occurred in offshore areas where sea otters reside, these samples provide valuable information on what prey sea otters are likely to encounter in offshore locations.

The most notable finding of trawl data from Donnelly et al. (2025) was the presence of relatively large sea urchins (average diameter = 45 mm to 67 mm) at several trawl sites in depths of <40 m (mean depth = 36 m; Figure 31), and thus well within foraging depths of sea otters (Bodkin et al. 2004). Urchins this large were similar in size to those targeted by sea otters when they first entered Glacier Bay in the early 1990s (Leach et al. 2024). One location where large urchins were found was on the western side of LCI north of AUGI where few sea otters currently occur (Figure 31). This is an indication that there may be adequate food resources in this area, but significant numbers of sea otters have not moved into this area for unknown reasons. However, the largest urchins were collected at a site that was 100 m deep, which is at the limit of the sea otter's dive limit (Bodkin et al. 2004), and thus is likely beyond practical foraging depths for most sea otters. Nonetheless, if there are abundant urchins in deep water, they may be a source of propagules that keep the abundance of urchins in shallower waters high and adequate to support the sea otters feeding there.

One relatively large (carapace width = 135 mm) Tanner crab was collected during the trawl surveys, and large crabs such as this would also be a preferred prey item. Large clams may also occur offshore. If so, Cook Inlet may be similar to Idaho Inlet in southeastern Alaska where some sea otters regularly dove to depths of 45 to 60 m to retrieve clams (Bodkin et al. 2004). While diving deep is energetically costly (Yeates et al. 2007), when prey are large and abundant, foraging at depth can be highly efficient and allow sea otters to spend less time per day feeding (Bodkin et al. 2007).

Additional bottom trawl surveys and potentially box-core sampling for infaunal prey in these offshore areas could increase our understanding of availability of sea otter prey.

6.6 Sea Otter Foraging Observations

Our primary goal in looking at sea otter foraging was as an index of sea otter population status relative to available food resources (Coletti et al. 2016; Dean et al. 2002). In general, while prey composition varied somewhat between areas, variables that determine overall foraging efficiency such as success rate, prey size, and handling times were similar for the various prey types (Figure 35 through Figure 37) leading to similar prey-specific EIRs (Figure 38). Moreover, the combination of these prey-specific values indicates that overall CR (gr/min) and EIR (kcal/min) were similar among areas. Finally, all intake rates were in the range of sea otter populations existing near carrying capacity or *K* (Figure 39). That is, an EIR of less than 8 kcal/min, generally around 4-6 kcal/min is indicative of a population at or near to *K* relative to populations that are not limited by food resources, which tend to have EIR of ~12 to >20 kcal/min (Coletti et al. 2016; Hale et al. 2019; Tinker 2015; Tinker et al. 2021).

Our sea otter foraging observations indicate that clams are the primary prey type consumed by sea otters in nearshore habitats of LCI (Figure 33). This finding is consistent with the finding of Hasan (2022) that nearshore LCI areas are dominated by soft-sediment habitat types (Section 5.4). The species of clam that sea otters take varies by area (Figure 34), with our most notable finding being that sea otters feed on Pacific razor clams along the east side of LCI (Geissinger 2024) in the same places where a subsistence Pacific razor clam fishery has occurred historically (Szarzi et al. 2010). This Pacific razor clam fishery has experienced a drop in Pacific razor clam abundance over the last decade (Kerkvliet et al. 2021). However, this relatively recent decline in Pacific razor clams along eastern LCI and the length of time sea otters have occurred there suggests that, while sea otters maybe be contributing to a lack of recovery of Pacific razor clams, they may not have been the primary driver of the decline (Geissinger 2024).

Our shore-based observations have an inherent near-shore bias. We had hoped to overcome this bias by at least observing the size and type of prey sea otters were obtaining in offshore areas during vessel surveys. However, as noted in Section 5.3 on vessel surveys, sea otters were generally wary of the vessel and rarely let us get close enough to observe what they may have been feeding on in offshore areas. The benthic trawls (Section 5.5) indicate the presence of several potentially valuable prey in offshore areas including crabs and large urchins. If clams are also abundant in offshore areas, these would also be a primary prey item for sea otters. However, we cannot at this time determine comparable prey consumption and EIRs in offshore areas even though it appears likely that many sea otters may be feeding in these areas regularly. Thus, the question remains, is the offshore area also a relatively food limited environment for sea otters? Or does it have relatively abundant prey resources attracting large numbers of sea otters to feed there? The only certainties are that the offshore area of LCI is the majority of sea otter habitat in LCI and that the offshore area still provides enough prey resources to allow sea otters to forage profitably at depths of 20–40 m.

6.7 Gene Flow across Cook Inlet

At the time that the southwest and southcentral stock structure was proposed by Gorbics and Bodkin (2001), the closest populations to the southwest / southcentral stock boundary where genetic material was available came from Prince William Sound and Kodiak Island (Bodkin et al. 1999; Cronin et al. 1996; Scribner et al. 1997). These locations had different remnant population sources (Kenyon 1969), so their distinct genetic makeup was not unexpected. Expansion to the west from Prince William Sound and north from Kodiak eventually lead to the reestablishment of the LCI populations. Sea otters from Katmai National Park (just south of Kamishak Bay) and Kachemak Bay were sampled after the stock designation occurred but represented populations more likely to pick up cross-stock movements if they had occurred. As it turns out, the mixing of the stocks across LCI now appears likely (Flannery et al. 2022). That is, the

genetic makeup of the most recently reoccupied area of eastern LCI includes an admixture from both the southwest stock and southcentral stocks (Flannery et al. 2022).

Considering that the water depth is generally ~100 m or less across the entire LCI, and the distance between high-density population centers within the 40 m depth contour on either side is only ~ 50 km, this result is not surprising. During recovery of sea otter populations in the western Aleutian Islands, sea otters were known to have crossed deep open-water gaps between islands of 50 km or more as they spread from islands with remnant populations to islands where they had been extirpated (Kenyon 1969).

Regardless of this finding, sea otter populations function at much smaller spatial scales than current sea otter population management units (Tinker et al. 2019), and the populations on the west and east side of LCI likely function independently of each another. As Gorbics and Bodkin (2001) noted, stock structure is based on multiple criteria, one of which is genetic information. Other factors include morphological, distributional, behavioral and physiological elements (Cronin 1993).

As one anecdotal example of behavioral differences between west and east LCI populations, the vessel surveys we conducted demonstrated to the observers that the sea otters on the west side of LCI were much more wary of our vessel than the sea otters on the east side, and they would begin to take notice and react at distances of 2 km or more. The reason for this wariness is unknown but may be in part due to the limited vessel traffic sea otters are exposed to on the west side and within Kamishak Bay in particular.

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8 Appendices

8.1 Appendix A. Locations of benthic trawl conducted another USGS BOEM-funded project (BOEM 2025e) in lower Cook Inlet, Alaska in summer 2024 where potential sea otter prey were recovered. These data are available in Donnelly et al. (2025).

Trawl ID	Latitude	Longitude	Station depth (m)	Distance (m)	Area sampled (m^2)
2024056013	59.97998	-151.939	33	573	1,720
2024056060	59.95918	-152.152	102	898	2,693
2024056504	59.57452	-152.691	57	626	1,879
2024056402	59.64513	-152.877	37	430	1,289
2024056412	59.635	-152.03	34	534	1,602
2024056512	59.55054	-151.994	41	490	1,470
2024080503	59.70476	-151.125	63	546	1,639
2024082201	59.66762	-151.184	56	507	1,521
2024080202	59.50358	-151.761	76	556	1,667
2024080204	59.63782	-151.686	27	499	1,498
2024080201	59.50265	-151.798	77	524	1,571
2024082102	59.66872	-151.874	20	543	1,628
2024080401	59.63528	-151.397	12	488	1,465
2024086155	59.86285	-152.612	32	351	1,054
2024086402	59.64536	-152.876	39	511	1,532
2024086404	59.66629	-152.729	35	519	1,557
2024086451	59.59629	-152.935	39	456	1,367
2024086504	59.57143	-152.707	55	479	1,438
2024086536	59.55403	-153.049	36	541	1,622
2024086552	59.51336	-152.882	44	559	1,678
2024087007	60.11411	-152.405	32	365	1,096
2024087999	60.10812	-152.594	46	465	1,396
2024086360	59.66979	-152.163	39	483	1,448
2024086411	59.63729	-152.1	39	443	1,329
2024086412	59.63392	-152.019	35	509	1,527
2024086512	59.55787	-151.995	41	502	1,505
2024086560	59.51371	-152.183	45	457	1,372

8.2 Appendix B. Epibenthic invertebrates that are potential sea otter prey collected in benthic trawl surveys by another USGS BOEM-funded project (BOEM 2025e) conducted in lower Cook Inlet, Alaska in summer 2024. These data are available in Donnelly et al. (2025).

Trawl ID	Station	Month	Year	Depth	Group	Common name	Scientific name	Length
2024056013	6013	May	2024	33	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	45
2024056060	6060	May	2024	102	crab	armed hermit	*Pagurus armatus*	
2024056060	6060	May	2024	102	crab	armed hermit	*Pagurus armatus*	
2024056060	6060	May	2024	102	crab	graceful decorator crab	*Oregonia gracilis*	
2024056060	6060	May	2024	102	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	80
2024056060	6060	May	2024	102	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	85
2024056060	6060	May	2024	102	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	90
2024056060	6060	May	2024	102	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	70
2024056060	6060	May	2024	102	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	60
2024056060	6060	May	2024	102	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	80
2024056060	6060	May	2024	102	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	55
2024056060	6060	May	2024	102	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	50
2024056060	6060	May	2024	102	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	68
2024056060	6060	May	2024	102	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	
2024056060	6060	May	2024	102	bivalve	Pacific pink scallop	*Chlamys rubida*	44
2024056060	6060	May	2024	102	crab	pygmy rock crab	*Cancer oregonesis*	16
2024056060	6060	May	2024	102	crab	pygmy rock crab	*Cancer oregonesis*	
2024056060	6060	May	2024	102	crab	pygmy rock crab	*Cancer oregonesis*	
2024056060	6060	May	2024	102	crab	pygmy rock crab	*Cancer oregonesis*	18
2024056060	6060	May	2024	102	crab	pygmy rock crab	*Cancer oregonesis*	
2024056060	6060	May	2024	102	crab	pygmy rock crab	*Cancer oregonesis*	
2024056060	6060	May	2024	102	crab	widehand hermit crab	*Elassochirus tenuimanus*	
2024056060	6060	May	2024	102	crab	widehand hermit crab	*Elassochirus tenuimanus*	
2024056060	6060	May	2024	102	crab	widehand hermit crab	*Elassochirus tenuimanus*	
2024056060	6060	May	2024	102	crab	widehand hermit crab	*Elassochirus tenuimanus*	
2024056060	6060	May	2024	102	crab	widehand hermit crab	*Elassochirus tenuimanus*	
2024056504	6504	May	2024	58	echinoderm	basket star	*Euryalina spp.*	62
2024056504	6504	May	2024	58	crab	pygmy rock crab	*Cancer oregonesis*	
2024056402	6402	May	2024	40	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	60
2024056402	6402	May	2024	40	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	80
2024056402	6402	May	2024	40	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	60
2024056402	6402	May	2024	40	crab	pygmy rock crab	*Cancer oregonesis*	18
2024056412	6412	May	2024	34	echinoderm	Pacific blood star	*Henricia leviuscula*	
2024056412	6412	May	2024	34	crab	graceful decorator crab	*Oregonia gracilis*	23
2024056412	6412	May	2024	34	crab	graceful decorator crab	*Oregonia gracilis*	17

Trawl ID	Station	Month	Year	Depth	Group	Common name	Scientific name	Length
2024056412	6412	May	2024	34	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	55
2024056412	6412	May	2024	34	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	60
2024056412	6412	May	2024	34	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	55
2024056412	6412	May	2024	34	echinoderm	Green sea urchin	*Strongylocentrotus droebachiensis*	50
2024056412	6412	May	2024	34	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	60
2024056412	6412	May	2024	34	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	55
2024056412	6412	May	2024	34	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	65
2024056412	6412	May	2024	34	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	50
2024056412	6412	May	2024	34	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	
2024056412	6412	May	2024	34	crab	pygmy rock crab	*Cancer oregonesis*	30
2024056512	6512	May	2024	41	crab	Alaskan hermit	*Pagurus ochotensis*	
2024056512	6512	May	2024	41	bivalve	Pacific pink scallop	*Chlamys rubida*	
2024080503	5	August	2024	62	crab	Tanner crab	*Chionoecetes bairdi*	135
2024082201	22	August	2024	60	bivalve	common nut clam	*Nuculana pernula*	15
2024082201	22	August	2024	60	bivalve	common nut clam	*Nuculana pernula*	13
2024082201	22	August	2024	60	bivalve	Pacific pink scallop	*Chlamys rubida*	28
2024082202	22	August	2024	50	bivalve	common nut clam	*Nuculana pernula*	15
2024082202	22	August	2024	50	bivalve	nuttall cockle	*Clinocardium nuttallii*	16
2024082202	22	August	2024	50	bivalve	nuttall cockle	*Clinocardium nuttallii*	15
2024080101	1	August	2024	20	crab	Alaskan hermit	*Pagurus ochotensis*	7
2024080101	1	August	2024	20	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	23
2024080101	1	August	2024	20	crab	greenmark hermit	*Pagurus caurinus*	21
2024080101	1	August	2024	20	crab	greenmark hermit	*Pagurus caurinus*	8
2024080101	1	August	2024	20	crab	unknown hermit crab	*Pagurus spp.*	23
2024080201	2	August	2024	80	bivalve	Pacific pink scallop	*Chlamys rubida*	41
2024080201	2	August	2024	80	bivalve	Pacific pink scallop	*Chlamys rubida*	20
2024080201	2	August	2024	80	bivalve	Pacific pink scallop	*Chlamys rubida*	27
2024080202	2	August	2024	78	bivalve	Pacific pink scallop	*Chlamys rubida*	34
2024080202	2	August	2024	78	bivalve	Pacific pink scallop	*Chlamys rubida*	26
2024080202	2	August	2024	78	bivalve	Pacific pink scallop	*Chlamys rubida*	33
2024080202	2	August	2024	78	bivalve	Pacific pink scallop	*Chlamys rubida*	24
2024080204	2	August	2024	23	crab	Alaskan hermit	*Pagurus ochotensis*	25
2024080204	2	August	2024	23	bivalve	Pacific pink scallop	*Chlamys rubida*	35
2024082101	21	August	2024	25	crab	graceful decorator crab	*Oregonia gracilis*	7
2024082101	21	August	2024	25	crab	graceful decorator crab	*Oregonia gracilis*	8
2024082102	21	August	2024	19	crab	graceful decorator crab	*Oregonia gracilis*	8
2024082102	21	August	2024	19	crab	threespine coastal shrimp	*Heptacarpus tridens*	8
2024080401	4	August	2024	12	crab	Alaskan hermit	*Pagurus ochotensis*	14
2024080401	4	August	2024	12	bivalve	common nut clam	*Nuculana pernula*	10
2024080401	4	August	2024	12	bivalve	common nut clam	*Nuculana pernula*	13
2024080401	4	August	2024	12	bivalve	common nut clam	*Nuculana pernula*	11

Trawl ID	Station	Month	Year	Depth	Group	Common name	Scientific name	Length
2024080401	4	August	2024	12	crab	graceful decorator crab	*Oregonia gracilis*	8
2024080401	4	August	2024	12	crab	graceful decorator crab	*Oregonia gracilis*	10
2024080401	4	August	2024	12	crab	graceful decorator crab	*Oregonia gracilis*	28
2024080401	4	August	2024	12	crab	graceful decorator crab	*Oregonia gracilis*	12
2024080401	4	August	2024	12	crab	graceful decorator crab	*Oregonia gracilis*	10
2024080401	4	August	2024	12	crab	graceful decorator crab	*Oregonia gracilis*	7
2024080401	4	August	2024	12	crab	graceful decorator crab	*Oregonia gracilis*	6
2024080401	4	August	2024	12	crab	graceful decorator crab	*Oregonia gracilis*	9
2024080401	4	August	2024	12	crab	graceful decorator crab	*Oregonia gracilis*	10
2024080401	4	August	2024	12	crab	graceful decorator crab	*Oregonia gracilis*	11
2024080401	4	August	2024	12	crab	graceful decorator crab	*Oregonia gracilis*	
2024080401	4	August	2024	12	crab	graceful kelp crab	*Pugettia gracilis*	11
2024080401	4	August	2024	12	crab	graceful kelp crab	*Pugettia gracilis*	8
2024080401	4	August	2024	12	crab	graceful kelp crab	*Pugettia gracilis*	16
2024080401	4	August	2024	12	crab	graceful kelp crab	*Pugettia gracilis*	9
2024080401	4	August	2024	12	crab	graceful kelp crab	*Pugettia gracilis*	6
2024080401	4	August	2024	12	crab	graceful kelp crab	*Pugettia gracilis*	
2024080401	4	August	2024	12	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	14
2024080401	4	August	2024	12	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	30
2024080401	4	August	2024	12	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	15
2024080401	4	August	2024	12	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	22
2024080401	4	August	2024	12	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	10
2024080401	4	August	2024	12	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	14
2024080401	4	August	2024	12	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	6
2024080401	4	August	2024	12	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	42
2024080401	4	August	2024	12	echinoderm	green sea urchin	*Strongylocentrotus droebachiensis*	11
2024080401	4	August	2024	12	bivalve	Pacific pink scallop	*Chlamys rubida*	9
2024080401	4	August	2024	12	crab	pygmy rock crab	*Cancer oregonesis*	30
2024080401	4	August	2024	12	crab	unknown hermit crab	*Pagurus spp.*	9
2024086155	6155	August	2024	32	crab	Bering hermit	*Pagurus beringanus*	
2024086155	6155	August	2024	32	echinoderm	crevice brittlestar	*Ophiopholis aculeata*	
2024086155	6155	August	2024	32	crab	graceful decorator crab	*Oregonia gracilis*	5
2024086155	6155	August	2024	32	bivalve	Pacific pink scallop	*Chlamys rubida*	21
2024086155	6155	August	2024	32	crab	pygmy rock crab	*Cancer oregonesis*	15
2024086402	6402	August	2024	43	bivalve	Pacific pink scallop	*Chlamys rubida*	26
2024086402	6402	August	2024	43	bivalve	Pacific pink scallop	*Chlamys rubida*	28
2024086402	6402	August	2024	43	bivalve	Pacific pink scallop	*Chlamys rubida*	24
2024086404	6404	August	2024	37	bivalve	unknown clam	*Angulus spp.*	7
2024086451	6451	August	2024	39	bivalve	Pacific pink scallop	*Chlamys rubida*	20
2024086504	6504	August	2024	55	echinoderm	eccentric sand dollar sea urchin	*Dendraster excentricus*	44
2024086525	6256	August	2024	35	bivalve	Pacific pink scallop	*Chlamys rubida*	28

Trawl ID	Station	Month	Year	Depth	Group	Common name	Scientific name	Length
2024086525	6256	August	2024	35	bivalve	Pacific pink scallop	*Chlamys rubida*	20
2024086525	6256	August	2024	35	bivalve	Pacific pink scallop	*Chlamys rubida*	20
2024086525	6256	August	2024	35	bivalve	Pacific pink scallop	*Chlamys rubida*	10
2024086525	6256	August	2024	35	bivalve	Pacific pink scallop	*Chlamys rubida*	21
2024086525	6256	August	2024	35	bivalve	Pacific pink scallop	*Chlamys rubida*	23
2024086525	6256	August	2024	35	crab	pygmy rock crab	*Cancer oregonesis*	20
2024086360	6360	August	2024	39	crab	pygmy rock crab	*Cancer oregonesis*	21
2024086411	6411	August	2024	39	crab	graceful decorator crab	*Oregonia gracilis*	5
2024086411	6411	August	2024	39	crab	graceful decorator crab	*Oregonia gracilis*	8
2024086411	6411	August	2024	39	crab	pygmy rock crab	*Cancer oregonesis*	37
2024086512	6512	August	2024	41	crab	Alaskan hermit	*Pagurus ochotensis*	
2024086512	6512	August	2024	41	crab	Alaskan hermit	*Pagurus ochotensis*	22
2024086512	6512	August	2024	41	crab	Alaskan hermit	*Pagurus ochotensis*	24
2024086512	6512	August	2024	41	crab	Alaskan hermit	*Pagurus ochotensis*	13
2024086512	6512	August	2024	41	crab	Alaskan hermit	*Pagurus ochotensis*	11
2024086512	6512	August	2024	41	crab	Alaskan hermit	*Pagurus ochotensis*	15
2024086512	6512	August	2024	41	crab	Alaskan hermit	*Pagurus ochotensis*	9
2024086512	6512	August	2024	41	crab	graceful decorator crab	*Oregonia gracilis*	36
2024086512	6512	August	2024	41	crab	graceful decorator crab	*Oregonia gracilis*	52
2024086512	6512	August	2024	41	echinoderm	sand dollar	*Dendraster excentricus*	67
2024086512	6512	August	2024	41	bivalve	unknown clam	*Angulus spp.*	6
2024086512	6512	August	2024	41	bivalve	unknown clam	*Angulus spp.*	7
2024086512	6512	August	2024	41	crab	widehand hermit	*Elassochirius tenuimanus*	35
2024086512	6512	August	2024	41	crab	widehand hermit	*Elassochirius tenuimanus*	25
2024086512	6512	August	2024	41	crab	widehand hermit	*Elassochirius tenuimanus*	20
2024086560	6560	August	2024	45	crab	Aleutian hermit	*Pagurus aleuticus*	
2024086560	6560	August	2024	45	crab	Aleutian hermit	*Pagurus aleuticus*	
2024086560	6560	August	2024	45	crab	Aleutian hermit	*Pagurus aleuticus*	
2024086560	6560	August	2024	45	crab	Aleutian hermit	*Pagurus aleuticus*	
2024086560	6560	August	2024	45	crab	graceful decorator crab	*Oregonia gracilis*	4
2024086560	6560	August	2024	45	bivalve	Pacific pink scallop	*Chlamys rubida*	47
2024086560	6560	August	2024	45	bivalve	Pacific pink scallop	*Chlamys rubida*	29