SPECIES STATUS ASSESSMENT FOR THE SOUTHWEST ALASKA DISTINCT POPULATION SEGMENT OF NORTHERN SEA OTTER (*Enhydra lutris kenyoni*) (Version 2.0)

Photo Credit: The Service

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LIST OF ACRONYMS

ADEC- Alaska Department of Environmental Conservation

ADFG - Alaska Department of Fish and Game

AIS - Automated Information System

AK - Alaska

ASLC - Alaska SeaLife Center

ASP - Amnesic Shellfish Poisoning

AU - Analysis Unit

BB - Bristol Bay

BOEM - Bureau of Ocean Energy Management

CITES - Convention on International Trade in Endangered Species of Wild Fauna and Flora

DDT - Dichlorodiphenyltrichloroethane

DPS - Distinct Population Segment

EA - Eastern Aleutians

ESA - Endangered Species Act

EVOS - Exxon Valdez Oil Spill

GCM - General Circulation Model

GHG - Greenhouse Gas

GOA - Gulf of Alaska

GWA - Gulf Watch Alaska

HABs - Harmful Algal Blooms

IHA - Incidental Harassment Authorization

ISU - Intensive Search Unit

ITR - Incidental Take Regulation

LCI - Lower Cook Inlet

LME - Large Marine Ecosystem

LOA - Letter of Authorization

MMC - Marine Mammal Commission

MMPA - Marine Mammal Protection Act

MTRP - Marking Tagging Reporting Program

MU - Management Unit

NMFS - National Marine Fisheries Service

NOAA - National Oceanic and Atmospheric Administration

NSO - Northern Sea Otter

OA - Ocean Acidification

PCB - Polychlorinated Biphenyl

PAH - Polycyclic Aromatic Hydrocarbons

POP - Persistent Organic Pollutants

PSP - Paralytic Shellfish Poisoning

PWS - Prince William Sound

RCP - Representative Concentration Pathway

SAP - South Alaska Peninsula

SERVICE - U.S. Fish and Wildlife Service

SSA - Species Status Assessment

SST - Sea Surface Temperature

SW - Southwest

UME - Unusual Mortality Event

USCG- U.S. Coast Guard

USGS - U.S. Geological Survey

WA - Western Aleutians

CONTENTS

List of Figures

List of Tables

EXECUTIVE SUMMARY

The northern sea otter (NSO; *Enhydra lutris kenyoni*) in Alaska consists of three stocks under the U.S. Marine Mammal Protection Act (MMPA): southcentral, southeast, and southwest. The southwest stock (hereafter known as the SW NSO) is designated a threatened distinct population segment (DPS) under the Endangered Species Act (ESA) due to rapid population declines in the western Aleutians in the 1990s. This document will focus on the listed stock. The purpose of this document is to synthesize scientific information relevant to assessing the current and future status of the SW NSO. This living document will also serve as a reference for regulatory actions associated with SW NSO conservation and management under the MMPA and ESA.

Throughout the document we use various terms to reference specific groups of sea otters. "Sea otters" is used to discuss the species generally. "Northern sea otters" (NSO) is used when discussing the subspecies that occurs in Alaska, British Columbia, and Washington. Finally, as described above, SW NSO is used to define the listed northern sea otter southwest distinct population segment in Alaska.

This document describes the taxonomy, distribution, and the biology and ecology of the SW NSO as well as population needs and stressors, current conditions and potential future conditions. An assessment of the viability of the SW NSOs accounted for future projections of the intensity of major stressors and the degree of resilience, representation, and redundancy exhibited by this stock.

The historical range of NSOs in Alaska was a function of the annual formation of sea ice in the north. The commercial fur trade, which began in the mid-1700's, reduced NSOs throughout their range in North America through the serial depletion of subpopulations beginning in the north and moving south. About 13 small and isolated populations still existed, primarily in Alaska. Following the cessation of the fur trade and implementation of protective legislation, these small and isolated NSO populations experienced population growth, limited natural expansion, and became a source for transplants in the 1960s and 1970s to the Pribilof Islands, southeast Alaska, Washington, and Oregon. Translocations to the Pribilof Islands and Oregon failed and were slow to take hold in the other areas. Currently, NSO abundance in Alaska are either stable or increasing and expanding their range.

Potential population stressors that we identified as important throughout the range of SW NSO include indirect effects of increasing sea surface temperatures (SST) and ocean acidification (OA) due to climate change, and ship traffic as it relates to the potential for a large oil spill and other contamination. Important localized stressors include oil and gas activities, subsistence harvest, pathogen outbreaks, and killer whale (*Orcinus orca*) predation.

The waters within the range of SW NSO in Alaska have warmed over the last several decades and will continue to warm in the near future. The resulting temperatures appear to be well within the thermal tolerances of SW NSOs and may be advantageous in terms of maintaining thermal neutrality. In addition, the warmer trend may allow for SW NSOs to expand their range further north due to lack of sea ice. However, increasing sea surface temperatures (SSTs) may result in distribution shifts, recruitment dynamics, and changes in abundance of various members of benthic communities, including some SW NSO prey species and other predators to those prey. Additionally, increasing SSTs may provide conditions that allow movement of novel benthic invertebrates northward. To date, the prey available to SW NSOs throughout their range in Alaska appears to be adequate to allow for numerical increases in some areas and stability in others. In addition, SW NSOs are flexible in the prey species consumed. Projections of the abundance of benthic invertebrates for the northern portion of the SW NSO range in Alaska indicate large annual fluctuations and a small decline in mass or little change to mid-century, depending on the area. Harmful algal blooms (HABs) are also associated with warmer SSTs. To date, there are no reports of NSOs exhibiting clinical signs of acute toxicosis (behavioral neuroexcitatory toxicity for domoic acid or paralysis from saxitoxin due to these blooms). However, toxins concentrate in some SW NSO prey and there is evidence that HAB toxins occur throughout Alaskan waters at levels high enough to be detected in marine mammals. Because the current trend in decreasing sea ice and increasing SST creates conditions favorable to HABs, the prevalence and concentrations of toxins, and their associated risk to SW NSOs, are expected to increase.

Marine waters are becoming more acidic as they absorb Carbon dioxide (CO_2) produced by the burning of fossil fuels and other sources. The availability of aragonite and calcite required by invertebrate prey of SW NSOs to form and repair their shells and other structures declines as waters become more acidic. Laboratory studies have shown that OA at levels projected for 2100, can compromise the growth, survival, and reproduction of calcifying invertebrates. However, field studies are more equivocal and indicate that some calcifying invertebrates that occur in naturally low pH waters are more tolerant of, and adaptable to, increasing OA. As noted above, SW NSO prey currently appears to be adequate and only small changes in some of those prey species will likely occur by mid-century. In addition, it is unlikely that declining pH will affect SW NSOs directly.

Ship traffic appears to have increased throughout the range of SW NSOs. While, routine ship traffic is unlikely to affect the SW NSOs negatively, the biggest risk to the SW NSO from shipping is the release of large amounts of crude oil from a tanker or other contaminants in an accident. Although oil spills are rare events, they could have large negative population-level effects on SW NSO as exemplified by the grounding of the T/V *Exxon Valdez* in 1989 in Prince William Sound (PWS). Shipping is likely to increase in the future, but we could not find any projections for areas inhabited by SW NSO.

Oil and gas exploration, development, and production are currently only active in Lower Cook Inlet (LCI) in southcentral Alaska. Oil and gas companies have obtained incidental harassment authorizations (IHA) and the U.S. Fish and Wildlife Service (Service) has issued Incidental Take Regulations (ITR) for their activities per the MMPA. Analyses of impacts of these activities indicate that they result in only small numbers of SW NSO being disturbed and impacts are negligible. A federal lease sale was completed in 2017 in LCI which will likely increase activities in the near future. In addition, the Pebble Mine Project is proposing port development on the west side of Cook Inlet and a pipeline crossing and the Alaska Liquefied Natural Gas Project is proposing port development near Nikiski.

Harvest of NSOs by Alaska Natives occurs throughout the range of SW NSOs. However, harvests are highest near villages and towns and considered sustainable at the stock level. Harvest levels in the future are likely to remain at current levels, but should remain sustainable with areas of localized reduced abundance.

The SW NSO is susceptible to a number of diseases and parasites and mortalities due to disease are occasionally elevated in certain places at certain times. The most recent concern involved a strep syndrome. Mortalities spiked in 2015 and have declined since, but due to the regional concentration of the stranding network, the full extent of disease related mortalities is unknown. It is likely that periodic outbreaks of disease in SW NSO will continue to occur, but the temporal and spatial scopes are unpredictable. The potential for a novel disease or parasite to become established in Alaskan waters is unknown.

The best available information indicates that SW NSO in the Aleutians declined by up to 90 percent in the 1990s due to suspected killer whale predation. Due primarily to that decline, the SW NSO was listed as a threatened DPS under the ESA. Recent surveys and analyses suggest that some areas within the SW NSO have stabilized and/ or are increasing. Although evidence suggests marine predation was at least partially responsible for the decline in the SW NSO in the past, the current impacts of predation on the SW NSOs remain uncertain.

The SW NSO possesses levels of resiliency, representation, and redundancy that have allowed for recovery of populations greatly reduced due to over exploitation during the commercial fur trade and a large oil spill in PWS. In addition, less intense stressors such as routine ship traffic, coastal development, disease outbreaks, and subsistence harvests do not appear to have had population-level effects. Resiliency of SW NSO is currently low to high due to the variation in density estimates across its range. Redundancy is moderate because of the various levels of gene flow estimated among the analytical units. Representation is moderate due to low genetic diversity. These traits are unlikely to change in the future and low genetic diversity may be an impediment to adapting to stressors associated with climate change. However, low genetic diversity has not significantly impacted the SW NSO ability to cope with the population-level stressors identified above.

1 INTRODUCTION

1.1 **Background**

The purpose of this document is to synthesize best available scientific and commercial information relevant to assessing the current and future status of the southwest stock of the northern sea otter (SW NSO; *Enhydra lutris kenyoni*) in Alaska. We compiled it using the U.S. Fish and Wildlife Service's (Service) guidance on developing a Species Status Assessment (SSA; Smith et al. 2018, p. 302). This document will also inform the Service's decisions related to the SW NSO under the U.S. Endangered Species Act (ESA) and actions under the U.S. Marine Mammal Protection Act (MMPA). We emphasize that this is not a decision document; instead, it forms the scientific basis from which the Service will draw conclusions and make decisions.

The northern sea otter (NSO) in Alaska consists of three stocks: southwest, southcentral, and southeast. The SW NSO was listed as a threatened distinct population segment (DPS) under the ESA in 2005 (70 FR 46366). This SSA will serve as the science base for ESA actions such as the ESA's five-year review. In addition, we aimed to improve efficiency and streamline regulatory processes under the MMPA for SW NSOs. The Regulatory Program of the Service's Marine Mammals Management Office frequently process requests for Incidental Harassment Authorizations (IHA) and may be requested to develop Incidental Take Regulations (ITR) for NSOs in Alaska. Documents associated with IHAs and ITRs often are large and somewhat redundant, containing information on the natural history, ecology, and status by stock for NSOs. This SSA will serve as a citable source for basic information on SW NSOs for IHAs and ITRs. Finally, this SSA will serve as a source document on SW NSOs for the general public, commercial fishers, developers, and other interested stakeholders.

1.2 **Analytical Framework**

The SSA report, the product of conducting a SSA, is intended to be a concise review of the species' biology and factors influencing the species, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA report to be easily updated as new information becomes available, and to support all functions of the Endangered Species Program. As such, the SSA report will be a living document upon which other documents, such as listing rules, recovery plans, and 5-year reviews will be based.

Using the SSA framework (Fig. 1), we consider what a species needs to maintain viability by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation (together, the 3 Rs) (Smith et al. 2018, entire). For the purpose of this assessment, we define viability as the ability of the species to sustain populations in ecosystems within a biologically meaningful timeframe. We chose to forecast out 30 years (2050), which is the time frame that corresponds with the sea surface temperature and benthic model timelines and is roughly 4 generations (7.9 years; Gagne et al. 2018, p. 1787).

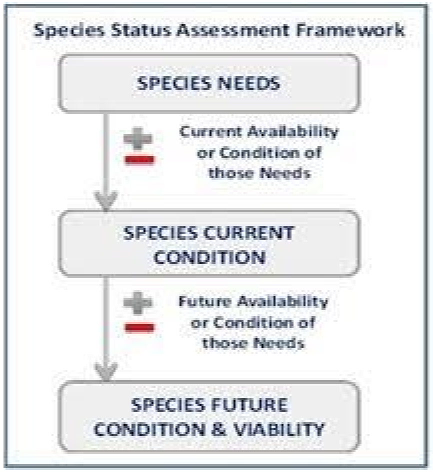

Figure 1.1 Species Status Assessment Framework.

We define resiliency, redundancy, and representation as follows:

- Resiliency is the ability of a species to withstand environmental stochasticity (normal, year-to-year variations environmental conditions such as temperature or rainfall), periodic disturbances within the normal range of variation (fire, floods, storms), and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity) (Redford et al., 2011, p. 40). Simply stated, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions.

  We can best gauge resiliency by evaluating population level characteristics such as: demography (abundance and the components of population growth rate – survival, reproduction, and migration), genetic health (effective population size and heterozygosity), connectivity (gene flow migration and population rescue), and habitat quantity, quality, configuration, and heterogeneity (diversity of habitat types or microclimates) are also important considerations.

- Redundancy is the ability of a species to withstand catastrophes. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population health and for which adaptation is unlikely (Mangal and Tier 1993, p. 1083).

  We can best gauge redundancy by analyzing the number and distribution of populations relative to the scale of anticipated species-relevant catastrophic events. The analysis entails assessing the cumulative risk of catastrophes occurring over time. Redundancy can be analyzed at a population or regional scale, or for narrow-ranged species, at the species level.

- Representation is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability to adapt to new environments—referred to as adaptive capacity—is essential for viability, as species need to continually adapt to their continuously changing environments (Nicotra et al.

> 2015, p. 1269). Species adapt to novel changes in their environments by either [1] moving to new, suitable environments or [2] by altering their physical or behavioral traits (phenotypes) to match the new environmental conditions through either plasticity or genetic change (Beever et al. 2016, p. 132; Nicotra et al. 2015, p. 1270). The latter (evolution) occurs via the evolutionary processes of natural selection, gene flow, mutations, and genetic drift (Crandall et al. 2000, pp.290-291; Sgro et al. 2011, p. 327; Zackay 2007, p. 1).
>
> We can best gauge representation by examining the breadth of genetic, phenotypic, and ecological diversity found within a species and its ability to disperse and colonize new areas. In assessing the breath of variation, it is important to consider both larger-scale variation (such as morphological, behavioral, or life history differences which might exist across the range and environmental or ecological variation across the range), and smaller-scale variation (which might include measures of interpopulation genetic diversity). In assessing the dispersal ability, it is important to evaluate the ability and likelihood of the species to adapt to suitable habitat and climate over time. Lastly, to evaluate the evolutionary processes that contribute to and maintain adaptive capacity, it is important to assess [1] natural levels and patterns of gene flow, [2] degree of ecological diversity occupied, and [3] effective population size. In our species status assessment, we assess all three facets to the best of our ability based on available data.

The information presented in this report includes not a prediction of the most likely future for the SW NSO, but rather an assessment of the species' risk of extinction. To inform this assessment of extinction risk, we describe the SW NSO's current biological status and how this status may change in the future under a range of scenarios to account for the uncertainty of the species' future. We evaluate the current biological status of the SW NSO by assessing the primary factors negatively and positively affecting the species to describe its current condition in terms of resiliency, redundancy, and representation. We then evaluate the future biological status of the SW NSO by describing a range of plausible future scenarios representing a range of conditions for the primary factors affecting the species and forecasting the most likely future condition for each scenario in terms of the 3Rs. As a matter of practicality, the full range of potential future scenarios and the range of potential future conditions for each potential scenario are too large to individually describe and analyze. These scenarios do not include all possible futures, but rather include specific plausible scenarios that represent examples from the continuous spectrum of possible futures.

1.2.1 *Analytical Units*

As our analytical unit (AU), we chose to use the management units used in the 2005 ESA listing of the SW NSO. The SW NSO was divided into five management units (MUs): Western Aleutians; Eastern Aleutians; South Alaska Peninsula; Bristol Bay; and Kodiak, Kamishak, and Alaska Peninsula. These were implemented to account for variation in populations among these areas and to set ESA recovery goals (Service 2013a, p. ii).

2 SPECIES INFORMATION

2.1 **Taxonomy and Species Description**

The NSO is one of three subspecies of sea otter that occur in the North Pacific Ocean. The southern sea otter (*E. l. nereis*) is found primarily in California and the Asian sea otter (*E. l. lutris*) is found along the coasts of Japan and the Russian Federation (Wilson et al. 1991, p. 23). The following is an abbreviated taxonomic hierarchy for the NSO; Kingdom: Animalia, Phylum: Chordata, Class: Mammalia, Order: Carnivora, Family: Mustelidae, Genus species: *Enhydra lutris*, Subspecies: *kenyoni* (ITIS 2018, pp. 1-3).

Throughout the document we use various terms to reference specific groups of sea otters. “Sea otters” is used to discuss the species generally. “Northern sea otters” (NSO) is used when discussing the subspecies that occurs in Alaska, British Columbia, and Washington. Finally, as described above, SW NSO is used to define the listed northern sea otter southwest distinct population segment in Alaska.

Sea otters are one of the largest members of the mustelid family, adapted for a marine existence, and the smallest marine mammal. The species is one of two marine mustelids, the other being the marine otter (*Lontra feline*) found along the west coast of South America (Valqui 2011, p. 2).

Adult NSOs reach more than 1.3 meters (m) in length, weigh 30-45 kilogram (kg), and have dark brown/black dense (>100,000 hairs/centimeter (cm^2) pelage. The fur may become progressively grizzled (lighter in color) on the head with age (Garshelis 1984, pp. 459-461). The muzzle has thick and prominent vibrissae. The forelegs are short, and the paws are very dexterous, sensitive, and important in securing and handling prey as well as nurturing dependent pups. The hind limbs are oriented backwards with flattened feet similar to flippers in other marine mammals. They have a short tail in comparison to river otters (*L. canadensis)*. The dental formula for sea otters is Incisors 3/2 (top/bottom), Canines 1/1, Pre-molars 3/3, and Molars 1/2.

Newborn pups are about 0.6-1.0 m in length and weigh 2.0-11.0 kg. Their appearance has been described as buff in color and very fluffy (Jefferson et al. 2008, p. 459).

Unlike other marine mammals, sea otters do not have a thick layer of blubber for insulation from cold water. Instead, they have the densest fur of any mammal (Murray 2015, p. 170) and a metabolism 2.5 – 3 times higher than that of land mammals of equal size to maintain homeostasis (Costa and Kooyman 1982, p. 2765).

2.2 **Range and Distribution**

Sea otters occur along the Pacific Coast of western North America, on both sides of the Alaska Peninsula, the Aleutian Islands, the eastern coast of Japan, and the Kamchatka Peninsula of the Russian Federation (Fig. 2.1).

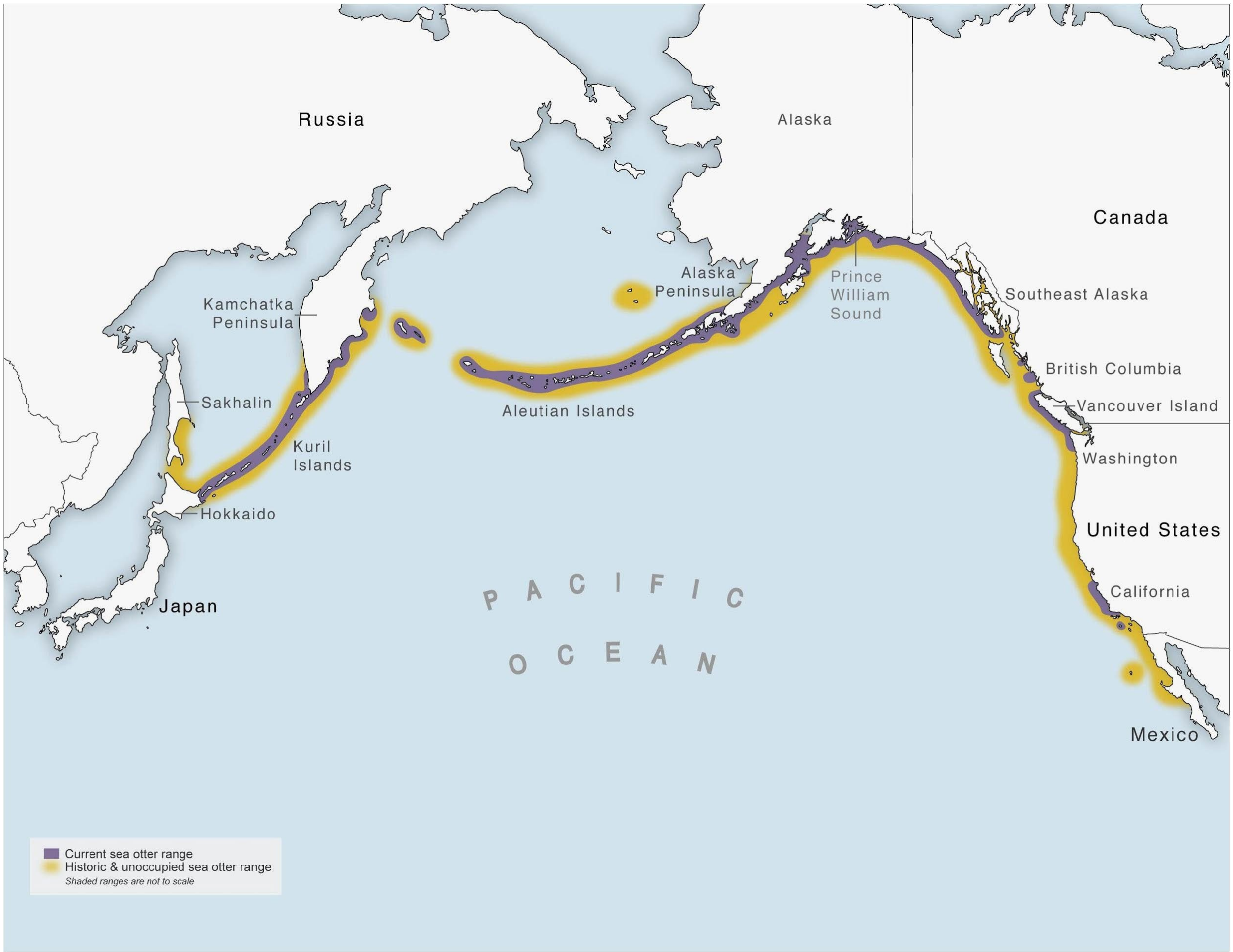

Figure 2.1 Current and historical map of sea otters (Larson et al. 2015, p. 67).

Sea otters historical range includes coastal habitats from Hokkaido, Japan to Baja California, Mexico (Kenyon 1969 pp. 133-135). The northern limit of NSOs was likely the maximum southern extent of ice in the Bering Sea (Kenyon 1969, p. 135; Schneider and Faro 1975, p. 91; Jameson et al. 1982, p. 104).

Although sea otters were once widely distributed, commercial harvest led to widespread declines. By 1911 when the North Pacific Fur Seal Treaty was signed, sea otters had been reduced to 13 isolated populations ranging from Japan to Mexico (Kenyon 1969, p. 134). Sea otters gradually expanded their range thereafter, and active reintroduction programs were implemented in southeast Alaska, British Columbia, and Washington State (Jameson et al. 1982 p. 100). The combination of translocations and lack of historical specimens have complicated delineation of the boundary between the northern and southern sub-species (Bodkin 2015, p. 52; Jameson et al. 1982, p. 100; Wilson et al. 1991, p. 22).

The current range of the NSO mirrors the presumed historical range, but there are areas within the historical range that do not currently have sea otters (Bodkin 2015, p. 45). Translocations in the 1960s and 1970s restored NSOs to several unoccupied areas, but not all efforts were successful (Jameson et al. 1982, p. 100). The MMPA afforded sea otters additional protection. Under the MMPA the Service identified three NSO stocks based on distribution, phenotypes, and genotypes for assessment and management purposes (Gorbics and Bodkin 2001, p. 632). These stocks include the southcentral, southeast, and southwest stocks (Fig. 2.2).

Following protection and reintroduction, NSOs were rebounding in southcentral and southwest Alaska. However, a precipitous decline in sea otters in the Aleutian archipelago in the 1990s (Doroff et al. 2003, p. 60; Burn and Doroff 2005, p. 274) prompted the Service to list the SW NSO as threatened under the ESA (70 FR 46366).

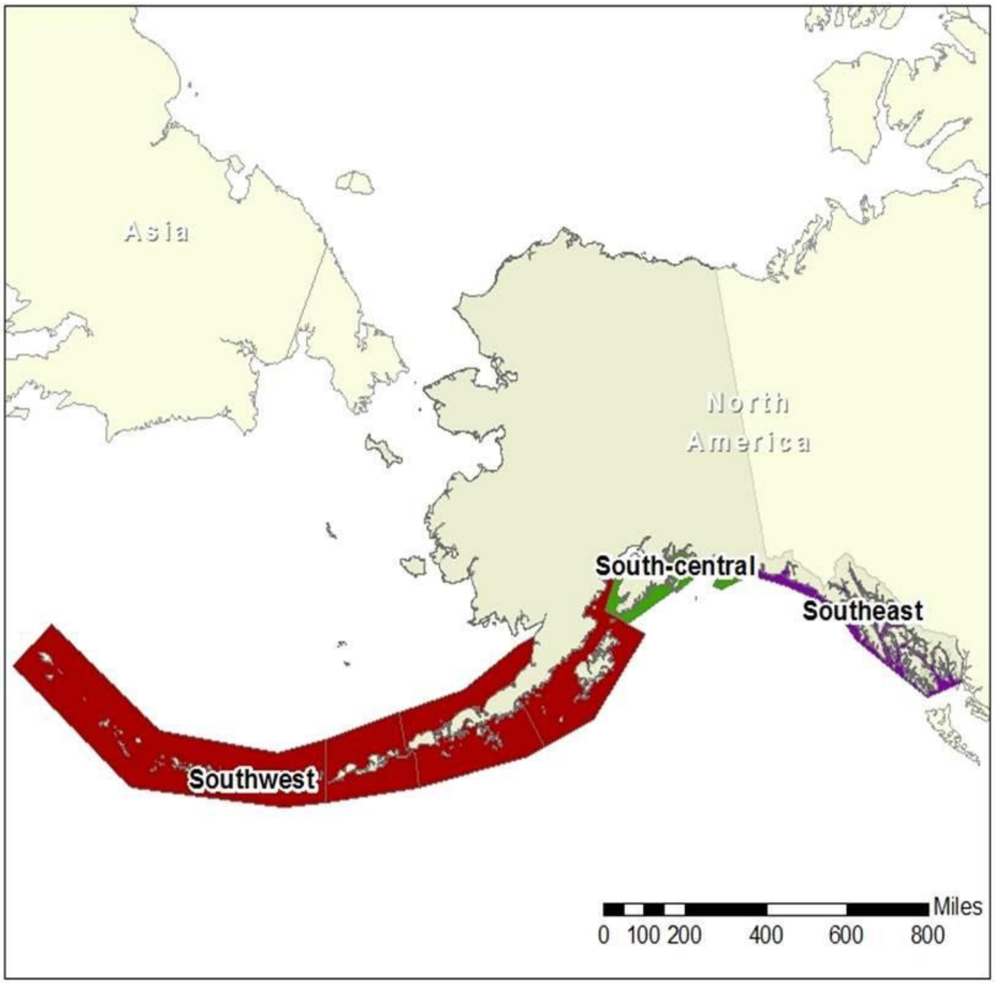

Figure 2.2 The three northern sea otter stocks in Alaska.

The southeast stock boundaries include Dixon Entrance to the south and Cape Yakataga to the north. NSOs currently do not extend to Dixon Entrance and there are large areas north of Glacier Bay with few or no NSOs. NSOs in southeast Alaska are most abundant in the north and expanding to the south and east (Tinker et al. 2019, p. 1083).

The southcentral stock occurs in the center of the NSO range in Alaska and extends from Cape Yakataga in the east to Cook Inlet in the west; including Prince William Sound (PWS), the eastern Kenai Peninsula coast, and Kachemak Bay (Service 2014a, p. 3). Several subpopulations occur within this area and sizes can vary 11-fold (Service 2014a, p. 5). Their distribution in Cook Inlet appears to be limited to the north by the formation of sea ice.

The SW NSO stock occurs from western Cook Inlet to Attu Island in the Aleutian chain (Fig. 2.3). NSOs were introduced to St. George Island in 1968, but did not establish a reproducing population (Jameson et al. 1982, pp. 102, 104; Bodkin 2015, p. 45). This SSA report will focus on the SW NSO.

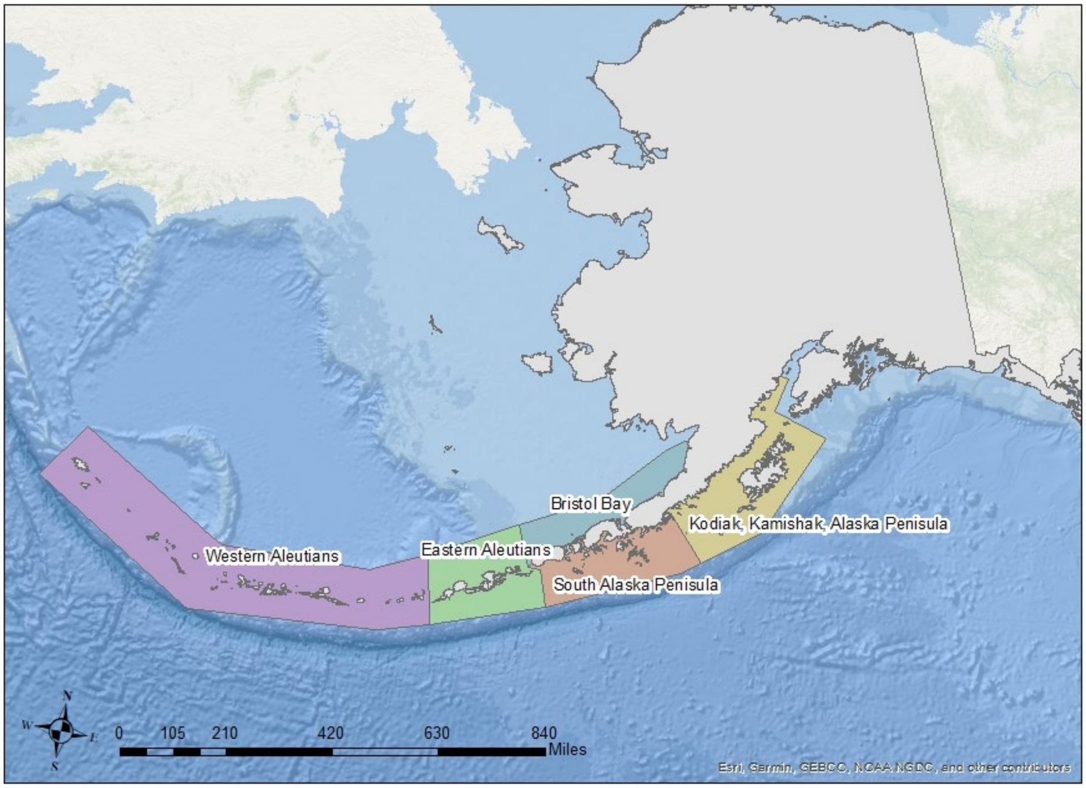

Figure 2.3 The SW NSO broken up into five different management units.

The SW NSO was listed as threatened under the ESA in 2005 as a DPS (70 FR 43666). The SW NSO inhabits a vast region (2,500 kilometers (km)) therefore it was divided into five management units (MU): Western Aleutians; Eastern Aleutians; South Alaska Peninsula; Bristol Bay; and Kodiak, Kamishak, and Alaska Peninsula (Service 2013a, p. iii). Flannery et al. (in review) recently evaluated the population genetics structure across these MUs and found that they were relatively consistent with the current MU boundaries with some gene exchange between the southcentral and SW stock in and around Kodiak Island and Cook Inlet. Critical habitat was designated for all five management units in 2009 (74 FR 51988).

Table 2.1 Geographic descriptions for each of the five SW NSO management units.

Management Unit	Geographic Description
Kodiak, Kamishak, Alaska Peninsula	Western Cook Inlet to Castle Cape on the south side of the Alaska Peninsula and Kodiak Island
South Alaska Peninsula	Castle Cape to the southwestern tip of Unimak Island
Bristol Bay	Cape Chichagof on the north side of the Alaska Peninsula to the northwestern tip of Unimak Island
Eastern Aleutians	Unimak Pass to Samalga Pass
Western Aleutians	Islands of the Four Mountains to Attu Island

2.3 **Life History**

Sea otters become sexually mature at 2-4 years of age (Kenyon 1969, p. 242; Bodkin et al. 1993, p. 1812). The percentage of females that produce a pup each year is age-dependent. In Kodiak sea otter reproductive rates ranged from 0.17 for 2-year old females to 1.0 for 5-year old females (Monson et al. 1995, p. 1164). The reproductive rate for sexually mature females in Kodiak that had previously produced a pup was 0.94 (Monson et al. 1995, p. 1164). Sea otter reproductive rates are generally considered to be at least 0.80 for females 4 years and older (Jameson and Johnson 1993, p. 164). Reproductive females can come into estrous immediately after the death, weaning, separation, or abandonment of a pup (Monson et al. 2000, p. 461). The length of time between mating and implantation is variable (Sinha et al. 1966, p. 128). The interval between mating and birth, inclusive of delayed implantation, is approximately six months, followed by a six-month period of dependence (Jameson and Johnson 1993, p. 164). Females give birth year-round (Kenyon 1969, p. 214; Bodkin et al. 1993, p. 1813; Monson and DeGange 1995, p. 1165; Tinker 2015, p. 277). Peaks in parturition in Alaska populations are related to food limitations and therefore depend on population status (Monson et al. 2000, p. 464). Peaks in parturition have been observed in April or May through August for populations near carrying capacity (Garshelis et al. 1984, p. 2649; Kenyon 1969, p. 239). Sea otters give birth to single pups, although twinning can occur very rarely (Williams et al. 1980 p. 575). Sea otter mortality is highest within the first month after birth and within the first six months post-weaning. (Johnson and Mayer 2015, p. 239). The probability of survival increases approximately six months post-weaning when they are reaching one year of age (Larson et al. 2015, p. 29).

Survival rates for sea otters are age- and sex-dependent and vary as a function of population density and prey availability (Ballachey et al. 2003, pp. 1501-1504; Monson et al. 2000, p. 464). Estimated survival rates for pups through the first year of life ranged from a low of 18 percent in Amchitka Island when the island was near equilibrium density prior (Monson et al. 2000, p. 465) to a high of 86 percent in Prince William Sound, where food was not limiting and the population was increasing (Ballachey et al. 2003, p. 1498). Survival of sea otters more than 2 years of age is generally high, approaching or exceeding 90 percent, but gradually declines over time (Monson et al. 2000, p. 464). Maximum ages achieved by sea otters outside captivity are approximately 22 years for females and 15 years for males. The average generation time of sea otters is 7.9 years (Gagne et al. 2018, p. 1787).

2.4 **Behavior**

Sea otters spend most of their time feeding and resting (Bodkin et al. 2007, pp. 2038-2039; Dean et al. 2002, p. 265; Esslinger et al. 2014, pp. 693-694; Yeates et al. 2007, p. 1961). Feeding behavior typically consists of a dive to the seabed to search for prey, capturing prey, and bringing it to the surface where the otter floats on its back while dismembering and consuming the prey item(s). Feeding dives presumably repeat until a sea otter is sated or needs to rest. The time a sea otter spends feeding is an inverse relationship to prey availability (Monson and Bowen 2015, p. 127). Sea otter foraging rates also differ by sex, season, and reproductive status, including whether a female has a dependent pup (Cortez et al. 2016, p. 6; Esslinger et al. 2014, pp. 695-696).

In general, NSOs rest in the water, floating on their backs (Kenyon 1969, p. 61), where they may use strands of canopy-forming kelp as anchors. NSOs also commonly rest on land and sea ice in Alaska. They spend approximately 10-30 percent of their time traveling, interacting with other individuals, and grooming their pelage to maintain its insulating properties (Bodkin et al. 2007, p. 2038).

NSOs segregate into groups by sex for most of the year with distinct male and female areas (Kenyon 1969, pp. 59-104; Schneider 1977, p. 14; Garshelis et al. 1984, p. 2648). Males often form territories within female areas where they may reside year-round, or they move back and forth between their territory and the male areas (Garshelis et al. 1984, p. 2651). Groups range in size from singles to hundreds of animals and group size is positively correlated with population density (Garshelis et al. 1984, pp. 2655-2656). Smaller groups of 10-50 are predominant. Male groups are usually the largest (Garshelis et al. 1984, p. 2655) and generally consist of adult and subadult males. Movement of individual males among male groups is frequent (Garshelis et al. 1984, p. 2654). Female groups are composed of adult females, dependent pups, and subadult females. Garshelis et al. (1984, p. 2657) listed dominance establishment, mating efficiency, foraging efficiency, predator avoidance, information sharing, and limited resting areas as factors affecting grouping behavior in NSOs.

Females do not compete for mates (Garshelis et al. 1984, p. 2656). Females, particularly with pups, avoid male areas due to aggressive sexual advances and food stealing (Garshelis et al. 1984, p. 2655). Breeding females often exhibit nose wounds from males biting the female's muzzle during copulation (Murray 2015, p. 181). Aggression in the form of fights and mock copulation among males can also occur as new members join a group (Garshelis et al. 1984, p. 2656).

2.5 **Resource Needs**

2.5.1 *Individual Needs*

The SW NSO habitat is remote and nearly pristine, with little obvious anthropogenic degradation (Ballachey and Bodkin 2015, p. 82). The resident human population generally is localized around small towns and villages creating a relatively small footprint in which to affect sea otters. SW NSOs do not occur near the city of Anchorage in upper Cook Inlet of southcentral Alaska (Garlich-Miller et al. 2018, pp. 4, 6).

NSOs generally occur in waters ≤ 40 m deep and within 1-3 km of the shore (Riedman and Estes 1990, pp. 22, 31, 55; Bodkin et al. 2004, p. 305; Bodkin 2015, p. 44). However, surveys in Bristol Bay have documented sea otters resting as far as 50 km offshore in water as deep as 82 m (Brueggeman et al. 1988, p. 4-12, Beatty et al. in review), and large numbers of NSOs may use shallow water shoals > 10 km offshore (Kenyon 1969, p. 66). The seabed and intertidal substrates range from soft mud/sand to hard rock (Kenyon 1969, p. 57; Estes 2015, p. 23). Areas of kelp forest, seagrass beds, and barrens are used. Habitat use is largely a function of prey abundance, foraging energetics, and predation pressure in some areas (Kenyon 1969, p. 57; Monson et al. 2000, p. 458; Tinker et al. 2008, p. 560).

Haulout areas

NSOs haulout of the water onto land (Kenyon 1969, p. 59), exposed bars, and rocks at low tides (Garshelis and Garshelis 1984, p. 672). Coastal haulouts are likely used primarily for resting (Kenyon 1969, p. 59) and perhaps escaping marine predators and protection during large storms (Garshelis and Garshelis 1984, p. 672). Use of coastal habitats may be opportunistic and driven mostly by proximity to feeding areas.

Benthic invertebrate prey

The primary prey of NSOs is clams, sea urchins, crabs, and other slow moving or non-motile benthic invertebrates (Estes 2015, p. 23), though use of over 150 species has been documented. Prey switching is common as they tend to specialize on preferred foods until those species are depleted and then feed on more abundant but less preferred species (Monson and Bowen 2015, p. 144). Sea otters will also take advantage of periodically abundant prey (Watt et al. 2000, p. 290). Due to their high metabolic rates and limited ability to store energy, NSOs consume on average 20-30 percent of their body weight in prey each day, depending on life stage (Kenyon 1969, p 126; Costa and Kooyman 1984, p. 203; Yeates et al. 2007, p. 1960). To meet this demand, sea otters need to spend 20-50 percent of the day foraging (Tinker 2004, p. 88).

Coastal marine waters <40 m in depth

Sea otters use a variety of coastal marine habitats, the usable depths of which are limited by their dive capacity. Most feeding dives occur in waters less than 40 m in depth (Riedman and Estes 1990, p. 22), but can occur at up to 100 m (Bodkin et al. 2004, p. 313). Males tend to make deeper dives than females (Bodkin et al. 2004, p. 312). When accompanied by a pup, adult females tend to be limited to shallower waters within the diving range of dependent pups.

Canopy-forming kelp

Kelp canopy is important resting habitat on the outer coast because it reduces tidal energy and provides a means of anchoring, removing the need for repeated repositioning when sea otters are resting. It can also serve as nursery habitat for adult females and their pups (Riedman and Estes 1990, p. 68). Kelp cover provides protection from some marine predators (Nicholson et al. 2018, p. 1757). Kelp forests also provide food and habitat for many prey species. Although kelp canopy is important, it is not essential to sea otters.

2.5.2 *Species Needs*

Representation is the ability of a species to adapt to changing environmental conditions, and redundancy spreads risk among multiple populations or areas to minimize the risk due to largescale, high-impact (i.e., catastrophic) events (Smith et al. 2018, p. 306). Gaining a better understanding of representation and redundancy for the SW NSO will help characterize the viability of the species. We define viability as the ability of the SW NSO to sustain populations over time.

One measure of representation is genetic diversity, and maintaining adequate genetic diversity is a concern for sea otters. The commercial harvest of NSOs in Alaska peaked at the turn of the 19th century when nearly 15,000 otters were being harvested per year (Larson et al. 2015, p. 45). The extirpation throughout much of their historic range created a genetic bottleneck resulting in a loss of over half their original genetic diversity (Larson et al. 2002, p. 1902). With these declines in NSO populations, translocation efforts to restore populations began in 1951. A second bottleneck is possible in some translocated populations in which only a few otters survive and remain to found the new population (Larson et al. 2015, p. 10). The effect of the reduced genetic variation on the SW NSO stock is uncertain. However, low population size, slow growth, and limited movements increase the probability of additional population reductions due to stochastic events. These declines could further reduce genetic diversity and increase SW NSO vulnerability (Larson et al. 2015, p. 10).

2.5.3 *Uncertainty*

Although much of the SW NSOs needs are understood and have been thoroughly studied, we lack a complete understanding of their habitat needs. We know SW NSOs utilize kelp beds. However, sea otters are found in areas without kelp present and the effects of this on those local populations is unknown. Information on kelp diversity, density, and coverage as well as prey diversity, density, and size is unknown across the SW NSO range. This information can have direct effects on the SW NSO's density and distribution.

Dispersal is an important ecological process that directly impacts the ability of NSOs to colonize or re-colonize suitable habitat (Bowler and Benton 2005, p. 216). Dispersal can be described as three independent process that have different ecological and environmental drivers (Bowler and

Benton 2005, p. 205). First, an animal must emigrate from its current patch. Proximate cues for an animal to initiate emigration could include high conspecific density, limited food resources, negative interspecific interactions, and an unfavorable sex ratio (Bowler and Benton 2005, p. 209). Second, an animal must transit unsuitable habitat, which could lead to an increased risk of mortality from predation, starvation, malnutrition, or extreme environmental conditions (Bowler and Benton 2005, p. 212). Finally, a dispersing animal must select a patch to immigrate to based on habitat and patch characteristics. Broadly, sea otter dispersal ecology is a key uncertainty (Davis et al. 2019, p. 2) and could play an important role in the observed spatial and temporal population trends in SW NSOs.

3 FACTORS INFLUENCING THE SPECIES

In this chapter, we evaluate past, current, and potential future factors that are affecting or could affect the current and future condition of the SW NSOs throughout all or some of its range. At the time of listing, recognized threats to the SW NSO included: habitat loss, oil spills, prey availability, subsistence harvest, infectious disease, predation, fishery bycatch, illegal take, disturbance, biotoxins, point-source contaminants, and non-point-source contaminants. We evaluated those threats and several additional threats related to coastal development, aircraft and vessel traffic, and climate change, including rising sea surface temperatures, increased ocean acidification, and increased frequency of storms.

3.1 **Effects of Climate Change**

3.1.1 *Ocean Warming*

Sea surface temperatures (SST) have been increasing around the world for several decades (IPCC 2013, p. 192), including the northeast Pacific Ocean and the southeast Bering Sea (IPCC 2013, p. 235). Regional variability is large (Bograd et al. 2005, p. 241) and coarse scale trends may be representative of trends in smaller areas in the narrow, near shore environment of SW NSOs.

Bograd et al. (2005, p. 241) analyzed SST records for the Gulf of Alaska from 1950-1997 and noted an overall increase from 1970-1997 across the region. They also identified five geographical clusters in the region with different temperature profiles (Bograd et al. 2005, p. 246), one of which intersects the nearshore areas of the eastern Bering Sea used by SW NSOs. The eastern Bering Sea had the lowest SST (≈5-7.3° C) during that time.

Although the analysis of Singh et al. (2013, p. 233) was focused on the Arctic, their maps of SST anomalies include the eastern Bering Sea and northern Gulf of Alaska. Those maps (Singh et al. 2013, pp. 235-236) indicate year to year variation of about 1.3° C from 1982-2010. Annual trends indicate cooling (-0.02 to -0.05° C) in these areas during that period, with average temperatures of 4-6° C (Singh et al. 2013, p. 237). The cooling of the Bering Sea during that time was also documented (Stabeno et al. 2012, p. 24).

In 2013 a large mass of warm water (2-4° C above normal, termed the "Blob") caused by a persistent ridge of high pressure formed in the Gulf of Alaska and the Bering Sea (NASA 2018, p. 1). The impacts of the Blob were evident after it dissipated in 2016. The region experienced shifts in fish distribution, evidence of starving marine mammals and sea birds, harmful algal blooms, and anomalous weather in the western United States. We know of no reports directly linking the Blob to any SW NSO anomalies or mortalities. However, there was a spike in mortalities related to viral and bacterial infections in SW NSO in 2015 from Kodiak to Dutch Harbor (see section 3.10), coincident with above normal SSTs. Another warm water anomaly appeared in the north Pacific in 2019 and continues to be monitored (NASA 2019, p. 1).

We did not find any studies directly linking SW NSO condition or mortality to increased SSTs. Recommended water temperatures for captive sea otters include a range of 7.0-15.5° C (PGAV 2013, p. 3). Jessup et al. (2012, pp. 9-10) experimented with several water temperatures associated with washing oiled sea otters (10.0-37.8° C) where the primary concern was maintaining their core body temperature. After cleaning, sea otters were held in recovery pools at temperatures that ranged from 10-20.6° C. These temperatures are generally higher than reported SSTs within the range of SW NSOs, suggesting that observed ocean warming is not exceeding their thermal tolerance. Thus, it appears unlikely that SW NSOs have experienced direct detrimental effects due to increases in SSTs.

Maldini et al. (2012, p. 67) suggested that southern sea otter hauling out patterns were related to periods of lower air and water temperature as a mechanism to maintain thermoneutrality when prey was limited and energy intake was inadequate. This observation suggests that an increase in SST within a certain range could benefit sea otters by reducing the energy needed to maintain thermal balance.

Potential indirect effects of increasing SSTs on SW NSOs are not well documented. Warmer waters promote the bloom of harmful algae (Gobler et al. 2017, p. 4975) that contain the biotoxins saxitoxin and domoic acid (see section 3.6.4), which can concentrate in NSO prey. In addition, warmer waters are thought to promote the spread and abundance of pathogens that may infect NSOs (see section 3.5.1). Additionally, changes in the distribution and abundance of temperate and subarctic prey are expected to occur (Kordas et al. 2011, p. 218). Details are described in *3.1.4 Benthic Prey Community*.

3.1.2 *Ocean Acidification*

Over the industrial era, the ocean has been a sink for anthropogenic carbon dioxide, absorbing about one-third of the atmospheric carbon dioxide (Feely et al. 2004, p. 362; Canadell et al. 2007, pp. 18867-18868). When carbon dioxide is absorbed by seawater, chemical reactions occur that reduce seawater pH and the concentration of carbonate ions, in a process known as ocean acidification (OA). The pH of ocean surface waters has decreased by about 0.1 units since the beginning of the industrial revolution (Caldeira and Wickett 2003, p. 365; Orr et al. 2005, p. 681; NOAA 2016, p. 1).

Studies of invertebrates and fish show that OA can alter sensory abilities and behavior, affecting feeding, burrowing, dispersal (Clements et al. 2016, pp. 103-108), and antipredator defenses (Simpson et al. 2011, p. 917; Ferrari et al. 2012, p. 553; Pistevos et al. 2015, p. 1). Similar behavioral studies on marine mammals are lacking. Sea otters may experience indirect effects of OA through changes in the benthic prey community. Details are provided in *3.1.4 Benthic Prey Community*.

3.1.3 *Primary Production*

The range of the SW NSOs covers two large marine ecosystems (LME), the eastern Bering Sea and the northern Gulf of Alaska, which are described as being moderately to highly productive (NOAA 2018a, p. 1). The National Oceanic and Atmospheric Administration (NOAA) publishes annual ecosystem status reports for each area, which are intended to provide information to the North Pacific Fishery Management Council for commercial fisheries management (NOAA 2018b, p. 1). These reports include information on ecosystem conditions relevant to SW NSOs.

Several Continuous Plankton Recorders were deployed in various areas in the Gulf of Alaska (GOA), Aleutian Islands, and eastern Bering Sea by NOAA in 1997 (NOAA 2018c, p. 1). The associated databases contain a number of primary productivity estimates such as chlorophyll and phytoplankton measures that cover the period from 1997-2017. The most consistent measurements that span the entire period of operation include two measures on surface chlorophyll (NASA-combo and OCCCI-v3.1 satellite chlorophyll [mg/m^3]) at all stations. The trend in chlorophyll estimates from 1997-2017 was either flat or increasing for all stations and metrics (NOAA 2018c, p. 1).

Macroalgae (kelps and other seaweeds) and vascular plants (eelgrass) can represent a large portion of the primary productivity in the nearshore environment. NSOs can occur at high densities in macroalgae, particularly in kelp forests. However, the world's kelp forests have declined by 38 percent over the past 50 years (Krumhansl et al. 2016, p. 13785). Available data from the Aleutian Islands (1993 - 2002) indicates kelp forests are in decline coinciding with an increase in sea urchins and decrease in sea otters (Krumhansl et al. 2016, p. 13786; Estes et al. 1998, p. 474). Coralline algae (*Clathromorphum nereostratum*), which forms the foundation for kelps, are also in decline due to a combination of overgrazing by sea urchins, ocean acidification, and warming ocean waters (Rasher et al. 2020, p. 1353). There is substantial variation in the magnitude and direction of kelp forest change, depending on the interaction among local, regional, and global processes (Krumhansl et al. 2016, p. 13786). In some regions, kelp forests have been replaced by mats of low-lying algae (Filbee-Dexter and Wernberg 2018, p. 2), which removes much of the structure that promotes biological diversity in kelp forests. Much of these global losses of kelp forests have been linked at least partially to increasing temperature (Filbee-Dexter and Wernberg 2018, p. 8).

Sea otters also occupy seagrass meadows and have been shown to promote sea grass health and productivity (Hughes et al. 2013, p. 15316). However, seagrass meadows have been in global decline for the past 100 years in both low and high latitudes (Waycott et al. 2009, p. 12377). These declines have been attributed to climate change, invasive species, overexploitation, human modification, and nutrient and sediment loading (Waycott et al. 2009, p. 12379). The impact of OA has been shown to increase photosynthesis rates in some taxa whereas others have shown little response to changes in pH (Kroeker et al. 2013, p. 1888). The impact of climate change and OA on seagrass meadows in Alaska's southwest region has not been the focus of extensive research. However, repeat surveys in Izembek Lagoon indicate seagrass stands have remained stable over the past 9 years (Ward and Amundson 2018, p. 7).

3.1.4 *Benthic Prey Community*

Benthic productivity in the eastern Bering Sea in 2019 was above the long-term mean, but was 10 percent lower than in 2018 (Siddon and Zador 2019, p.1). The mass of motile benthic epifanua was above the long-term average, including urchins (*Echinoidea spp.*), brittle stars (*Ophiuroidea spp.*), and cucumbers (*Holothuroidea spp.*). However, king (*Lithodidae spp.*) and tanner (*Chionoecetes bairdi*) crabs decreased. SW NSOs primarily prey on hard-shelled invertebrates, including sea urchins (*e.g. Strongylocentrotus droebachiensis*), abalone and other marine snails (e.g., *Haliotis kamtschatkana)*, crabs (e.g. *Telmessus spp*.), mussels (*Mytilus spp*.), and clams (e.g. *Saxidomus spp*.). Changes in carbon dioxide concentrations and pH can affect reproduction, larval development, growth, behavior, and survival of calcifying marine organisms (Green et al. 1998, p. 23; Kurihara and Shirayama 2004, pp.163-165; Berge et al. 2006, p. 685; Fabry et al. 2008, pp. 420-422; Kurihara 2008, pp. 277-282; Pörtner 2008, pp. 209-211; Ellis et al. 2009, pp. 44-45; Talmage and Gobler 2009, p. 2076; Findlay et al. 2010, pp. 680-681; Kroeker et al. 2010, p. 1419; Kroeker et al. 2013, p. 1; Kroeker et al. 2016, p. 771). Pörtner (2008, p. 211) suggested that heavily calcified marine groups may be among those with the poorest capacity to regulate acid-base status. Although some animals have been shown to be able to form a shell in undersaturated conditions, it comes at an energetic cost which may translate to reduced growth rates (Talmage and Gobler 2009, p. 2075; Findlay et al. 2010, p. 679; Gazeau et al. 2010, p. 2938; Waldbusser et al. 2015, p. 273), muscle wastage (Pörtner 2008, p. 210), or potentially reduced reproductive output. If aragonite undersaturation inhibits planktonic larval bivalves from constructing shells (Kurihara 2008, p. 277; Waldbusser et al. 2015, p. 273) or inhibits them from settling (Hunt and Scheibling 1997, p. 274; Green et al. 1998, p. 26; Green et al. 2004, p. 730; Kurihara 2008, p. 278), the increased mortality would likely have a negative effect on bivalve populations, which is a large portion of the SW NSO prey.

Although a number of organisms appear to be able to adapt over the long-term or are resistant to declining pH levels (Lohbeck et al. 2012, p. 346; Parker et al. 2012, p. 92; Jin et al. 2013, p. 1; Pespeni et al. 2013, p. 1; Schluter et al. 2014, p. 1024; Kroeker et al. 2016, p. 777; Ramajo et al. 2016, p. 19374; Ventura et al. 2016, p. 23728), this often comes at the expense of other processes such as growth or reproduction (Gazeau et al. 2010, p. 2060; Small et al. 2010, p. 11; Winans and Purcell 2010, p. 39; Fitzer et al. 2014, p. 6218). Aragonite undersaturation has already been observed to occur seasonally and locally in many areas including the Chukchi Sea (Bates and Mathis 2009, p. 2441; Yamamoto-Kawai et al. 2016, p. 1) and the Bering Sea (Fabry et al. 2009, p. 164).

Four meta-analyses of OA research on calcifying organisms have been conducted (Hendriks et al. 2010, p. 157; Kroeker et al. 2010, p. 1419; Harvey et al. 2013, p. 1016; Kroeker et al. 2013, p. 1884). Kroeker et al. (2013, p. 1884) conducted the most comprehensive meta-analysis, examining 288 papers. Their conclusions were: (1) when pooled across species, survival, calcification, growth, development, and abundance declined, however, the magnitude of decline varies among species, (2) mollusk larvae were most sensitive, (3) the variability increases with multi-species assemblages, (4) nutritional status or source population cause substantial variation in responses, and (5) there was a trend towards enhanced sensitivity when taxa are also exposed to elevated temperatures.

In general, most OA studies indicate that the early life stages of bivalves and gastropods, particularly broadcast spawners with an extended pelagic larval phase, are most susceptible to the negative impacts of OA. However, individuals and populations that are periodically exposed to acidified conditions either daily or seasonally (e.g. tidal, upwelling, deep sea, and high latitude areas) may be more tolerant. In addition, increased primary productivity may give some species the extra energy needed to balance the costs of compensating for altered acid-base metabolism, shell formation, and shell protection/repair.

3.1.5 *Extreme Weather*

Extreme weather events, including storm intensity and precipitation rates, have increased with a warming climate. These extreme weather events could directly affect SW NSOs through increased mortality rates and indirectly affect habitat modification. For example, increased frequency of intense winter storms may reduce cover of surface forming kelps (Nicholson et al. 2018, p. 1758), which can potentially increase sea otter risk of predation (Nicholson et al. 2018, p. 1760). The loss of kelp habitat can also alter the prey community available to SW NSOs (Estes and Palmisano 1974, p. 1058). Decreased foraging opportunities can reduce energy intake, which can lead to sea otters shifting to new habitats and potentially abandonment of pups (Chinn et al. 2018, p. 8435). Newsome et al. (2015, p. 57) noted that local depletion in preferred prey results in diversification of prey sources and may not result in population level impacts. However, the combined impact of habitat loss and prey loss could have detrimental population effects.

3.2 **Habitat Modification**

Developments that physically modify sea otter habitat are mostly limited to nearshore waters immediately adjacent to towns, villages, and military bases, and are usually in the form of docks, piers, and boat harbors, as well as oil and gas drilling platforms. Many of these areas occur near towns such as Unalaska in the Aleutian Islands and Kodiak. However, much of the shoreline remains relatively free of such development as the shorelines are within federal and state refuges, parks, preserves and sanctuaries.

3.2.1 *Coastal Development*

While much of the Alaskan coastline in the range of SW NSOs is undeveloped, coastal development in SW NSO habitat ranges from busy commercial and industrial centers like the City of Kodiak and Unalaska, to small, isolated, residential boat docks. Developments that have potential to affect SW NSOs include aquaculture facilities, fish processing centers, and construction activities associated with port facilities (pile driving, dredging, placement of fill and riprap, jetty construction). Infrastructure for oil and gas exploration and development may also be located along the coast or in offshore areas inhabited by SW NSOs. The primary concern associated with construction activities is the in-water and airborne noise levels these activities generate that can compromise sea otter hearing or temporarily displace sea otters from important areas. Monitoring and mitigation procedures exist that allow development activities to protect SW NSOs. With mitigation procedures implemented, displacement of SW NSOs from most coastal construction is likely temporary.

3.2.2 *Commercial Activities*

Oil and gas activities involve exploration, development, production, and transportation. These types of activities typically include seismic surveys, production drilling from existing oil and gas facilities, geophysical and geohazard surveys, drilling exploration wells, dock construction, and decommissioning of facilities. Support activities include pile driving, dredging, trenching, fill placement, anchor handling, and transport by vessel and aircraft. The activities that have the most potential to adversely impact SW NSOs (directly or indirectly) are seismic surveys and dredging.

Open-water seismic exploration, which produces underwater sounds typically with air gun arrays, may affect SW NSOs. Sea otters can detect air-born sounds in the range of 0.2 to 40 kHz and are most sensitive at 2-16 kHz (Ghoul and Reichmuth 2012, p. 2008). Their underwater hearing sensitivity is not as great as some pinnipeds, particularly below 1 kHz (Ghoul and Reichmuth 2013, p. 78) and sea otters are primarily adapted to hearing airborne sounds (Ghoul and Reichmuth 2014, p. 967). There is no indication that sea otters use underwater vocalization to communicate. Effects of seismic surveys on hearing and communications is not completely understood. However, seismic surveys could result in SW NSOs avoiding areas of activity, and permanent or temporary hearing impairment (Delarue et al. 2012, p. 109; Hermannsen et al. 2015, p. 1).

Injury from seismic surveys likely would occur only if animals entered the zone immediately surrounding the sound source (Southall et al. 2007, p. 441) or were in the area when surveys started if ramp-up procedures (gradually increasing decibel levels) were not implemented. Although seismic survey vessels are transitory, sea otters likely exhibit behavioral responses to the passage of the vessels, which may result in energetic costs if they are displaced from foraging habitat (Ireland et al. 2009, pp. xiii-xvi; Service 2013b, p. 35392). Future research is needed to determine whether vessel traffic has long-term, detrimental effects on individual sea otters.

Unlike seismic surveys, effects of dredging are most likely to be expressed as changes to macroinvertebrate prey. Benthic prey tend to be relatively immobile and can be affected by sediment in the water column and direct burial at disposal sites. In a study performed by Van Dolah et al. (1984, p. 30), adverse effects from dredging appear to be influenced by the attributes of the dredged material, receiving habitat, and the community composition of the disposal site. Additionally, Angonesi et al. (2006, p. 419) suggests that macrobenthic communities can often adapt to sediment deposition at frequent disposal sites.

Additional impacts from oil and gas activities may include seafloor shading from docks affecting the amount of light penetration to the sea floor, localized seafloor disturbance from drilling, water quality impacts from drilling-related discharges, and temporary behavioral changes in invertebrates with the presence of increased sound levels from seismic surveys and pile-driving activities (Fewtrell and McCauley 2012, pp. 989-990). How the impacts from these activities to habitat and prey may affect SW NSOs at the stock level is unknown.

3.2.2.1 *Ongoing Oil and Gas Activities*

The Bureau of Ocean Energy Management (BOEM) completed a lease sale for the Cook Inlet area in 2017 (BOEM 2016, entire) and a number of seismic surveys and exploratory drilling activities were set to begin in 2019-2020 and have since occurred. There are additional areas considered for oil and gas activities, however it is not possible to predict the pace or success of development of either federal or state lease sales. The areas impacted by ongoing or proposed projects would likely only impact a limited area within the SW NSO range.

Oil and gas activities currently proposed for the Cook Inlet include work to support oil and gas exploration, development, production, transport, and decommissioning of existing facilities. These projects are proposed to occur between now and 2024. Hilcorp Alaska, LLC and Harvest Alaska, LLC jointly plan to conduct the following activities: two-dimensional (2-D) and three-dimensional (3-D) seismic surveys in Lower Cook Inlet; production drilling from, routine operation of, and maintenance of existing oil and gas facilities in middle Cook Inlet; redevelopment of an existing four exploration wells in the Outer Continental Shelf waters of LCI and one to three wells in middle Cook Inlet; construction of a dock facility in Chinitna Bay; and decommissioning of an existing facility at the Drift River Terminal in Cook Inlet. Support activities include pipe and pile driving, vertical seismic profiling, and use of a water jet for pipeline and platform maintenance. Most of these proposed activities lie outside of the southwestern stock boundary, however some activities, such as 3-D seismic, possible exploratory wells, and support activities, may lie just within the eastern extent of the southwestern stock distribution and surrounding areas will likely experience increased vessel traffic due to project activities outside the stock boundary.

3.2.3 *Ship and Air Traffic*

A common source of disturbance for SW NSOs is vessel and air traffic. Commercial shipping and marine transportation vessels include oil and gas tankers, container ships, cargo ships, cruise ships, research vessels, icebreakers, and commercial fishing vessels. These vessels may travel to or from destinations within the range of the SW NSO (destination traffic) or may use the area as a passageway between distant ports (non-destination traffic).

Available information suggests that routine commercial shipping occurring within the range of the SW NSOs is currently limited in intensity and extent, but has increased since 2010. Due to their near-shore habitat use, interactions between SW NSOs and large vessels are few. However, small spills of fuel and other contaminants associated with vessel traffic seem to be increasing (Service 2016a, unpublished data) and have the potential to affect a small number of SW NSOs in localized areas (see section 3.3 Oil Spills).

Boat strikes of NSOs have been documented as a cause of mortality across Alaska. From 1996-2019, 1,474 necropsies were conducted by the Service. Of these, boat strike or blunt trauma were identified as a definitive or presumptive cause of death in 65 cases (approximately 4 percent of mortalities). However, contributing factors such as disease or biotoxin exposure may have incapacitated the animal prior to boat strike (Service 2014c, p. 16). At least two cases in November 2009 in which sea otters were stuck and killed in Kodiak Harbor, suggest saxitoxin intoxication. The SW NSOs were lethargic and non-reactive at the surface of the water prior to being hit, and subsequent screening of their urine revealed high concentrations of saxitoxin (Lefebvre et al. 2016, p. 21). However, the way concentrations of toxins relate to clinical signs of toxicity is not well understood. Because NSOs spend a considerable portion of their time at the surface of the water, they are typically visually aware of approaching boats and are able to move away. Most collision reports have come from small, fast moving vessels (NMFS 2003, unpublished data), and it has been observed that the probability of death or serious injury increases as vessel speed increases (Vanderlaan and Taggart 2007, p. 149). Given the small human population within the SW NSO range, it is unlikely that boat strikes are having a significant effect on SW NSO mortality at the stock level.

Research investigating the injury or disturbance threshold from airborne noise and aircraft size is limited. However, a review of literature by Southall et al. (2007, p. 441) suggests thresholds for permanent and temporary shift in hearing sensitivity for sea lions exposed to non-pulsed airborne noise of 172.5 and 159 dB re (20 µPa) 2-s SEL. The potential effects of prolonged or repeated disturbance from noise include displacement from preferred feeding areas, increased stress levels, increased energy expenditure, masking of communication, and the impairment of thermoregulation of neonates that have to spend too much time in the water. Although there is limited information regarding vessel disturbance impacts on sea otter females with pups, there is potential of pup abandonment. Abandonment would be most likely in cases where extended displacement from foraging areas resulted in reduced energy intake (Chinn et al. 2018, p. 8435).

The energetic impacts of such disturbance has the potential to be significant over long periods of time. The spatial extent of disturbance, however, is likely to be very localized and, thus, not a major concern at the stock level. Sea otters have the highest mass specific metabolic rate of any marine mammal (Yeates et al. 2007, p. 1967), and require a large amount of food to support the energetic demand. NSOs spend up to 45 percent of their time feeding, and most of the remaining time resting to reduce energetic costs (Yeates et al. 2007, p. 1963). With increased disturbance, there is the potential for decrease in time spent foraging, resting, and grooming. Barrett (2019, p. 22) found that the potential disturbance effect increased as the distance between the stimulus and the otter group decreased, with spikes in sea otter activity occurring with disturbances being 20 m or closer to the otter group. The source of disturbance used in this study was primarily kayakers, therefore distances may vary with larger sources of disturbance. With six disturbances at 20 m, the average net daily cost of metabolic expenditure was 210.1 kJ ± 80.76 (Barrett 2019, pp. 22-23). The daily prey consumption needed to account for the additional energetic costs for a typical male is roughly equivalent to an extra third of a Dungeness crab (*Metacarcinus magister*), 11 pacific littleneck clams (*Leukoma staminea*), or 20 snails (*Tegula montereyi*) representing <1 percent of the daily food requirement. This increased energetic cost seems insignificant on a daily basis; however, chronic disturbance would have significant impacts over long periods of time (Barrett 2019, pp. 26-28).

In addition to energetic costs of disturbance, there could also be spatial impacts. Over the past century, the spatial distributions of SW NSOs have varied on a seasonal, inter-annual and decadal scale, in response to variations in human hunting pressure, other anthropogenic disturbances, predation, and regional trends in prey abundance. The NSO's flexibility in spatial use patterns allows them to mitigate some impacts associated with environmental changes and stressors, however, SW NSOs small home ranges and sedentary nature limits their flexibility in that it may take many decades to colonize unoccupied habitats.

3.2.4 *Oil Spills*

Oil spills come from a variety of sources including boats, pipelines, platforms, mechanical equipment, and marinas. While large spills happen infrequently, small-scale spills (such as vessel spills) are more common (Fig. 3.1).

Although it is a rare event, a large-scale spill of crude oils, fuels, or other contaminants can have a significant and negative population-level impact. For example, in 1989, a large tanker grounded in northern Prince William Sound and released 260,000 barrels of crude oil contaminating at least 1990 km of shoreline, known as the *Exxon Valdez* oil spill (EVOS). When the EVOS occurred in Prince William Sound, Alaska, several thousand NSOs were killed despite rehabilitation efforts (Ballachey et al. 1994, p. 51). Additionally, in December of 2004 a 225 m (738 ft) freighter, the Selendang Ayu, ran aground and broke apart near Unalaska Island in the Eastern Aleutians. The rupture resulted in the release of about 350,000 gallons of oil and diesel, as well as 132 million pounds of soybeans (NOAA 2020d). At least two SW NSO were killed due to oiling from this event but the extent to which it effected SW NSO and their prey is unknown.

Short-term impacts of oil spills include impairment of thermoregulation and toxicity from the oil and its fumes (Rebar et al. 1995, p. 349). Long-term population impacts include chronic exposures of sediment-affiliated species (Dean et al. 2002, p. 268; Bodkin et al. 2012, pp. 279-281). NSOs that are not killed in the immediate aftermath of an oil spill, may experience adverse effects, including a compromised immune system, reduced growth, and a decrease in reproduction and survival rates (Peterson et al. 2003, pp. 2083-2084; Monson et al. 2000, pp. 6566-6567).

NSO are particularly vulnerable to oil contamination as their fur mats when it comes into contact with oil, which prevents the fur from properly insulating their bodies (Siniff et al. 1982, p. entire). They rely on their pelage for thermoregulation as they do not have a thick layer of blubber to protect them from the cold water (Bodkin et al. 2002, pp. 237-238). Compromising the thermoregulation of NSOs can quickly lead to hypothermia. In addition to hindering thermoregulation, the toxicity of the oil and its fumes can also be harmful to sea otters. Oil toxicity and the associated noxious fumes has been documented to cause brain lesions, disorientation, liver damage, kidney failure, and severe damage to their eyes and lungs (Peterson et al. 2003, p. 2082). These impacts can be seen from both large- and small-scale oil spills.

Suspension-feeding clams and mussels concentrate and slowly metabolize hydrocarbons. This contamination builds up in the tissues later consumed by NSOs (Jewett et al. 1999, pp. 71-72) which could lead to chronic exposure (Bodkin et al. 2002, p. 248). Sublethal doses have been shown to negatively affect the early stages of vertebrate development potentially increasing mortality and hindering reproduction through endocrine disruption and developmental abnormalities (Arkoosh and Collier 2002, p. 274). With EVOS there was a dramatic initial loss of macroalgae and gastropods, which resulted in algal blooms and increased barnacle densities. Without the algal canopy, associated invertebrates declined, inhibiting the recovery of the aquatic vegetation. With a loss of 50 percent of NSOs in western Prince William Sound after the EVOS, there was an increase in sea urchin size and density, which could potentially lead to overgrazing of kelp and macroalgae degrading the structural habitat of fishes and invertebrates (Bodkin et al. 2002, p. 249). The overall extent of impacts to SW NSOs depends on the size and location of the spill.

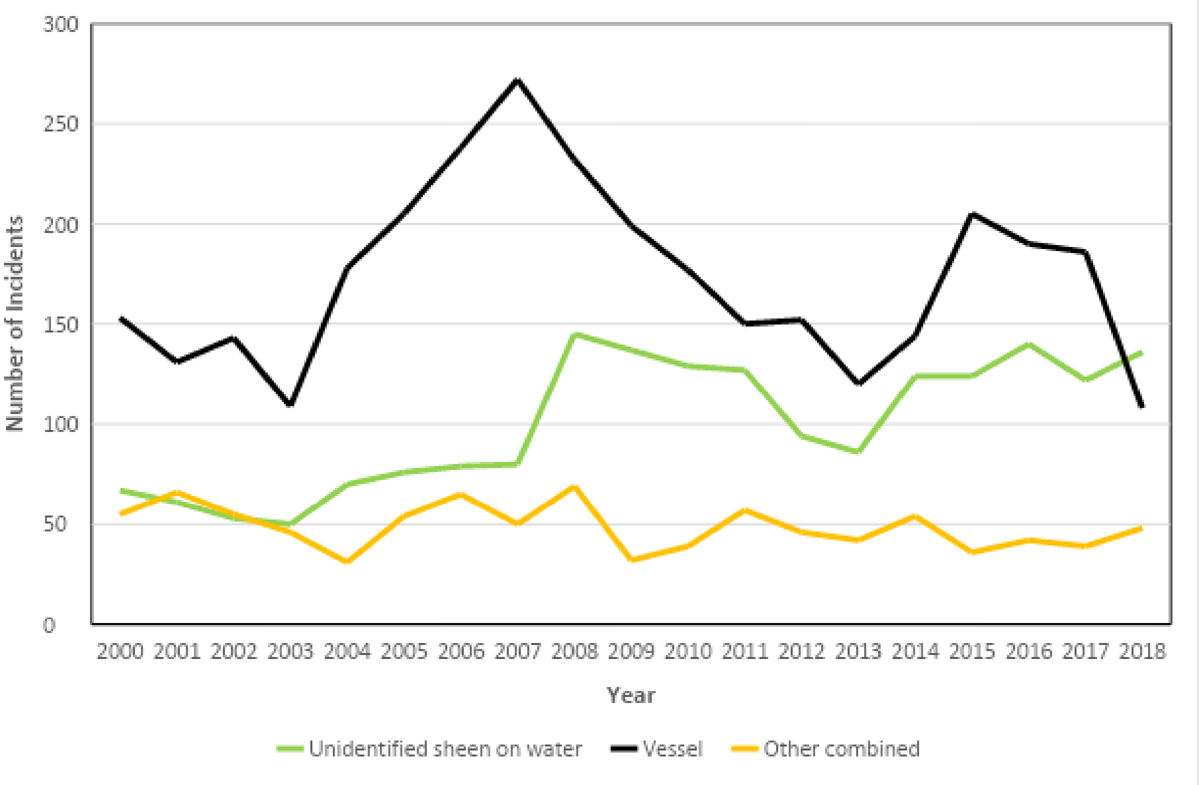

Figure 3.1 Trends in spills in marine waters in Alaska within the range of the NSOs from 2000-2018 associated with vessels, other sources, or unidentified sheen on the water as reported to the U.S. Coast Guards National Response Center. Data is from the U.S. Coast Guard National Response Center (http://nrc.uscg.mil/ 2000-2018 Reports).

3.3 **Contaminants and Biotoxins**

3.3.1 *Contaminants*

Several anthropogenic contaminants occur in areas occupied by SW NSOs. Sources of contaminants in Alaska include local point sources associated with ports and military installations that have reduced activity or are now vacant. Historically, it was common to dispose of contaminants through burial and many sites are now in the cleaning process as containers have leaked and been exposed through beach erosion. Contaminants can also be from sources far from Alaska via both air and water transport.

NSOs are important predators in the nearshore ecosystem and preferentially feed on filter-feeding invertebrates. Marine bivalves are highly effective biological filters known to bioaccumulate terrestrial-origin pollutants (Miller et al. 2010 p.10). NSOs frequently occupy or forage in bays, sloughs, harbors, or river mouths, putting them at risk for exposure to terrestrial-origin pathogens and pollutants via coastal run-off and contamination of prey (Miller et al. 2010 p.10; Oates et al. 2012, p. 64; Ballachey and Bodkin 2015, p. 77). As a result, NSOs provide a direct link between terrestrial and marine ecosystems. Detrimental inputs both from watersheds (e.g. disease and contaminants) and from the marine environment (e.g. oil spills, biotoxins) threaten the health and function of the nearshore ecosystem (Colletti et al. 2016, p. 2).

3.3.1.1 *Persistent Organic Pollutants*

Persistent organic pollutants (POPs) include compounds like polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT), chlordanes, toxaphene, lindane, mirex, brominated flame-retardants, organometals, and pharmaceuticals. These compounds can affect the health and survival of NSOs directly and indirectly (Jessup et al. 2007, p. 1649; Bodkin et al. 2012, p. 273).

Most of the work on POPs and sea otters has occurred in California due to prevalence of contaminants in that area (Jessup et al. 2007, p. 1650; Ballachey and Bodkin 2015, p. 78). However, levels of total PCBs were1.7 times higher in SW NSOs from the Aleutian Islands than in California (Bacon et al. 1999, p. 454). The source of PCBs to the Aleutian Islands is unclear, but the study by Reese et al. (2012, p. 873) did not indicate that PCBs were a significant factor in the declines in the SW NSOs. However, Hanni et al. (2003, p. 845) suggests that PCB exposure in NSOs sampled closely after the decline may account for observed deviations in certain serum chemistry values. Comerci et al. (2001, p. 46) noted that some SW NSOs had elevated levels of PCBs, implying areas of local contamination; also noted by Reese et al. (2012, p. 873) specifically at Amchitka, Adak, and Unalaska Islands. Exposure to environmental contaminants can compromise the immuno-competence of animals, thereby predisposing them to infectious agents and/or endemic pathogens (Jessup et al. 2010, p. 1215; Kannan et al. 2006a, p. 2160). Indeed, studies on southern sea otters found correlations between immunotoxic contaminants detected in tissues (kidney, liver) and infectious disease (Nakata et al. 1998, p. 51; Kannan et. al 2006b, p. 4946; Kannan et al. 2006a, p. 2164). Recent studies in the listed Western DPS of Steller sea lions (), which have experienced population declines since the 1970s, provide evidence for mercury exposure as a factor limiting recovery, possibly by reducing natality and pup survival (Rea et al. 2013, p. 281; Lian et al. 2020, p. 4). Extensive studies of POPs in NSOs occurred in conjunction with the release of crude oil into PWS with the EVOS. Studies in PWS spanning over two decades indicate long term chronic exposure may be as harmful as acute exposures to oil spills (Ballachey and Bodkin 2015, p. 78; Monson et al. 2011, p. 2929). The age at death distribution in the PWS population was significantly affected following EVOS related mortality and included high mortality rates in prime-age animals (Monson et al. 2011, p. 2925). In summary, POPs and PAHs can have both acute and long-term, cumulative chronic effects capable of limiting population recovery in a localized area as seen in EVOS (Monson et al. 2011, p. 2917).

3.3.2 *Biotoxins*

Biotoxins are compounds produced by algae (dinoflagellates and diatoms) that can reach high levels under certain conditions known as harmful algal blooms (HABs). HABs occur most often in warm water conditions, but biotoxins can occur in the environment at high levels at any time, particularly in bivalve mollusks. Biotoxins associated with HABs that cause significant illness and mortality in marine mammal species are an emerging concern in Alaska as SSTs increase including neurotoxins domoic acid and saxitoxin (Burek et al. 2008, p. S130).

Lefebvre et al. (2016, p. 13) found detectable concentrations of domoic acid and saxitoxin in 13 marine mammal species sampled in Alaskan waters, including NSOs, indicating that harmful algal blooms are occurring in areas occupied by SW NSOs specifically in Kodiak and Bristol Bay MUs. In the NSOs tested, 43 of 172 (25 percent) tested positive for domoic acid and 37 of 163 (23 percent) tested positive for saxitoxin (Lefebvre et al. 2016, p. 16). Of note, the levels of domoic acid found in NSO urine and feces or gastrointestinal contents were similar to those of California sea lions that exhibited clinical signs of toxicosis (such as seizures, coma, ataxia; Lefebvre et al. 2016, p. 19).

Algal toxins have been implicated, but not confirmed, as a potential mortality factor for NSOs because butter clams (*Saxidonus gigantues*), a primary prey item, concentrate saxitoxin (DeGange and Vacca 1989, p. 836). However, saxitoxin has not been demonstrated to be a major mortality factor for NSOs (Lefebvre et al. 2016, p. 21), perhaps because NSOs appear to be able to detect and avoid highly contaminated prey via modification of foraging behavior and the discarding of the most highly toxic body parts of their prey (Kvitek et al. 1991 p.393; Kvitek and Bretz 2004, p. 233). Despite avoidance behavior, NSOs are still susceptible to biotoxins. Additionally, oxicosis may predispose SW NSOs to boat strikes, and potentially predation. Lefebvre et al. (2016, p. 21) suggested that acute toxicosis from saxitoxin may have contributed to two SW NSO boat strike mortalities in Kodiak harbor. Urine samples from these two sea otters were documented to be the highest saxitoxin concentrations for all the otters tested in this study, and their behavior prior to the incident was suggestive of intoxication. While SW NSOs are at risk for exposure and uptake of biotoxins, it is unknown how the concentrations reported in NSOs to date relate to concentrations known to cause clinical signs of toxicity or mortality in other animals, and therefore the population level health effects to the SW NSO are not well understood.

3.4 **Overutilization**

For thousands of years, NSO hunting has been an important component of the economy and culture of Native communities along the Pacific coast. Historically, NSO pelts were valued for trade and as status symbols. Local populations were managed by indigenous hunters through a spatial marine tenure system and harvesting protocols (Salomon et al. 2015, p. 303) that likely contributed to sustainability of indigenous harvest.

During the commercial fur trade era, harvest of NSOs began in the western Aleutians and moved from west to east across the Aleutians and Alaska Peninsula then south along the coast of Alaska and Canada as populations became depleted in the north (Bodkin 2015, p. 46). This harvest pattern resulted in about 13 remnant populations, mostly in the north that were isolated and small (Kenyon 1969, pp. 134, 198; Bodkin 2015, p. 47). Unprofitable small isolated populations and international and state protection measures effectively ended the commercial harvest of NSOs.

Indigenous harvest was greatly reduced for more than a century until populations increased, expanded, or reintroductions were successful.

3.4.1 *Harvest*

The commercial fur trade that began around 1750 resulted in extirpation or large reduction of NSOs from most of Alaska. At the turn of the 19th century, the Russian American Co. instituted a limited male-only harvest regime that resulted in increased populations and greater subsequent harvests. With the sale of Alaska to the United States by Russia, another wave of unsustainable harvest occurred and the scarcity of NSOs effectively ended commercial harvesting in about 1890. Attempts to limit the harvest of sea otters began in 1897 with the International Fur Seal Conference (VanBlaricom 2015, p. 398). Over the next several decades, several conventions and treaties protected NSOs, but only in international waters. However, NSOs in Alaska territorial waters received protection by federal code in 1899 and California outlawed the killing and possession of sea otters in its coastal waters in 1913. The Submerged Lands Act of 1953 gave jurisdiction of lands below navigable waters to the states out to 5.6 km from the mean high tide line of the mainland and gave those states authority to manage sea otters within that area. From that time on, the four states with extant sea otter populations provided protections to important sea otter areas. States banned or limited hunting as they focused on protections and translocations to restore extirpated populations.

In 1972, with enactment of the MMPA, the hunting of NSOs ended, with the exception of subsistence harvest by Alaska Natives that dwell along the coast. Harvest by Alaska Natives must be for the development of handicraft or for subsistence purposes and cannot be conducted in a wasteful manner (16 U.S.C. §§ 1361 et seq.). In 1990, the Marine Mammals Management Office in Alaska implemented a statewide monitoring, tagging, and reporting program (MTRP) that tracks harvest of NSOs by Alaska Natives.

Since the MMPA, reported harvest of NSOs in Alaska has likely been greatest around coastal villages and can change greatly from year to year (Fig. 3.2). However, reported harvests have been generally less than 300 otters per year in most years from 2010 to 2019 in the SW NSO population.

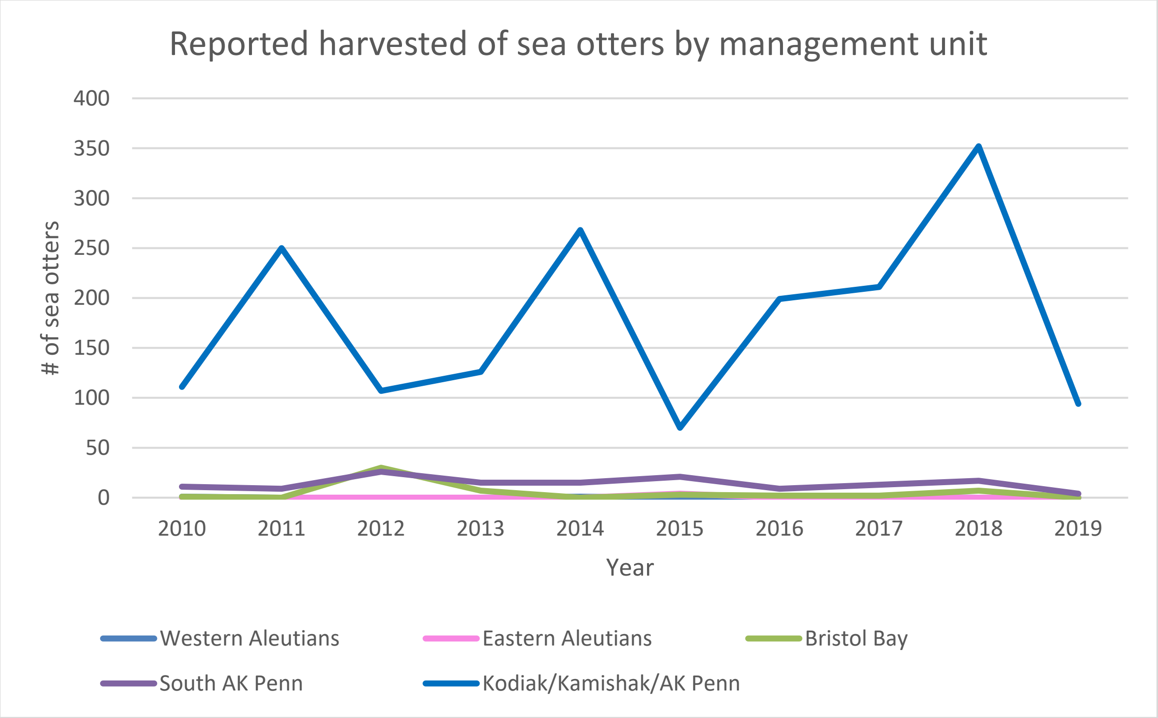

Figure 3.2 Total number of SW NSO reported harvest by management units from 2010-2019 (Service 2019a unpublished data).

Recent (2010–2019) annual reported harvests of SW NSOs have ranged from 95 to 352 individuals, averaging 195 per year (Fig. 3.2). The average reported harvest from 2010-2019 is about 0.03 percent of the estimated SW NSO population (Service 2019a. unpublished data, see Chapter. 4). The potential biological removal (PBR) is defined as the maximum number of animals, not including natural mortalities, which may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimal sustainable population. The PBR is calculated as PBR= Nmin x 0.5 Rmx x Fr (Service 2014a-c, p. 9) where Rmx is the maximum theoretical net productivity rate (21.6 percent; Estes 1990, p. 395) and Fr is the recovery factor for a threatened species (0.5; Wade and Angliss 1997, p. 62). Therefore, the estimated removal rate is 5 percent. Applied to the minimum current population size for surveyed areas of 52,232 (Service unpublished data, see Chapter. 4) then the PBR is calculated to be 2,820 otters, confirming the subsistence harvest is occurring at a sustainable rate.

With the exception of the Kodiak Island, SW NSO reported harvest has been minimal over the last 8 years (Fig. 3.2). Despite an increase in reported harvest numbers around Kodiak Island, the SW NSOs harvested in that area (352 individuals) represent roughly 3 percent of the Kodiak Island population (Cobb 2018, p. 1). While SW NSOs are taken through subsistence harvest, the numbers appear to be sustainable and have little population level impacts.

3.4.2 *Fisheries Bycatch*

Fisheries of various types, including bottom and pelagic trawling, troll and longlining, gill net, purse seining, pot fisheries, and dive fisheries (ADFG 2018a, p. 1) occur in SW NSO habitat throughout their range. These fisheries may have direct or indirect effects on the population. Since the 1970s, bycatch has increasingly been identified to play a significant role in reducing or limiting recovery of marine mammal populations (Reeves et al. 2013, p. 71). Fisheries may have direct effects on SW NSOs through interactions that result in the incidental take (collisions, entanglements, and disturbance while resting, foraging, or travelling). Numerous commercial fisheries in Alaska contribute to marine mammal mortality or serious injury, including set and drift gill net salmon fisheries which have been documented to injure or kill SW NSOs via entanglement and drowning (Reeves et al. 2013, p. 89; NOAA 2020a, entire). Stranding program data for 2008-2018 indicate at least 14 NSO entanglements with gear of this type within the SW and southcentral stocks between 2008 and 2018; six interactions resulted in death, seven NSOs were released alive, and the outcome of one interaction was unknown (Service 2018a, Service 2018c unpublished).

Stranding data provides some insight, but information is insufficient to determine how many SW NSOs may be injured or killed in these fisheries throughout their range (Service 2014a, p. 9; Service 2014b, p. 10; Service 2014d, c. p. 11). While the National Marine Fisheries Service (NMFS) does have a fisheries observer program (AFSC 2018, inclusive), it is focused on halibut and other groundfish fisheries that rarely interact with SW NSOs. State observer programs focus narrowly on crab fisheries. Of the 14 coastal Alaskan gillnet salmon fisheries only six have been observed (and never concurrently) by the Alaska Marine Mammal Observer Program and none for more than 2 years (Benaka et al. 2019, p. 35). However, fishers are required to self-report bycatch of marine mammals. Salmon drift gillnet fisheries occur in Bristol Bay (1,862 vessels) and the Alaska Peninsula/Aleutian Islands (162 vessels), and no interactions with salmon drift gillnets have been reported for the SW NSO although interactions have been observed with the southcentral Alaska stock (Muto et al. 2019, p. 269).

Crab fisheries are also a notable source of bycatch. In 2014, a study was conducted by Alaska Department of Fish and Game (ADFG) to determine SW NSO interactions on Dungeness crab pots near Kodiak. A total of 650 pot lifts occurred during the study. No SW NSO were observed in the vicinity of the fishing gear, there were no SW NSOs caught, and there were no interactions with either the SW NSO and the gear or the captured crabs (ADFG 2015, p. 7). However, sea otters are known to interact with pot fisheries in California and Alaska (Hatfield et al. 2011, p. 219), and it is possible that observer effort for pot fisheries in Alaska has been too low to detect SW NSO bycatch.

Commercial fisheries in Alaska that potentially have indirect effects with SW NSOs include bottom and pelagic trawling, and dive fisheries (ADFG 2018a, p. 1). Trawling may indirectly impact SW NSOs through prey habitat destruction or degradation (Mecum 2009, p. 57). Wilson and Evans (2009, p. 14) reported on the bycatch of potential NSO prey items in the non-pelagic trawl fishery in the Northern Bristol Bay Trawl Area. Data came from the NMFS Fisheries Observer program and aggregated for the years 2001 to 2008. Bivalves (mussels, oysters, scallops, and clams) accounted for 99 kg of the 430 kg (23 percent) of total bycatch reported. Net mesh size was large enough to allow mollusks and other infauna to escape, but it is believed that bycatch of these species is low because the footrope and bobbins dislodge few of them from the bottom sediments (Rose, 2010 pers. comm.).

Commercial fishers dive for and harvest invertebrates that NSOs feed on. The State of Alaska, which manages these stocks, has closed areas and reduced harvests in areas where SW NSOs have increased in abundance and reduced the availability of their prey to commercial fishers. Commercial harvests of SW NSO prey do not appear to have affected NSOs enough to cause population-level declines. In addition to the threat posed by commercial fisheries, subsistence and personal use fisheries do not appear to be affecting SW NSOs.

In summary, although information is insufficient to definitively determine the extent of take from fisheries, we found that the effects of fisheries on SW NSOs are likely to be limited, with few site-specific takes in salmon set and drift net fisheries. The effects on prey and benthic habitats of SW NSOs by trawling are likely small as they are limited in space and time with little overlap with NSOs habitat in most fishing areas. Overall, current fisheries activities do not appear to be affecting SW NSO.

3.4.3 *Illegal take*

Distinct from bycatch, other illegal take associated with fisheries may also occur. SW NSOs have also been shot by fishers that perceive them as a threat to their livelihood due to competition for resources such as clams, crabs, and urchins. Illegal, intentional take of SW NSOs in some areas may be more of an issue than legal incidental takes, but this level of take is unknown and anecdotal.

3.5 **Disease, Parasites, and Predation**

A number of infectious diseases and parasites have been found in NSOs (Rausch 1953, pp. 587-560; Gill et al. 2005, p. 106; Burek-Huntington et al. 2014, p. 389). Several instances of elevated mortalities have been attributed to disease or parasites, which has raised concern for their population-level effects in these areas (Service 2013a, pp. 3-5).

3.5.1 *Infectious Disease and Parasites*

Many infectious diseases have been identified in NSO carcasses, but few have been associated with large mortality events (Murray 2015, pp. 182-186). In addition, the presence of a pathogen is not indicative of a diseased animal (Murray 2015, p. 187). Disease is normal in free-ranging wildlife, and not all diseases are indicative of an unhealthy population.

In 2003, the Service and several partners implemented an NSO stranding network in Alaska that retrieved and necropsied NSOs found dead on Alaskan beaches, primarily in Kachemak Bay, the Alaska Peninsula, and Kodiak Island. The most common cause of death was vegetative infective endocarditis and septicemia attributed to streptococcal bacterium (Burek et al. 2005, p. 1).

Due to these findings and the large number of carcasses involved, the Service recommended that an Unusual Mortality Event (UME) be declared per the MMPA (Murray 2015, p. 183). The MMPA Working Group agreed and an investigation team convened, and an UME was formally declared in September 2006. Subsequent surveys in Kachemak Bay and the adjacent Kenai Peninsula found that NSO abundance had recovered and numbers were increasing, suggesting a density-dependent response, and the UME was closed shortly thereafter (Service 2013a, pp. 3-12). Since 2013, the stranding program has continued primarily in Kachemak Bay but reports of stranded NSOs from citizens and Service personnel occasionally come from Kodiak Island, the Alaska Peninsula, and the Aleutian Islands. Fresh carcass collections have occurred every year and necropsies indicate the most frequent cause of death continues to be strep related mortality. Other common sources of mortality include predation, boat strikes, and fishing gear entanglement (Service 2019b, unpublished).

Elevated mortalities of SW NSOs on Amchitka Island in 1951 were attributed to two parasites (a nematode and trematode) that were presumed to result from heavily feeding on fish (Rausch 1953, p. 594). Another case of parasites leading to mortalities was documented in the 1990s where waste from fish processing plants was consumed by NSOs in Resurrection Bay (Tuomi and Burek 1999, pp. 1-2; Ballachey et al. 2002, p. 1). Although there have since been changes in fish waste management, instances of unauthorized discharges have occurred in several locations, including in the Eastern Aleutians, potentially impacting SW NSOs (Ballachey and Bodkin 2015, p. 83).

Several helminth parasites were found in NSOs in Prince William Sound by Margolis et al. (1997, p. 161) recovered from beaches associated with oiling from the EVOS. Most of those parasites also occur in other sea otter populations and many come from pinnipeds and fish. Only one species was unique to sea otters. Massive infections of helminth parasites have been reported to cause mortality in southern sea otters due to perforation of the intestinal wall (Mayer et al. 2003, p. 77). Helminth parasites including tapeworm (Cestoda), flukes (Trematoda), Nematoda, and Acanthacephala species are also prevalent in the SW NSOs (Service 2019b, unpublished).

Protozoal parasites, *Toxoplasma gondii* and *Sarcocystis neurona*, can cause fatal protozoal encephalitis in sea otters, and both are identified as a significant cause of morality in southern sea otters (Burgess et al. 2020, p. 1). However, only low prevalence for antibodies to these parasites have been found in NSOs (Goldstein et al. 2011, p. 586; Burgess et al. 2020, p. 5).

Reported stranding mortalities of SW NSOs over the past five years have been less than 100 individuals per year (Table 3.1) throughout their range. In 2018 a mortality event occurred in

Bristol Bay with up to 70 carcasses observed which was high based on previous years in this region. In response to reports of increased mortality, an aerial survey was flown from Cape Leontovich to Cape Menshikof (near Pilot Point) in March by the Service to look at the extent of the die-off. The majority (91 percent) of carcasses were found in the Nelson Lagoon and Port Moller area. *Streptococcus* (strep) was the leading cause of death from the carcasses (n=6) sampled in the Bristol Bay area. Three sick or dead seals were also found during the survey (Service 2018b, 2018c, p. 1).

Table 3.1 Reported mortalities to the Service stranding program, 2014-2019 (Service 2019b, unpublished data).

Management Unit	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Eastern Aleutians	2	3	4	1	3	2
Western Aleutians	0	1	0	1	2	1
Kodiak, Kamishak, AK Pen.	11	6	15	3	1	3
Bristol Bay	0	0	0	0	70	0
Total	**13**	**10**	**19**	**5**	**76**	**6**

While infectious disease is a primary cause of death in NSOs from Washington (White et al. 2018, p. 242), and is an important driver to southern sea otter populations (Kreuder et al. 2003, entire), it is not known whether disease and parasites are considered to be a contributing factor to population declines in SW NSOs, and opportunities for sampling have been limited. The number of carcasses retrieved with positive tests in the region are typically less than five percent of population estimates. Furthermore, data on disease and parasite prevalence are largely from beach cast carcasses, which may not be representative of the population, and are subject to several biases such as limited geographic scope where carcasses are detected and reported, the frequency of sampling, and carcass condition when observed. Results of targeted health assessments conducted spatially and temporally coincident with the decline of SW NSOs by Hanni et al. (2003, p. 843) did not reveal specific disease processes that were responsible for the decline. However, the same study also found absence or low prevalence of antibodies to pathogens with the potential to cause high mortality in sea otters (such as morbillivirus). Naïve populations may be susceptible to disease epidemics if these pathogens were ever to be introduced. The stranding network provides valuable observations but is inadequate for determining prevalence of disease and parasites at the stock level.

3.5.2 *Predation*

Sea otters are an apex predator in nearshore marine communities, yet there have been many reports of sea otters as prey for other top predators. In Alaska, these predators include marine species such as killer whales (*Orcinus orca*) and several species of shark, and terrestrial species such as bald eagles (*Haliaeetus leucocephalus*), wolves (*Canis lupus*), and brown bears (*Ursus arctos*). Below, we summarize documented instances of predator-caused mortality of SW NSOs.

3.5.2.1 *Marine Predators*

At the time of the ESA listing, predation by killer whales was suspected to be the primary cause of decline of SW NSOs (Service 2013a, pp. 3-1 & 3-4). Killer whales are predators of sea otters, yet prior to 1990 only a handful of documented interactions between the two species existed. One aggressive interaction was reported in the Kuril Islands (Nikolaev 1965, p. 231) along with a few inconclusive reports of presumed attacks in the Commander Islands (Hatfield et al. 1998, p. 889). However, most killer whale-NSO interactions in Alaska and elsewhere were considered to be non-aggressive (Kenyon 1969, p. 279). In the early 1990s, this pattern appeared to change, based on nine documented observations of killer whales apparently attacking NSOs; three of these incidents occurred in PWS (Southcentral stock) and six occurred in the Aleutian Islands (SW NSO) (Hatfield et al. 1998, p. 889). The increase in these predation events was thought to be the result of "transient" (mammal-eating) killer whales adjusting their diet to include SW NSOs, potentially as a response to declines in other marine mammal prey, including harbor seals (*Phoca vitulina*) and Steller sea lions (*Eumetopias jubatus*) (Estes et al. 1998, p. 475). In addition, U.S. Geological Survey (USGS) and the Service field staff provided reports since 1995 of observations of apparent killer whale attacks on groups of NSOs (USGS, unpublished data). The details of these attacks and the regularity with which they occur are uncertain.

Owing to their rarity in space and time, it is difficult to observe predation events, verify them after they occur, or determine whether they were successful. Kuker and Barret-Lennard (2010, p. 107) noted that of the six interactions in the Aleutians reported by Hatfield et al. (1998, p. 889), one was positively identified as a predatory attack that resulted in a confirmed kill of a NSO, while the other five could be described as probable kills or harassment. In two of these cases, no signs of injury occurred following the attacks, in another case, the NSO was apparently injured but escaped, and in two cases, the fate of the NSOs is uncertain although the observer believed that they died. In the most conservative sense, observations of killer whale attacks are classified as predation only when strong evidence of actual consumption is found, such as blood, blubber, or other tissues from the prey floating on the water surface after the attack (Ford et al. 1998, p. 1459). Although strong evidence of actual consumption was found in only one of nine observed attacks (Hatfield et al. 1998, p. 889), the fact that the skeletal remains of at least five NSOs were recovered from the stomach of a male killer whale carcass in PWS confirms that NSOs are eaten by killer whales (Vos et al. 2006, p. 203).

The potential for transient killer whales to cause a substantial decline in NSOs was evaluated based on killer whale nutritional needs. Williams et al. (2004, p. 3376) estimated the caloric needs of free-ranging killer whales at 163,738 kcal/day for a 2,800 kg adult female and 243,501 kcal/day for a 4,733 kg adult male. Based on the estimated caloric value of male and female sea otters, it was estimated that an adult male killer whale would need to consume five male or seven female sea otters per day to meet full nutritional needs, while an adult female killer whale would need three male or five female sea otters per day. Summed across the year, a killer whale specializing on sea otters could consume 1,095–2,555 sea otters/year (Williams et al. 2004, p. 3378). These estimates helped formulate the hypothesis that a group of transient killer whales, potentially as few as four males or six females, could account for the estimated added mortality of 9,982 sea otters/year to cause the observed SW NSO decline in the Aleutian archipelago (Williams et al. 2004, p. 3380).

Lack of recent observations of killer whales preying on SW NSOs make it difficult to assess the current severity of the threat. In addition, SW NSO numbers in the Western Aleutians, have remained low, but relatively stable since 2005 (Tinker 2018, p. 11). The current predation rate is unknown.

In the 1990s, SW NSOs appeared to alter space use patterns from all nearshore habitats to select nearshore habitats (Steward et al. 2015, p. 646). Three different mechanisms behind the shift have been proposed. First, the shift in space use patterns could reflect increased prey availability in the select areas (Kuker and Barrett–Lennard 2010, pp. 109-110). Second, the select nearshore habitats could offer increased protection from storms (Kuker and Barrett–Lennard 2010, p. 109). Finally, the shift in space use patterns to select habitats could reflect selection for habitats that offer increased protection from predator attacks (Stewart et al. 2015, p. 646). A study on SW NSO space use around Adak Island evaluated the efficacy of all three of these hypotheses. The authors concluded that space use patterns suggested animals selected areas based on physical habitat complexity, which would provide increased protection from marine predators (Stewart et al. 2015, p. 651). However, the study compared 2008 space use patterns to historical survey data from the 1990s (Stewart et al. 2015, p. 647). Thus, current space use patterns of SW NSOs are uncertain.

Information on shark predation on NSOs in Alaska is limited to one unconfirmed incident involving a salmon shark (*Lamna ditropis*) that reportedly attacked and consumed an NSO in PWS (Service 2013a, p. 3-1). In California, there are significant mortalities associated with white sharks (*Carcharodon carcharias*) (Ames and Morejohn 1980, p. 196; Estes et al. 2003, p. 198; Kreuder et al. 2003, p. 500). However, there have been very few sightings of white sharks in Alaskan waters (Martin 2004, p. 18).

While predatory attacks have been observed in the past, our understanding of how frequently these attacks occur currently and whether they have a significant effect on the population has not improved since the time of listing. Furthermore, there is debate within the scientific community about the relative importance of killer whale predation on SW NSO population dynamics. The effects of current levels of predation, particularly killer whale predation, remain uncertain.

3.5.2.2 *Avian Predators*

Bald eagles are frequent predators of NSO pups, with NSO pup remains accounting for up to 20 percent of the prey items found in some eagle nests in the Aleutian Islands (Sherrod et al. 1975, p. 702). However, because this predation is limited to very young pups (< 5 kg), a stage with naturally high mortality, it is believed that bald eagle predation has a small demographic impact, at least at high NSO densities (Sherrod et al. 1975, p. 701; Riedman and Estes 1990, p. 69). It is possible that bald eagle predation could limit population growth when NSO densities are low, such as some areas in the Aleutian Islands. However, recent searches of bald eagle nests in the Aleutians indicate that eagle diets have shifted to focus on offshore fish and seabirds, possibly as a result of decreases in nearshore fish populations associated with the loss of kelp (Reisewitz et al. 2006, p. 623) or a decrease in availability of sea otter pups (Anthony et al. 2008, p. 2727). We consider this a minor threat and did not consider it in the future analysis.

3.5.2.3 *Terrestrial Predators*

Terrestrial predators can prey on SW NSOs in areas where they haul out on land, although confirmed reports of predation by land predators on live NSOs are remarkably few suggesting that scavenging could be prevalent. It can be challenging to observe or record predation events by land predators and therefore difficult to discern whether or not the sea otter was scavenged or killed by a land predator.

Along the coast of Katmai National Park on the Alaska Peninsula, brown bears have been recorded with remote camera systems stalking and killing SW NSOs resting on offshore reefs and small islands throughout the summer months (Monson et al., in review). Age-at-death ratios of skulls found on islands where brown bear predation occurs included a larger-than-expected proportion of prime-age animals, suggesting that brown bears were not scavenging dead animals but were actively hunting and killing SW NSOs (Monson et al., in review). The frequency and scope of bears preying on sea otters is uncertain, though research currently is underway to assess potential impacts to the local sea otter population and to evaluate the importance of sea otters as a prey resource for coastal brown bears. Brown bears have been reported to be a significant source of predation on NSOs in late winter and early spring along the Kamchatka Peninsula, Russia (Riedman and Estes 1990, p. 7). Predation of NSOs is likely a learned behavior for brown bears and likely has a relatively small overall demographic effect on the SW NSO given our understanding of the foraging habits of brown bears and the limited overlap between the two species.

NSOs also are consumed by gray wolves and possibly coyotes (*C. latrans*), in Alaska. Scat of gray wolves collected in three different areas of southeastern Alaska (Pleasant Island/Gustavus, Kuiu Island, and Prince of Wales Island) between 2014 and 2017 contained NSO remains. The frequency of occurrence of NSOs in wolf scats was low on Prince of Wales Island (<1 percent), moderate on Kuiu Island (~15 percent), and high on Pleasant Island and the Gustavus forelands (~60 percent; Roffler, 2018 pers. comm. 2018; McAllister 2019, pp. 1-6). NSOs were the most common prey in gray wolf scat collected on Pleasant Island and the Gustavus forelands, though researchers do not know if these remains represent predation or scavenging. Stable isotope analyses and DNA metabarcoding and sequencing of prey species in wolf scats to quantify geographic variation in wolf diets, including consumption of sea otters, in southeastern Alaska is currently underway (Roffler, 2018 pers. comm.). Gray wolves on the Alaska Peninsula have also been documented feeding on SW NSOs (Watts et al. 2010, p. 145). These events are believed to occur when sea otters are attempting to cross land to gain access to ice-free areas (Service 2013a, p. 2-4).

Other terrestrial predators in Alaska, such as fox (*Vulpes* spp.) and wolverine (*Gulo gulo*), also may scavenge or predate on sea otters with some level of regularity, but we are not aware of any confirmed reports. In the Commander Islands, Arctic foxes (*V. lagopus*) frequently scavenge sea otter carcasses and also occasionally kill live sea otters, although such predation is limited mostly to young or already moribund (in a dying state) animals (Service 2013c, p. 3-2). We posit a similar situation throughout most of coastal Alaska, except the Aleutian Islands, which lack terrestrial carnivores. Although released or escaped farmed foxes once occurred on many islands in the Aleutians, eradication efforts began in the 1950s and foxes are now absent from nearly all of the islands. We determined the effects of terrestrial predation on SW NSOs are limited or site specific and do not appear to be affecting the SW NSO population. We consider this a minor threat and did not consider it in the future analysis.

3.6 **Protections and Conservation Measures**

The following is a brief description of the important laws, regulations, and conservation measures that protect NSOs and their habitats. In the U.S., key protections to NSOs and other marine mammals are provided by the MMPA, which prohibits unauthorized take of marine mammals in U.S. waters. The Service has responsibility for implementing the MMPA and ESA for SW NSOs.

The MMPA was enacted in response to growing concerns among scientists and the general public that certain species and populations of marine mammals, including sea otters, were in danger of extinction or depletion as a result of human activities. The MMPA set forth a national policy to prevent marine mammal species or population stocks from diminishing to the point where they are no longer a significant functioning element of the ecosystems.

Although the MMPA recognizes marine mammals as an important ecosystem component and establishes management goals based on optimum sustainable populations, there are no direct provisions for ecosystem or habitat protection, unless activities associated with ecosystem or habitat modification are considered a “take”. The MMPA includes a general moratorium on the taking and importing of marine mammals, which is subject to a number of exceptions. Some of these exceptions include take for scientific purposes, public display, subsistence use by Alaska Natives, and unintentional incidental take coincident with lawful activities, for example oil and gas development. Take is defined in the MMPA to include the “harassment” of marine mammals. “Harassment” includes any act of pursuit, torment, or annoyance which “has the potential to injure a marine mammal or marine mammal stock in the wild” (Level A harassment), or “has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering” (Level B harassment). The Secretaries of Commerce and of the Department of the Interior have primary responsibility for implementing the MMPA.

Certain exceptions from the prohibitions on taking are provided. The MMPA exempts Alaska Natives from the prohibitions on taking for subsistence purposes. Section 119 of the MMPA provides for the adoption of cooperative agreements with Alaska Native organizations to conserve marine mammals and provide co-management of subsistence uses. In addition, sections 101(b)(3) and 103 of the MMPA provide for the adoption of subsistence harvest regulations for stocks designated as depleted, after notice and administrative hearings. U.S.

citizens who engage in a specified activity other than commercial fishing (which is specifically and separately addressed under the MMPA) within a specified geographical region may petition the Secretaries to authorize the incidental, but not intentional, taking of small numbers of marine mammals within that region for a period of not more than five consecutive years (16 U.S.C. 1371(a)(5)(A)). The Secretary "shall allow" the incidental taking if the Secretary finds that the total of such taking during each 5 year (or less) period concerned will have a negligible impact on such species or stock and will not have an immitigable adverse impact on the availability of such species or stock for taking for subsistence uses. If the Secretary makes the required findings, the Secretary also prescribes regulations that specify; (1) permissible methods of taking, (2) means of affecting the least practicable adverse impact on the species, their habitat, and their availability for subsistence uses, and (3) requirements for monitoring and reporting. The regulatory process does not authorize the activities themselves, but authorizes the incidental take of the marine mammals, such as sea otters, in conjunction with otherwise legal activities described within the regulations.

In addition to the MMPA the SW NSO is protected by the ESA. The ESA establishes statutory requirements for conservation of species in danger of or likely to become in danger of extinction. For example, per special rule 4(d) (71 FR 46864) and section 9 of the ESA [16 U.S.C. 1533(d) and 1538], the taking of SW NSOs is prohibited, except pursuant to an incidental take authorization or statutory exemption. In addition, under Section 7 of the ESA (16 U.S.C. 1536), all Federal agencies must ensure through consultation with the Service that actions they authorize, fund, or conduct are not likely to jeopardize the continued existence of the SW NSO or result in the destruction or adverse modification of designated critical habitat.

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is a treaty aimed at protecting species at risk from international trade. CITES regulates international trade in animals and plants by listing species on one of its three appendices. The level of monitoring and control to which an animal or plant species is subject depends on which of the three appendices the species is listed. Appendix I includes species threatened with extinction, and their trade is only allowed in exceptional circumstances. Appendix II includes species not necessarily threatened with extinction, but for which trade must be controlled in order to avoid utilization incompatible with their survival. Appendix III includes species that are protected in at least one country, and for which that country has asked other CITES party countries for assistance in controlling and monitoring international trade in that species.

All sea otters are currently listed as an Appendix II species under CITES. As such, member countries to CITES must determine, amongst other things, that any sea otter, sea otter part, or product made from sea otters was legally obtained and that the export will not be detrimental to the survival of the species, prior to issuing a permit authorizing the export of the animal, part or product. Additionally, because of the stricter provisions of the MMPA, the only currently allowable exports of SW NSO, or their parts or products, may be for scientific research purposes or personal effects hand carried out of the United States for non-commercial purposes.

Conservation and protection of SW NSO habitat occurs at both state and federal levels. Alaska has several State-managed Conservation Areas such as refuges, sanctuaries and critical habitat areas (ADFG 2018b, p. 1), with at least 12 providing for NSO conservation. Federal lands managed by the Service, National Park Service, Forest Service, and Department of Defense that border coastal areas or encompass islands occupied by SW NSOs directly and indirectly provide for SW NSO conservation and protection (VanBlaricom 2015, pp. 402-416). In addition, other federal management programs that protect Steller sea lions and northern fur seals (*Callorhinus ursinus*) also benefit SW NSOs.

Private efforts and public/private partnerships also foster SW NSO conservation. Following the EVOS, measures were put in place to help prevent, monitor, and mitigate future oil spills. The Regional Citizens' Advisory Council was developed with industry funding for PWS to Kodiak Island and Cook Inlet (PWSRCAC 2018, p. 1), and includes representatives from communities, aquaculture, commercial fishing, environmental, Alaska Native, and recreation and tourism organizations. There was also development of a modular NSO rehabilitation facility located at the Valdez Marine Terminal (NOAA 2018d, p. 1) that can be operational within 72 hours of notice of a spill. The Alaska SeaLife Center (ASLC) also helps aid oil spill mitigation and rehabilitation efforts by conducting annual training exercises in capture, handling, de-oiling, and release of NSOs. In conjunction with ASLC, industry funded Cook Inlet Spill Prevention and Response, Inc. is also developing a similar rehabilitation facility located in Seldovia, AK (CISPRI 2017, p. W5-1). Additional response programs include Alaska Chadux Corp. (Alaska Chadux Corporation 2018), an industry funded oil spill response and clean-up organization, and the Alaska Department of Environmental Conservation. Both programs have spill response equipment stationed in a number of coastal villages throughout Alaska (ADEC 2016). These spill response organizations may help mitigate effects of oil spills within the SW NSO range.

3.7 **Small Population Size Effects**

NSO populations that occur at low abundance and densities could have increased extinction risk from small population size effects. Demographic stochasticity could increase the risk of local extirpation through variation in individual survival and reproductive rates that are a function of individual traits (Lande 1998, p. 1457). Additionally, demographic stochasticity could arise through sampling variance in vital rates such as survival and reproductive rate as well as the sex ratio (Kendall and Fox 2002, p. 109). Thus, decreased survival and reproduction combined with a skewed sex ratio to males in one generation could substantially increase the probability of extinction in small, local NSO populations.

An Allee effect has been broadly defined as a positive relationship between abundance and/or density in a population and a component of individual fitness (Stephens et al. 1999, p. 186). Allee effects could be present in small NSO populations, although the precise mechanism behind an Allee effect (Stephens et al. 1999, p. 186) in SW NSOs is uncertain. For example, one possible mechanism behind an Allee effect that could impact NSOs is decreased antipredator vigilance in small sea otter groups compared to large sea otter groups with large sea otter groups more likely to form in large populations. Another possible mechanism is limited access to mates for females in estrous in the WA MU (Davis et al. 2019, p. 11).

NSO populations experienced a bottleneck due to exploitation during the fur trade, leading to a loss of over half of their genetic diversity (Larson et al. 2015, p. 10). Overall, sea otter abundance has increased over the last century aided in part with translocations that occurred outside the range of SW NSOs. However, low genetic diversity paired with small, isolated populations could impact a population's ability to adapt to diseases, prey, shifts, and changing environmental conditions (Larson et al. 2015, p. 84). In the Aleutians, low numbers and lack of dispersal (possibly as a result of killer whale predation effects, both direct and indirect), likely results in increased isolation and additional potential for small population size effects. However, the impact on genetic diversity on SW NSOs is uncertain.

3.8 Uncertainties

There are a number of uncertainties associated with SW NSOs and their threats. The greatest uncertainty is around climate change and its direct or indirect effects on the SW NSOs. There are also uncertainties associated with habitat modifications, contaminants, overutilization, and the extent that disease, parasites and killer whales currently affect SW NSOs. Below is a breakdown of each of those uncertainties within the different categories (Table 3.2).

Table 3.2 Uncertainties associated with SW NSOs current threats and stressors.

Section	Uncertainties
3.1 Climate Change	- ocean warming impacts on SW NSOs prey - potential increases in HABs, pathogens, infections, and novel diseases and their impacts on the population - magnitude of impacts seen from extreme weather which can be highly localized events - prey species range shifts and how new species may impact communities - whether sea otters will require additional foraging time or strategies to meet energetic needs
3.2 Habitat Modification	- noise thresholds used in disturbance mitigation measures are based on surrogate species - habitat and population level impacts of small-scale oil spills
3.3 Contaminants	- biotoxin and algal bloom triggers and impacts
3.4 Overutilization	- impact of salmon or trawl fisheries directly and through disturbance or bycatch - numbers of illegal intentional take
3.5 Disease, Parasites, and Predation	- unknown prevalence and impacts of disease and parasites on SW NSOs - geographic variability of disease and parasite occurrences - lack of observations or inability to verify predation events - magnitude of predation impacts on low density populations - the extent to which killer whales and terrestrial predators can impact populations - dispersal rates and the impact of predation on dispersal capacity of SW NSOs

4 CURRENT CONDITIONS

The SW NSOs habitat consists of lands owned and managed by the state of Alaska (e.g. Department of Natural Resources), federal agencies (e.g. National Park Service, Service, Bureau of Land Management, and Department of Defense), Alaska Native (Alaska Native Claims Settlement Act (ANCSA) Patented or Interim Conveyed), local governments, and private individuals and companies. Federally protected areas include three national parks, Aniakchak, Katmai, and Lake Clark, in the southwestern Alaska Peninsula, all managed by the National Park Service. The Service oversees numerous national wildlife refuges spanning terrestrial and marine environments, including Becharof, Izembek, Kodiak, and Alaska Maritime.

Economic development within the SW NSO region is centered around commercial fishing. Numerous fishing vessel ports are spread across the five management units with the largest ports, located at Dutch Harbor and Kodiak Island, which support two of the largest commercial fishing operations in the world. Off-shore oil and gas production occurs in the LCI and the Bering Sea, with additional lease sales possible in the near future.

Vessels in support of commercial fishing, commerce, and the oil and gas industry are widespread in southwestern Alaska (Fig. 4.1). The high density of shipping vessel traffic in waters occupied by SW NSOs poses a risk from vessel strikes, ballast water exchanges (contaminants, invasive species), and spills or leaks as a result of vessel damage or sinking.

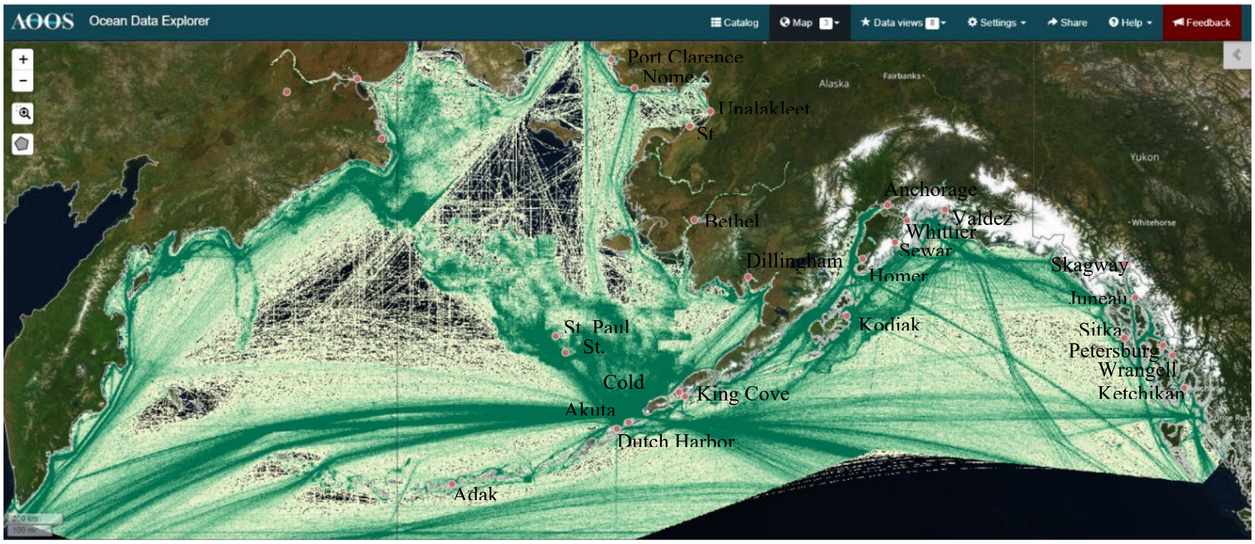

Figure 4.1 Vessel traffic density in 2015 – 2016. Map is based on satellite-based Automatic Identification System (AIS) data collected across multiple vessel types. Each track represents one vessel for each day of travel. Map provided courtesy of the Alaska Ocean Observing System (AOOS 2020) Ocean Data Explorer web mapping service. Additional details on this data set are available in the Ecological Atlas of the Bering, Chukchi, and Beaufort Seas (Smith et al. 2017).

Catastrophic oil spills, such as the EVOS affected NSOs, their habitat, and prey resources in the Gulf of Alaska, with oil spreading as far as the southwestern peninsula. It is important that vessel traffic is monitored, and response plans are in place in case of leaks/spills. Additionally, understanding the duration in which leaked oil (and other contaminants) will linger in the nearshore environment based on the physical environment and ocean currents will help identify the potential long-term effects on SW NSOs dynamics and their associated ecosystems (Fig. 4.2).

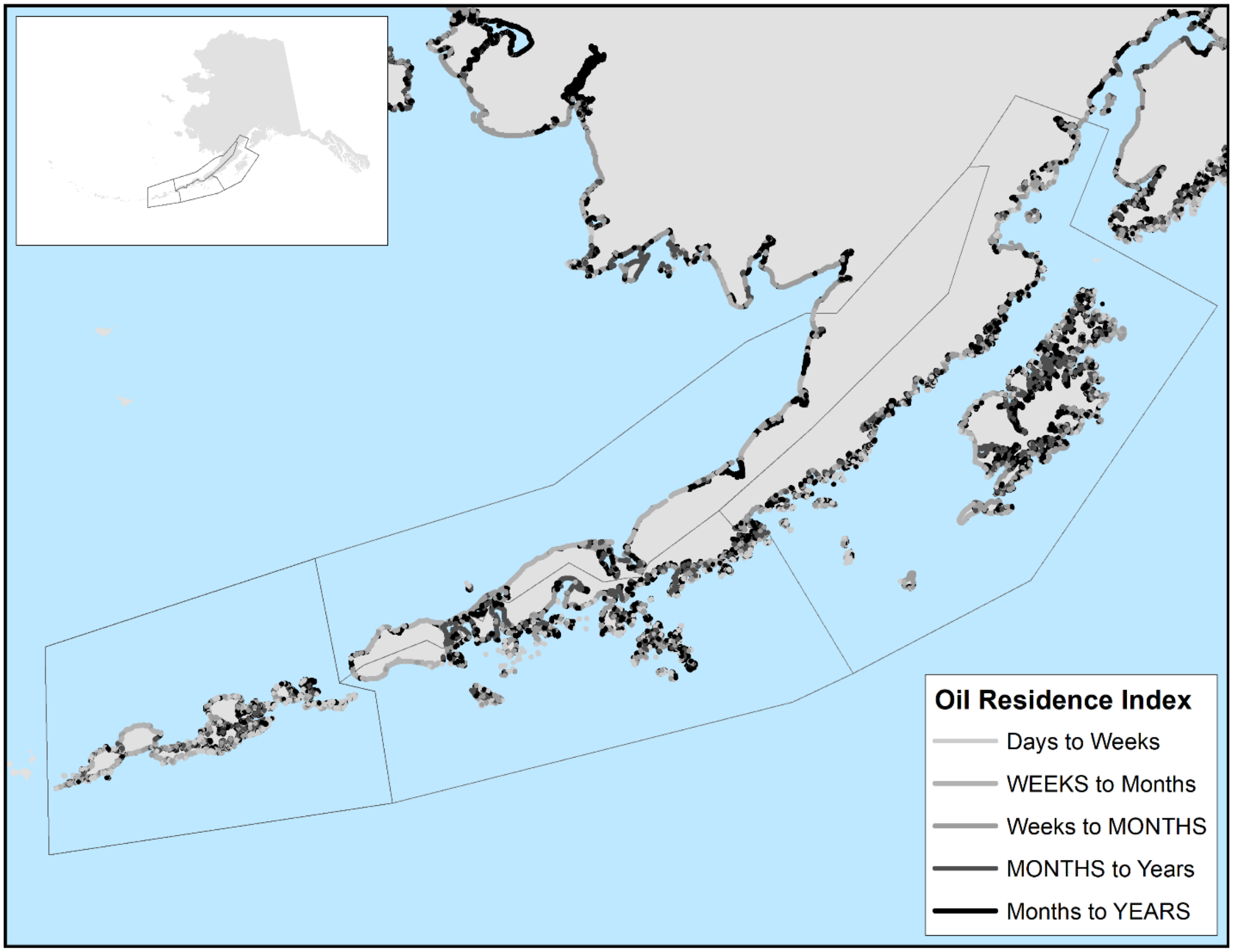

Figure 4.2 Oil residence index represents the assessment of the potential persistence of a crude oil spill that strands on a shoreline. The index is based on the combination of wave exposure and shore type and provided through Shorezone Alaska (Harper and Morris 2014, pp. 66-67).

Ecological condition description

NSO habitat is typically defined in terms of two strata. High density habitat extends from shore to the 40 m depth contour and low density habitat extends from the 40 m depth contour to the 100 m depth contour. The bathymetry data (General Bathymetry Chart of the Ocean [GEBCO] 2020) we used for this document is different than the data used in the 2013 Recovery Plan (NOAA Southern Alaska Coastal Relief Model; Lim et al. 2009, entire). Using this sea floor depth criteria, the total area (up to 100 m depth contour) of suitable SW NSO habitat per management unit ranges from a low of 12,999 km^2 in the Eastern Aleutians to 50,640 km^2 in Bristol Bay.

The distribution of SW NSOs is patchy. However, SW NSOs are locally abundant throughout this area. There appears to be unoccupied habitat in Alaska, particularly in portions of the Aleutian archipelago and the Pribilof Islands (Bodkin 2015, p. 45).

Within the 100 m depth profile of SW NSO habitat exists substantial variation in the physical environment including sea floor substrate and wave exposure. Additional variation in nearshore vegetation exists, which is related to the physical environment, variation in climate (e.g. temperature, salinity), and interactions with other species through competition and herbivory.

NSOs can have strong limiting effects on herbivores, such as sea urchins, which can have cascading effects on the structure and composition of marine vegetation (Estes and Palmisano 1974, p. 1060; Estes and Duggins 1995, p. 96). Variation in the physical and biotic environment can also influence where sea otters occur through availability of food and habitat resources.

Currently, there is limited information on the distribution of macro-invertebrates, which serve as a primary food resource, in the SW NSO range. Most field data is collected at the local and regional scales, with limited information on distribution across all sea otter management units. Recent efforts by the Shorezone Alaska program (NOAA 2020b) have started to fill the information gap on the distribution of coastal macro-algae (e.g. kelps) and seagrasses (e.g. eelgrass), as well as the physical environment (e.g. substrate, wave exposure). Information on the spatial variation in aquatic vegetation, prey resources, and physical-environmental conditions can help refine our estimates of SW NSO habitat, and in turn, estimated SW NSO carrying capacity across their range (Tinker et al. 2019, p. 1087).

Shorezone is a coastal habitat mapping system spanning British Columbia, Oregon, Washington, and two thirds of Alaska. Since 2001 more than 75,000 km of Alaska's coastline has been mapped (Harper and Morris 2014, p. 5). The largest remaining tract of Alaska coastline to be mapped is the Aleutian chain west of Umnak Island. Maps of coastal vegetation and physical environment were created from spatially referenced, oblique aerial photographs and videos recorded by helicopter at an altitude of ~100 m along the coastline. Flights occurred during the spring and summer at low tide. The end products are available through an online searchable database and web platform (NOAA 2020b). Available spatial products relevant to SW NSOs include shapefiles of seagrass, numerous kelps, and the physical environment including substrate and wave exposure. These layers are available for four of the five MUs for SW NSOs. Habitat maps for the Western Aleutians MU are not yet available.

Subtidal kelps in southwestern Alaska include the canopy-forming bull kelp (*Nereocystis luetkeana*) and dragon kelp (*Eularia fistulosa*) (Fig. 4.3). Lower intertidal and nearshore subtidal macro-algae in southwestern Alaska include understory kelps Alaria species (e.g. *Alaria marginata*), soft brown kelps (*Saccharina latissimi*, *Cystoseira sp.*, *Sargassum muticum*), and dark brown bladed kelps (e.g. *Laminaria setchelli*, *Lessoniopsis littoralis*, *Laminaria longipes*, *Laminaria yezoensis*) (Fig. 4.4).

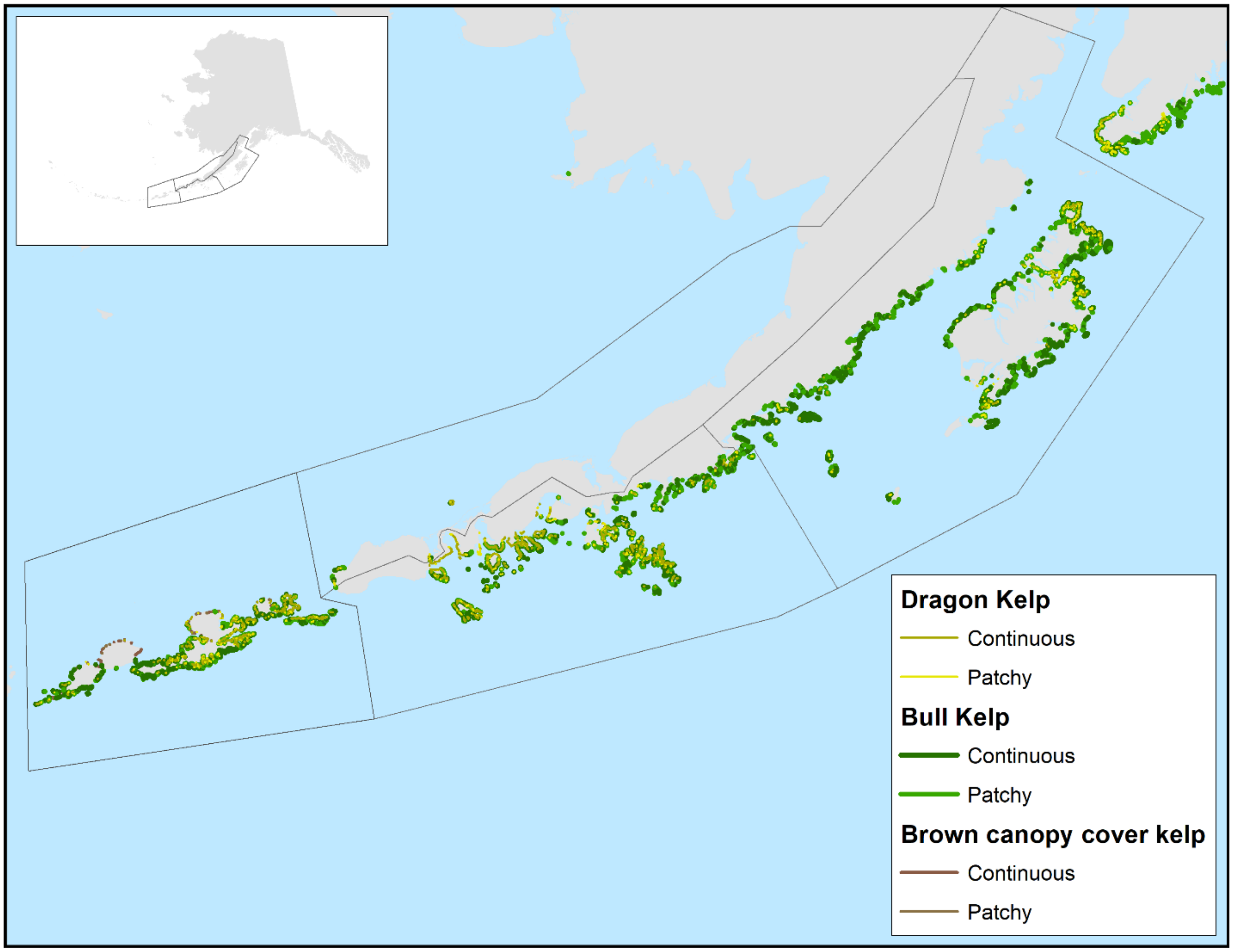

Figure 4.3 Distribution of canopy-forming dragon kelp (*Eularia fistulosa*), bull kelp (*Nereocystis luetkeana*), and unidentifiable brown canopy cover kelp across the SW NSOs management units based on Shorezone Alaska coastal habitat mapping system.

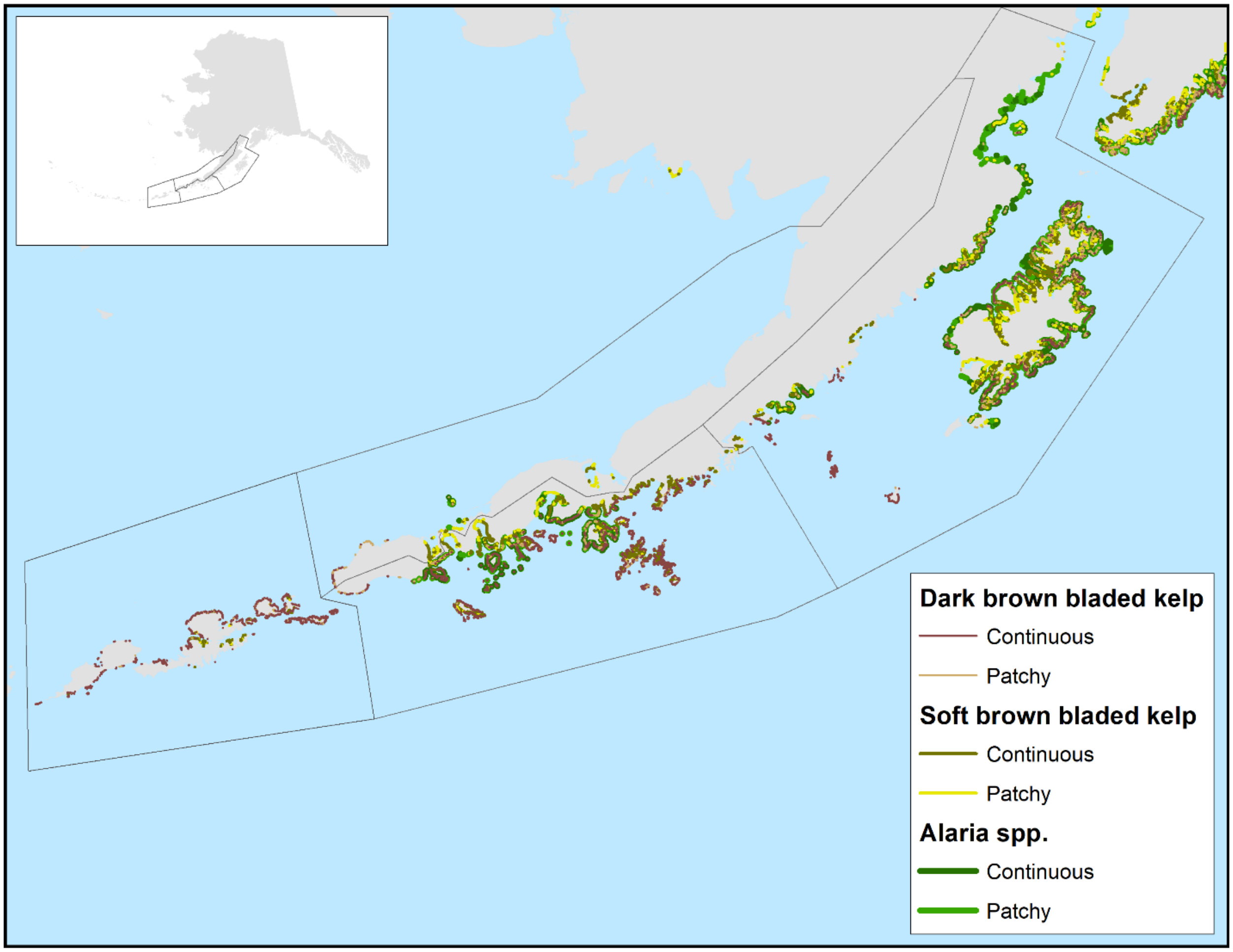

Figure 4.4 Distribution of dark brown bladed kelps (e.g. *Laminaria setchelli*, *Lessoniopsis littoralis*, *Laminaria longipes*, *Laminaria yezoensis*), soft brown bladed kelps (*Saccharina latissimi*, *Cystoseira sp.*, *Sargassum muticum*), Alaria species kelps (e.g. *Alaria marginata*) across four of the SW NSOs management units covered in the Shorezone Alaska coastal habitat mapping system.

Wave exposure and nearshore substrate can serve as an indicator for the potential macro-algae, seagrass, and benthic invertebrate taxa that can occupy the coastal environment (Fig. 4.5). These geographic features are less likely to change inter-annually than coastal vegetation and may therefore serve as useful variables to consider when evaluating spatial distribution and status of SW NSOs through time. In this chapter, we will break down all of the ecological drivers within each MU.

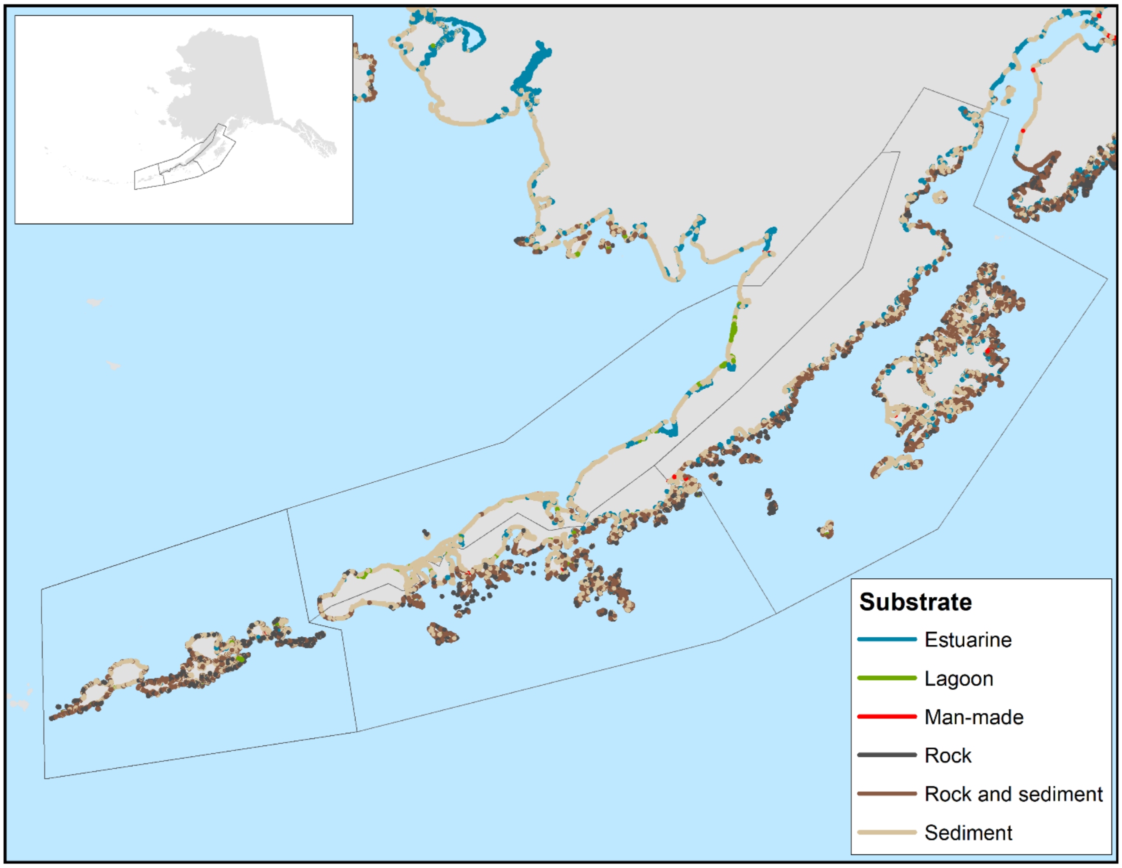

Figure 4.5 The substrate across four of the SW NSOs management units covered in the Shorezone Alaska coastal habitat mapping system. Nearshore substrates limit the types of coastal vegetation and macro-invertebrates that can be supported

Historical population surveys

Based on surveys from 2000-2008, the SW NSO was estimated to be 53,674 (Service 2013a, pp. 2-22). At that time, SW NSOs in three of five management units had declined since the last survey (Service 2013a, pp. 2-23). In contrast, the 2014 stock assessment report for the SW NSO provided a population size estimate of 47,676 for 2008 (Service 2014c, p. 5) and an estimate of 54,771 for 2014. Nonetheless, the Service (2014c, p. 8) concluded that the overall population of the SW NSO had stabilized, albeit at significantly lower numbers compared to historical levels.

Estimates of trend and abundance of SW NSOs are from both aerial and skiff surveys, depending on access and logistics. Generally, the aerial surveys result in abundance estimates, while the skiff surveys, conducted at "index sites", provide trend estimates only.

In spring 2000, Doroff et al. (2003, p. 55) repeated an aerial survey first conducted in 1992 and observed widespread declines in SW NSOs throughout the Aleutian Islands, with the greatest decreases occurring in the central Aleutians. In 2000, the uncorrected count for the area was 2,442 animals, and in 1992 the uncorrected count for the same area was 8,048 (Doroff et al. 2003, p. 59). Burn et al. (2003, p. 147) estimated that the SW NSO population in the Aleutians in 2000 may have been at 8.2 percent of carrying capacity (K) for the area. Since then, no stock-wide survey for SW NSOs has been conducted, though some smaller scale surveys were completed along Kodiak Island in 2014, the north and south Alaska Peninsula in 2016, Eastern Aleutians in 2017 and the Western Aleutians in 2015 (results in sections 4.1.3, 4.2.3, 4.3.3, 4.4.3 and 4.5.3).

Due to logistical constraints, SW NSO population trends are monitored using skiff surveys at five of the more remote islands (index sites) in the Western Aleutians MU. A Bayesian state-space trend analysis (Clark and Bjornstad 2004, p. 3140) based on those skiff surveys from 1993 to 2003 indicated that population trends were strongly negative, with an average rate of decline of approximately 20 percent per year (Service 2013a, p. 4-5). From 2003 to 2015, population trends varied by year and index site, with an overall average growth rate of approximately zero. These results suggest that population trends of SW NSOs have stabilized in recent years in the Western Aleutians, but at a reduced level compared to surveys that were conducted before the decline (Service 2013a, p. 4-5; Service 2014c, p. 7; Tinker 2018, p. 15; section 4.5.3).

Unlike the Aleutian Islands and western Alaska Peninsula, SW NSOs in the eastern portion of the range do not appear to have undergone a population decline over the last few decades. In the Kodiak Archipelago, the Alaska Peninsula coast from Castle Cape to Cape Douglas, and Kamishak Bay in lower western Cook Inlet, SW NSO numbers are stable and may be increasing (Coletti et al. 2009, p. 33; Service 2014c, p. 5; Garlich-Miller et al. 2018, p. 13).

Historical survey methodologies

SW NSOs have been surveyed with a variety of methods over the years and the specific survey method used in the field constrains subsequent statistical modeling and inferences on population trends. Imperfect detection and its two components are important considerations when evaluating sea otter survey field methodology. Detection probability (p) can be conceived as two separate processes. First, availability (a) represents the probability that a sea otter (or at least one member of a sea otter group) is on the surface of the water and available to be counted by an observer (Sólymos et al. 2013, p. 1047; Marsh and Sinclair 1989, p. 1017). Second, perceptibility (q) is the conditional probability that a sea otter (or at least one member of a sea otter group) that was available to be counted was actually detected by an observer in the survey (Sólymos et al. 2013, p. 1047; Marsh and Sinclair 1989, p. 1017). The product of perceptibility and availability represents the overall detection probability ($p = qa$). Generally, survey methods that do not account for both perceptibility and availability are considered biased estimates of animal abundance and often the magnitude of this bias is unknown. Table 4.1 presents a comparison of the most recent survey methodologies for each MU.

SW NSO count data in the Western Aleutians skiff surveys (Table 4.1) do not take into account perceptibility or availability, but counts are assumed to have a consistent relationship to true sea otter abundance in space and time (Pollock et al. 2002, p. 108). Notably, this assumption has never been evaluated for Western Aleutians count data due to the logistical and statistical difficulties of estimating abundance in these remote areas. Nevertheless, count data from select islands in the Western Aleutians provides clear evidence that the population has declined since 1993. However, the magnitude of the decline and the current population trend in the Western Aleutians is uncertain due to the limitations of the count data.

Recent surveys in the Bristol Bay and South Alaska Peninsula MUs in 2016 flew line transects and collected distance data to account for perceptibility in a distance sampling framework (Beatty et al. in review). Field methodology and other considerations precluded researchers from accounting for availability in these surveys. Thus, abundance estimates from the South Alaska Peninsula and Bristol Bay MUs should be considered minimum abundance estimates (Table 4.1).

The Eastern Aleutians survey in 2017 also collected distance data to correct for perceptibility with distance sampling. In addition, observers also conducted focal behavioral observations from the ground during the survey period, which provided an estimate of the proportion of time sea otters spent on the surface to account for availability with a correction factor in a Bayesian framework (Wilson et al. in review). Consequently, estimates of abundance in the Eastern Aleutians survey in 2017 can be considered true abundance estimates (Table 4.1). Surveys in the Kodiak, Kamishak, and Alaska Peninsula MU (2014, 2017, and 2018) have used strip counts paired with intensive search units (Bodkin and Udevitz 1999, p. 19) to account for overall detection probability (p) with a correction factor, but this method confounds availability and perceptibility (i.e. p is estimated, a and q are unknown). Nevertheless, abundance estimates from these surveys can also be considered true abundance estimates (Table 4.1).

In addition to perceptibility and availability, survey timing also may have significant impacts on abundance and density estimates. Brueggeman et al. (1988, entire) conducted multiple surveys in Bristol Bay and South Alaska Peninsula MUs in 1986, and abundances estimates varied considerably among surveys within the same year. For example, the maximum abundance estimate for Bristol Bay subunit B was approximately 2.5 times larger than the minimum abundance estimate for the same subunit in 1986 (Burn and Doroff 2005, p. 274). The large differences in abundance estimates within the same year could be partially attributed to a failure to account for the observation process (perceptibility, availability). However, the size of the difference indicates that abundance fluctuated significantly within the same study area in 1986. We are not aware of any studies that have quantified seasonal differences in sea otter population abundance and density. Thus, we acknowledge that survey timing may impact abundance estimates, but we have no available information to address the issue.

Table 4.1 Sea otter survey characteristics for current conditions. Management unit (MU), survey year (Year), and survey platform are included. Perceptibility accounts for sea otters that are on the surface and available to be counted but are not sighted by observers. Availability accounts for sea otters that are diving during the survey and not available to be counted.

MU	Year	Platform	Availability	Perceptibility	Metric
Western Aleutians	2015	Skiff	No	No	Counts
Eastern Aleutians	2017	Aero Commander (twin-engine fixed wing)	Yes	Yes	Abundance
Bristol Bay	2016	Aero Commander (twin-engine fixed wing)	No	Yes	Minimum abundance
South Alaska Peninsula	2016	Aero Commander (twin-engine fixed wing)	No	Yes	Minimum abundance
South Alaska Peninsula	2016	Hughes 396 helicopter	No	No	Counts
Kodiak, Kamishak, and Alaska Peninsula	2014	American Champion Scout (single engine fixed wing)	Yes[1]	Yes[1]	Abundance
Kodiak, Kamishak, and Alaska Peninsula	2017	American Champion Scout (single engine fixed wing)	Yes[1]	Yes[1]	Abundance

[1] Perceptibility and availability were not explicitly estimated, but both were accounted for in abundance estimates.

In this chapter we will describe the most recent population estimates and trends by the different MUs. However, we caution comparing abundance and density estimates across years due to the different survey methodologies and statistical approaches applied to estimate these metrics as mentioned above.

4.1 **Kodiak, Kamishak, and Alaska Peninsula**

The Kodiak, Kamishak, and Alaska Peninsula Management Unit covers an area of 143,820 km^2. The MU extends from the northwest corner at Lake Clark National Park and Preserve in Cook Inlet south along the coast to Augustine Island and Kamishak Bay, Katmai National Park and Preserve, Becharof and Alaska Peninsula National Wildlife Refuges, Aniakchak National Park, and into Chignik Bay at the southwest corner (Fig. 4.6). Chowiet and Chirikof Island in the Alaska Maritime National Wildlife Refuge comprise the southeastern corner of this MU. The northeast corner includes the Kodiak archipelago, which is separated 40-65 km from the Alaska Peninsula by the Shelikof Strait. Land ownership consists of federal agencies (Bureau of Land Management, National Park Service, the Service), the State of Alaska, Alaska Native, private, and municipal.

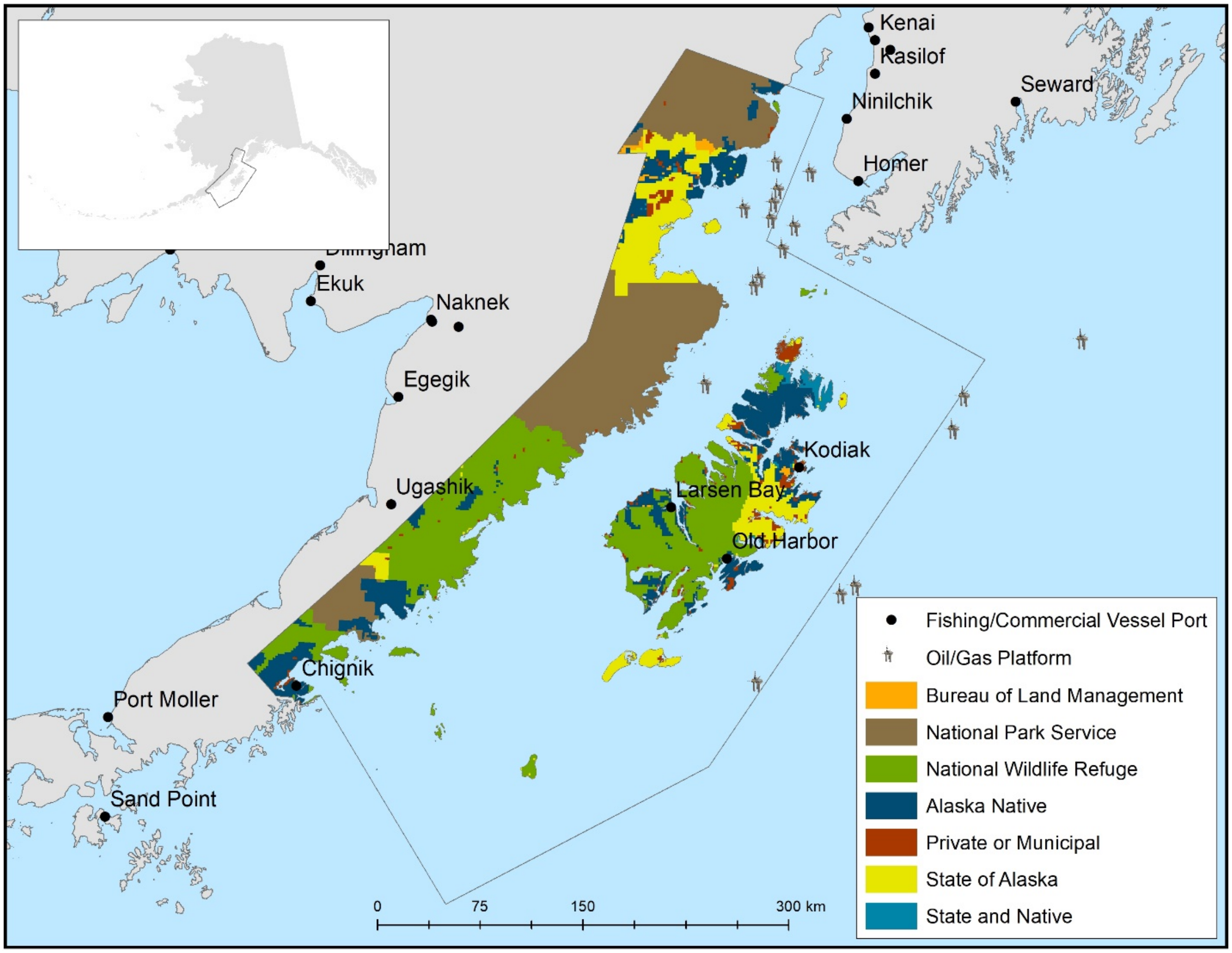

Figure 4.6 Land status and development in the Kodiak, Kamishak, and Alaska Peninsula Management Unit.

4.1.1 *Human Population and Local Economy*

The majority of this MU’s human population resides on Kodiak Island with approximately 13,000 residents (State of Alaska 2020a) and is home to Alaska’s largest Coast Guard Air Station (USCG 2020). Approximately 6,000 residents live in the town of Kodiak, which is the main transportation hub in the region. The Kodiak fishing port is the largest in the state. The Kodiak economy is supported primarily by commercial fishing, with additional support from retail trade, transportation, and tourism. Oil and gas operations have provided additional economic development opportunity in the region. Current oil and gas wells are located in LCI and the Gulf of Alaska (Fig. 4.6). Future oil, gas, and mining operations, including Pebble Mine, have been proposed for development along the northeastern peninsula and LCI.

4.1.2 *Ecological Conditions*

A total coastal area of 45,646 km^2 is considered suitable SW NSO habitat (<100 m depth). Within this area, 30 percent (14,250 km^2) is considered high SW NSO density habitat (<40 m depth) and 70 percent as (31,396 km^2) low SW NSO density habitat (40 m – 100 m depths; Fig. 4.7). The southern coast of the Alaskan Peninsula and western coast of Kodiak Island experience lower levels of wave exposure than other portions of this MU. This is due to Kodiak Island serving as a natural barrier from the Gulf of Alaska and a large number of protected waters along the jagged coastline (Fig. 4.8). Coastal substrate is comprised primarily of rock and sediment and scattered man-made developments. Estuaries and lagoons are uncommon in this MU relative to other MUs (Fig. 4.5). The physical environment is well suited to support canopy-covering brown kelps, including dragon kelp (*Eularia fistulosa*) and bull kelp (*Nereocystis luetkeana*), which are widespread except for the northeastern section of the MU. Dark brown bladed kelps (e.g. *Laminaria setchelli*, *Lessoniopsis littoralis*, *Laminaria longipes*, *Laminaria yezoensis*), soft brown bladed kelps (*Saccharina latissimi*, *Cystoseira sp.*, *Sargassum muticum*), and *Alaria* species kelps (e.g. *Alaria marginata*) are also widespread, but are less common in portions of the southern Alaska Peninsula near Becharof and Alaska Peninsula National Wildlife Refuges (Fig. 4.3 and 4.4). Eelgrass is distributed around Kodiak Island and in scattered patches along the southern coast of the Alaska Peninsula.

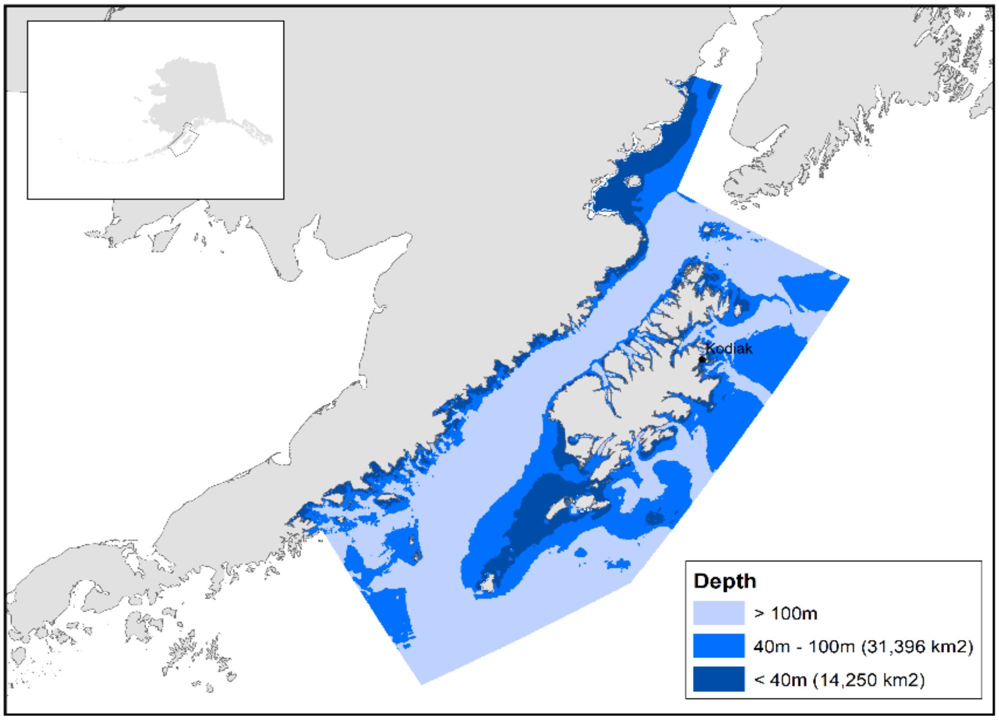

Figure 4.7 Sea floor depth categorized as < 40 m (high sea otter density strata), 40 m – 100 m (low sea otter density strata), and > 100 m in the Kodiak, Kamishak, Alaska Peninsula Management Unit. Total sea otter habitat (45,646 km^2) is listed per strata in parentheses.

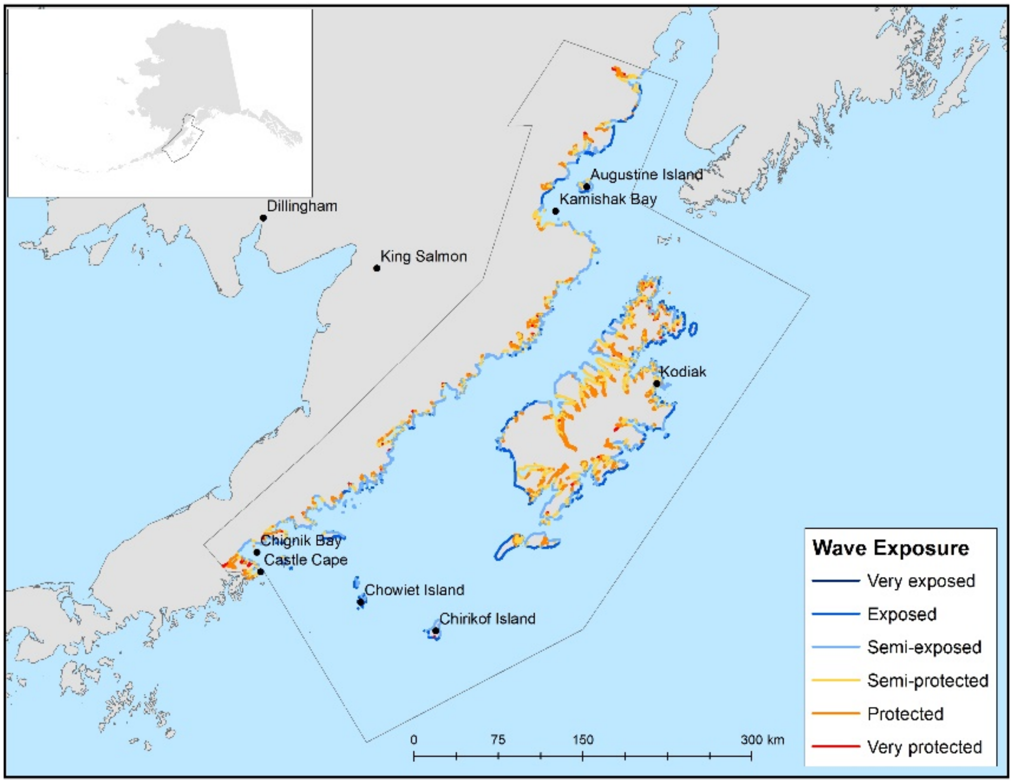

Figure 4.8 Wave exposure in the Kodiak, Kamishak, Alaska Peninsula Management Unit identified from Shorezone imagery.

Information on distribution and abundance of macro-invertebrate prey species are available along the coastline of Katmai National Park and Preserve through the vital signs monitoring program initiated in 2006 by the National Park Service and later adopted into the Gulf Watch Alaska (GWA) long-term monitoring program (Coletti et al. 2016, p. 5). Limited information in other portions of the Kodiak, Kamishak, and Alaska Peninsula MU is available on water quality, nearshore vegetation, and invertebrate communities which comprise SW NSO habitat and prey resources.

4.1.3 *SW NSO Population Surveys*

A small remnant population of SW NSO remained in the Kodiak archipelago in the early 20th century (Kenyon 1969, p. 179). The SW NSO population increased from a few hundred in the 1950's to several thousand by the mid-1980's (Cobb 2018, pp. 1-2). In 1989, helicopter surveys (with detection probability accounted for using 'hover counts') were conducted after the Exxon Valdez oil spill along the south Alaska Peninsula (spring) and around Kodiak Island (spring, fall) (DeGange et al. 1995, p. 19). Beginning in the early 1990's more regular SW NSO surveys were initiated using fixed-wing aircraft and skiffs by the Service, U.S. Geological Survey, and the National Park Service using the Bodkin and Udevitz Intensive Search Unit (ISU) method. These surveys have been concentrated in three focal areas, the Kodiak archipelago, Katmai National Park, and Cook Inlet. Below is a breakdown of survey results by area (Fig. 4.9).

4.1.3.1 *Kodiak Archipelago*

Fixed-wing aerial surveys using the Bodkin and Udevitz ISU method have been conducted in 1994, 2001, 2004, and 2014. Observers were trained in advance until the observer achieved a minimum detection rate of 90 percent, as assessed by concurrent observations by boat-based observers (Cobb 2018, p. 3). The pilot attempted to fly at 92 m and maintain an airspeed of 117 km/h. Surveys were flown in two strata: 1) the high density stratum, which extended from shoreline to 400 m seaward, or to the 40 m depth contour, whichever was greatest, and 2) the low density stratum, which began at the boundary of the high density stratum and extended 2 km offshore, or to the 100 m depth contour, whichever was greater. In 2014, for safety reasons, surveys in the low density stratum were constrained to within 12 km of shore (Cobb 2018, p. 3). All SW NSOs were counted, and a correction factor was used following the Bodkin and Udevitz ISU method. The estimated SW NSO population in 1989 (helicopter/hover counts) was 13,536 sea otters (SE = 1,199). SW NSO population estimates from 2001 – 2014 (fixed wing/ISU method) indicated SW NSOs declined to a low of 5,894 (SE = 1,342) in 2001, increased to 11,005 (SE = 2,138) in 2004, and increased slightly to 13,274 SW NSOs (SE = 1,885) in 2014 (Cobb 2018, p. 11) (Table 4.2).

Skiff-based surveys have been conducted by Kodiak National Wildlife Refuge biologists in 2011-2013, 2014-2016, and 2019-2020 (Corcoran 2020, pers. comm.). Surveys in 2014-2016 were conducted in nearshore areas (tide line – 400 m from coastline) and offshore areas (>400 m – 5 km from coastline) using distance sampling methods (Corcoran 2016, pp. 8-9). Population estimates that account for detection probability based on distance data are pending. Unadjusted population estimates based on raw counts from the 2014-2016 surveys indicate SW NSO population size is within the range of recent fixed-wing ISU methods (11,314 – 31,442 sea otters; Corcoran 2016, pp. 20-21).

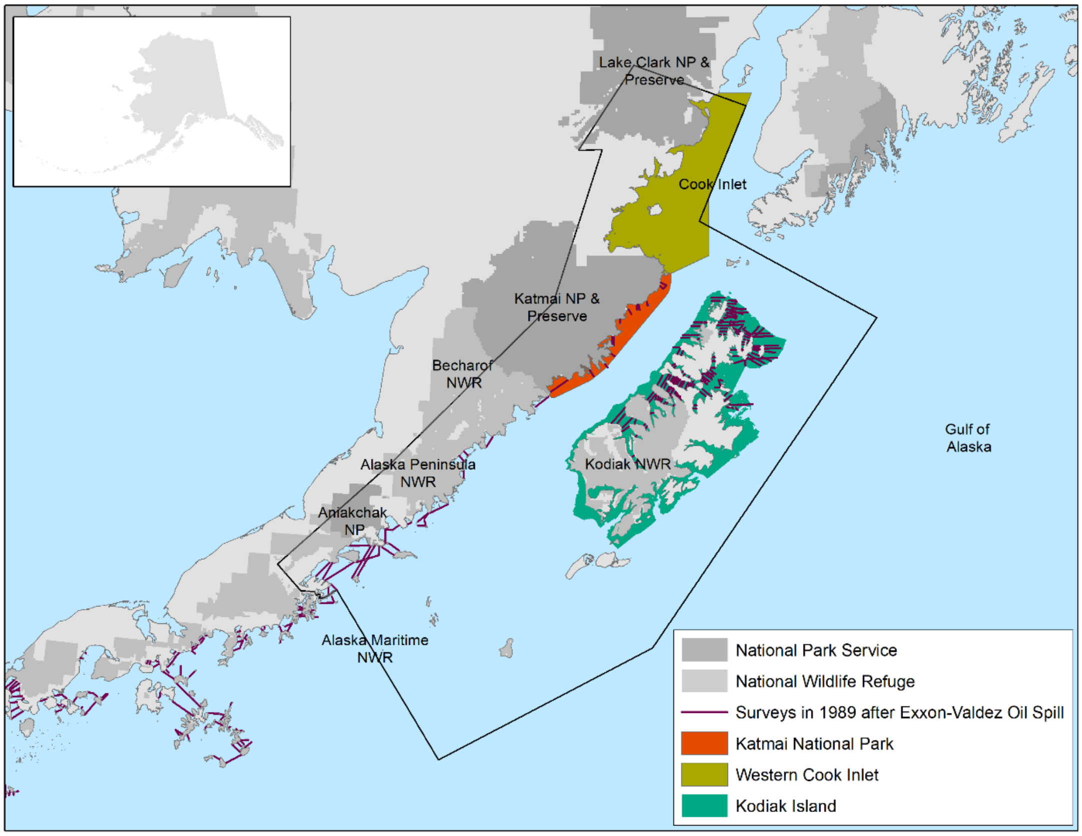

Figure 4.9 Sea otter surveys were conducted by helicopter following the 1989 Exxon-Valdez oil spill. Since the 1990's, sea otter surveys have been conducted primarily by fixed-wing aircraft and skiffs in three focal areas - the Kodiak archipelago, Cook Inlet, and Katmai National Park. The coastline south of Katmai National Park and Preserve to Chignik Bay south of Aniakchak National Park has not been subject to regular sea otter populations surveys.

4.1.3.2 *Katmai National Park*

SW NSO population surveys were conducted in 2012, 2015, and 2018 using the Bodkin and Udevitz ISU method via fixed-wing plane (Coletti et al. 2016, p. 9). Surveys were stratified to areas considered high otter density (between the shore and 40 m depth contour and deep water within the protection of bays) and low density (sea depths of 40 m – 100 m). Population estimates were 7,095 (SE=922) in 2008, 8,644 (SE=1,243) in 2012, 6,873 (SE=959) in 2015 and 6,647 (SE=1,283) in 2018 (Table 4.2; Coletti et al. 2016, p. 10; Esslinger 2020, pers. comm. unpublished data). It is hypothesized that the Katmai National Park population reached carrying capacity in 2012 and was declining towards equilibrium with the environmental carrying capacity in 2015. Shore-based surveys of sea otter carcasses from 2006-2015 revealed a large portion of dead otters were prime-aged, which along with declines in food availability, supports the hypothesis that the sea otter population had exceeded carrying capacity (Coletti et al. 2016, pp. 13-14).

4.1.3.3 *Lower Cook Inlet*

Surveys were conducted in western and eastern Cook Inlet in 2002 and 2017 using the fixed-wing ISU protocols (Bodkin et al. 2003, p. 2; Garlich-Miller 2018, p. 2), but only the western Cook Inlet area falls within the Kodiak, Kamishak, Alaska Peninsula MU. The low density stratum (40 m – 100 m depths) was not flown in the 2017 survey due to safety concerns with a single engine aircraft over open water and the 2002 surveys recorded very few SW NSOs in this strata (Bodkin et al. 2003, p. 6). Population estimates in 2002 in western Cook Inlet were 6,918 (SE=2,290) and increased to 10,737 (SE=2,323) in 2017 (Table 4.2). A high concentration of SW NSO was observed in 2017 in Kamishak Bay near Augustine Island (Garlich-Miller 2018, pp. 19-20).

Within the areas surveyed, the estimated total number of SW NSOs in the Kodiak, Kamishak, and Alaska Peninsula is 30,658 (SE=5,491) based on surveys conducted in Kodiak (2014), Katmai (2018), and Alaska Peninsula (2017). However, the abundance estimate may be biased in an unknown direction and magnitude because surveys were combined from three separate years. The estimated density on Kodiak was 1.56 otters/km^2 (2.54 otters/km^2 in the high density strata), 2.25 otters/km^2 in the Alaska Peninsula (only surveyed high density strata), and 6.46 otters/km^2 in Katmai National Park. All of these surveys used the ISU method, accounting for perceptibility and availability. The total area surveyed was 14,696 km^2, which is approximately 1/3 (32 percent) of the total area of suitable habitat (<100 m depths) in this MU (total suitable habitat = 45,646 km^2; Table 4.2).

Table 4.2 Sea otter population estimates from aerial surveys that accounted for imperfect detection (e.g. Bodkin and Udevitz ISU method, or helicopter – hover counts). An additional section of coastline extending south of Katmai National Park and Preserve extending to Chignik Bay is an area where sea otters likely occur, but limited sea otter population data exists. High density strata is the area extended from shoreline to 400 m seaward, or to the 40 m depth contour, whichever was greatest.

Area	Year	Method	Estimate	SE	Density: overall otters/km^2	Area (km^2)	Density: High Strata	Reference
Western Cook Inlet	2002	Fixed-wing ISU	6,918	2,290	1.13	6,109	1.13	Bodkin et al. 2003
Western Cook Inlet	**2017**	**Fixed-wing ISU**	**10,737**	**2,323**	**2.25**	**4,762**	**2.25**	**Garlich-Miller et al. 2018**
Katmai	2012	Fixed-wing ISU	8,644	1,243	5.96	1,450		Coletti et al. 2016
Katmai	2015	Fixed-wing ISU	6,873	959	4.74	1,450		Coletti et al. 2016
Katmai	**2018**	**Fixed-wing ISU**	**6,647**	**1,283**	**4.64**	**1,431**	**6.46**	**Esslinger 2020 (pers. comm.)**
Kodiak	1989	helicopter-hover	13,526	1,199				DeGange et al. 1995
Kodiak	1994	Fixed-wing ISU	9,817	2,637	1.83	5,362	3.00	Corcoran 2016, Doroff et al. 2006; Cobb 2018
Kodiak	2001	Fixed-wing ISU	5,894	1,342	0.82	7,220	1.46	Corcoran 2016, Doroff et al. 2006; Cobb 2018
Kodiak	2004	Fixed-wing ISU	11,005	2,138	1.93	5,697	3.52	Corcoran 2016, Doroff et al. 2006; Cobb 2018
Kodiak	**2014**	**Fixed-wing ISU**	**13,274**	**1,885**	**1.56**	**8,484**	**2.54**	**Corcoran 2016; Cobb 2018**
TOTAL (recent)			**30,658**	**5,491**				

4.2 **South Alaska Peninsula**

The South Alaska Peninsula (SAP) MU lies on the south side of the Alaska Peninsula between the western tip of Unimak Island to Castle Cape (near Chignik Lagoon) to the east. This MU also contains the Shumagin and Pavlof islands, Deer and Sanak Island, and Sandman Reefs. Land ownership primarily consists of the Service's National Wildlife Refuges (Alaska Maritime, Izembek, and Alaska Peninsula), Alaska Native, private, and municipal entities (Figure 4.10).

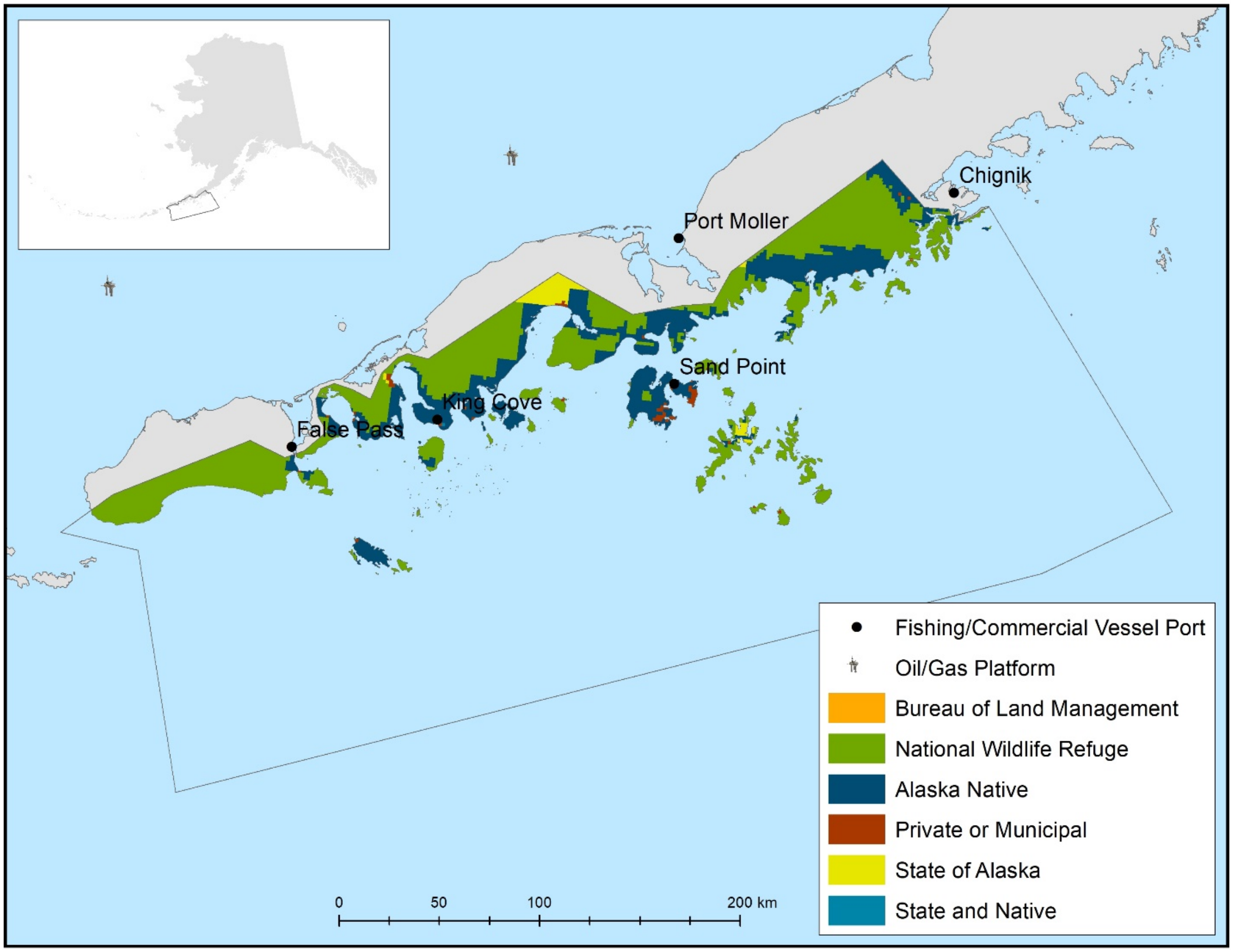

Figure 4.10 Land status and development in the South Alaska Peninsula Management Unit.

4.2.1 *Human Population and Local Economy*

The population of the South Alaska Peninsula MU in concentrated in the communities of King Cove and Sand Point, each of which have approximately 900 residents (State of Alaska 2020a). Sand Point is home to the largest fishing fleet in the Aleutian chain (State of Alaska 2020b), while other communities within the region also have strong ties to commercial fishing. There are several fish processing facilities within the MU, in the communities of False Pass, King Cove, Sand Point, and Chignik (ADEC 2020).

4.2.2 *Ecological Conditions*

A total coastal area of 34,040 km^2 is considered suitable SW NSO habitat (<100 m depth). Within this area, 15 percent (5,158 km^2) is considered high density habitat (<40 m depth) and 85 percent (28,882 km^2) as low SW NSO density habitat (40 m – 100 m depths; Fig. 4.11). The majority of the islands within the MU have exposed coastlines. However, there are large, protected bays (Morzhovoi, Cold, and Pavlof) along the Alaska Peninsula (Fig 4.12). Canopy-covering brown kelps are widespread throughout the MU expect for the southern side of Unimak

Island (Fig 4.3). Dark brown bladed kelp are distributed throughout the MU expect for the southern side of Unimak Island as well (Fig 4.4).

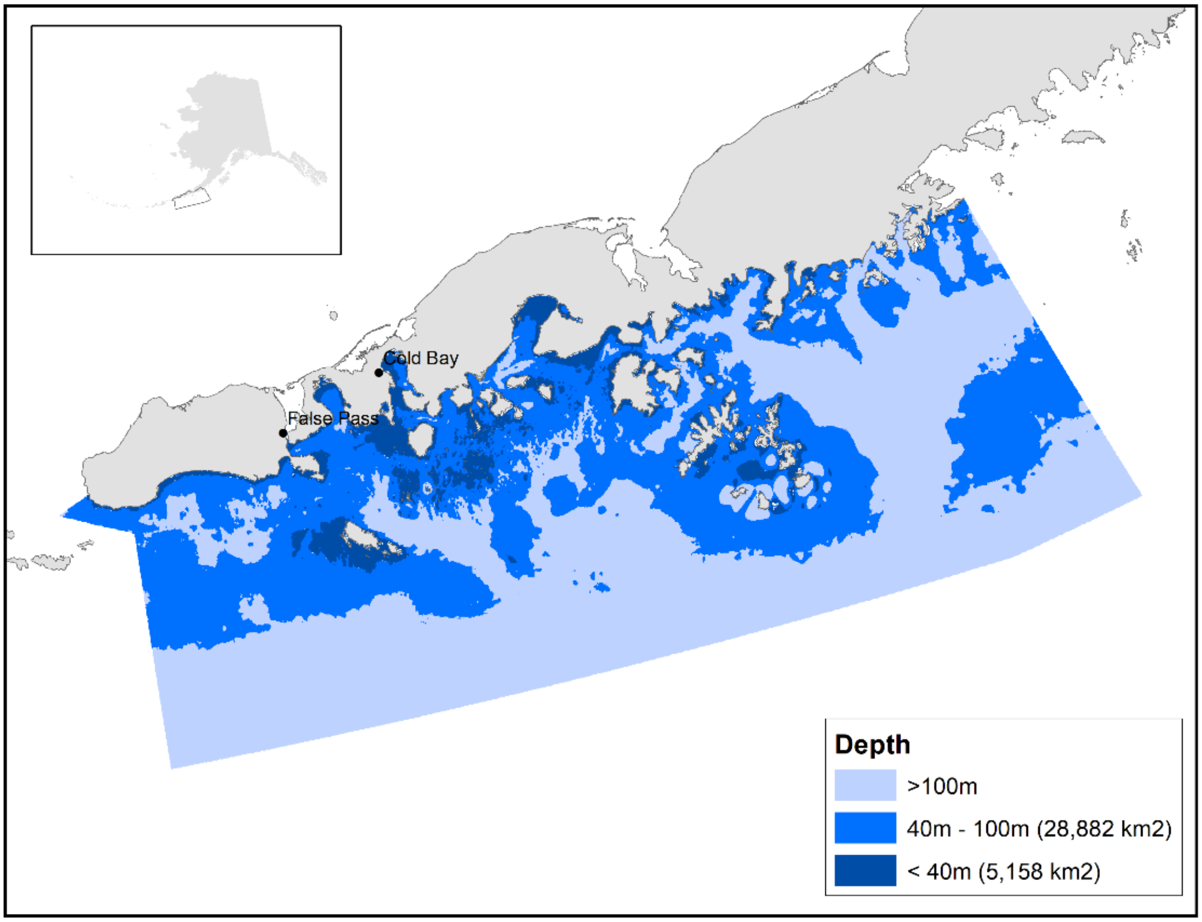

Figure 4.11 Sea floor depth categorized as < 40 m (high sea otter density strata), 40 m – 100 m (low sea otter density strata), and > 100 m in the South Alaska Peninsula MU. Total sea otter habitat (34,040 km^2) is listed per strata in parentheses.

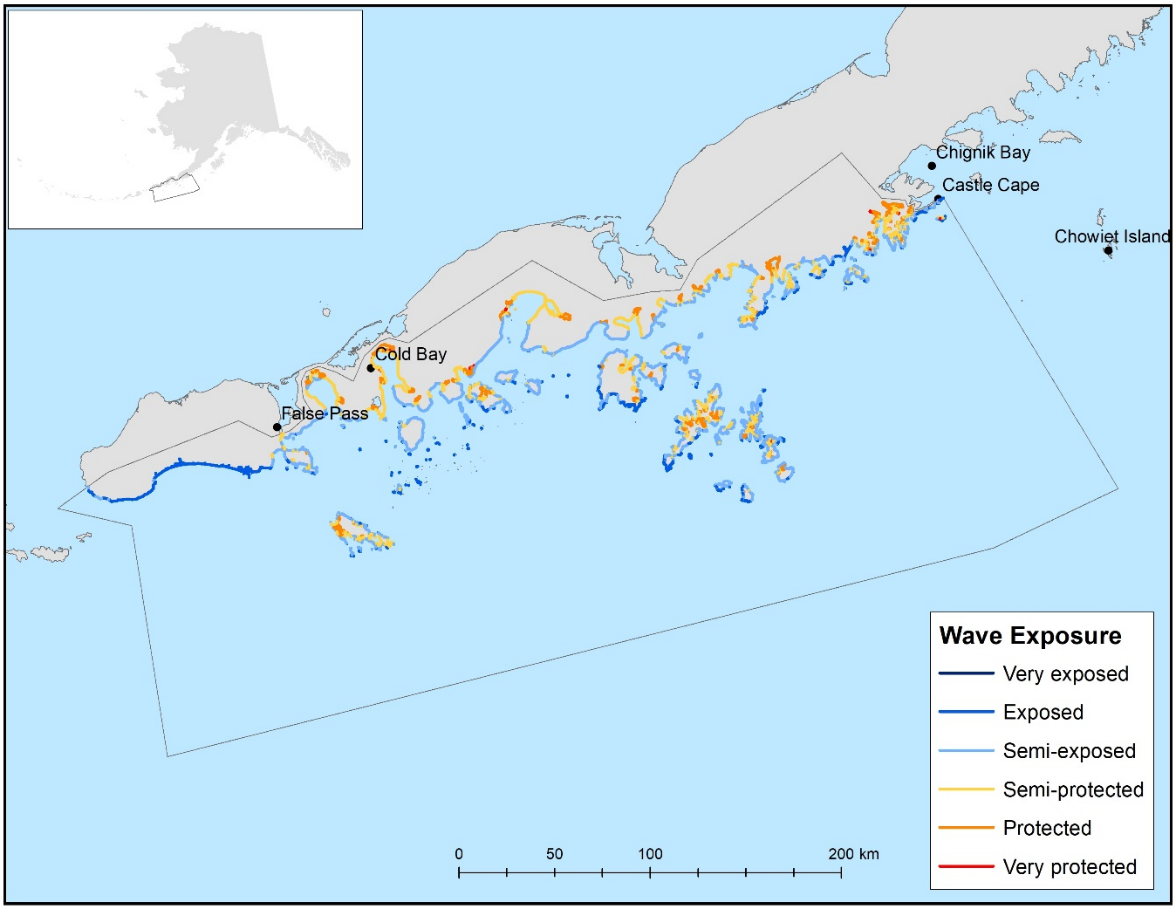

Figure 4.12 Wave exposure in the South Alaska Peninsula Management Unit identified from Shorezone imagery.

4.2.3 *SW NSO Population Surveys*

Fixed wing surveys

Historical information on population size and trends has been sparse for SW NSOs along the South Alaska Peninsula and near islands. Surveys were conducted in 1986 and again in 2001 to assess SW NSO abundance and distribution along the northern and southern Alaska Peninsula. The results from the 2001 survey indicated abundance in offshore habitat had declined by 93-94 percent since 1986 (Burn et al. 2005, p. 270). Specifically, the 2001 survey estimated abundance in the study area as 1,005 sea otters with a group density of 0.035 groups / km^2 and overall density of 0.11 sea otters / km^2 (Burn and Doroff 2005, p 274). In 2016, a comparable aerial survey to the 2001 survey was conducted in offshore habitat, which generated an abundance estimate of 546 sea otters (95 percent CrI: 322–879) (Table 4.3). The corresponding realized density estimate from the 2016 survey was 0.06 sea otters / km^2 (95 percent CrI: 0.03–0.09) with a group density of 0.03 groups / km^2 (95 percent CrI: 0.02–0.04). In the 2016 survey, SW NSO density in high density habitat (from shore to 40 m depth contour) was estimated as 0.15 sea otters / km^2 (95 percent CrI: 0.08–0.24). The 2016 study area encompassed approximately 62 percent of total high density habitat in the MU.

Data from the 2016 South Alaska Peninsula survey were analyzed with different statistical techniques than data from previous surveys. Burn and Doroff (2005, p. 273) did not account for perceptibility nor availability in their abundance estimates, but they restricted their observations to the second and third distance bins. In contrast, Beatty et al. (in review) accounted for perceptibility within a distance sampling framework, but did not account for availability. Furthermore, Burn and Doroff (2005, p. 274) assumed that the observed SW NSO group size of 3.0 was representative of true sea otter group size. In contrast, Beatty et al. (in review) analyzed data from the 2016 survey with models that accounted for the effect of sea otter group size on the probability of perception. For example, Beatty et al. (in review) observed a mean sea otter group size of 3.9 in 2016 whereas the true sea otter group size was modeled with a Pareto distribution with a mean of 2.2 sea otters. Nevertheless, evidence suggests that the SW NSO population in the South Alaska Peninsula MU study area decreased from 2000 to 2016, but the differences discussed above between Burn and Doroff (2005, p. 274) and Beatty et al. (in review) could account for the majority of the decrease. Thus, the SW NSO in the study area has likely decreased since 2001, but the size and biological significance of the decrease are unknown. Overall, methodological differences between the three surveys (1986, 2001, 2016) could not account for the observed decrease since 1986, indicating the decrease in abundance from 1986 to the 2001/2016 surveys is significant and biologically relevant.

Table 4.3 Fixed wing survey results for the offshore study area in the South Alaska Peninsula MU from 1986, 2001, and 2016.

Year	Month	Method	Study Area Abundance Estimate	95% CI	Area (km^2)	Reference
1986	March	twin otter; transects perpendicular to shore	13,900	±6,456	9,469	Brueggeman et al. 1988; Burn and Doroff 2005
1986	June/July	twin otter; transects perpendicular to shore	14,042	±5,178	9,469	Brueggeman et al. 1988; Burn and Doroff 2005
1986	October	twin otter; transects perpendicular to shore	17,500	±5,768	9,469	Brueggeman et al. 1988; Burn and Doroff 2005
2001	April	aero commander; transects perpendicular to shore	1,005	±1,597	9,469	Burn and Doroff 2005
2016	May	aero commander; transects perpendicular to shore	546	322 to 879*	9,575	Beatty et al. in review

*95 percent credible interval

Helicopter surveys

Historical information on population size and trends has been sparse for SW NSOs along the near islands. Helicopter surveys were conducted in 1986 and 1989 to assess SW NSO abundance and seasonal distribution at select islands in the MU in response to the EVOS. In 2001, the Service conducted similar surveys around these islands. The 2001 survey showed a 78 percent decline in SW NSO density, relative to the 1986 survey. However, the 2001 survey was conducted using a fixed wing aircraft instead of a helicopter which may have reduced the visibility of animals. Partial surveys were conducted in 2004 by the Service and again in 2007 and 2008 led by the Aleut Marine Mammal Commission. However, 2016 marked the first complete helicopter survey for SW NSO in this area since 2001. In 2016, the SW NSOs densities ranged from 0 to 2.50 sea otters / km^2 and results indicated an approximately 61 percent decline in density relative to the 1989 survey, which was also conducted with a helicopter (Table 4.4). The helicopter survey results provide a contrast to the low density estimates from the fixed wing surveys, indicating the actual density in the entire SAP management unit is likely higher than the estimated density of 0.06 sea otters / km^2 from the fixed wing surveys.

Table 4.4 SW NSO densities around the Shumigan and Pavlof islands in 1986, 1989, 2001, and 2016. Counts in 2001 were conducted using a fixed wing, aero commander. All other surveys were conducted with a helicopter. **In 2016, Sanak and Caton islands were surveyed using an aero commander.

Island	Coastline (km)	1986	1989	2001	2016
Nagai	342	0.58	1.03	0.33	1.19
Big Koniuji	160	0.35	0.28	0.45	0.02
Turner and the Twins	16	0.41	1.41	0.00	0.16
Bendel	17	2.24	1.03	0.26	0.15
Spectacle	15	1.23	2.00	1.01	0.17
Little Koniuji	95	0.74	0.53	0.00	0.63
Simeonof	49	1.44	0.26	1.06	2.14
Chernabura	30	0.72	0.17	0.00	0.00
Bird	31	2.81	0.89	0.28	0.00
Sanak and Caton	178	0.08	2.36	0.15	0.18**
Andronica	22	1.53	1.70	0.00	0.00
Korovin	65	1.69	1.81	0.30	1.50
Popof	72	1.09	2.53	0.12	0.76
Unga	231	2.67	2.98	1.71	2.24
Wosnesenski	32	0.99	2.19	0.20	0.00
Ukolnoi	38	1.54	8.75	1.20	0.72
Poperechnoi	22	3.95	2.95	0.10	0.00
Dolgoi	94	2.14	2.47	0.35	1.86
Goloi	14	8.77	11.07	0.16	1.07
Inner Illiask	13	6.44	13.08	1.51	2.50
Outer Illiask	17	5.24	44.85	0.51	1.03
Deer	61	4.37	2.91	0.68	0.12
Total		1.46	2.46	0.54	0.95

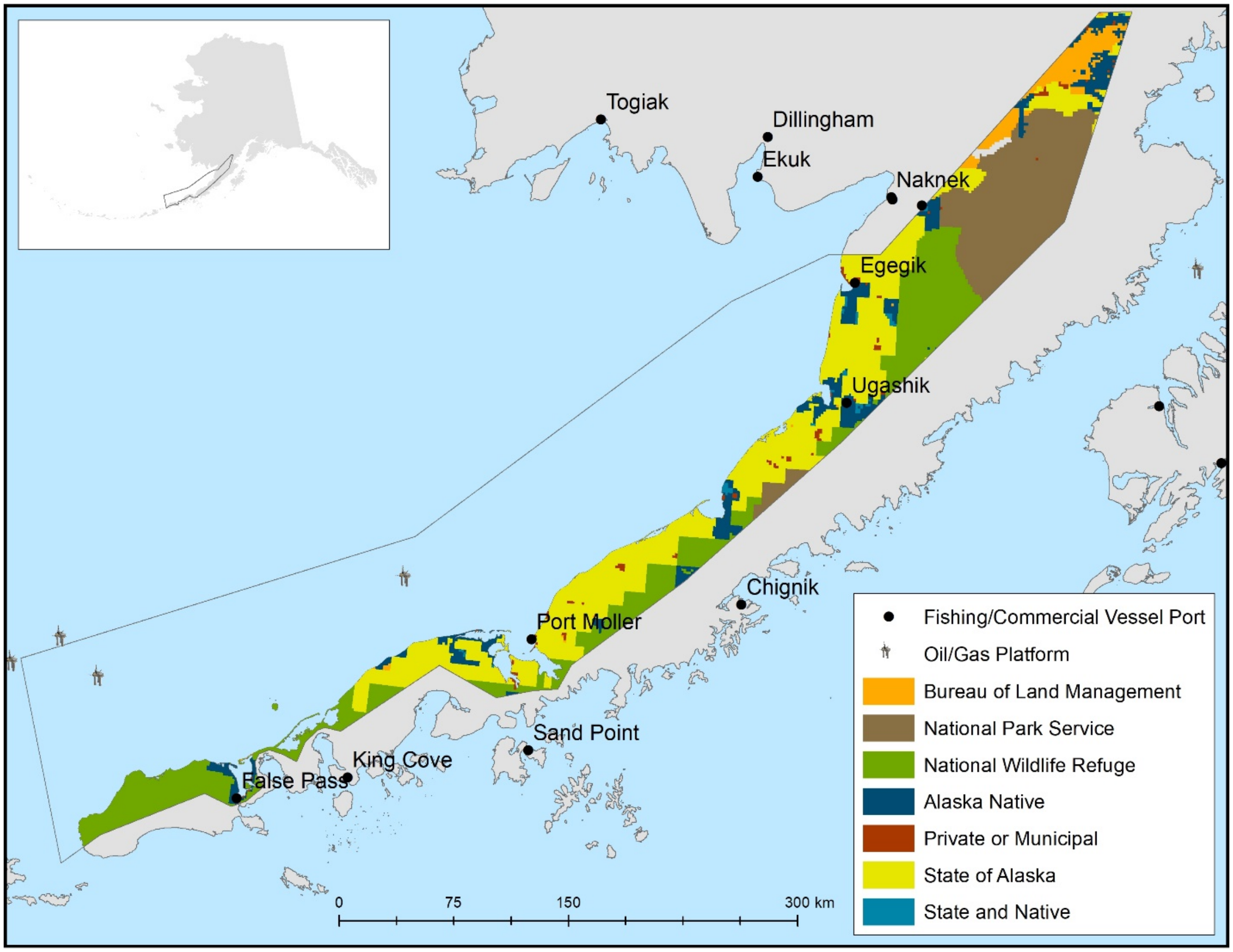

Figure 4.13 Land status and development in the Bristol Bay Management Unit.

4.3 **Bristol Bay**

The Bristol Bay (BB) MU lies on the north side of the Alaska Peninsula. It spans from Unimak Pass (western boundary) to the north side of Egagik Bay (eastern boundary). Lands include those owned by State of Alaska, Alaska Native, Federal, and municipal or private entities (Fig. 4.13).

4.3.1 *Human Population and Local Economy*

The BB MU includes several small communities whose population totals approximately 300 people (State of Alaska 2020a). Commercial fishing is the primary economic activity in the region. Within the MU, there are fish processing facilities in Egegik and Port Moller.

4.3.2 *Ecological Conditions*

A total coastal area of 50,640 km^2 is considered suitable SW NSO habitat (<100 m depth). Within this area, 35 percent (18,101 km^2) is considered high density habitat (<40 m depth) and 65 percent (32,539 km^2) as low sea otter density habitat (40 m – 100 m depths; Fig. 4.14). This MU has the largest suitable habitat area of the five MUs based solely on depth. The majority of the coast is exposed expect for the large bays (Ugashik, Port Heiden, Herendeen, and Bechevin bays) and Izembek Lagoon (Fig. 4.15). Canopy-covering kelps and dark brown bladed kelp are few and scattered along the coastline (Fig 4.3 and 4.4).

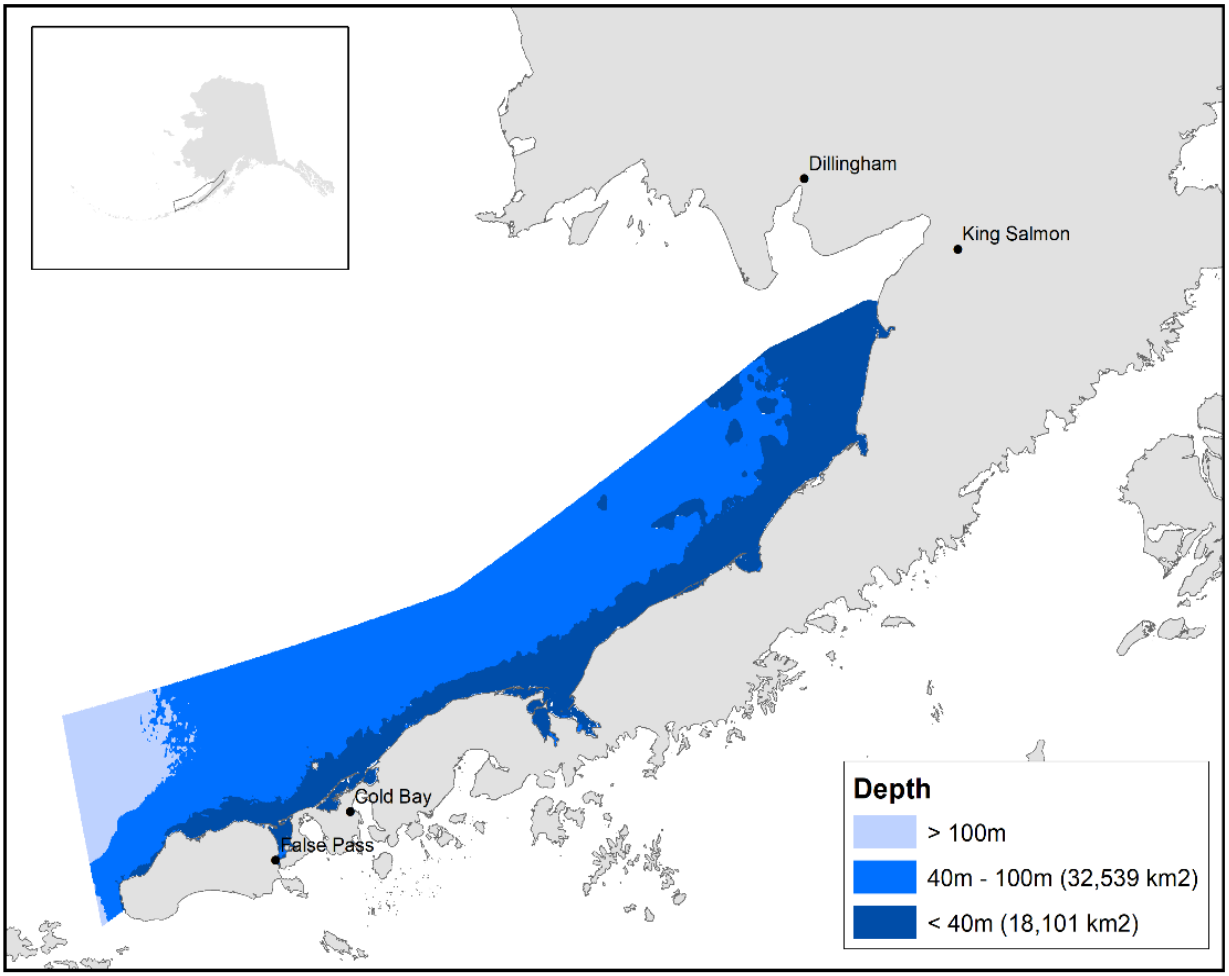

Figure 4.14 Sea floor depth categorized as < 40 m (high sea otter density strata), 40 m – 100 m (low SW NSO density strata), and > 100 m in the Bristol Bay MU. Total SW NSO habitat (50,640 km^2) is listed per strata in parentheses.

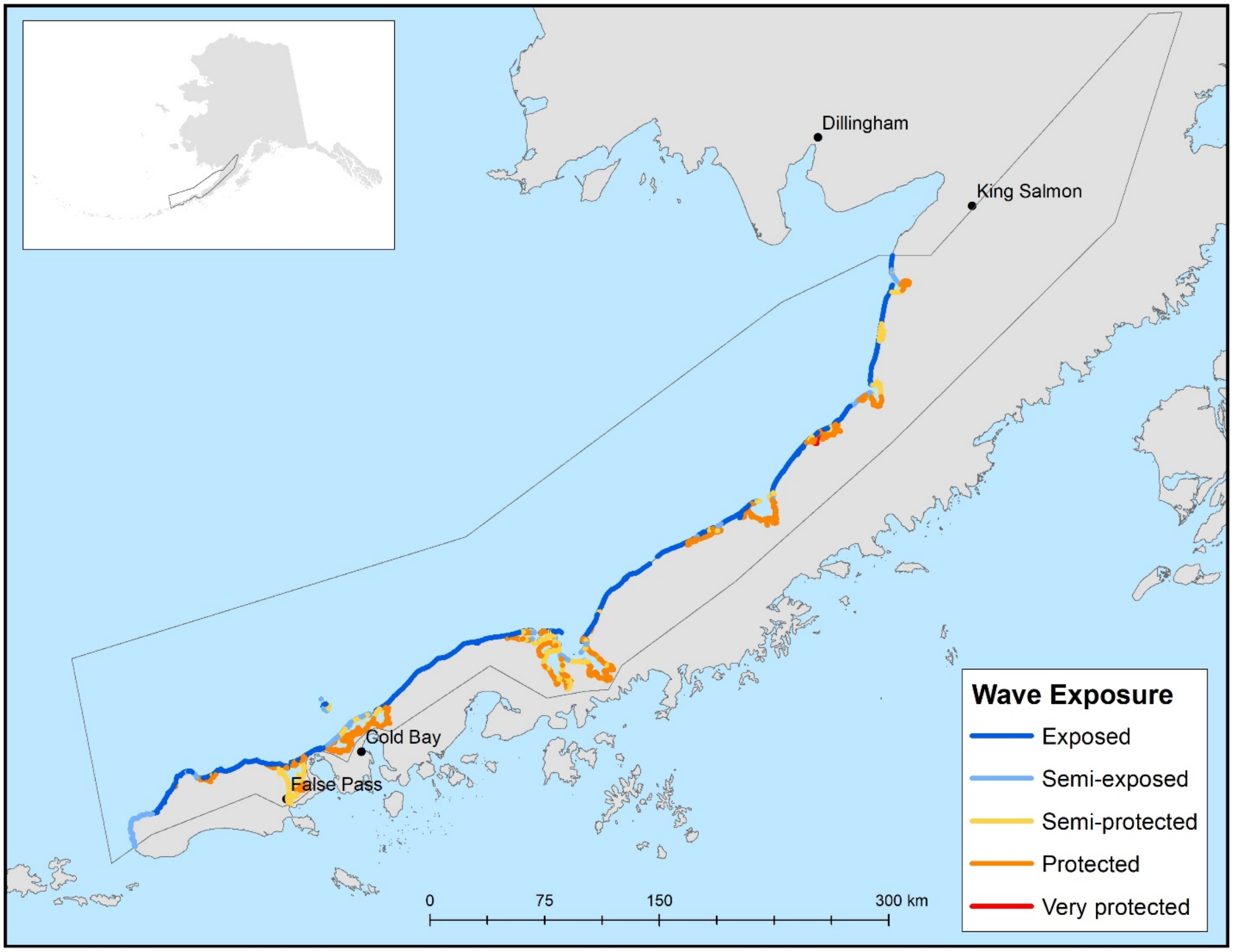

Figure 4.15 Wave exposure in the Bristol Bay Management Unit identified from Shorezone imagery.

4.3.3 *SW NSO Population Surveys*

Historical information on population size and trends has been sparse for SW NSOs in BB. Aerial surveys were conducted in 1986 and again in 2000 to assess SW NSO abundance and distribution in the area. In both surveys, the BB study area was divided into two subunits, Bristol Bay A and Bristol Bay B at the 162° longitude (Fig. 4.16). The results from the 2000 survey indicated abundance estimates had declined by 27-49 percent since 1986 (Table 4.5) in both subunits in BB (Burn and Doroff 2005, p. 270) with most of the observed animals occurring in bays and lagoons (Burn and Doroff 2005, p. 277). Furthermore, Burn and Doroff (2005, p. 274) estimated SW NSO density in the Bristol Bay MU as 0.40 otters / km^2 and group density as 0.20 groups / km^2 with an observed mean group size of 1.89 sea otters based on data from the 2000 survey. In 2016, a similar aerial survey was conducted. The 2016 survey estimated total sea otter abundance in both subunits as 9,733 sea otters (95 percent CrI: 6,412–17,819) with a group density estimate of 0.18 (95 percent CrI 0.16–0.20) groups / km^2 and sea otter density estimate of 0.82 sea otters / km^2 (95 percent CrI: 0.54–1.49) (Beatty et al. in review). SW NSO density in high density habitat (from shore to 40 m depth contour) was estimated as 1.30 sea otters / km^2 (95 percent CrI: 0.86–2.35) from the 2016 aerial survey. The study area for the 2016 survey included approximately 41 percent of the total amount of high density habitat (from shore to 40 m depth contour) in the MU. Abundance estimates for subunits and the total of the two subunits were generated from separate simulations (Table 4.5). Consequently, abundance estimates from the two subunits do not precisely sum to the total reported above.

Data from the 2016 BB survey were analyzed with different statistical techniques than data from previous surveys. Burn and Doroff (2005, p. 273) did not account for perceptibility nor availability in their abundance estimates, but they restricted their observations to the second and third distance bins. In contrast, Beatty et al. (in review) accounted for perceptibility within a distance sampling framework, but did not account for availability. Furthermore, Burn and Doroff (2005, p. 274) assumed that observed sea otter group sizes were representative of true sea otter group sizes. In contrast, Beatty et al. (in review) analyzed data from the 2016 survey with models that accounted for the effect of sea otter group size on the probability of perception. For example, Beatty et al. (in review) observed a mean sea otter group size of 5.67 in 2016 whereas the true sea otter group size was modeled with a Pareto distribution with a mean of 4.45 sea otters. Nevertheless, evidence suggests that the sea otter population in the BB MU study area increased from 2000 to 2016 based on mean densities of 0.40 and 0.82 sea otters / km^2 retrospectively. However, the methodological differences between Burn and Doroff (2005, p. 273) and Beatty et al. (in review) discussed above could account for some of the observed increase in abundance but not all of the observed increase. Thus, the size and biological significance of the population increase are unknown.

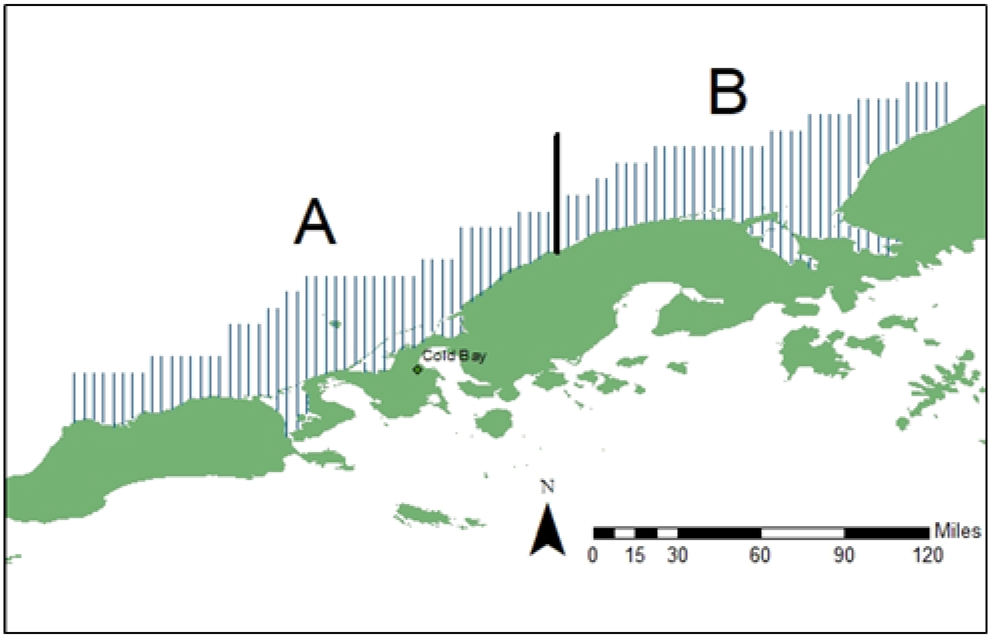

Figure 4.16 Fixed wing survey transects flown in 1986, 2000, and 2016 within the Bristol Bay MU broken into two subunits (A and B) at 162 degree longitude.

Table 4.5 Fixed wing survey results for the study area in the Bristol Bay MU in 1986, 2001, and 2016. Brueggeman et al. 1988 split Bristol Bay into two subunits, Bristol Bay A and Bristol Bay B. Subsequent surveys in 2000 and 2016 also used these subunits. Burn and Doroff (2005, p. 272) reanalyzed data from Brueggeman et al. (1988).

Year	Month	Method	Subunit	Abundance Estimate	95% CI	Area (km^2)	Reference
1986	Mar	twin otter; transects perpendicular to shore	A	7,096	±2,558	6,257	Brueggeman et al. 1988; Burn and Doroff 2005
	June - July	twin otter; transects perpendicular to shore	A	4,236	±1,818	6,257	Brueggeman et al. 1988; Burn and Doroff 2005
	Aug	twin otter; transects perpendicular to shore	A	7,240	±2,978	6,257	Brueggeman et al. 1988; Burn and Doroff 2005
	Oct	twin otter; transects perpendicular to shore	A	6,642	±2,050	6,257	Brueggeman et al. 1988; Burn and Doroff 2005
2000	May	aero commander; transects perpendicular to shore	A	374	±318	6,257	Brueggeman et al. 1988; Burn and Doroff 2005
2016	May	aero commander; transects perpendicular to shore	A	4,472	2,878 to 9,138*	6,333	Beatty et al. in review
1986	June - July	twin otter; transects perpendicular to shore	B	2,238	±840	5,531	Brueggeman et al. 1988; Burn and Doroff 2005
	Aug	twin otter; transects perpendicular to shore	B	1,975	±2,212	5,531	Brueggeman et al. 1988; Burn and Doroff 2005
	Oct	twin otter; transects perpendicular to shore	B	897	±467	5,531	Brueggeman et al. 1988; Burn and Doroff 2005
2000	May	aero commander; transects perpendicular to shore	B	4,354	±3,007	5,531	Brueggeman et al. 1988; Burn and Doroff 2005
2016	May	aero commander; transects perpendicular to shore	B	5,312	3,265 to 10,368*	5,602	Beatty et al. in review

*95 percent credible interval

4.4 **Eastern Aleutians**

The Eastern Aleutians (EA) MU lies between Unimak Pass (eastern boundary) to Nikolski (western boundary) and includes 10 volcanically formed islands with 1,949 km (1,211 miles) of rugged, irregular shoreline. These islands are also known as the Fox Islands. The region includes terrestrial and marine protected areas managed by the Alaska Maritime National Wildlife Refuge. Land ownership consists of Federal (Service and military), the State of Alaska, Alaska Native, and private lands (Fig. 4.17).

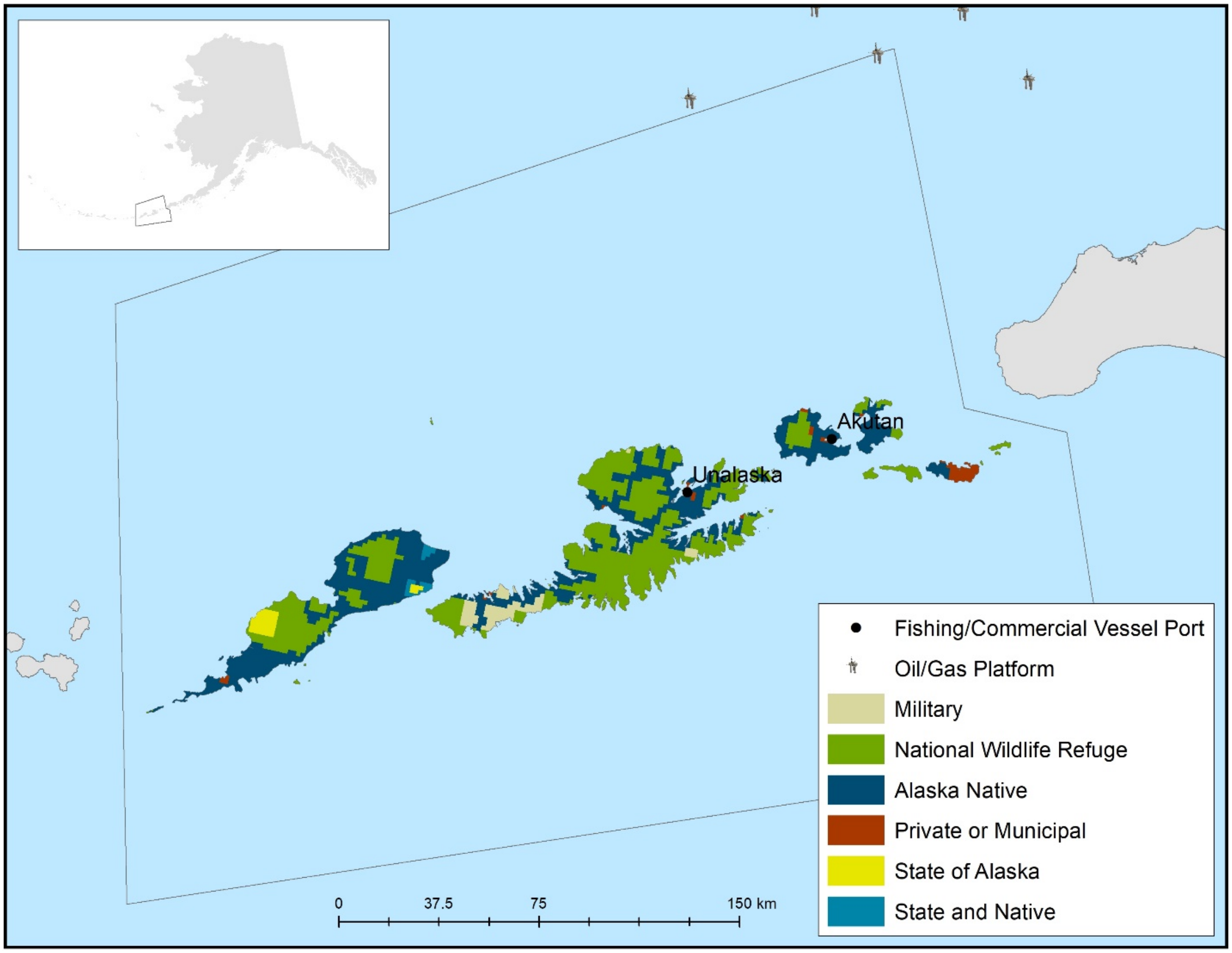

Figure 4.17 Land status and development in the Eastern Aleutians Management Unit.

4.4.1 *Human Population and Local Economy*

The economic hubs in the EA MU are Dutch Harbor, with a resident population of nearly 5,000 and a peak processing population of up to 10,000, and Akutan, with a population of approximately 1,000 (State of Alaska 2020a; Unalaska Comprehensive Plan 2020; City of Unalaska Planning Department, February 2011). Commercial fishing and fish processing dominate the economy in both communities. Dutch Harbor is one of the world’s largest fishing ports and includes four seafood processing plants. Akutan has one of the largest fish processing plants in North America (ADEC 2020). Dutch Harbor is also the home of the western-most container terminal in the U.S. and is one of the most productive ports for transshipment of cargo in Alaska.

In 2015, 174 vessel calls (calls to port) occurred in Dutch Harbor for 4 types of vessels: liquid barges, refrigerated cargo ships, bulk carriers, and container ships (Army Corp of Engineers 2019). In addition, tourism from cruise ships in Unalaska are increasing. In 2019, 18 cruise ships stopped in Unalaska (Boots, 2019).

4.4.2 *Ecological Conditions*

A total coastal area of 12,999 km^2 is considered suitable SW NSO habitat (<100 m depth). This is the lowest amount of suitable habitat of the five MUs. Within this area, 15 percent (1,967 km^2) is considered high density habitat (<40 m depth) and 85 percent (11,032 km^2) as low density habitat (40 m – 100 m depths; Fig. 4.18). The majority of this MU has exposed coastlines with some protected waters occurring in the large bays on Unalaska and Akun islands (Fig. 4.19). Canopy-covering brown kelps are widespread throughout the MU (Fig. 4.3). Dark brown bladed kelp are distributed throughout the MU except for the southern side of Unalaska and northwestern section of Umnak Island (Fig. 4.4).

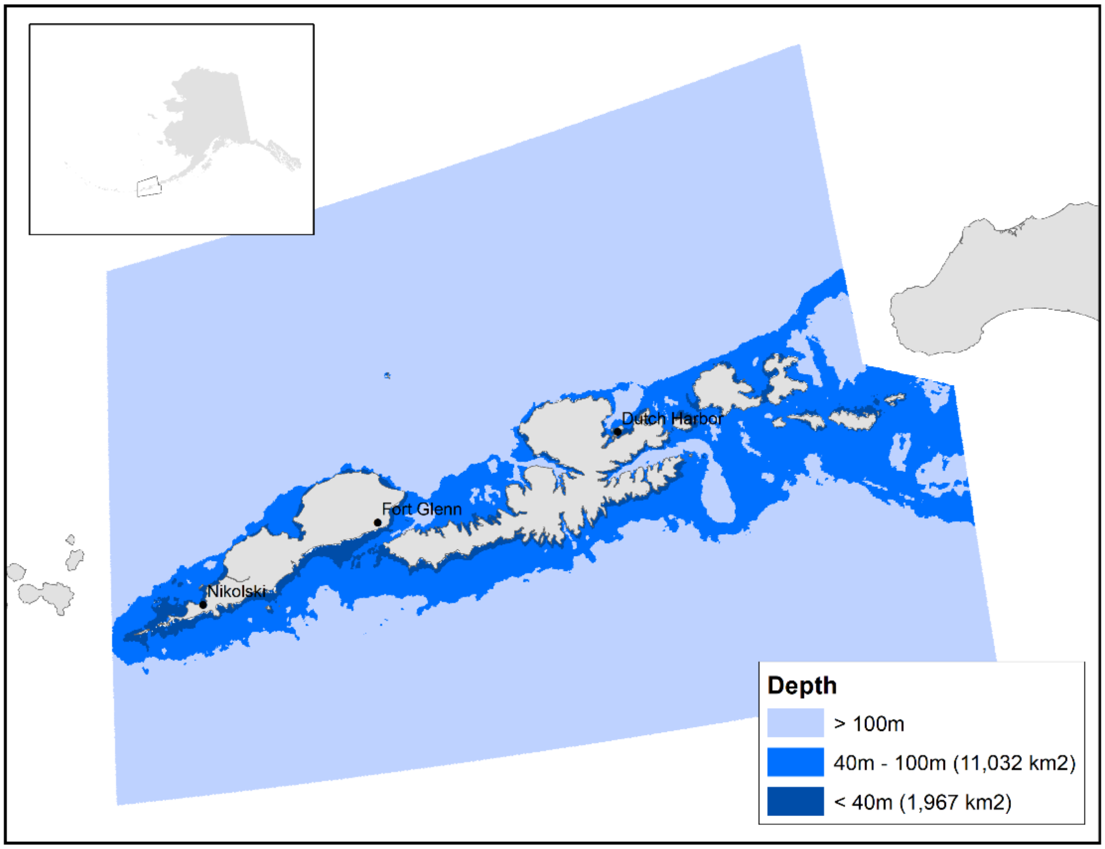

Figure 4.18 Sea floor depth categorized as < 40 m, 40 m – 100 m, and > 100 m to coincide with suitable sea otter habitat in the Eastern Aleutians Management Unit. Total sea otter habitat (12,999 km^2) is listed per strata in parentheses.

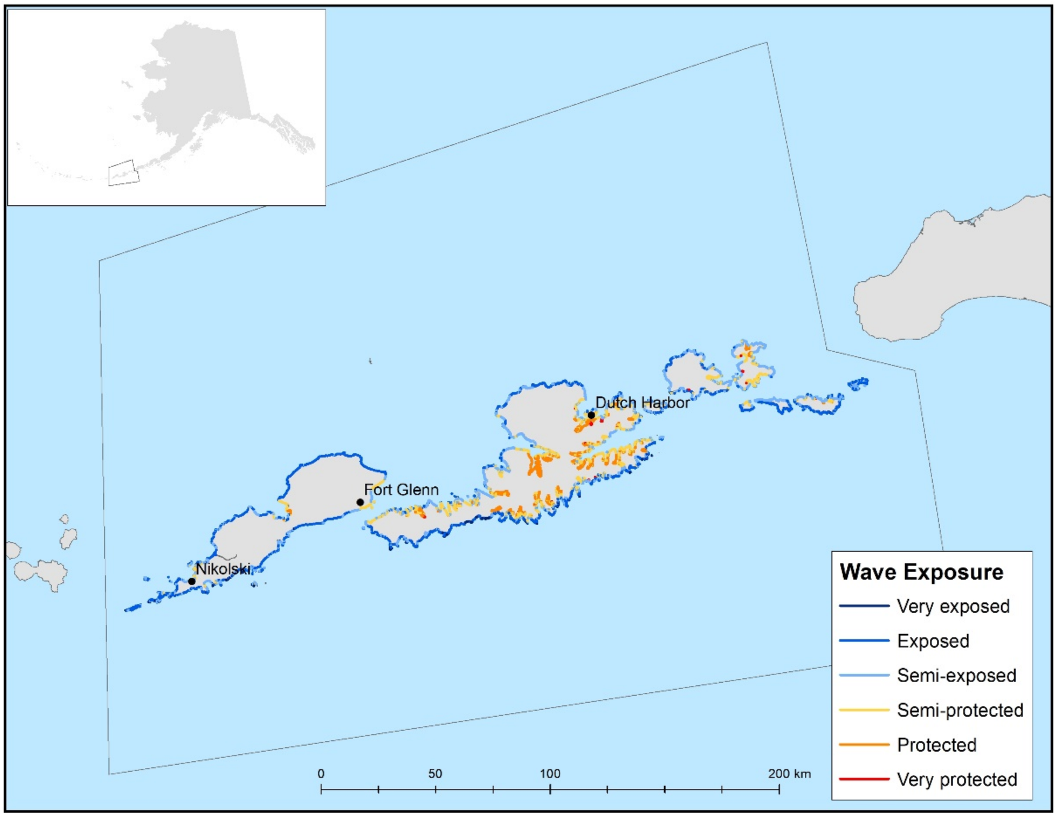

Figure 4.19 Wave exposure categorized by Shorezone Alaska for the Eastern Aleutians Management Unit.

4.4.3 *SW NSO Population Surveys*

The EA MU was surveyed from 1957 to 1965 (Kenyon 1969, p. 140). There were two small populations totaling 41 otters observed in 1962 in the Fox and Krenitzen islands (Kenyon 1969, pp. 169-171). By the time of the next aerial survey in 1992, SW NSO were present throughout Fox and Krenitzen islands (Evans et al. 1997, pp. 17-18). A similar survey was conducted in 2000, and SW NSO abundance had declined from 1992 by an estimated 55 percent in the MU (Doroff et al. 2003, p 59). Since then, partial skiff based surveys have occurred on Unalaska by the Qawalangin Tribe of Unalaska. In 2017, the Service conducted an aerial and skiff based surveys of the MU and estimated population abundance as 8,593 sea otters (95 percent CrI: 7,450–9,984) with a corresponding density estimate of 0.78 sea otters / km^2 (95 percent CrI: 0.68–0.90; Wilson et al. in review). In the 2017 survey, the density estimates in high density habitat (shore to 40 m depth contour) was 3.22 sea otters / km^2 (95 percent CrI: 2.78–3.72). The 2017 study area encompassed approximately 96 percent of high density habitat in the MU.

Although the 2017 abundance estimate appears to indicate a large increase compared to the most recently published minimum population estimate (2,291; Doroff et al. 2003, p. 59; Service 2013a; Table 4.6), it is unclear how to compare the results from the Doroff et al. (2003, p. 59) study with those of Wilson et al. (in review). Specifically, Doroff et al. (2003, p. 59) did not account for the perceptibility, availability, or sampling effort in different study area strata. In contrast, Wilson et al. (in review) accounted for these processes. Given these factors, it is unknown whether the population increased in size since previous surveys, or if the population has remained stable but appears larger given the analytical methods employed by Wilson et al. (in review).

Even though our methods differ substantially from previous survey efforts, we can compare some results to help better understand potential population trends for the EA MU since the mid-1990s. Whereas Doroff et al. (2003, p. 59) did not provide information on SW NSO density for islands within the EA MU, Evans et al. (1997, pp. 17-18) did from their survey in 1992. They estimated SW NSO density within 0.46 km of shore to be 3.75 sea otters/km^2 and 0.27 sea otters/km^2 for offshore areas. When we restrict our abundance estimates to only the area within 0.46 km shore, we estimate a density of 5.14 sea otters/km^2 (95 percent C.I. 4.37 – 6.04). We estimated offshore density (i.e., > 1 km from shore) to be 0.31 sea otters/km^2 (95 percent C.I. 0.24 – 0.39). Thus, our offshore SW NSO densities are very similar with the results of Evans et al. (1997, pp. 17-18). Conversely, our nearshore density estimates are considerably higher. This could easily be the result of Evans et al. (1997, pp. 17-18) not accounting for detection of SW NSO. These results suggest that the number of SW NSO in the EA MU is likely more similar to that found by Evans et al. (1997, pp. 17-18) in 1992 than the estimate obtained by Doroff et al. (2003, p. 59) in their 2000 survey. Therefore it seems likely that even though our population estimate is not directly comparable to the results of previous studies, the EA MU has rebounded from the population declines observed in 2000 (Doroff et al. 2003, p. 59), and is possibly greater than that found in 1992 (Evans et al. 1997, pp. 17-18).

In the SW NSO recovery plan (Service 2013a, p. B-7), a population viability analysis (PVA) was developed to provide recommendations for abundance thresholds for the EA MU and the Western Aleutians MU to be considered relative to up-listing and de-listing the DPS. However, the 2013 PVA was developed with skiff survey data from seven islands in the Western Aleutians MU and did not include any skiff survey data from the EA MU (Service 2013a, p. B-12). Consequently, the most recent population viability analysis (see section 4.5.3) is not applied to the Eastern Aleutians MU because skiff survey data for the EA MU is sparse and incomplete.

Table 4.6 SW NSO population estimates for the Eastern Aleutians MU from surveys conducted in 1992, 2000, and 2017. Density is restricted to within 0.46 km of shore for comparison purposes between 1992 and 2017 surveys. Area surveyed for 1992 and 2017 surveys differed substantially and area and density values are not available for the 2000 survey. Estimates from 1992 and 2000 surveys should be interpreted as minimum abundance estimates whereas the 2017 survey should be interpreted as an unbiased abundance estimate.

Year	Method	Population Estimate	95% CI	Density (otters/km^2)	Area (km^2)	Correction factor applied	Reference
1992	twin otter; parallel to shore	3,470	±594	3.75	921.16	2.38	Evans et al. 1997
2000	aero commander; parallel to shore	2,291	NA	NA	NA	3.58	Doroff et al. 2003
2017	aero commander and skiff; offshore, perpendicular transects	8,593	7,450 – 9,984	5.14	11,079	NA	Wilson et al. in review

4.5 **Western Aleutians**

The Western Aleutians (WA) MU lies between Samalga Pass (eastern boundary) to the western tip of Attu Island. This MU is the longest of the five MUs and spans over 1,225 km (761 miles) of rugged, and remote islands. This MU contains several island groups including Islands of the Four Mountains, Andreanof, Delarof, Rat, Semichi, and Near Islands. The region largely includes terrestrial and marine protected areas managed by the Alaska Maritime National Wildlife Refuge. Land ownership also consists of Federal (Service and military) and Alaska Native lands (Fig. 4.20).

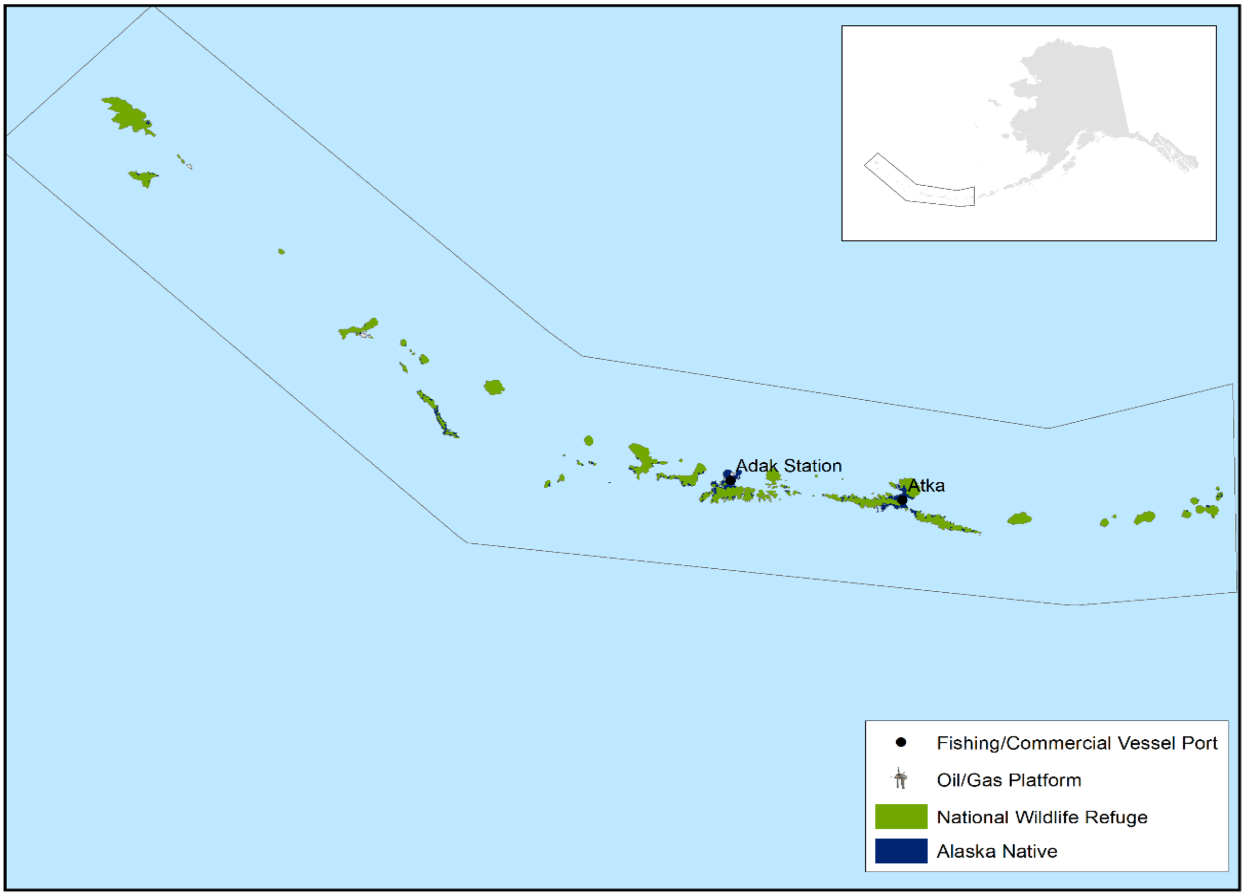

Figure 4.20 Land ownership and economic and development interests in the Western Aleutians Management Unit.

4.5.1 *Human Population and Local Economy*

Most of the WA MU's inhabitants reside in Adak, which is home to approximately 300 people. Until 1997, Adak was home to a large naval base that housed up to 6,000 people (State of Alaska 2020a). It has several deep-water docks, fueling stations and other facilities that serve the fishing industry (State of Alaska 2020c). In addition, fish processing facilities occur on Adak and Atka islands. Very few people live within this MU. Other notable features in this MU include the Eareckson Air Station, an active military site on Shemya Island, and Amchitka Island where nuclear tests were conducted in the 1960's and early 1970's.

4.5.2 *Ecological Conditions*

A total coastal area of 16,110 km^2 is considered suitable SW NSO habitat (<100 m depth). This is the second lowest amount of suitable habitat within the five MUs. Within this area, 22 percent (3,473 km^2) is considered high density habitat (<40 m depth) and 78 percent (12,637 km^2) as low sea otter density habitat (40 m – 100 m depths; Fig. 4.21). We do not have any shapefiles showing exposed coastlines and kelp considerations since this area has not yet been surveyed by Shorezone. However, zooplankton and epibenthic communities have recently been studied in the Aleutian chain. Previous zooplankton studies found a distinct community change to the east and west of Samalga Pass, the divider for the EA and WA MUs, which was correlated with changes in water temperature and salinity (Coyle, 2005, p. 86; Konar et al. 2017, p. 84). The epibenthic communities studied in Bland et al. (2019, p. 12) did not find a distinction between communities east and west of Samalga Pass. However, Bland et al. (2019, p. 9) found the area west of Buldir Strait (includes Agattu, Semichis, and Attu) had the most distinct epibenthic shelf community structure of all the regions surveyed through Unalaska. The top three taxa in the far west, in terms of abundance, were shrimp (*Crangonidae spp*.), sand dollars (*E. parma*), and rock sole (*Lepidopsetta spp.)* (Fig. 4.22). It appears that Buildir Strait is an important biogeographic break in the WA in terms of benthic structure.

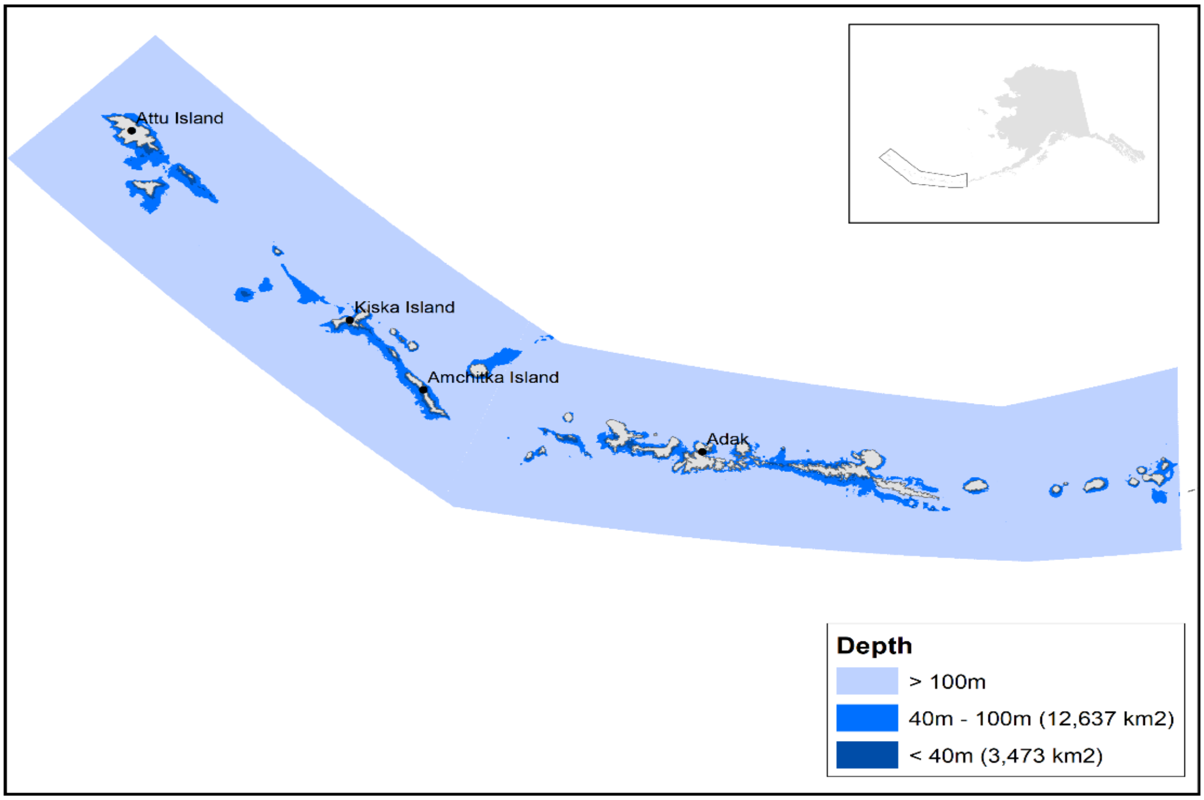

Figure 4.21 Sea floor depth categorized as < 40 m (high sea otter density strata), 40 m – 100 m (low sea otter density strata), and > 100 m in the Western Aleutians MU. Total sea otter habitat (16,110 km^2) is listed per strata in parentheses.

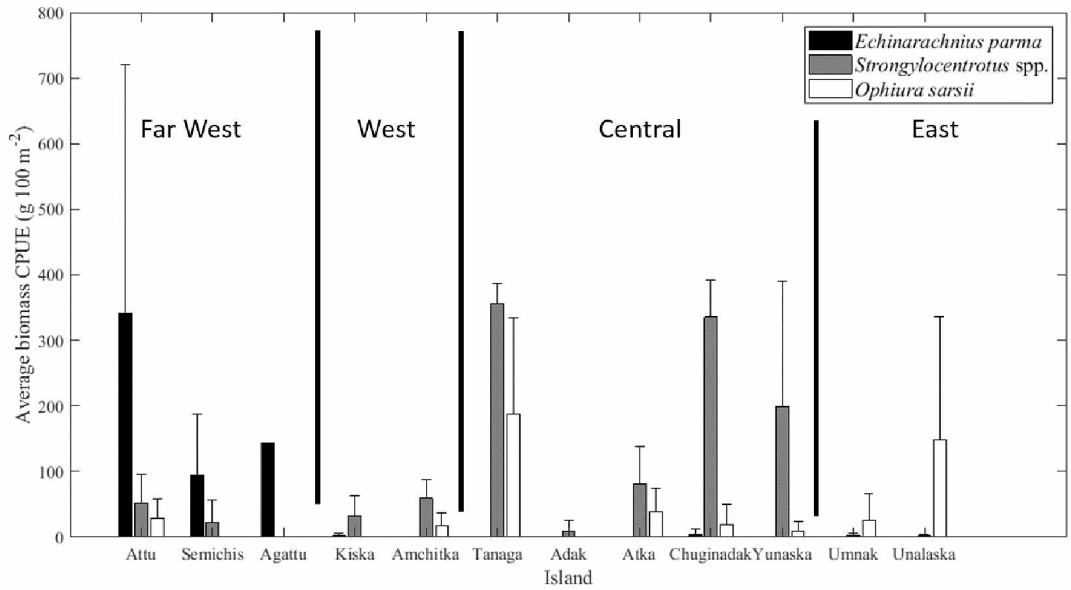

Figure 4.22 Average biomass per island for three epibenthic taxa (sand dollars, *Echinarachnius parma;* sea urchins, *Strongylocentrotus* spp.; and mollusk, *Ophiura sarsii*) found in the Aleutian chain with standard error bars. Figure taken directly from Bland et al. (2019, p. 12).

4.5.3 *SW NSO Population Surveys*

Population surveys have been conducted more frequently in the WA MU compared to other MUs. In 1992 and 2000, select islands were surveyed with twin engine aircraft (Doroff et al. 2003, p. 56). In both surveys, aircraft were flown parallel to shore and two observers counted all sea otters from the shore to approximately 700 m offshore (Doroff et al. 2003, p. 56). SW NSO densities for surveyed islands in the WA MU were estimated by dividing uncorrected counts by the length of the surveyed shoreline (Doroff et al. 2003, p. 57). Aerial survey data indicated a decline of 17.66 percent (±2.98 percent) in sea otter densities from 1992–2000 for the islands of Adak, Amchitka, Attu, Kagalaska, Little Kiska, and the Semichi Islands (Doroff et al. 2003, p. 60).

SW NSO population surveys have also been conducted from skiffs in the WA MU (Table 4.7). Data from skiff surveys were used to develop a population model and conduct a PVA for the WA MU (Appendix A). Briefly, the PVA included three general steps to estimate SW NSO population viability in the WA MU for the 37 major islands. First, all available data are used to estimate demographic parameters. Second, updated parameters from the first step are used to develop a spatially structured population model for all 37 major islands in the WA MU. Third, population dynamics are simulated to examine the probability that sea otters in the WA MU will be functionally extinct in the next 25 years, which was defined as all islands having less than 5 adult females and 1 adult male. The most recent survey in 2015 counted a total of 620 independent SW NSO at seven islands (Table 4.7). The corresponding population estimate for 2015 from an extrapolation of growth rates (lambda) from the seven islands from 2000 to 2015 applied to all 37 islands was 1,852 sea otters with a 95 percent CI of 1,368–2,514 SW NSO (Tinker 2020, pers. comm.; Appendix A). The updated PVA revealed the estimated risk of regional extinction in the next 25 years in the WA MU was >5 percent for a population size of ≤436 sea otters. A subsequent set of simulations indicated that a total population size of 6,450 was required for a <5 percent chance that the population would decrease to ≤436 SW NSO in 25 years.

Table 4.7 Number of SW NSOs counted per linear km for select islands in the WA MU, 1993-2015.

Island	1993	2000	2003	2005	2007	2009	2011	2015
Adak	6.12	1.92	0.82	0.58	0.62			
Agattu			0.36	0.35	0.37	0.79	0.64	0.44
Amchitka	12.98	3.87	2.38	0.67	1.73	1.28	0.73	0.92
Attu		3.52	0.42	0.47	1.01	1.00	1.01	1.02
Kagalaska	2.15	0.48	0.12					
Kiska	5.92		1.17	0.81	0.95	1.32	0.65	0.62
Little Tanaga		0.51	0.17					
Rat				0.51	0.46	0.24	0.32	0.35
Semichis	4.75	2.14	0.38		0.42	0.42		0.32

4.6 **Summary of SW NSO surveys**

Various SW NSO surveys have been conducted in each of the five MUs over the past 6 years. Surveys were conducted in a defined survey area within each management unit so therefore abundance estimates for each management unit represent abundance for the surveyed area only with the exception of the EA MU in 2017, which included the entire MU. Table 4.8 summarizes the most recent surveys. A detailed description of these surveys can be found within this chapter.

Table 4.8 Summary of recent SW NSO surveys in five management units. Area surveyed represents the total area surveyed in the most recent survey effort(s), which includes both high density habitat (≤40 m depth) and low density habitat. *N* represents the abundance estimate from the most recent survey(s) for the specific surveyed area in the corresponding management unit. Blank cells indicate the metric could not be estimated given available data.

				95% CI	
Management Unit	**Survey Year(s)**	**Area Surveyed km^2**	***N***	**Lower**	**Upper**
Kodiak, Kamishak, Alaska Peninsula	2014 - 2018	14,697	30,658	19,896	41,420
Bristol Bay	2016	11,935	9,733	6,412	17,819
South Alaska Peninsula	2016	9,575	546	322	879
Eastern Aleutians	2017	11,079	8,593	7,450	9,984
Western Aleutians	2015		1,852	1,368	2,514

4.7 **Current Conditions: 3 Rs**

4.7.1 *Resiliency*

Resiliency is the ability of a species to withstand environmental stochasticity (normal, year-to-year variations in environmental conditions such as temperature, rainfall), periodic disturbances within the normal range of variation (fire, floods, storms), and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity) (Redford et al. 2011, p. 40). Simply stated, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions.

The SW NSOs are widespread throughout their range. A body of evidence suggests that NSO populations exhibit density-dependent competition for food resources at relatively fine spatial scales (Davis et al. 2019, p. 4). Consequently, NSOs have historically been conceptualized as an apex predator in nearshore marine ecosystems that is regulated by prey availability, but in certain areas populations could also be susceptible to top-down regulation via direct and indirect effects of predation (Davis et al. 2019, p. 5). Although features such as kelp, depth, and food influence SW NSO occurrence, we believe, based on scientific data and observations, that these features are adequate and therefore not a limiting factor at broad spatial scales. Therefore, they were not included in our analysis of resiliency.

To help us understand resiliency among SW NSOs, we broke down current threats by MU (Table 4.11) to see how they influenced resiliency within MU, habitat and SW NSO within MU. We focused resiliency on the density of SW NSO within each MU (Table 4.9); and habitat characteristics such as kelp presence and depth are not limiting factors for SW NSO so we did not include them in our resiliency determination. We defined ≥3 otters / km^2 within the 40 m depth contour as a healthy condition. Although the SW NSO recovery plan identified 3 otters / km^2 as density at carrying capacity for three MUs (Service 2013a, p. 6-3; Table 4.9), we identified several recent studies that provide new information on sea otter carrying capacity.

Specifically, Tinker et al. (2019, p. 1084) estimated mean NSO density at carrying capacity for 12 subregions in southeast Alaska as 4.2 otters / km^2 with 95 percent credible intervals of 2.06 - 7.66 sea otters / km^2. In addition, Coletti et al. (2016, pp. 13-14) suggested that carrying capacity in Katmai National Park is somewhere between 4.74 and 5.96 sea otters / km^2 whereas carrying capacity density in Kenai Fjords National Park is approximately 1 sea otter / km^2. Furthermore, research in California estimated sea otter carrying capacity density of 5.05 otters / km^2 (Laidre et al. 2001, p. 298).

The SW NSO recovery plan also identified 15 otters / km^2 as carrying capacity density for the WA and EA MUs (Service 2013a, p. 6-2). We determined 15 otters / km^2 is likely an overestimate of carrying capacity density based on recent research (Tinker et al. 2019, p. 1084; Coletti et al. 2016, pp. 13 – 14), and uncertainty around the historical data used to generate the estimate (Burn et al. 2003, p. 147; Kenyon 1969, pp. 150, 159, 162). Consequently, evidence suggests that density at carrying capacity is likely greater than 3 otters / km^2 and more than likely less than 15 otters / km^2. Thus, we identified densities ≥3 otters/ km^2 as a reasonable indicator of a healthy population.

We defined a moderately healthy MU as one with a density of 2.99 - 0.75 otters / km^2. The lower bound is based on our best professional judgement, and it not based on specific criteria. However, the lower bound for the moderately healthy category (0.75 otters / km^2) is relatively consistent with habitat specific carrying capacity density estimates for sandy bottom, which is considered the least productive substrate for sea otters. Specifically, DeMaster et al. (1996, p. 81), California Fish and Game (1976, p. 100) and Laidre et al. (2001, p. 298) estimated sandy bottom carrying capacity density as 0.35 otters / km^2, 0.38 - 0.77 otters / km^2, and 0.84 - 1.32 otters / km^2, respectively. Finally, we defined low, or unhealthy, conditions as having a density at or below 0.74 otters / km^2.

Based on our definitions of demographic conditions (Table 4.9), we categorized resiliency of the Eastern Aleutians MU as high, the Kodiak, Kamishak, and Alaska Peninsula MU and Bristol Bay MU as moderate, and South Alaska Peninsula MU and Western Aleutians MU as low (Table 4.10).

Table 4.9 Condition category table, defining high, moderate, and low conditions used to analyze SW NSOs current resiliency.

	Demographic / Distribution Factors
Condition Category	**Density (otters/km^2)**
HIGH (healthy)	High number of otters evenly distributed across the MU ≥3.00 otters/km^2
MODERATE (moderately healthy)	2.99 - 0.75 otters/km^2
LOW (unhealthy)	Low number of otters, patchy distribution ≤0.74 otters/km^2

Table 4.10 Summary of current conditions of the SW NSOs within MUs in relation to overall resiliency based on current densities from Table 4.9. Blank cells represent metrics that cannot be estimated from the survey methodological and available data. High density habitat is defined as areas from shore out to the 40 m depth contour with the exception of Kodiak, Kamishak, and Alaska Peninsula MU, which defined high density habitat as the farther offshore of the 40 m depth contour or 400 m offshore. High density habitat density was derived from the surveyed area.

Management Unit	High Habitat Area (km^2)	High Density (otters/km^2)	Resiliency
Kodiak, Kamishak, Alaska Peninsula	14,250	2.25 – 6.46[a]	Moderate
Bristol Bay	18,101	1.30 (CrI: 0.86-2.35)	Moderate
South Alaska Peninsula	5,158	0.15[b] (CrI: 0.08-0.24); 0.29	Low
Eastern Aleutian	1,967	3.22 (CrI: 2.78-3.72)	High
Western Aleutian	3,473		Low

[a] Range is provided based on three different surveys. Confidence intervals are not available.

[b] Fixed wing survey estimated 0.15 otters / km^2 in high density habitat, and 0.29 otters / km^2 is a combination of densities from both helicopter and fixed wing surveys in 2016.

Table 4.11 List of current primary potential threats to SW NSO and intensity of each stressor. We defined high as a high level of population level effects that occur MU wide; moderate as individual level effects with high chances of localized effects; and low as low level individual effects that are very localized.

Management Unit	**Benthic Communities**	**OA**	**SST**	**Extreme Weather**	**Disease**	**Pollution/ Contaminants**	**Oil Spill**	**Marine predators**	**Land/Avian Predators**	**Commercial activities (including oil & gas)**	**Coastal Development**	**Fisheries Bycatch**	**Subsistence harvest**	**Illegal Take**	**Genetic Diversity**
Kodiak, Kamishak, Alaska Peninsula	low	low	low	low	mod.	low	mod.	unk.	low	mod.	low	low	mod.	mod.	low
Bristol Bay	low.	low	low	low	mod.	low	low	unk.	low	low	low	low	low	low	mod.
South Alaska Peninsula	low.	low	low	low	low	low	low	unk.	low	low	low	low	low	low	mod.
Eastern Aleutians	low.	low	low	low	low	low	mod.	unk.	low	low	low	low	low	low	mod.
Western Aleutians	low.	low	low	low	low	low	low	unk.	low	low	low	low	low	low	mod.

4.7.2 *Redundancy*

Redundancy is characterized by having multiple, resilient populations distributed within the species ecological settings and across the species range (Service 2016b, p. 12). We measure redundancy of the SW NSO based on their fidelity to small areas, their patchy, but wide-spread distribution, and their ability to colonize, eventually, unoccupied habitat. The SW NSO has five distinct management units that are somewhat independent with infrequent exchange of individuals among neighboring units. Based on a recent genetics study, there is gene exchange between the Southcentral stock and SW NSO in and around Kodiak Island and Cook Inlet. These results also show some gene exchange between the Bristol Bay and South Alaska Peninsula (Flannery et al. in review). In addition, resiliency of two of the five management units were categorized as low. Based on these characteristics, we categorize SW NSO redundancy as moderate.

4.7.3 *Representation*

Representation is characterized by the breadth of genetic and environmental diversity within and among populations (Service 2016b, p. 12). The genetic diversity of SW NSOs is low, largely due to decreases in population size due to commercial exploitation, small founding populations, and few source areas to reestablish SW NSOs through translocations. Nonetheless, low genetic diversity has not been identified as a primary cause of the extirpation of any population.

In a recent study, Flannery et al. (in review) estimated mean dispersal distance of SW NSOs based on genetic data as 103 km with 95 percent of potential mating pairs within 414 km, but these estimates should be interpreted with caution because they are based on a series of assumptions regarding effective population size, population abundance, relatedness among individuals, and sampling location. These results indicate that SW NSOs exhibited a pattern of isolation-by-distance, which suggests there are no discrete barriers to gene flow in the SW NSO population (Flannery et al. in review). However, results from Flannery et al. (in review) do not preclude a relatively recent barrier to gene flow that could have emerged in the 1990s.

Environmental diversity of areas occupied by the SW NSO populations varies by location, duration of sea otter occupancy, and the intrinsic characteristics of an area. SW NSOs occupy a wide variety of areas (section 2.5) including rocky substrates, coarse gravels, and fine sands and muds. SW NSOs are able to adapt to these diverse areas because they are dietary generalist that can consume a variety of prey within these different habitats. Based on the low genetic diversity of SW NSOs and high environmental diversity of their range, representation in SW NSOs is moderate.

4.7.4 *Uncertainty*

The adaptive capacity of SW NSOs has allowed them to persist through anthropogenic stressors associated with overharvest, oil spills, shipping, and commercial fishing. Currently, the population exhibits degrees of resiliency, representation, and redundancy that have likely facilitated population persistence and reestablishment through these events as well as past climate warming and cooling, population bottlenecks, low genetic diversity, and small founding populations. Current population trends in the SW NSOs suggest that current conditions are favorable. However, the factors keeping the densities low in the Western Aleutians is unknown.

In the Western Aleutians, predation of dispersing SW NSOs may have served as a selective force that effectively reduced the capacity of the population to disperse. Alternatively, high levels of local food availability and the risk of predation may simply be deterrents to dispersal. Nevertheless, both scenarios generate reduced rates of gene flow among islands in the Western Aleutians. Current dispersal rates among islands in the Western Aleutians and South Alaska Peninsula MUs are unknown.

4.8 **Summary of Current Conditions**

SW NSOs are subject to a number of stressors throughout their range (Table 4.11). Most of these stressors are limited in space and time and are of low to moderate intensity. In addition, there are areas with SW NSOs where the human population is low and anthropogenic impacts are minimal. The effects of climate change to date on SW NSOs and their habitats appear to be minimal or unknown. Within the stock, populations within the four of the five MUs are either stable or increasing. However, two MUs (South Alaska Peninsula and Western Aleutians) have low resiliency despite the low level of threats currently acting upon them. This may be due to cumulative effects of multiple low-level threats could account for low densities; or threats could be higher due to uncertainty associated with threat categories identified as unknown.

5 POTENTIAL FUTURE CONDITIONS

5.1 **Climate Related Threats**

5.1.1 *Ocean Warming and Acidification*

Ocean temperatures are increasing at more than twice the global average in Alaskan waters (Hansen et al. 2006, p. 14289). Warming and increasingly acidified waters are creating oceanic conditions that have not been seen for millions of years (Hoegh-Guldberg and Bruno 2010, p. 1524). These changes will likely not have a strong direct impact on SW NSO physiology given that current and predicted temperatures are within their thermal tolerance. However, given that SW NSOs expend a lot of time and energy feeding to maintain thermal neutrality in a cold ocean, any increase in sea ocean temperatures could be beneficial by reducing that constraint.

Declining sea ice extent in Bristol Bay and upper Cook Inlet may also allow SW NSO to expand their range.

The extent to which SW NSOs can persist and expand their populations will depend in part on the ways in which the local ecosystems respond to elevated water temperatures and ocean acidification. The diverse and productive ecosystems where SW NSOs occur will likely undergo transformations as the community of photosynthesizing organisms (phytoplankton, kelp, and sea grasses) and their consumers (invertebrate and vertebrate animals) are exposed to warmer and more acidic waters (Harley et al. 2006, p. 231). It is expected that some photosynthesizing and consumer species will persist, and others disappear. Range expansion of new species and or invasive species could occur (Hoegh-Guldberg and Bruno 2010, p. 1527; Doney et al. 2012, p. 17). The overall outcome of these changes will include novel assemblages of organisms, including possible emergence of novel ecosystems (Doney et al. 2012, p. 28), with unknown consequences for SW NSO populations.

Global average temperatures have increased by ~0.2° C per decade over the past 30 years (Hansen et al. 2006, p. 14289). Most of this added thermal energy is being absorbed by the world's oceans leading to increase in ocean temperature of 0.6° C over the past 100 years (IPCC 2007a, p. 30). This trend is predicted to continue. Globally, averaged surface and near-surface ocean temperatures are predicted to increase by up to 2° C by 2060 compared to temperatures from 1986-2005 (IPCC 2013, p. 993; Carton et al. 2015, p. 7684). Downscaled regional projections of SSTs for the Bering Sea indicate SSTs in the Bering Sea reach their maximum in August and minimum in March or April (Wang et al. 2012, p. 52). Projected trends for the Bering Sea in December (winter), May (spring), July, and September (summer/fall) to 2100 indicate SSTs increase over time. Estimates vary substantially by season, rate, and magnitude ranging from increases of ≤0.5 - 1.4° C for 2060 and an increase of 2.5° C by 2100. Dorn et al. (2018, p. 13) provided SST projections for the Gulf of Alaska for Representative Concentration Pathway (RCP) 8.5 conditions to 2085. Temperatures are expected to increase by 1.7° C by 2050 and 3.3° C by 2080 based on general circulation model (GCM) ensemble mean, but the range extends from 1.4 - 3.9° C for both periods for 80 percent of the models considered.

Ocean water CO_2 levels have steadily risen in the industrial era causing a decrease in ocean water pH levels of 0.02 pH units per decade over the past 30 years, with the ocean now 30 percent more acidic than in the pre-industrial era (IPCC 2007b, p. 48). The greatest changes in ocean acidification (i.e. decreasing pH) are occurring in the high latitudes where colder waters absorb more of the CO_2. Increasing ocean acidification is associated with a substantial reduction in the concentration of calcium carbonate ($CaCO_3$) (Hoegh-Guldberg and Bruno 2010, p. 1524). As a result, surface waters of the high latitudes are projected to become undersaturated with respect to aragonite by mid-century, with potential negative impacts on shell-forming animals

(Orr et al. 2005, p. 685). Reductions in calcium saturation states can affect shell-forming marine organisms ranging from plankton to benthic invertebrates (e.g. mollusks, echinoderms, crustaceans, corals), as well as carbon fixation rates of primary producers (Doney et al. 2009, p. 172).

Over the next century, ocean surface water pH levels are expected to decline by 0.4 units, which would be the largest change in pH to occur in the last 20 million years (Feely et al. 2004, p. 362). In Alaska, the pH of seawater throughout the range of the NSO is likely to decrease by 0.34-0.35 units by 2095 and aragonite saturation by 0.68-0.79 units (Mathis et al. 2015a, p. 80). In the Gulf of Alaska and southern Bering Sea, aragonite saturation is projected to be around one or a few units below one, depending on the area (Mathis et al. 2015a, p. 79). Aragonite levels below one are potentially corrosive to calcifying organisms, which includes sea urchins, abalone, crabs, mussels, clams, marine snails, marine worms, sea stars, and squid. These SW NSO prey species could experience population declines if they are unable to adjust to these changes (Gazeau et al. 2007, pp. 2-5; Fabry et al. 2008, p. 415; Talmage and Gobler 2009, p. 2076; Findlay et al. 2010, pp. 680-681; Waldbusser et al. 2015, p. 275). Long-term monitoring of benthic invertebrate communities will help identify how the availability of sea otter prey species will change as the ocean becomes more acidic.

The physical environment of the range of the NSO is characterized by historically high levels of variability that can be inter-annual, periodic, or display long-term patterns like regime shifts (Stabeno et al. 2004, p. 859; Overland et al. 2010, pp. 308, 310). However, under projections of climate change, environmental predictions are expected to be unidirectional, most notably with an increasing trend in ocean temperature and ocean acidification. These changing conditions will have implications on the composition and diversity of primary producers and benthic organisms that will propagate through the ecosystem via the food web. Predicting how SW NSOs will respond to altered ecosystems hinges on our understanding of the changes occurring across trophic levels in complex and tightly coupled food webs.

5.1.2 *Primary Production*

Future primary productivity is likely to change due to warming waters and increased stratification (Brown and Arrigo 2013, p. 51). The overall impacts on primary production will likely vary across space, dependent on the taxa in the community and the changes that may occur through time. Identifying the potential impacts on phytoplankton, macro-algae, seagrasses, will help identify some of the changes that could occur at the foundation of the food web in coastal ecosystems where SW NSOs occur.

Changes in phytoplankton abundance can have bottom-up effects on filter-feeding SW NSO prey such as mussels (Menge et al. 2009, p. 389). The impact of increasing temperatures on phytoplankton abundance and diversity in coastal ecosystems will depend on the maximum growth rate, optimum temperature for growth, and thermal niche width of represented taxa. Phytoplankton will maximize growth rates at their optimal temperature and these rates will decline at temperatures greater or lesser than this optimum (Thomas et al. 2012, p. 1085). If temperatures exceed the thermal niche width, and that taxa is unable to adapt to the changing temperature regime, then that species could disappear from the phytoplankton community (Thomas et al. 2012, p. 1085). High latitude, cold-temperature taxa could be replaced by lower latitude, warmer water taxa shifting north, with potential increases in plankton diversity (Thomas et al. 2012, p. 1087). Phytoplankton are also exposed to increasing ocean acidification, which could be particularly detrimental to plankton taxa with calcium carbonate shells (Tillmann and Siemann 2011, p. 30).

NOAA's Pacific Marine Environmental Laboratory estimated trends in overall large phytoplankton production to 2040 based on three GCMs. Estimates for the southern Bering Sea, Aleutian Islands, Alaska Peninsula, Kodiak Island, Cook Inlet, and Kenai Fjords are available from 2020 – 2039 (2040 excluded because limited only to winter data; AOOS 2018). In general, the linear trend over that period was slightly negative for each region, except the Aleutian Islands which were stable (Fig. 5.1). The most productive region was the Alaska Peninsula coast, followed by the Aleutian Islands with the other regions similar in the amount and trend in large phytoplankton production. For the more northern regions, there is large projected annual variation, most notably in the Alaska Peninsula.

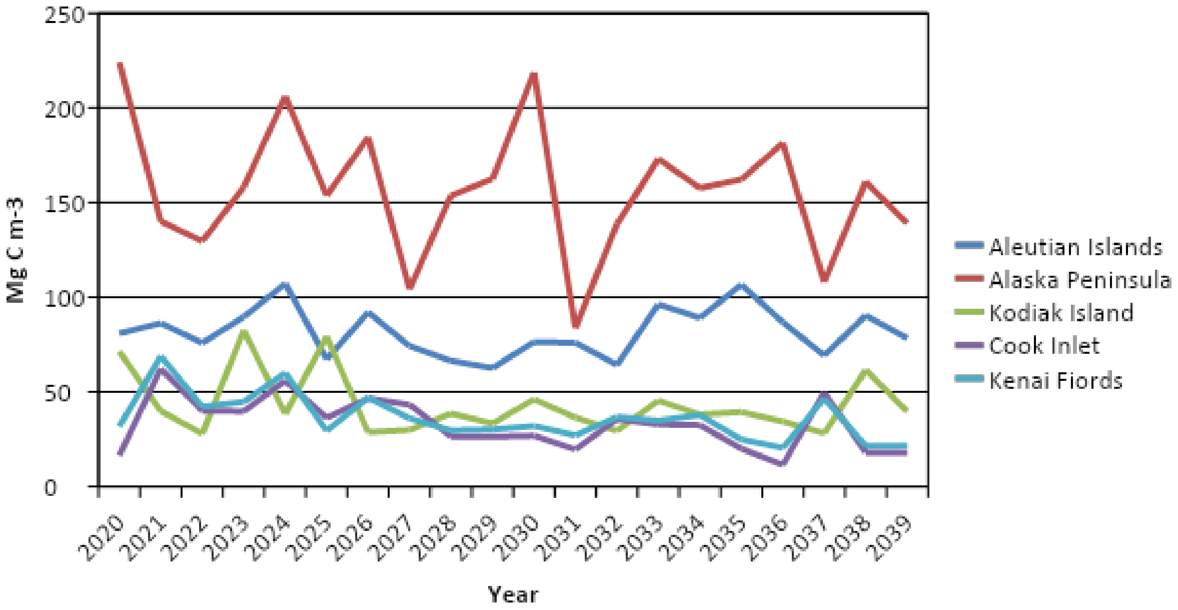

Figure 5.1 Projected trends in the mass of large phytoplankton (milligrams of carbon per cubic meter) from 2020-2039 for five regions within the range of NSOs in Alaska by NOAA’s Pacific Marine Environmental Laboratory based on three global circulation models (AOOS 2018).

A meta-analysis of research investigating the effects of future ocean acidification conditions on kelps indicates an overall positive effect on kelp growth (Kroeker et al. 2013, p. 1888). However, this contrasts with the documented downward trend in the world's kelp forests by 38 percent over the past 50 years (Krumhansl et al. 2016, p. 13785). Gradual temperature warming or heat waves that exceed the physiological tolerance limits of kelp can be lethal to kelp, but also may manifest through reductions in growth and reproduction and increased vulnerability to disease and other drivers (Wernberg et al. 2013, p. 690). Warming waters may also increase the potential for introduced species to take hold and outcompete native species that may be impaired by warming conditions (Filbee-Dexter and Wernberg 2018, p. 9).

In Alaskan waters between latitudes of 40-60°, kelp is more likely to be influenced by sea urchins than temperature (Steneck et al. 2002, p. 442). In the Gulf of Alaska out to the Alaska Peninsula, kelp forests are increasing (Krumhansl et al. 2016, pp. 13786-13787). In the Aleutian Islands, kelp forests have declined in response to sea otter population declines, which has released sea urchins from predation (Estes et al. 2010, p. 856). A recent experimental study explored the impact of rising temperature and ocean acidification on a giant kelp (*Macrocystis pyrifera*) in the Aleutian Islands. They found that elevated temperatures, but not CO_2, led to reductions in kelp growth and photosynthetic carbon uptake when considered independently (Brown et al. 2014, pp. 209-210). However, the interaction of elevated temperature and CO_2 had the opposite effect, with both growth and photosynthetic carbon uptake increasing (Brown et al. 2014, pp. 209-210). This indicates that future conditions may still support giant kelps if SW NSO rebound and can limit sea urchin populations through predation.

Seagrass meadows have been in global decline for the past 100 years (Waycott et al. 2009, p. 12377). These declines have been attributed to climate change, invasive species, overexploitation, human modification, and nutrient and sediment loading (Waycott et al. 2009, p. 12379). The effects of future climate change and ocean acidification on seagrass meadows in Alaska is unknown. The relationship of observed changes in seagrass meadows with SW NSOs and their prey is unknown (Hughes et al. 2013, p. 15314).

5.1.3 *Invertebrate Prey Community*

Ocean acidification and associated decreases in calcium carbonate saturation has the potential to affect calcifiers, including echinoderms, bivalves, and crustacean species, all of which are prey for NSOs (Kurihara 2008, p. 281). The best available information suggests that ocean acidification will have a generally negative effect on calcifying invertebrates (Kroeker et al. 2013, p. 1890). Organisms that depend on more soluble forms of calcium carbonate (high-magnesium calcite) are considered to be more resilient to ocean acidification than species that rely on less soluble forms (calcite and aragonite) (Kroeker et al. 2010, p. 1422). The magnitude of the impact and the specific environmental conditions resulting in a negative response are unknown across genera. There is additional uncertainty as to which life stage(s) are most vulnerable, such as fertilization, cleavage, larva, settlement and/or reproductive stages (Kurihara 2008, p. 281). Many factors influence the severity of ocean acidification impacts on different species and life stages, including previous exposure to under-saturated seawater, natural variation in aragonite saturation, and available food resources (Doney et al. 2009, p. 184). Additionally, the effects of ocean acidification are likely to interact with ocean warming in complex and unpredictable ways, creating the need to study both stressors simultaneously (Kroeker et al. 2013, p. 1893).

Alaska coastal ecosystems already experience temporally and spatially low levels of pH and aragonite saturation due to natural variability. However, documentation of that variability is lacking for most areas. Mathis et al. (2015b, p. 126) used the observed range of variability in aragonite saturation to estimate when conditions may become detrimental to marine calcifiers in the Bering and Chukchi seas. Model projections for 2012 – 2044 indicate that aragonite saturation will fall below minimum levels experienced by these taxa in the Bering Sea. Similar information is not available for the Gulf of Alaska; however, the projected rate of change in aragonite saturation in the Gulf of Alaska is 16 percent greater than in the Bering Sea (Mathis et al. 2015b, p. 80). These conditions fall outside the natural range of variability for most marine invertebrates with unknown future impacts on their population status and availability as prey to SW NSO. A meta-analysis of studies conducted globally by Kroeker et al. (2013, p. 1888) indicated ocean acidification has negative effects on marine invertebrate abundance, calcification, development, and growth. However, variation exists among taxonomic groupings on the magnitude of the effects. Reduced survival is more evident in mollusks (e.g. clams, abalone, sea snails) than echinoderms (e.g. sea urchins) and crustaceans (e.g. crabs) (Kroeker et al. 2013, p. 1888). Mollusks also show a strongly negative reduction in calcification due to ocean acidification (Kroeker et al. 2013, p. 1888). Reductions in growth and development are most apparent in mollusks and echinoderms (Kroeker et al. 2013, pp. 1888-1889). Ocean acidification may also have an effect at different life stages. For example, mollusks and sea urchins experience reduced development in early life stages (Kroeker et al. 2013, p. 1889). Mollusk survival was lowest at the larval stage relative to the other life stages (Kroeker et al. 2013, p. 1889). When ocean acidification is combined with current and warmer temperatures in the future, there is an overall negative effect on marine invertebrate calcification, development, growth, and survival (Kroeker et al. 2013, p. 1892). The long-term impact of these changes on marine invertebrate abundance are less clear (Kroeker et al. 2013, pp. 1888-1889). It is uncertain how these changes at the species level will affect the broader invertebrate prey community for SW NSOs.

The specific responses of individual prey species in Alaska need future investigation (Mathis et al. 2015a, p. 79). However, recent research in Alaska indicated ocean acidification negatively affected red king crab (*Paralithodes camtschaticus*) and Tanner crab (*Chionoecetes bairdi and C. opilio*) through reduced growth and increased mortality rates (Long et al. 2013, p. 46). The long-term impact of these changes on crab population abundances are less certain (Mathis et al. 2015a, p. 86). The Pacific oyster (*Crassostrea gigas*) and Atlantic blue mussel (*Mytilus edulis*), a closely related species to Alaskan blue mussels (*M. trossulus*), experienced reduced calcification rates in acidified waters (Gazeau et al. 2007, p. 2). Experimental research on sea urchin (*Strongylocentrotus polyacanthus*) response to near-future ocean warming predictions indicated reduced survival, calcification, and growth rates (Weitzman 2020, pers. comm.). The overall impact of temperature was more limiting on sea urchins than ocean acidification (Weitzman 2020, pers. comm.). Under near-future ocean acidification predictions, sea urchin calcification rates were reduced by higher levels of CO_2 in the water. Increasing CO_2 had no effect on survival or growth rates, but investment in reproduction increased (based on gonad-somatic index; the proportion of gonad tissue per urchin), which could be of nutritional benefit to sea otters (Weitzman 2020, pers. comm.).

NOAA's Pacific Marine Environmental Laboratory synthesized existing benthic invertebrate data and produced estimates of benthic invertebrate infauna mass (milligrams [mg] of carbon [C] per square meter [m^{-2}]; AOOS 2018, p. 1), which can serve as an index of SW NSO prey availability. These projections were based on three GCMs out to 2039 for the same areas as the large phytoplankton analysis in section 5.1.3 above (Fig. 5.2). These projections include the potential effects of changes in ocean temperature and primary productivity (Hermann et al. 2013, p. 124), but not ocean acidification, on infauna mass. Those projections exhibit large variation among the regions as well as from year to year for all regions.

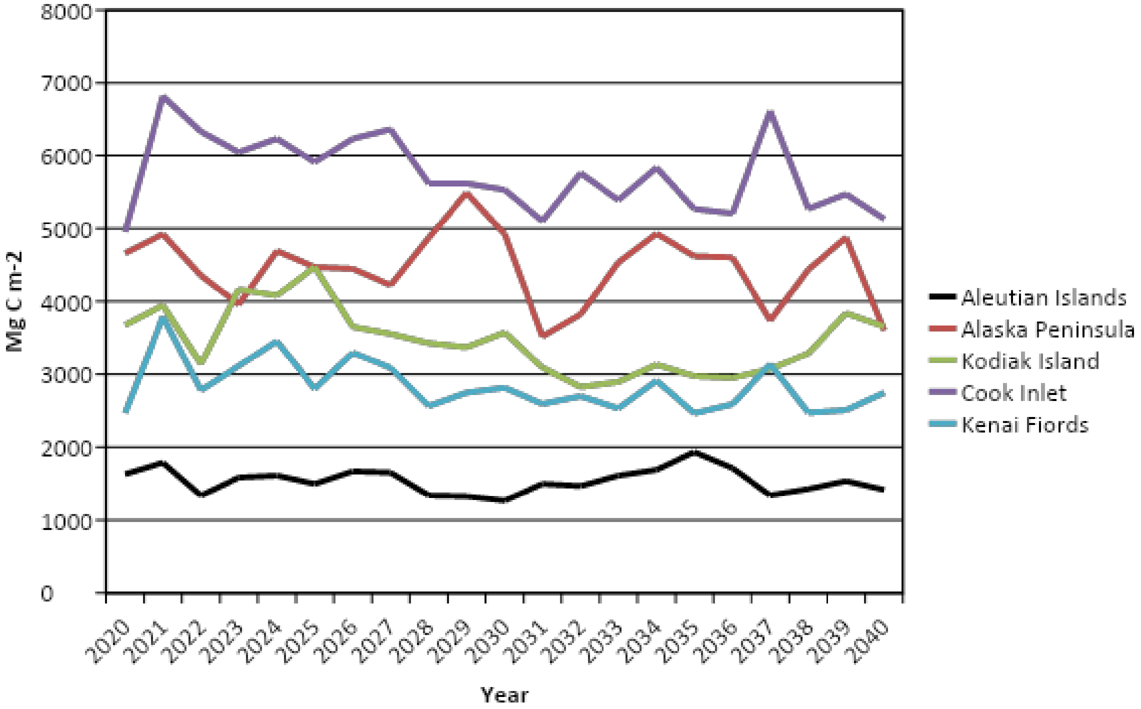

Figure 5.2 Projected trends in benthic infauna mass (milligrams of carbon per square meter) for five regions occupied by NSOs in Alaska by NOAA's Pacific Marine Environmental Laboratory based on three global circulation models (AOOS 2018).

In summary, based on the best available information, there likely will be changes in primary production and benthic invertebrate prey of SW NSOs, including taxonomic range shifts, changes in abundance, and altered community composition and diversity. The limited amount of species-specific information on the response of primary producers and invertebrates to changing ocean conditions make it difficult to understand how complex nearshore ecosystems will be structured and function in the future, and how this will affect the future status of SW NSOs.

5.1.4 *Invasive Species*

The combination of warming ocean waters and increased vessel traffic (see section 3.1.3) could increase the likelihood of introduced marine species to become established in SW NSO range (Miller and Ruiz 2014, p. 413). This includes photosynthesizing organisms and consumer species that previously may not have been able to tolerate historic ocean temperatures, salinity, and pH levels (Doney et al. 2012, p. 28). In general, marine species invasions are expected to increase at higher latitudes as extremely cold water temperatures become less of a limiting factor (Stachowicz et al. 2002, p. 15500).

For photosynthesizing organisms, sea grasses have declined globally over the past 100 years due in part to the establishment of invasive species following natural or human-caused disturbances

(Williams 2007, p. 99). There is evidence that kelp species can be introduced through ballast water of vessels and become invasive in other parts of the world (Casas et al. 2004, pp. 411-412). However, no invasive photosynthesizing organisms have been documented as established in coastal waters occupied by SW NSOs (Ashton et al. 2008, p. 133).

In the early 2000's, marine fouling community surveys detected an invasive crustacean, the Japanese skeleton shrimp (*Caprella mutica¸* native to northeastern Asia) in Dutch Harbor in the Eastern Aleutians, Kachemak Bay in southcentral, and Sitka and Ketchikan in southeast (Ashton et al. 2008, pp. 133-135). This was the first confirmed invasive crustacean to become established in Alaskan waters (Ashton et al. 2008, pp. 135-136).

Only three other non-indigenous marine animals have been documented in Alaska, including American shad (*Alosa sapidissima*), Atlantic salmon (*Salmo salar*), and soft-shell clam (*Mya arenaria;* Droghini et al. 2020, p. 2). Droghini et al. (2020, p. 2) evaluated the potential for other marine animals to become established in the Bering Sea, a hotspot of vessel traffic that is expected to increase with warming waters (see section 3.1.3). They determined temperature and salinity conditions of the Bering Sea under recent (2003–2012) and mid-century predictions (2030–2039) (Droghini et al. 2020, p. 3). They then compared these conditions against the thresholds of non-indigenous species to estimate which species could become established and whether any hotspots of invasion were apparent. Their assessment predicted western Bristol Bay and the Aleutian Islands would support the highest number of non-indigenous species in both time periods.

By 2039, an estimated 50 percent of the Bering Sea continental shelf could be suitable for additional non-indigenous species (Droghini et al. 2020, p. 6). Coastal waters located between 52° and 53° latitude are expected to support the highest number of non-indigenous taxa, and waters up to 59° latitude could be suitable for some species to become established (Droghini et al. 2020, p. 6). The port at Dutch Harbor is one of the busiest commercial ports in North America, receiving vessels that originate from more than ten countries in a given year (Droghini et al. 2020, p. 6). Therefore, it is possible that a suite of non-indigenous species could become established in SW NSO range, with potential implications of available food resources. Although SW NSOs are generalists capable of adjusting their foraging based on availability, it is uncertain how they will adjust to novel prey species or novel prey communities.

5.1.5 *Extreme Weather*

The Arctic is warming at twice the rate of the global average, a process known as Arctic amplification. As an integral part of the Earth's climate system, dramatic changes in the Arctic cryosphere have increased the severity and frequency of extreme weather events, altered storm tracks, and enhanced wave action and coastal erosion (Cohen et al. 2014, p. 627; Overeem et al.

2011, p. L17503). High intensity storms and increased wave exposure can destroy established kelp forests or modify other important coastal habitat like protected bays, lagoons, and sloughs. An increase in the severity or frequency of storms may also disrupt daily sea otter activity (e.g. foraging, resting), resulting in changes to daily energy balance with potential for long-term physiological impacts on body condition.

Kelp canopy provides shelter and refuge from predators, access to quality prey resources, and nursery habitat to sea otters. Increased frequency of storms decreases kelp forest diversity and complexity as species go locally extinct, which has direct impacts on top predators like sea otters (Brynes et al. 2011, p. 2520). Loss of foundation species like kelp can thus have cascading impacts through entire ecosystems, resulting in collapsed food webs, reduced species richness and reduced overall heterogeneity (Byrnes et al. 2011, p. 2522).

Furthermore, gaps in kelp canopy cover has been linked to higher levels of predation, increased prevalence of neurological disease, increased pup loss, and inhibition of range expansion thereby limiting population recovery in sea otters in California (Nicholson et al. 2018, p. 1758). Climate-driven disturbances that cause significant reduction in kelp or nearshore habitat may lead to decreased individual survival and reproductive success with potential population level consequences. At this time, given the amount of uncertainty and breadth at which extreme weather may occur in the future, it is unclear what level of effect extreme weather events may have on the SW NSOs at a stock level.

5.2 **Habitat Modification**

5.2.1 *Coastal Development*

Coastal development in Alaska takes many forms ranging from residences, lodges and hotels, boat launches, marinas, port facilities, and seafood processing facilities, etc. The pace of coastal development is often related to economic development, which in southwest Alaska, depends heavily on fisheries, transportation, and public sector spending. The Gulf Coast region (the Alaska Peninsula, Kodiak, Kenai Peninsula, and Cook Inlet) also has a large tourism sector, which can fluctuate with changes in resource supply and consumer demand, and future forecasts vary by location. Predicting the pace of development has become difficult following economic turmoil caused by the 2019 novel coronavirus, but long-term increases are predicted in transportation, tourism, and oil and gas production, while mixed trends are expected among fisheries. Within the range of the SW NSO, the general pace of coastal development will remain highest in Cook Inlet and near Unalaska and the City of Kodiak. Other, more isolated areas between large expanses of undeveloped coastline will likely experience periods of intense but localized development associated with fisheries, mining, or oil and gas production. For example, mining may also play an important role as the proposed Pebble Mine Project would include the construction of a terminal on the west side of Cook Inlet in Kamishak Bay.

Currently, BOEM is considering another two lease sales in Cook Inlet in 2021 and 2023 (BOEM 2018, p. 10). In addition, sales are also being proposed for several areas in Bristol Bay, the Aleutians, near Kodiak Island, and the Gulf of Alaska for 2023. Alaska Gasline Development Corporation has plans to install a pipeline extending into the Cook Inlet ending near Nikiski, Alaska, east of the SW NSO boundary. The State of Alaska also has a number of active oil and gas leases in upper Cook Inlet (ADNR 2015, p. 1). Four leases were sold in June 2017 in upper Cook Inlet by Hilcorp Alaska LLC (ADNR 2017, p. 1). In general, these leases were north of the current distribution of NSOs in Cook Inlet. While some of these leases and planned activities lie outside of the range of SW NSOs, they may still be impacted by an increase in vessel traffic associated with these activities.

All economic development in coastal regions (and coastal development by proxy) will be subject to future changes brought on by climate change. Melvin et al. (2017, p. E122) predicted the cumulative expenses from increased damage to infrastructure due to climate-related events in the State of Alaska from 2015 to 2099 would total $5.5 billion (2015 dollars) under RCP 8.5 and $4.2 billion under RCP 4.5 unless preventative or adaptive measures are taken to mitigate climate effects. Damages from coastal erosion and increased flooding to coastal infrastructure, especially airports, roads, buildings, and electrical infrastructure, will account for the greatest portion of damages in southwestern Alaska (Melvin et al. 2017, pp. E125-E126).

The effects of climate change on SW NSOs may be exacerbated by coastal development, however mitigation measures for coastal development activities can be utilized to help reduce local impacts. Development activities can cause behavioral disturbances, habitat changes, or direct effects such as boat strikes. Increases in water temperature, changes in invertebrate community composition, and extreme weather events may compound the localized effects of development. Actions taken to mitigate economic costs of climate change in areas of coastal development will benefit coastal wildlife, including the SW NSO. For example, coastal setbacks, standardized building codes, and wetland protections may prevent damage to fuel pipelines, tank farms, landfills, and water treatment facilities, thereby preventing climate-related accidents from releasing pollutants into SW NSO habitat.

5.2.2 *Commercial Activities*

There are areas within LCI, and potentially additional locations, considered for oil and gas activities; however, it is not possible to predict the pace or success of development of either federal or state lease sales. In areas where oil and gas activities occur, there will likely be an increase of vessel traffic and potential for large and small oil spills.

With the increase in vessel traffic, it is likely that there will be an increase in SW NSO disturbance and potentially small oil spills which can result in injury or mortality. Along with vessel traffic, seismic operations associated with oil and gas activities have potential impacts including injury or mortality of sea otters that are within the ensonification zones during the seismic surveys. While these are the main sources of impacts, there are likely to be some impacts from support activities such as drilling and construction. These both include noise components that can injure or displace SW NSO as well as result in habitat degradation.

In summary, it is unlikely that routine oil and gas activities will have a significant negative impact on SW NSOs in the near future due to the limited area involved and the current Incidental Harassment Authorization (IHA) and anticipated future Incidental Take Regulations (ITR) provisions (see section 3.6). However, the BOEM determined the probability of a large spill in Cook Inlet at 22 percent (BOEM 2016, p. ES-4). A major accident (e.g., well blowout, pipeline rupture, or tanker grounding) that releases large quantities of oil into the marine environment could severely affect the SW NSO population in the oiled area, similar to Exxon Valdez in 1989, where an estimated 1,000 to 2,800 NSOs were killed (Peterson et al. 2003, p. 2082). A spill of that size-could result in a large decline in abundance.

5.2.3 *Ship and Air Traffic*

Plausible future scenarios forecast an increase in human activities in southwestern Alaska. Modest and gradual increases in human populations were predicted by Howell (2020, p. 2) prior to widespread effects of the 2019 novel coronavirus. The virus altered economic and commercial influences on net human migration in ways that were not accounted for in population projections. Short term changes are uncertain, but long-term trends are likely to return to gradual population increases along with increases in global shipping, development, and other activities. These will likely lead to increases in boat strikes, acoustic disturbance, and incidental harassment of SW NSOs.

Important ports and harbors are likely to experience localized areas of increased congestion due to increasing vessel and aircraft traffic. Ship strikes are usually associated with small high-speed vessels, which become more common when human populations increase. Most low-level underwater noises and surface disturbances from individual vessels and aircraft are unlikely to cause significant effects to SW NSOs, but high-level acoustic sources such as military sonar, seismic surveys, and pile driving can lead to hearing loss and interfere with communications between SW NSOs. Collectively, increasing levels of disturbances from multiple sources could cause chronic stress, affecting health of SW NSOs, and ultimately altering the population distribution. The likelihood and extent of effects from increased ship and air traffic and ocean noise on SW NSO populations are unknown, however the effects are limited to a small portion of the range of SW NSOs in the foreseeable future.

5.2.4 *Oil Spills*

Forecasting patterns of future oil spills is challenging; there are a large number of economic and environmental factors to consider, and a great deal of uncertainty (NOAA 2014, p. 57). Generally, long-term trends in oil transport will vary with fluctuations in national and international costs of oil, including transportation costs. However, currently it is projected to stay the same or increase (WSDE 2017, p. 95).

The NOAA Assessment of Marine Oil Spill Risk and Environmental Vulnerability for the State of Alaska (2014, entire) modelled risk of potential future oil spills in Alaska's waters. The risk model consisted of three elements: (1) vulnerability of the environment to oil spill impacts, (2) probability of a spill based on past and projected future incident rates, and (3) potential maximum most probable discharge and worst-case discharge volumes that could result from an incident now or in the future (NOAA 2014, p. 4). Future spill risks were modelled to the year 2025. The report found the Aleutian Islands (WA MU) to have the second highest relative risk for a future oil spill, based upon a high environmental vulnerability due to the species diversity found in the region (NOAA 2014, pp. 62, 77).

Vessel traffic in the Aleutian Islands is relatively heavy. Although fishing vessels make up the majority of traffic in and out of ports, ships traveling between North America and Asia along the North Pacific Great Circle Route comprise the majority of vessels using the area. Primarily bulk carriers and container ships, these vessels transit the Aleutian Islands via Unimak and several other passes. In 2012, there were an estimated 4,500 transits of Unimak Pass (Nuka Research and Planning Group 2016, pp. 13-16). It is unknown to what degree transit of the Aleutian Islands will increase in the future. However, shipping routes through the Arctic Ocean are expected to become more accessible as sea ice retreats (Nuka Research and Planning Group 2016, p. 55), which will likely result in a commensurate increase in vessel traffic through the Aleutian passes.

LCI is the only area within the range of the SW NSO where ongoing oil and gas activities occur. Oil and gas activities within the SW NSO range are ongoing with some future leases in the LCI (see section 5.2.2). Although much of the area lies outside of the SW NSO's range, future changes in production or shipping could impact the SW NSO populations.

Production forecasts for Cook Inlet oil and gas are trending downward (Nuka Research and Planning Group 2015, pp. 6-7), which may result in a reduced risk of production-associated spills. Despite lower production, vessel traffic through Cook Inlet, including oil-bearing vessels, may remain steady due to increased imports for consumers and for the refinery located in Nikiski. Overall, population growth and economic indicators suggest flat to moderate increases in vessel traffic through Cook Inlet (Cape International 2012, p. 4).

One study estimated that incident rates across all vessel types would increase from the historical average of 3.4 spills annually to 3.9 spills between 2015 and 2020. It is unknown whether spill rates are predicted to continue to increase in Cook Inlet beyond 2020, or whether the magnitude of those spills might increase (Nuka Research and Planning Group 2015, p. 7). A qualitative assessment of the consequences of spills within Cook Inlet suggested that even small spills of non-persistent fuel may have a significant negative environmental and socioeconomic impacts and concluded that all areas of Cook Inlet are vulnerable to the impacts of spills, regardless of season. Although NSOs were not specifically considered in the analysis, other birds and mammals were included and it is reasonable to assume that sea otters would be similarly impacted (Nuka Research and Planning Group 2015, pp. 7-8).

The potential for future oil spills is dependent on whether cargo shipping or shipping routes increase, future economic conditions, frequency of extreme weather events, and mitigation measures that may be implemented (e.g. double hull tanks; NOAA 2014, p. 58). Depending on the severity of the spill, it may have large population level effect to the SW NSOs.

5.3 **Contaminants and Biotoxins**

Due to their widespread use and dispersive nature, contaminants are ubiquitous in the marine environment where they readily exert adverse health effects via biomagnification in food webs and accumulation in tissues. Many contaminants have been documented to cause endocrine disruption, altered immune function, abnormal fetal development and reproductive pathology in marine mammals and laboratory animals (O'Shea and Tanabe 2002, pp. 99-134). The immunotoxic effects of contaminants may exacerbate nutritional and disease stress, leading to significant morbidity and mortality (Burek et al. 2008, p. S130). By creating "reservoirs" for new pathogens in contaminated marine mammals, immunotoxic contaminants may further facilitate disease emergence in susceptible populations (Ross 2002, p. 277). As a result of climatic warming, changes in atmospheric and oceanographic conditions are expected to alter the pathways, persistence in the environment, and concentrations of contaminants that enter the Arctic via atmospheric transport and ocean currents (MacDonald et al. 2005, p. 5). Additionally, contaminants sequestered or "trapped" in sea ice may be secondarily released into the water or re-volatized as sea ice dynamics change. There are already measurable increases in atmospheric pollutant concentrations due to re-emission from repositories in Arctic waters, soils, ice, snow, and permafrost (Ma et al. 2011, p. 255). Climate warming is also expected to increase human activity (agriculture, industry, and shipping) in the Arctic, thereby further increasing the risk of exposure to anthropogenic pollutants. More frequent or increased severity of storms may increase coastal run-off of these pollutants. Finally, conditions favorable to HABs, such as higher SSTs, reductions in sea ice (higher light levels), and increased eutrophication are expected to occur.

Concurrent climate-mediated and anthropogenic threats to SW NSOs regarding exposure to biotoxins and contaminants are expected to increase. However, the paucity of baseline data on

NSO health parameters in general and the various chemistries of the biotoxins and contaminants themselves make adverse health consequences challenging to predict. It is also unknown to what degree synergistic interactions of contaminants and other stressors have on population health.

5.4 **Overutilization**

Subsistence harvest, illegal poaching, fisheries interactions, and unauthorized take will all be influenced by increases in human populations, shipping, vessel traffic, and other development activities. Changing ocean conditions will affect many of the commercial interests and economic drivers within the range of the SW NSO and may influence trends in each source of potential overutilization among SW NSOs.

5.4.1 *Harvest*

NSO hunting has decreased substantially from levels that historically reduced populations, but lower levels of subsistence harvest by Alaska Natives are expected to continue into the future. SW NSO harvest fluctuates with shifts in demand for fur products, and popularity of subsistence hunting. Local reductions of sea otters may reduce conflicts over invertebrate fishery resources important to Alaska Native subsistence users. It is uncertain whether subsistence harvest of SW NSOs by Alaska Natives will be at higher levels than today, but it is unlikely that it will become unsustainable. If harvest increases to the point that local populations are affected, this pressure will exacerbate effects of climate-related ecosystem changes.

5.4.2 *Fisheries Bycatch*

Climate-mediated changes in fisheries will influence frequency of NSO fisheries interactions in the future. In the range of the SW NSO, climate change may result in shifts in community composition, changes in primary productivity, and diversification of phytoplankton species. Declines in sea ice and increases in temperature are predicted to cause shifts in the food web from an ice algae–benthos–benthic predator pathway to a spring bloom–zooplankton–planktivore dominated ecosystems (e.g. Wassmann and Reigstad 2011, p. 226). Pelagic species (zooplankton, planktivorous fish) may benefit over benthic species (benthos, benthic feeding fish). Increases in primary productivity in the pelagic zone may support additional harvest of pelagic fish and lead to additional accidental entanglements and bycatch of SW NSOs in fishing gear.

Climate-related changes in community structure will not be uniform throughout the range of the SW NSO. Several highly productive fisheries are located in areas projected to experience rapid transitions in temperature and chemical parameters related to ocean acidification. Some commercially valuable fish species such as salmon rely on pteropods as important prey during juvenile stages. Pteropods and other types of zooplankton that calcify aragonite may be severely affected by ocean acidification. Adverse changes in prey composition may outweigh any benefits of increased primary productivity for commercial fisheries. In southwest Alaska, human population centers that are reliant on commercial fishing will be exposed to a high level of risk of declining fisheries harvest due to effects of climate change on ocean dynamics (Mathis et al. 2015a, p. 86). A net reduction in fisheries harvest in SW NSO habitat would reduce the associated level of incidental SW NSO bycatch and possible competition between SW NSO and fishers for benthic species.

Commercial aquaculture in Alaska is increasing. Aquatic farms specializing in growing seaweed are on the rise, some of which also grow shellfish. Aquatic farms are not yet common in southwest Alaska; however, this industry is established and growing in Kodiak. Where these occur, there exists a greater potential for conflict, which could lead to illegal disturbance and lethal take of SW NSOs by fishers protecting their harvest. However, the MMPA allows for the lawful take of animals for the protection of fishing gear provided that measures are in place for limiting the effects of take on the population. The overall effect of future changes in fisheries impacts on SW NSO are uncertain.

5.5 **Disease, Parasites, and Predation**

5.5.1 *Infectious Disease and Parasites*

Pathogens (bacteria, fungi, viruses, parasites) can exert population level effects by lowering resistance to stressors, increasing morbidity and mortality, and reducing fertility or fecundity. The lack of long-term data on baseline health parameters, disease, and toxicant effects in NSOs limits our ability to both assess and predict future outcomes for overall population health. Furthermore, individual health and susceptibility to disease is a complex interaction of several factors such as immune status, body condition, and environmental conditions (Burek et al. 2008, p. S126). However, climate change is altering infectious disease ecology and the prevalence of disease among animal populations in the arctic and subarctic regions is expected to increase (Dudley et al. 2015, p. 713). Rising sea temperatures, dramatic loss of sea ice, and ocean acidification are creating complex ecosystem shifts that may drive exposure to new pathogens in Arctic marine mammals. Shifts may also be driven as changes in human activity accelerate global transport of species, uniting novel pathogens and naïve hosts (Harvell et al. 1999, p. 1505).

Climate warming has resulted in range expansion and changes in geographical distribution of host, pathogen, and vector populations (Dudley et al. 2015, p. 715). Moreover, pathogen and vector survival has increased as overwintering conditions have become more tolerable (Burek et al. 2008, p. S128). Novel pathogens from temperate regions are expected to expand their range northwards. Warmer water coupled with nutrient enrichment (a result of increased rainfall and runoff) is also expected to expand the northern geographic range and increase the duration of favorable conditions that support HABs (Lefebvre et al. 2016, p. 14). These produce neurotoxins known to cause significant illness and mortality events in marine wildlife, as well as immunomodulatory effects (Jensen et al. 2015, p. 10) that may interact with disease processes.

The loss of sea ice might also aid in infectious disease transmission as pathways open in the Arctic and facilitate movement and contact between marine mammal populations. There is evidence for cross-species transmission due to changes in behavior in response to sea ice reduction. The loss of suitable ice habitat is contributing to range overlap between species, the increase in density at haul-outs, and the increase in mixed-species haul-outs (VanWormer et al. 2019, entire). For example, Goldstein et al. (2009, p. 926) provided evidence for exposure to phocine distemper virus (PDV) in Alaska NSOs through the introduction of the virus to the Arctic and Pacific Oceans from the Atlantic via overlap in species range. The overlap of multiple hosts capable of cross-species transmission may also lead to increased pathogen persistence in the Arctic ecosystem. Furthermore, immunologically naïve host populations are at an increased risk for disease epidemics with possible population level effects (Goldstein et al. 2011. 580). Previous health assessments on SW NSOs in the Aleutian Islands showed absence or low prevalence of antibodies to several pathogens, suggesting they might be susceptible should these pathogens be introduced in the future (Goldstein et al. 2011, p. 589; Hanni et al. 2003, p. 848). Furthermore, exposure to the infectious zoonoses *Brucella spp.* and Influenza A virus were recently detected for the first time in NSOs in Washington (White et al. 2018, p. 896). Additionally, recent studies in Alaskan NSOs documented a potentially novel marine-adapted *Bartonella spp*. (Carrasco et al. 2014, p. 332), and a case of *Histoplasma capsulatum* infection far outside its known range in Kodiak (Burek et al. 2014, p. 389).

Overall, threats to SW NSOs regarding exposure to infectious disease and parasites are expected to increase as climate variability and human activity together create favorable conditions that both undermine host resistance and facilitate pathogen transmission. However, the paucity of baseline data on NSO health parameters in general, make adverse health consequences challenging to predict in the future due to the inability to make meaningful comparisons through time. At this time, it is uncertain what effect increase in disease and parasites may have on SW NSOs in the future.

5.5.2 *Marine Predators*

5.5.2.1 *Killer Whales*

Although the ultimate cause of the decline is unknown, the hypothesized cause was increased rates of predation on sea otters (Service 2013c, p. iii). Killer whales were suspected as the primary threat to SW NSOs at the time of listing (Service 2013c, p. iii). This was based on a number of independent pieces of information from anecdotal reports to changes in SW NSO distribution and behavior following the decline in sea otter numbers in the Aleutians (Service 2013a, pp. 3-2 – 3-3). However, we emphasize that the ultimate cause is unknown. There continues to be debate within the scientific community about the impact killer whales have on the SW NSOs. Regardless of whether the SW NSOs decline was attributable to killer whales, there is a known predator/prey relationship between these two species. It is not clear how important this relationship will be to SW NSO in the future, however. The two main factors that could influence predation rates on SW NSOs are killer whale abundance and changes to primary prey abundance.

Killer whales can be divided into 3 ecotypes: resident, offshore, and transient (Herman et al. 2005, p. 282; Krahn et al. 2007, p. 102). Zerbini et al. (2006, pp. 1039-1040) found that, near Kodiak Island, around Umnak and Unalaska islands in the eastern Aleutians, and in Seguam Pass (sea otter WA MU) resident killer whales were the most abundant. Resident killer whales typically feed on fish and are not believed to be influential in sea otter population dynamics. Offshore killer whales are believed to occur far from shore, and also feed primarily on fish. Given that these two ecotypes are not believed to consume marine mammals and therefore have little influence on SW NSO abundance, they will not be discussed further.

It is postulated that only transient whales consume marine mammals as prey. It has been reported, based on unpublished data, that roughly 10 percent of killer whales in the western Gulf of Alaska and Aleutian Islands specialize in marine mammal prey (William et al. 2004, p. 3379). The transient population estimate from the Gulf of Alaska to central Aleutian Islands was 345 (95 percent CI 255-487), based on samples collected in the early 2000s (Durban et al. 2010, p. 1601). The most recent minimum population estimate from the Gulf of Alaska, Aleutian Islands and Bering Sea (larger study area than Durban et al. 2010), found a minimum population estimate of 587 animals (NOAA 2018e, p. 140). However, there is insufficient data to understand trends in the population (NOAA 2018e, p. 141).

Numerous observations of transient killer whales have been reported in Unimak and Samalga Passes (east and west boundaries to the Eastern Aleutians MUs) which are movement corridors for cetaceans and pinnipeds (Sinclair et al. 2005, p. 229; Durban et al. 2010, p. 1602). Several studies have shown that the main prey items for transient killer whales in the Eastern Aleutians, South Alaska Peninsula, and Bristol Bay MUs were gray whales(*Eschrichtius robustus*), minke whales (*Balenoptera acutorostrata*), northern fur seals (*Callorhinus ursinus*) and Steller sea lions during the spring and summer months (Wade et al. 2006, pp. 27-28; Krahn et al. 2007, p. 102; Matkin et al. 2007, p. 82). Though observations are lacking for winter and fall months, SW NSOs are not believed to be a primary prey item for transient killer whales.

Although the relative importance of transient killer whale prey items has not been studied, it may be important to consider the energy density of various marine mammals. Killer whales have high energetic demands. In order for an adult male killer whale to meet these demands, it would have to consume five male or seven female sea otters per day (Williams et al. 2004, p. 3378). An adult sea lion is roughly 4.5 times more energy dense than a sea otter, which presumably makes it a more preferred prey. However, it is unknown what factors influence prey selection of transient whales or how they will change in the future. Despite these uncertainties, if killer whales were to target sea otters, there could be a population level effect. It has been estimated that one animal could consume up to 1,095 - 2,555 sea otters per year (Williams et al. 2004, p. 3377), which could have dramatic consequences, especially in areas with lower densities such as the Western Aleutians.

Killer whales may also have indirect impacts on sea otters, specifically in the WA MU. High rates of killer whale predation could have served as a selective force that has effectively reduced the dispersal capacity of SW NSOs in the WA MU (Davis et al. 2019, p. 4). In this scenario, a genetic component that presumably increases dispersal propensity has been reduced or effectively removed from the WA MU population. Consequently, a reduced capacity for dispersal could persist for many generations, regardless of current and future predation rates of killer whales on sea otters (Davis et al. 2019, p. 12). Alternatively, high levels of local food availability combined with a perceived risk of predation may be limiting dispersal in the WA MU. In this scenario, dispersal would increase when local sea otter densities reached carrying capacity and/or perceived risk of predation decreased. However, we are not aware of any empirical studies that have evaluated dispersal of SW NSOs in the WA or EA MUs. Thus, dispersal rates and the impact of killer whale predation on dispersal capacity of SW NSOs is highly uncertain.

Marine predators may also have non-consumptive effects on SW NSOs that emerge from a behavioral response to the threat of predation. For example, SW NSOs in the WA MU may select areas with high physical habitat complexity to alter space use patterns to reduce the probability of encountering a potential predator (Stewart et al. 2015, p. 651; Peckarsky et al. 2008, p. 2420). Consequently, areas that exhibit less physical habitat complexity and high food availability would be considered marginal or unavailable habitat in the presence of a predation threat. Thus, in the presence of a predation threat, carrying capacity in the area would decrease compared to carrying capacity prior to emergence of the predation threat.

Future predation rates of SW NSOs by killer whales may depend on the abundance of other common prey species. The gray whale, a primary prey item in the spring, appears to be increasing in abundance (NOAA 2018e, p. 159). However, a UME was declared in 2019. While this may be a cause for concern, the consequences of previous gray whale UMEs have been short lived (NOAA 2018e, p. 159). The northern fur seal, a primary prey item in the summer, has experienced population declines as a whole, but small localized areas (i.e. Bogoslof Island) appear to be increasing (NOAA 2018e, pp. 30-31). Similar results for the Steller sea lion have been reported. Portions of the listed Western DPS of Steller sea lions are increasing (Gulf of Alaska and eastern Bering Sea east of Samalga Pass), with negative trends west of Samalga Pass in the Aleutian Islands (the division between the EA and WA MUs for sea otters; NOAA 2018e,

p. 4). Finally, minke whale trends are unknown at this time (NOAA 2018e, p. 238; Rone et al. 2017, p. 23). It is unknown how the abundance of these prey species will change in the future or what effect it will have on predation by killer whales on SW NSOs.

In addition to changes in prey abundance, threats to killer whales include habitat loss, oil spills, disturbance from vessels and sound (NOAA 2020c). Climate change may exacerbate these effects, but it is unknown to what degree killer whale populations will be affected and what the impact will be for SW NSOs.

Given these uncertainties, it is unknown what effect killer whales will have on SW NSOs in the future. Though killer whales were cited as a primary cause of decline of SW NSOs at the time of listing, there is debate within the scientific community about the relative importance of killer whale predation on SW NSOs. We have little new information with which to develop our understanding of this predator-prey relationship. Consequently, we are unable to say with confidence what effect killer whales will have on SW NSOs into the future.

5.5.2.2 *Sharks*

Information on shark predation on NSOs in Alaska is limited to one unconfirmed incident involving a salmon shark that reportedly attacked and consumed a sea otter in Prince William Sound (Service 2013a, p. 3-1). In spite of their apparent rarity, shark attacks are a potential source of SW NSO mortality and therefore we outline the pertinent information below.

Pacific sleeper sharks (*Somniosus pacificus*) occur in Alaskan waters, and in the 1990s their abundance increased substantially in the Gulf of Alaska and Bering Sea (Gaichas 2002, p. 802). Sleeper sharks are known to feed on marine mammals other than sea otters (Hulbert et al. 2006, p. 407). Formerly thought to be scavengers, recent evidence shows that they also prey on salmon and other fast-moving species and sometimes make diurnal vertical migrations to waters of 100 m or less in depth (Hulbert et al. 2006, p. 423), bringing them into the maximum forage depth range of sea otters. During a recent survey, stomachs of 25 out of 198 sleeper sharks caught in the northern Gulf of Alaska contained marine mammal remains, none of which could be identified as NSO or determined to have been acquired by predation (Sigler et al. 2006, pp. 399-401).

Abundance of salmon sharks also has increased in Alaska since the 1990s, with schools of hundreds being reported in nearshore areas (Gaichas 2002, p. 802; Okey et al. 2007, p. 362). In 2003, fishermen reported increasing densities of sleeper and/or salmon sharks at five locations in the Aleutian Islands (Okey et al. 2007, p. 362). Salmon sharks are known to feed on salmon and cephalopods (Hulbert et al. 2005, p. 490), and the only indication that they may prey on NSOs is the unconfirmed report described above. It also is worth noting that in areas where salmon shark abundance has increased dramatically (e.g., Prince William Sound), NSO numbers have increased or remained stable (Bodkin et al. 2002, p. 237).

White shark attacks represent a significant source of mortality for sea otters in California, particularly at the northern end of that subspecies' range (Ames and Morejohn 1980, p. 196; Estes et al. 2003, p. 198; Kreuder et al. 2003, p. 500). Based on the beach cast (deposited on shore) carcasses having evidence of shark bites, it appears that these carcasses do not represent true predation – that is, sharks are not targeting and consuming sea otters but rather they are killed incidentally during shark predation on pinnipeds (Ames and Morejohn 1980, p. 196). This interpretation is consistent with the lack of sea otter remains in white shark stomachs (Riedman and Estes 1990, p. 88). Regardless of whether or not fatal shark bites represent true predation or just cases of "mistaken identity", sharks have high potential for limiting population growth in parts of the California sea otter's range (Gerber et al. 2004, p. 1563).

Martin (2004, p. 18) found 15 occurrences of white sharks in Alaskan waters in 40 years of records (1961–2001). Of those that were examined, none of their stomachs contained NSO remains. In addition, recent satellite telemetry studies showed that none of the 68 white sharks tagged in the coastal concentration area off of central California ranged northward into Alaskan waters (Jorgensen et al. 2010, pp. 3, 5).

Anecdotal reports show a potential increase in shark related injuries on seals and sea lions in the Bering Strait and North Slope Borough regions (Dobbyn 2018, entire). However, distribution and population numbers of white sharks in Alaska is currently unknown. Recent observations and tagging locations of 165 white sharks in California showed white sharks moved out of the areas occupied by killer whale (Jorgensen et al. 2019, pp. 4-5). It is unknown whether killer whale presences in the western Aleutians will prevent colonization by white sharks in the future. In general, it is unclear what effect sharks will have on SW NSOs in the future.

5.6 **Conservation Measures**

Various conservation mechanisms are expected to continue to apply to SW NSO management into the future. Changes to legal protections are not anticipated; the protections of the MMPA will continue into the foreseeable future. State and federal agencies will continue to implement conservation efforts mandated by law and will foster and promote additional efforts when directed by leadership priorities. Public interest in sea otters will continue to generate conservation support in the private sector. The Service's SW NSO Recovery Plan highlights priority conservation issues as well as specific actions to be taken and implementation timelines (Service 2013a, entire). The plan highlights continued population monitoring, habitat study, disease testing, and predation monitoring. These efforts will provide information to support existing proactive conservation programs and develop new ones. Programs for protecting important habitat, reducing incidental and illegal take, and reducing effects of oil spills are expected to benefit SW NSO populations. For example, Automatic Information System (AIS) data has been used to assess seasonal movements of vessels along the Great Circle Route (Fig. 4.1). Analyzing this information in a shoreline vulnerability assessment can help to identify areas where small changes in vessel routes will yield large reductions in risks to marine species (Robards et al. 2014, p.1; Robards et al. 2016, pp. 81, 87).

The degree of conservation benefit received by SW NSOs from actions in the recovery plan will depend on the timing, scale, and success of implementation. Many of the specific actions and targets depend on available funding, making implementation schedules uncertain. Conservation efforts targeting disease and predation are confounded by a great deal of inherent complexity. The benefits of these efforts will not direct the trajectory of SW NSO but will interact with the effects of climate change. Conservation actions that have been prioritized for SW NSOs are not likely to result in dramatic changes in sea otter abundance or habitat conditions in the near future, but small contributions to species viability now may result in large impacts to the viability of the species in the future.

5.7 **Small Population Size Effects**

A recent analysis of genetic diversity of NSOs from PWS to the Commander Islands in Russia was conducted by the Service and collaborators (Fig. 5.3; Table 5.1). Samples were opportunistically collected from 1989–2017, and results indicated a high degree of genetic divergence across the study area. However, overall genetic diversity was low based on 14 microsatellite loci (Flannery et al. in review). This is expected given the significant genetic bottleneck sea otters went through in the 18th and 19th centuries due to the fur trade. Larson et al. (2012, p. 9) documented a loss of half of the heterozygosity and 2/3 of the allelic diversity during the fur trade decline. Flannery et al. (in review) suggested even at low genetic diversity ",…sea otters may not be at levels that present immediate risks of inbreeding and loss of genetic diversity…". However, other authors raise concern about the effect of low genetic variation on the long-term viability of the species and their ability to adapt to anthropogenic changes (Aguilar et al. 2008, pp. 42-43).

Flannery et al. (in review) also evaluated the population structure across the MUs and found that they were relatively consistent with the current MU boundaries (Fig. 5.4; Table 5.1). The Southcentral sea otter stock shows signs of genetic mixing with the Kodiak, Kamishak, and Alaska Peninsula MU. There are also signs of overlap between the Bristol Bay and South Alaska Peninsula MUs. These results are likely from SW NSOs moving south (overland or through Isanotski Strait) during years when sea ice extended into the Bristol Bay area and bays froze. Overland emigration from Bristol Bay has been witnessed (Watts pers. comm. 2019) by numerous people in the area. If sea ice extent continues its downward trend, (NOAA Climate 2019, entire) events like these may no longer occur and gene flow may be restricted. Reduced gene flow could have a deleterious effect on the SW NSO's ability to adapt to future conditions (i.e. disease).

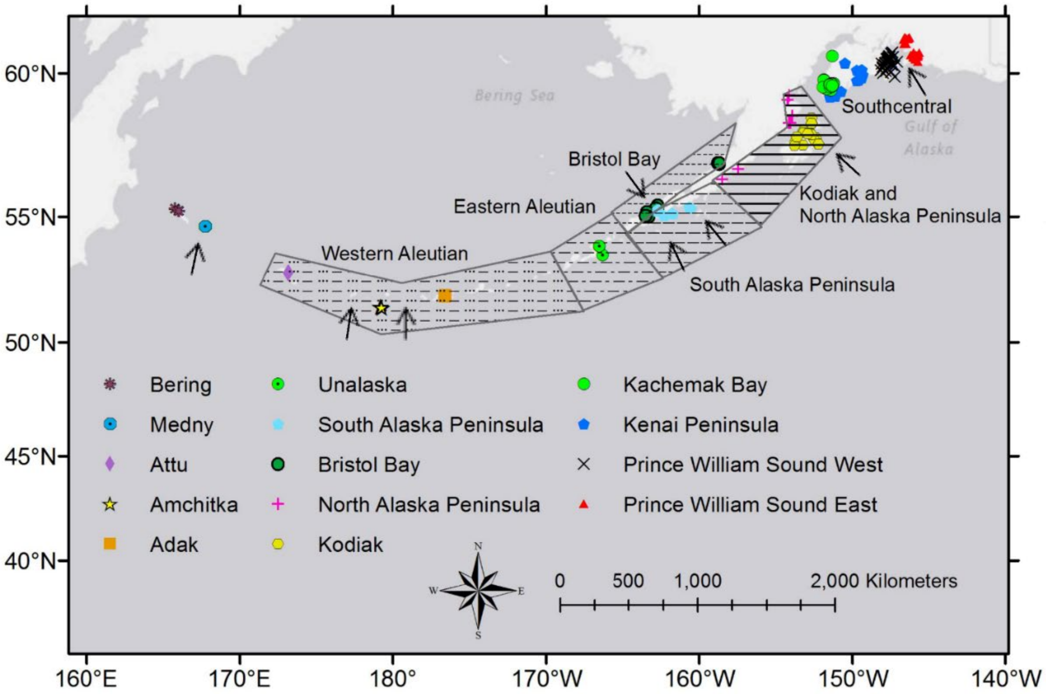

Figure 5.3 Map of fourteen sample locations (symbols), remnant isolated populations surviving fur trade (arrows), and five MUs (hashed lines). The Southcentral stock is noted on map whereas the SW NSO encompasses the five MUs. Sea otters from the Commander Islands (Bering and Medny) are the subspecies *E. l. lutris*, whereas sea otters from the other locations are the subspecies *E. l. kenyoni*. (figure copied from Flannery et al. in review).

Table 5.1 Sampling location, stock, monitoring unit, number of samples (N), and year collected. Management units have only been defined for the SW NSO (copied from Flannery et al. in review).

Location	Stock	Monitoring Unit	*N*	Year
Prince William Sound East	Southcentral	Prince William Sound	47	1989-2014
Prince William Sound West	Southcentral	Prince William Sound	67	1989-2012
Kenai Peninsula	Southcentral	Kenai Peninsula	42	1989-2014
Kachemak Bay	Southcentral	Cook Inlet	47	1996-2015
Kodiak	Southwest	Kodiak, Kamishak, Alaska Peninsula	50	1995-2015
North Alaska Peninsula	Southwest	Kodiak, Kamishak, Alaska Peninsula	32	1989-2014
Bristol Bay	Southwest	Bristol Bay	18	1995-2014
South Alaska Peninsula	Southwest	South Alaska Peninsula	36	1997-2010
Unalaska	Southwest	Eastern Aleutians	12	2010-2017
Adak	Southwest	Western Aleutians	44	1991-1995
Amchitka	Southwest	Western Aleutians	17	1992
Attu	Southwest	Western Aleutians	19	1991-2008
Medny	Russia	Commander Islands	14	1997-2006
Bering	Russia	Commander Islands	56	1997-2006

5.8 **Plausible Future Scenarios**

We examined two plausible future scenarios to estimate SW NSO populations into the future. We chose to forecast out 30 years (2050), which is roughly 4 generations (7.9 years; Gagne et al. 2018, p. 1787). This time frame also roughly corresponds with the sea surface temperature and benthic model timelines (2039-2044). Although models are available beyond the 2050 timeframe, the projections depend on an increasing number of assumptions, becoming more uncertain with time. Projections to 2050 provide the best balance of the scope of potential impacts and the certainty of those impacts being realized. We chose two RCP trajectories for our future scenarios evaluation: RCP 8.5; and RCP 4.5. We projected the threats into the future, based on two potential and plausible scenarios. The scenarios are based on RCP projections as most of the threats are linked to a changing climate. Additionally, we identified any new threats or stressors that do not currently influence SW NSOs, such as changing benthic invertebrate communities and new marine predators. We selected only two possible scenarios due to the uncertainty in how a changing climate will directly and indirectly effect SW NSO.

5.8.1 *Scenario 1: RCP 8.5 (2050)*

We defined our first future scenario as one where greenhouse gas (GHG) concentrations would follow the RCP 8.5 trajectory, which would generate increased threats to the SW NSO compared to current conditions and the second future scenario (Table 5.2). In the first scenario, we assumed increased levels of ocean acidification due to increased GHG concentrations in the atmosphere, increased sea surface temperature, increased disease prevalence, and increased risk of oil spills relative to current conditions. We also assumed this scenario would include increased intense storm events due to elevated sea surface temperature and reduced sea ice, which would reduce overall kelp coverage in range of SW NSO. Furthermore, we assumed this scenario would include increased commercial activities, and increased marine predators (Table 5.4).

5.8.2 *Scenario 2: RCP 4.5 (2050) - Improved Conservation Scenario*

We defined our second future scenario as one where GHG concentrations would follow the RCP 4.5 trajectory, resulting in a lower magnitude of threats to the SW NSO compared to the first scenario. As above, we set the time period for the second scenario as 2050. In this scenario, we assumed climate-related stressors (i.e. ocean acidification, sea surface temperature, intense storms, and disease prevalence) would increase relative to current conditions. However, climate related stressors in the second scenario are of a lower magnitude relative to the first scenario. We assumed the second scenario would also include an increased stress associated with pollution and contaminant, and oil spills but this increase would be less than that expected in the first scenario (Table 5.6).

5.9 **Future Condition Analysis and Summary**

For each scenario outlined above, we assessed the effect of each threat on habitat and demographic rates (Table 5.2). To evaluate resiliency under each of the two plausible scenarios, we broke down future threats by management unit and defined conditions based on otter density and predicted population trend (Table 5.3). We evaluated threats currently acting on the SW NSOs, and additional threats that may affect them in the future. It is important to note, not all of the identified threats will act equally across the different management units.

Table 5.2 Anticipated changes in threats to SW NSOs for each plausible future scenario.

Threat	**Plausible Future Condition**	
	Scenario 1 (RCP 8.5)	**Scenario 2 (RCP 4.5)**
Ocean Acidification	moderate population effect on recruitment, and/or reproductive rate (due to negative effects on prey items)	slight population effect
Sea Surface Temperature	less sea ice, range expansion to the north, expansion of new prey (inverts and fishes), reduced kelp beds	reduced kelp beds, range expansion
Extreme Weather	increase in storms frequency and intensity destroys kelp beds, increases direct mortality of adults and pups, decrease reproductive rates and recruitment, increased energetic demands	slight increase in storm frequency and intensity destroys kelp beds, slight increase in direct mortality of adults and pups, decrease reproductive rates and recruitment, increased energetic demands
Disease	increase in disease prevalence, novel pathogens	slight increase in disease prevalence, potential novel pathogens
Pollution/Contaminants	substantially increases in algal blooms, nuclear radiation exposure	slight increase in algal blooms, nuclear radiation exposure
Oil Spills	significant increase with increased ship traffic	increases in likelihood with increased ship traffic
Marine Predators	less kelp protection, increased marine predation; potential new predators associated with warm waters	same as current conditions
Commercial Activities	increased production, leading to increased oil spill risk, increased ship traffic, and increased dredging impacts benthic communities	some areas with increased production, ship traffic, and dredging impacts
Coastal Development	isolated pockets of development, populations may become separated, not able to disperse, genetic isolation	small, isolated pockets of development
Fisheries Bycatch	decrease, fishery collapse	same as current
Illegal Take	increased competition with fisheries and aquaculture industry	same as current
Genetic Diversity	indirect effects based on direct threats	indirect effects based on direct threats
Invasive Species	unknown -potential shift in benthic community to invasive species.	unknown effect

5.9.1 *Resiliency*

Resiliency describes the ability of populations to withstand stochastic events (arising from random factors). We measured condition based on population density (see section 4.6.1 for an explanation of density thresholds) and trend (Table 5.3). Because we cannot project demographic trends into the future, our analysis of this component is based on professional judgement.

Table 5.3 Future condition categories based on SW NSO densities, distribution and trend.

Condition Category	Demographic/Distribution Factors
High	Population stable or increasing above 3+ otters/km^2 but remaining below carrying capacity
Moderate	Population stable or slightly increasing (with densities between 2.9 - 0.75 otters/km^2)
Low	Population is stable or in substantial decline (with densities less than 0.74 otters/km^2)

Scenario 1 (RCP 8.5)

Under scenario 1 we assessed the increased pressures from current (Table 4.11) and the new threats (i.e. invasive species/change in benthic communities and the potential for increased predation by sharks). All climate change related stressors (extreme weather, disease, pollution and contaminants, and marine predators) increased uniformly across all management units to moderate levels (Table 5.4). There is still significant uncertainty about how the benthic communities and potential invasive communities will directly affect SW NSOs within the 30-year timeframe. Therefore, we didn't assign a category to these threats. We specifically looked at direct effects for OA and SST to SW NSOs and found these to remain low for the next 30 years. However, indirect threats caused by increases in OA and SST levels were considered to have moderate effects on all MUs (Table 5.4).

Based on our definitions of future demographic conditions and trends (Table 5.3), we categorized the Kodiak, Kamishak, Alaska Peninsula, Bristol Bay, and Eastern Aleutians MUs as moderate resiliency, and the South Alaska Peninsula and Western Aleutians as low resiliency (Table 5.5).

For four MUs (Kodiak, Kamishak, and Alaska Peninsula, Bristol Bay, South Alaska Peninsula and Western Aleutians) resiliency did not change under the 8.5 scenario. For the Bristol Bay, South Alaska Peninsula and Western Aleutians MUs, future threats did not increase enough to change their resiliency. For the Kodiak, Kamishak, and Alaska Peninsula MU, there was a significant increase in threats due to climate change, oil spills, coastal development, and commercial activities. Despite this, our assessment of resiliency didn't change for this MU based on our definition of future demographic conditions and trends and threats. Because SW NSO densities throughout this MU currently appear to be healthy and there is genetic overlap within the Cook Inlet area with the Southcentral stock, the increased threats did not warrant a resiliency change in this MU. Even if a large stochastic event were to occur the Kodiak, Kamishak, and Alaska Peninsula MU would remain in moderate resiliency.

The fifth MU, Eastern Aleutians, changed from high to moderate resiliency under the 8.5 scenario. Increased threats due to climate change, coastal development, commercial activities (related to oil and gas), and oil spills, combined with the limited amount of habitat (smallest amount of suitable habitat of all five MUs) put the overall resiliency of this MU into the moderate category.

Table 5.4 List of future RCP 8.5 (Scenario 1) primary potential threats to SW NSO and intensity of each stressor. We defined high as a high level of population level effects that occur MU wide; moderate as individual level effects with high chances of localized effects; and low as low level individual effects that are very localized.

Management Unit	**Benthic Communities**	**OA**	**SST**	**Extreme Weather**	**Novel Marine Predators**	**Disease**	**Pollution/ Contaminants**	**Oil Spill**	**Marine predators**	**Land/Avian Predators**	**Commercial activities (including oil & gas)**	**Coastal Development**	**Fisheries Bycatch**	**Subsistence harvest**	**Illegal Take**	**Genetic Diversity**
Kodiak, Kamishak, Alaska Peninsula	mod.	low	low	mod.	low	mod.	mod.	high	mod.	low	high	mod.	unk.	mod.	mod.	low
Bristol Bay	mod.	low	low	mod.	low	mod.	mod.	mod.	mod.	low	mod.	low	unk.	low	low	mod.
South Alaska Peninsula	mod.	low	low	mod.	low	mod.	mod.	mod.	mod.	low	low	low	unk.	low	low	mod.
Eastern Aleutians	mod.	low	low	mod.	low	mod.	mod.	high	mod.	low	mod.	mod.	unk.	low	low	mod.
Western Aleutians	mod.	low	low	mod.	low	mod.	mod.	mod.	mod.	low	low	low	unk.	low	low	mod.

Table 5.5 Future conditions categories for each MU within the RCP 8.5 scenario.

Management Unit	Suitable habitat ≤40m depth(km²)	Condition Category	Overall Resiliency
Kodiak, Kamishak, Alaska Peninsula	14,250	Moderate	Moderate
Bristol Bay	18,101	Moderate	Moderate
South Alaska Peninsula	5,158	Low	Low
Eastern Aleutians	1,967	Moderate	Moderate
Western Aleutians	3,473	Low	Low

Scenario 2 (RCP 4.5)

Under scenario 2, threats to the SW NSO increased relative to current conditions but more moderately than the first scenario (Table 5.6). In general, climate change threats remained low and oil spill threats increased across all MUs. Based on our definitions for future condition categories (density and trends) and threats, we categorized the resiliency of one MU as high (Eastern Aleutians), two as moderate (Kodiak, Kamishak, and Alaska Peninsula, and Bristol Bay), and two as low (South Alaska Peninsula, and Western Aleutians) (Table 5.7). For all MUs, resiliency under scenario #2 was the same as the current resiliency (see section 4.6.1).

Not all threats acted equally across the range. For example, pollution and contaminates and coastal development increased slightly in the Kodiak, Kamishak, and Alaska Peninsula MU, relative to current conditions. Despite these slight increases, we determined this MU has a moderate resiliency. Similarly, for the Eastern Aleutians MU, modest increases in disease and pollution and contaminants occurred, yet resiliency remains high. We believe under RCP 4.5, the Eastern Aleutians population will continue to grow because the threats identified above may have only localized effects on the MU and will not result in a change in resiliency.

Table 5.6 List of future RCP 4.5 (Scenario 2) primary potential threats to SW NSO and intensity of each stressor. We defined high as a high level of population level effects that occur MU wide; moderate as individual level effects with high chances of localized effects; and low as low level individual effects that are very localized.

Management Unit	**Benthic Communities**	**OA**	**SST**	**Extreme Weather**	**Novel Marine Predators**	**Disease**	**Pollution/ Contaminants**	**Oil Spill**	**Marine predators**	**Land/Avian Predators**	**Commercial activities (including oil & gas)**	**Coastal Development**	**Fisheries Bycatch**	**Subsistence harvest**	**Illegal Take**	**Genetic Diversity**
Kodiak, Kamishak, Alaska Peninsula	unk.	low	low	low	low	mod.	mod.	high	low	low	high	mod.	unk.	mod.	mod.	low
Bristol Bay	unk.	low	low	low	low	mod.	low	mod.	low	low	mod.	low	unk.	low	low	mod.
South Alaska Peninsula	unk.	low	low	low	low	low	low	mod.	low	low	low	low	unk.	low	low	mod.
Eastern Aleutians	unk.	low	low	low	low	mod.	mod.	high	low	low	mod.	mod.	unk.	low	low	mod.
Western Aleutians	unk.	low	low	low	low	low	low	mod.	low	low	low	low	unk.	low	low	mod.

Table 5.7 Future conditions categories for each MU within the RCP 4.5 scenario.

Management Unit	Suitable habitat ≤40m depth(km²)	Condition Category	Overall Resiliency
Kodiak, Kamishak, Alaska Peninsula	14,250	Moderate	Moderate
Bristol Bay	18,101	Moderate	Moderate
South Alaska Peninsula	5,158	Low	Low
Eastern Aleutians	1,967	High	High
Western Aleutians	3,473	Low	Low

The ability of the SW NSO population to adapt to or cope with increasing stressors in the future is a topic of uncertainty. While NSOs are adapted to living in a dynamic environment, increasing stressors may negatively affect the population to an unknown extent. However, our estimates of future resiliency do not change significantly between the two scenarios (Table 5.8).

SW NSOs have the potential for high rates of increase when prey is abundant, and mortalities are low. They appear to be highly resilient to stochastic and other events. Examples include the natural recovery of some populations following the end of the commercial fur trade and the recovery of the population in PWS following the EVOS. Given the expected magnitude of change in stressors and the generalist nature of NSO, we do not expect resiliency of SW NSOs to change in the foreseeable future.

Table 5.8 Summary of potential future conditions of MUs under two plausible future scenarios forecasts to 2050: (1) Status Quo (RCP 8.5); (2) Less pressure of climate change stressors (RCP 4.5).

Management Unit	Current Condition	Scenario 1: RCP 8.5	Scenario 2: RCP 4.5
Kodiak, Kamishak, Alaska Peninsula	Moderate	Moderate	Moderate
Bristol Bay	Moderate	Moderate	Moderate
South Alaska Peninsula	Low	Low	Low
Eastern Aleutians	High	Moderate	High
Western Aleutians	Low	Low	Low

5.9.2 *Redundancy*

As previously described, redundancy is typically characterized by having multiple, resilient populations distributed within the species ecological settings and across the species range. The resiliency of the SW NSO population appears adequate. The SW NSOs exhibit a high degree of spatial structure at range-wide, and local scales. Three stocks of NSOs in Alaska persist despite a history of exploitation, extirpation and subsequent recovery through protection and translocation, distribution gaps, low densities, and low genetic diversity. Within the SW NSO, population structure is characterized by semi-isolated, localized populations with few individuals moving among those local populations. The five MUs of the SW NSO reflect differences in population size, demographics, habitat features, and genetics. Conservation theory (Price and Gilpin 1996, pp. 217-230) suggests that spatially structured populations (e.g., meta-populations) will be most resilient to stochastic events, suggesting that redundancy is moderate in SW NSOs. Based on the projections of climate models for some potential stressors and current trends or management plans for others, we do not expect the redundancy of SW NSOs to change in the future. Our estimates of future redundancy were similar in both scenarios.

5.9.3 *Representation*

Representation describes the ability of a species to adapt to changing environmental conditions and is the breadth of genetic or environmental diversity within and among populations. As noted previously, the SW NSO population survived a severe genetic bottleneck associated with large reductions in populations during the commercial fur trade. Nonetheless, the low genetic diversity of SW NSOs has not been limiting population growth. In the WA MU, a lack of dispersal among islands could reduce genetic diversity in the MU overall. However, the proximate causes of dispersal in SW NSOs are uncertain and empirical dispersal rates among islands in the WA MU are unknown.

The environmental diversity of the SW NSOs is currently characterized by high variability in the ecological settings where the species is found. They inhabit large marine ecosystems. Habitats used by SW NSOs range from nearshore rock substrates to soft muds and sands which harbor a diverse set of plant communities and prey species. Variability in the ecological setting where the species is found is unlikely to change.

Representation of the SW NSO is therefore moderate due to low genetic diversity, but high environmental diversity. Representation is not expected to change under future conditions. Accordingly, our estimates of representation were similar under both scenarios.

5.9.4 *Conclusion*

The best available information suggests that four of the five MUs are either stable or increasing. The scope and intensity of potential stressors is currently low to high (Table 5.4) and much of the nearshore habitat of SW NSOs is lightly populated, undeveloped, and remote. Subsistence harvests at the stock level are below levels that are unsustainable, but harvests in a few localized areas may be excessive. As the human population increases in Alaska, it is likely that activities such as shipping and air traffic will increase due to increased demand.

Increased mortalities from diseases such as the strep syndrome occur periodically. The latest analyses for four of the Aleutian Islands of the SW NSO suggests the populations have been stable, but at low numbers since 2005 following the initial decline from 2000-2005 (Tinker 2018, p. 11). It is likely that predation by killer whales has declined due to fewer SW NSOs in the area and a change in sea otter behaviors that have reduced their vulnerability (Ballachey and Bodkin 2015, p. 74). Studies of kelp forest abundance and distribution may eventually provide the information needed to assess the status of the ecosystem-base recovery criterion.

Oil and gas exploration and development in LCI will likely increase in the near future, increasing the chance of a large spill. In addition, lease sales may occur for several areas in the northern portion of the SW NSO range. In general, these activities are well regulated and mitigated, but the potential for a large oil spill increases as activities increase. The potential effects of a large oil spill on the SW NSO population will likely be similar to those of the EVOS in 1989. The probability of a large oil spill is small, but the effects can be significant.

There is little basis, beyond expert opinion, to assess the intensity of the other stressors identified in this assessment into the future. The lack of projections for most stressors beyond midcentury significantly limits what we can infer beyond that time.

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APPENDIX A – POPULATION VIABILITY ANALYSIS

Southwest Alaska Distinct Population Segment of the Northern sea otter (*Enhydra lutris kenyoni*) Population Viability Analysis (PVA) Update

June 2018

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Background

As part of the 5-year review of the southwest Alaska sea otter, the U.S. Fish and Wildlife Service (USFWS) Marine Mammals Management Office has requested a re-analysis of the status and trends of sea otter populations, including a revision and update of a Population Viability Analysis (PVA) model using the most up-to-date available data. In accordance with the Endangered Species Act, a recovery plan was developed in 2013 (USFWS 2013), which included a PVA model used to determine appropriate up-listing and delisting thresholds. A key advantage of the PVA model structure is that it is both possible and in fact recommended that the model be re-run as new data or information become available, thereby avoiding the inevitable obsolescence of fixed listing threshold recommendations. In particular, it was recognized that if survey trends remained stable or positive, that the incorporation of more years of survey data into the PVA model parameterization would potentially lead to a higher proportion of simulations with positive population growth, thereby reducing the listing thresholds. It was recommended that this process be conducted at 5-year intervals, and the up-listing and de-listing thresholds be updated accordingly. In the re-running of the PVA model, the probabilistic definitions of the thresholds would not change, but the specific numerical estimates could change to reflect the most recent survey data. Accordingly, data have been compiled from all skiff surveys that have been conducted at index sites in the Western Aleutian Management Unit between 1991 and 2015 by USFWS and U.S. Geological Survey (see Table 1).

In addition to the incorporation of updated data into the PVA analysis, an update and revision of the PVA model structure has also been requested. This revision must accomplish two goals: 1) to simplify future re-analyses by converting all model code to R programming language and creating the ability to automate running the code with new data; and 2) to take advantage of the longer time series now available, together with state-of-the-art analytical approaches for analyzing such time series (specifically, Bayesian state-space population models; Calder et al. 2003), to improve the accuracy and precision of demographic estimates (age and density-dependent survival, time-varying age-independent mortality, demographic stochasticity). By improving these demographic estimates, and incorporating them seamlessly into the PVA model structure, the results of the simulations (and the associated recommendations for uplisting and de-listing thresholds) will be more reliable, repeatable, and easier to update in future.

In the last few decades there has been a proliferation of computationally intensive techniques for making inferences about underlying demographic processes by fitting population models to time series of survey data (Wang 2009). State-space process models, fit using Bayesian or maximum likelihood methods to time series data, are particularly useful in that they can partition variation in the demographic processes from variation due to sampling or measurement error (de Valpine and Hastings 2002, Calder et al. 2003, Yang and Rannala 2006, Moore and Barlow 2011). A state-space model can be conceptually divided into a process model, which describes true population dynamics due to births, deaths and dispersal, and an observation model that relates the true but "hidden" dynamics to the observed data (e.g. survey counts). The process model can incorporate such phenomenon as density-dependence, environmental stochasticity, and even age and sex structure (Miller and Meyer 2000, Rivot et al. 2004).

Model Summary

The SW Alaska sea otter PVA model consists of three general steps: 1) a trend analysis is conducted using all available data, to obtain updated estimates of key demographic parameters: these include density-dependent survival, environmental stochasticity and an age-independent mortality factor that is assumed to vary with time and density (this age-independent mortality factor is believed to be responsible for the population decline and continued reduced population abundance); 2) the parameter estimates from step 1 are incorporated into a spatially-structured population model (built using stage-structured projection matrices) which simulate dynamics of the meta-population of sea otters in SW Alaska over a 25-year period. These simulations include density-dependent variation in vital rates, environmental and demographic stochasticity, as well as density/time-based variation in additive age-independent mortality; 3) The simulations are iterated many times, with different initial values for sea otter density, and the distribution of results of these simulations are used to determine a) the initial abundance at which there is a significant probability that the population will decline to quasi-extinction within 25 years (this is used to set the up-listing threshold), and b) the initial abundance at which there is a significant probability that the population will decline to the up-listing threshold within 25 years (this is used to set the down-listing threshold).

Methods

Overview

The PVA is a spatially-structured matrix model that incorporates separate age and sex classes, density-dependence, environmental stochasticity in vital rates, inter-island dispersal, and the inclusion of additional "age-independent hazards" (e.g. killer whale predation) that can vary over time: detailed methods for the original PVA are reported in "Appendix B”" of the SW Alaska Sea Otter Recovery Plan (USFWS 2013). Parameterization of baseline vital rates and dispersal are based on literature sources, while parameterization of environmental stochasticity and time-varying age-independent Hazards are accomplished by fitting a state-space model to time series of survey data from index Islands (Table 1). The PVA model analyses are intended to be conducted separately for management units within SW Alaska, but at present are limited to Western Aleutian Islands; however, the listing thresholds, expressed in terms of % of carrying capacity, can be extrapolated to other management units.

We note that for all analyses described in this report, the units of sea otter density correspond to un-corrected skiff survey counts (i.e. otters counted per unit of habitat covered during standardized skiff surveys), rather than true abundance. This convention corresponds to previous population analyses of SW Alaska sea otters (Estes et al. 1998, Burn et al. 2003, Doroff et al. 2003, Estes et al. 2005) and is necessary because at present there is no standardized means of converting sea otter skiff survey counts to units of true abundance. The skiff counts represent a minimum estimate of true abundance and is referred to throughout this report as "relative abundance".

The Data

Skiff surveys by USFWS and U.S. Geological Survey have been conducted opportunistically for 9 index islands (or index island groups, such as the Semichi Islands) over the last 3 decades (Table 1). These surveys include counts of adults and pups made within all or portions of the coastal waters around the Islands. Because the surveys for a given Island varied from year to year in terms of the percentage of the Island's perimeter was surveyed (ranging from ~50% to 100%), we standardized the counts in terms of linear density (otters per km of coastline surveyed), and then extrapolated from these linear densities to estimate the total counts each year had the entire coast had been surveyed. Our demographic model tracks the relative abundance of juveniles (6months – 2.5 years old) and adults (>2.5 years old), but only implicitly tracks pups (i.e. the model incorporates reproductive success but does not track a separate age class for pups because they are entirely dependent on their mothers); therefore, for consistency between model dynamics and observed data we restricted consideration to independent otters only (i.e. non-pups). The full data set required for fitting the hazards model (see below) is provided in Supp. Materials, "Survey_Sum_2015.xlsx"

Time Series Analysis: Base Model and Estimation of Age-independent Hazards

To estimate key demographic parameters for sea otters in SW Alaska, a Bayesian state-space model is fit to time series of survey data. The hidden process consists of the demographic transitions for distinct age/sex classes, and as with previous sea otters models (Tinker 2015) these are modeled using a stage-structured projection matrix that describes demographic transitions and population growth over time (Caswell 2001). The projection matrix for the SW Alaska sea otter PVA describes transitions among four age/sex classes: 1) juvenile females (weaning-2.5 y), 2) adult females (2.5-19.5 y), 3) juvenile males (weaning-2.5 y) and 4) adult males (2.5-19.5 y). Stage transition probabilities are determined by 3 vital rates: stage-specific annual survival (*S*), adult female reproductive output (*R*, defined as the probability an adult female gives birth to and successfully weans a male or female pup into the juvenile age class), and a "growth transition parameter" (*G*) defined as the probability that juveniles advance to the adult age class, conditional upon survival. These demographic transitions can be visualized as a loop diagram (Figure 1).

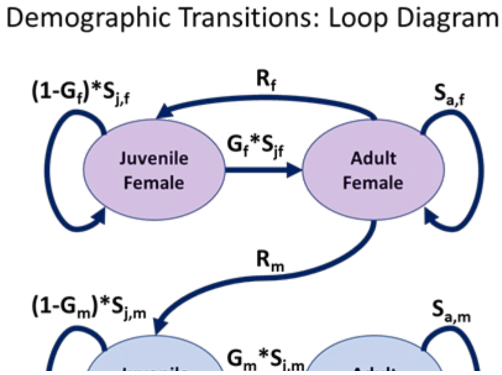


Figure.1. Loop diagram describing demographic transitions for sea otters

Survival rates for sea otters are age- and sex-dependent and also vary as a predictable function of population density (Siniff and Ralls 1991, Eberhardt and Schneider 1994, Monson et al. 2000, Tinker et al. 2006). To accommodate the effects of age, sex and relative density (defined as proportion of carrying capacity, or *K*), we use a proportional hazards formulation to estimate survival, following (Breslow 1975) and previous sea otter models (Eberhardt and Siniff 1988, Brody et al. 1996, Tinker et al. 2017):

$$S_i = \exp\left(-1 \cdot \exp\left[\zeta_0 + (\zeta_j \mid i) + (\zeta_m \mid i) + \zeta_d \left({}^{N}\!/_{K}\right)\right]\right) \qquad (1)$$

where the z symbols represent log instantaneous hazards (sources of mortality which are additive in log form) that vary by density and by the age/sex of an otter: z_0 represents base hazards common to all animals, z_j represents additional hazards unique to juveniles, z_m represents additional hazards unique to males, and z_d represents density-dependent hazards (note that the latter effect is negligible when relative density approaches zero and is maximal as N/K approaches 1). The conditional modifiers in equation 1 indicate hazards that apply to some age/sex classes but not others: z_j is forced to 0 for adults and z_m is forced to 0 for females. Thus survival of adult females ($S_{i=2}$) is determined only by z_0 and z_d, while survival of juvenile males ($S_{i=3}$) is determined by z_0, z_j, z_m and z_d. Values for z parameters (Table 2) were selected so as to maximize consistency between the resulting survival rates and published age/sex/density-dependent survival rates for sea otters, as summarized by (Gerber et al. 2004). The resulting survival functions vary by age/sex and show slightly accelerating decreases with density, thus driving density-dependent variation in population growth rates consistent with the theta-logistic model of population dynamics (Figure 2).

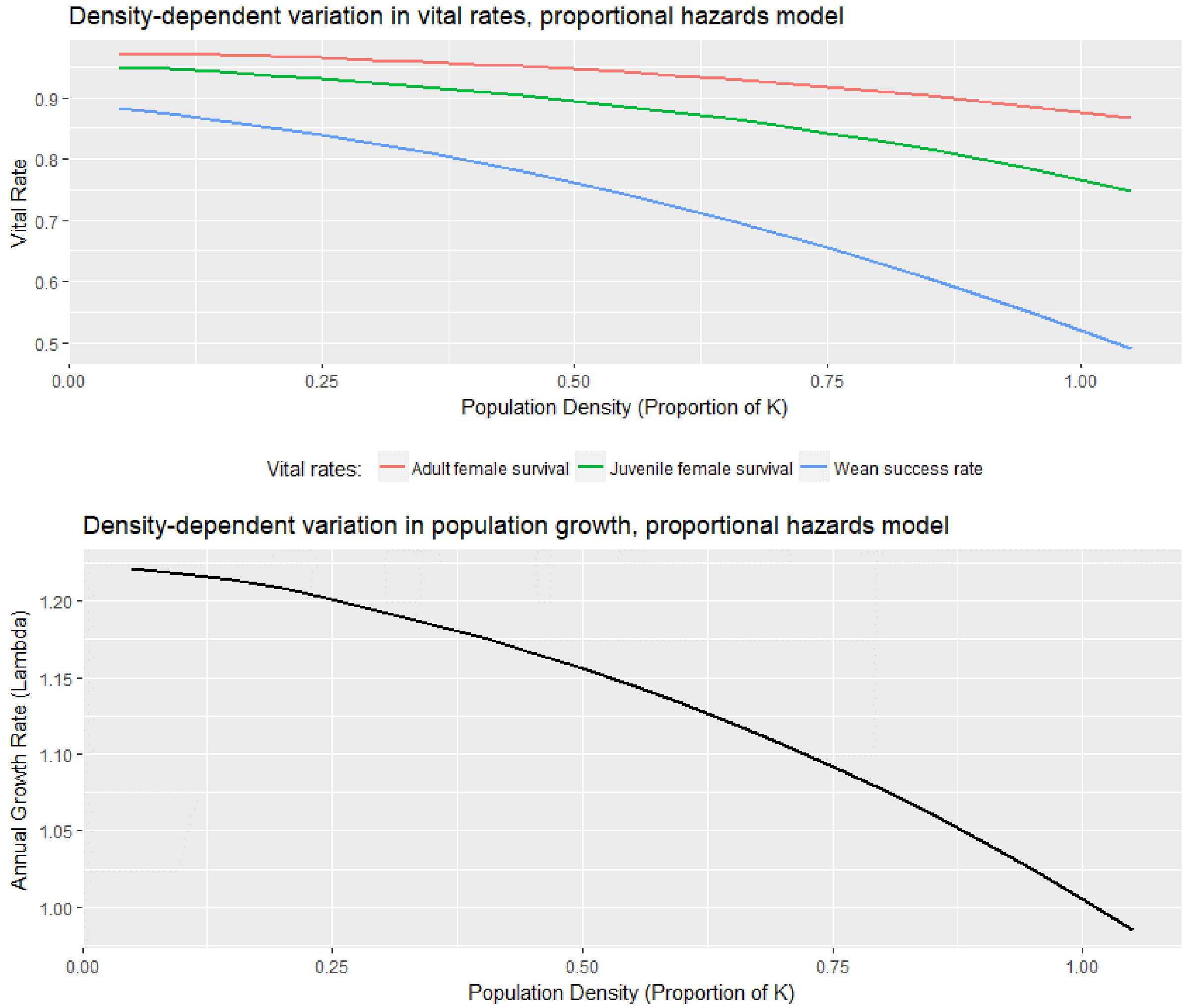


Figure 5 Variation in age-specific survival (top panel) and the resulting variation in population growth rates (bottom panel) as a function of relative density with respect to carrying capacity. Predicted patterns reflect proportional hazards model (equations 1-5) with parameter values listed in Table 2.

Reproductive output by adult females is assumed to reflect a 50:50 sex ratio at birth and is estimated as:

$$R = S_2 \cdot \tfrac{1}{2} b \cdot w \tag{2}$$

where b is birth rate (held constant at 0.97; Tinker et al 2006) and w is weaning success rate, or pup survival, which like adult and juvenile survival is modeled using a proportional hazards formulation:

$$w = \exp\left(-1 \cdot \exp\left[\zeta_0 + \zeta_p + \zeta_d \left(N/K \right)\right]\right) \tag{3}$$

where z_p represents the additional hazards experienced by pups (Table 2), and z_d ensures that weaning success, like survival, is density-dependent (Figure 2). Note that equation 2 also reflects the fact that pup survival is conditional upon adult female survival (S_2).

Growth transition probabilities for each sex are calculated using a standard equation for fixed-duration age classes (Caswell 2001):

$$G_f = \left(\frac{(S_1/\lambda)^T - (S_1/\lambda)^{T-1}}{(S_1/\lambda)^T - 1} \right), \; G_m = \left(\frac{(S_3/\lambda)^T - (S_3/\lambda)^{T-1}}{(S_3/\lambda)^T - 1} \right) \tag{4}$$

where T is the stage duration for juveniles (2 years) and l is the annual rate of population growth associated with a specified matrix parameterization. Combining all parameters into matrix form, we can estimate annual population dynamics using matrix multiplication (Caswell 2001):

$$\begin{pmatrix} n_{1,t+1} \\ n_{2,t+1} \\ n_{3,t+1} \\ n_{4,t+1} \end{pmatrix} = \begin{pmatrix} \left(1-G_f\right)S_1 & R & 0 & 0 \\ G_f \cdot S_1 & S_2 & 0 & 0 \\ 0 & R & \left(1-G_m\right)S_3 & 0 \\ 0 & 0 & G_m \cdot S_3 & S_4 \end{pmatrix} \times \begin{pmatrix} n_{1,t} \\ n_{2,t} \\ n_{3,t} \\ n_{4,t} \end{pmatrix} \tag{5}$$

where the population vector $n_{i,t}$ tracks the numer of otters in each age/sex class (i = 1:4) in year t. The relative abundance of independent otters at a given Island (x) in a given year (t) is computed as the sum of the population vector for that island, $N_{x,t}$ = S$n_{i,x,t}$. Note that we initiated $n_{i,1}$ by multiplying the matrix-predicted stable stage distribution by $N_{x,1}$, which we treated as a fitted parameter in the state space model. The value of K_x for each island was set by multiplying the assumed equilibrium density of 12.5 (units of otters per km^2 of subtidal habitat) by the amount of sub-tidal habitat around each Island: this density corresponds to the literature-reported value of 15 otters per km2 (Burn et al. 2003) adjusted by the average pup ratio (0.2) to obtain a density value that excluded dependent pups.

Equations 1 to 5 describe a "base" process model for sea otter population dynamics, with all parameter values derived from previously-reported data and analyses in the peer-reviewed literature, as cited above. We next modify the base model to allow for environmental stochasticity (i.e. process error, the unexplained stochastic variation in survival across years) and for additive age-independent mortality, believed to be responsible for the population decline between 1990 and the mod 2000s (Doroff et al. 2003, Estes et al. 2005, USFWS 2013). We accomplish this by modifying equation 1 to incorporate both additional age-independent hazards (denoted as g) and process error (s_p), parameters to be fit to observed data using Bayesian methods. Specifically, stage-specific survival rates for a given Island (x) and year (t) are estimated as:

$$S_{i,x,t} = \exp\left(-1 \cdot \exp\left[\zeta_0 + (\zeta_j \mid i) + (\zeta_m \mid i) + \zeta_d \left(N/K\right) + \gamma_{x,t} + \varepsilon_{x,t}\right]\right) \tag{6}$$

where $g_{x,t}$ represents additive age-independent hazards for island x in year t, while $e_{x,t}$ represents the effect of environmental stochasticity and is drawn from a normal distribution with mean of 0 and standard error s_p (where s_p is a fitted parameter with uninformative prior). It has been found that age-independent hazards in SW Alaska have varied both as a declining function of population density and as a non-linear function of time (USFWS 2013); accordingly, we decompose $g_{x,t}$ into density-varying and time-varying components:

$$\gamma_{x,t} = \phi\left(\frac{N_{x,t}}{K_x}\right) + \rho_t \tag{7}$$

where f determines the density-varying portion of age-independent hazards (as it is scaled by the ratio of N/K at island x and year t) and r_t represents time-varying hazards. Preliminary examination of the time series and previous analyses (USFWS 2013) suggested that a) islands within regions tended to exhibit correlated trends (suggesting a regional time-varying function for r_t is appropriate, as opposed to island-specific functions); and b) that a simple linear or quadradic function was unlikely to capture the non-linear nature of trends from 1991-2015. Accordingly, we used conditional auto-regressive (CAR) methods for estimating r_t (Carlin and Banerjee 2003). To normalize values for CAR fitting (since r_t is biologically limited to positive values in the 0-5 range), we applied a logit transform prior to fitting, whereby $y_t = logit(r_t /5)$. The CAR estimation methods are recursive in nature: in year 1, y_1 is drawn from a normal distribution (N) with mean 0 and arbitrarily large variance (effectively a flat prior); in year 2, y_2 is drawn from a normal distribution with mean of y_1 and standard deviation s_t (itself a fitted parameter with uninformative prior); and in all subsequent years y_t is estimated as:

$$\psi_t \sim \mathcal{N}\left(2\cdot\psi_{t-1} - \psi_{t-2}, \sigma_t\right) \tag{8}$$

The time-varying component of age-independent hazards (r_t) was then calculated by back-transformation fromy_t. Equation 8 results in a flexible but temporally-smoothed function for time-varying hazards, with the degree of smoothing driven by the data.

The final step of the state-space model is linking the hidden process model to observed data. For a given set of parameter values, equations 1-8 can be solved to estimate latent variable $N_{x,t}$, the true (but hidden) relative abundance of otters at each Island and year. We assume that the observed survey counts, $C_{x,t}$, are distributed around these true values with precision determined by observer error. We use a negative binomial distribution to describe the over-dispersed nature of sea otter survey counts, with fitted dispersion parameter "n" determining the magnitude of observer error. Specifically, observed variable $C_{x,t}$ is sampled from a negative binomial distribution (NB) with mean of $N_{x,t}$ and variance determined by n:

$$C_{x,t} \sim \mathcal{NB}\left(p_{x,t}, \nu\right), \quad where\ p_{x,t} = \nu \Big/ \left(\nu + N_{x,t}\right) \tag{9}$$

We fit the parameters s_p, s_t, n, r, $N_{x,1}$ and f using standard Markov Chain Monte Carlo (MCMC) procedures, implemented using R and JAGS ("Just Another Gibbs Sampler") software. We used uninformative priors (half-Cauchy distributions for variance parameters, uniform distributions for $N_{x,1}$ and f), and we saved 1,000 samples for each of 20 chains (for a total of 20,000 posterior samples) after 5,000 burn-in replications for each chain. We evaluated model performance and convergence based on effective mixing of chains (assessed by examination of trace plots and values of the potential scale reduction factor or psrf; Gelman and Rubin 1992) and by distinction between posterior and prior distributions. We also graphically examined the consistency between survey counts at index Islands and the model-predicted values of $N_{x,t}$, with associated uncertainty (95% Credible Intervals). The code necessary to run the model is provided in the Supplementary Materials ("FitAiHaz.r" and "FitHaz.jags"). The model-estimated parameters s_p and f were then used to parameterize environmental stochasticity and the density-varying portion of age-independent hazards (g) in the PVA simulations (see below). A lognormal distribution (LN) was fit (using maximum likelihood methods) to the distribution of model-estimated *r* values for 1991-2015, and the resulting lognormal distribution parameters (m and t) were used to parameterize future variation in r_t, the time-varying portion of age-independent hazards.

PVA Simulations

The PVA model structure and simulation methods were based on those described in Appendix B of the Final Recovery Plan document (USFWS 2013). We used a stochastic matrix model to simulate dynamics in a meta-population that is spatially structured into demographically-distinct sub-populations, linked by dispersal. We initialized population vectors for each Island population by multiplying an estimated starting abundance (see next section, below) by the stable stage structure associated with the parameterized matrix (Caswell 2001). We calculated annual demographic transitions for each sub-population using standard matrix multiplication, as shown in equation 5, with stage-specific survival rates estimated by solving equation 6 and using parameter values provided in Table 2. Survival rates thus varied by age-sex and included density-dependence, environmental stochasticity (the value of $e_{x,t}$ each year was drawn randomly from a normal distribution with mean of 0 and standard error s_p) and additional age-independent mortality. The value of $g_{x,t}$ for each island/year combination was calculated using equation 7, with the time-varying component ($r_{x,t}$) drawn randomly from a log-normal distribution with parameters m and t (see previous section, above). For population sizes <50, we modified the matrix multiplication to explicitly account for demographic stochasticity, following methods described elsewhere (Morris and Doak 2002).

Dispersal between Islands was assumed to be density-dependent and stochastic, with probability of movements between Islands expressed as a function of relative density and distance between Islands. We used a non-linear function to describe $E_{x,t}$, the proportion of a source population expected to emigrate from a source population on a given year:

$$E_{x,t} = \exp\left(-\alpha_4 \cdot \left(\alpha_1 \cdot (\Delta_{x,y})^{\alpha 2} \Big/ \alpha_3 \cdot \left(N_{x,t} \big/ K_x \right) \right) \right) \tag{10}$$

where $D_{x,y}$ is the distance (in km) between the source population (*x*) and the nearest neighboring island (*y*), and $a_{a=1:4}$ represents a vector of parameters to be fit. Because there existed no empirical data on inter-island movements in SW Alaska with which to fit equation 10, we instead used expert opinion-based estimates of inter-island dispersal rates for conceptual island populations of varying distances apart and density relative to K (USFWS 2013). Fitting equation 10 to these expert-generated "pseudo-data" resulted in the parameter estimates shown in Table 3, which model $E_{x,t}$ as a declining function of $D_{x,y}$ and relative density (Figure 3). Note that a_4 is effectively a scaling parameter, used to scale emigration values between low-dispersal and high-dispersal scenarios that spanned the range of expert opinion estimates.

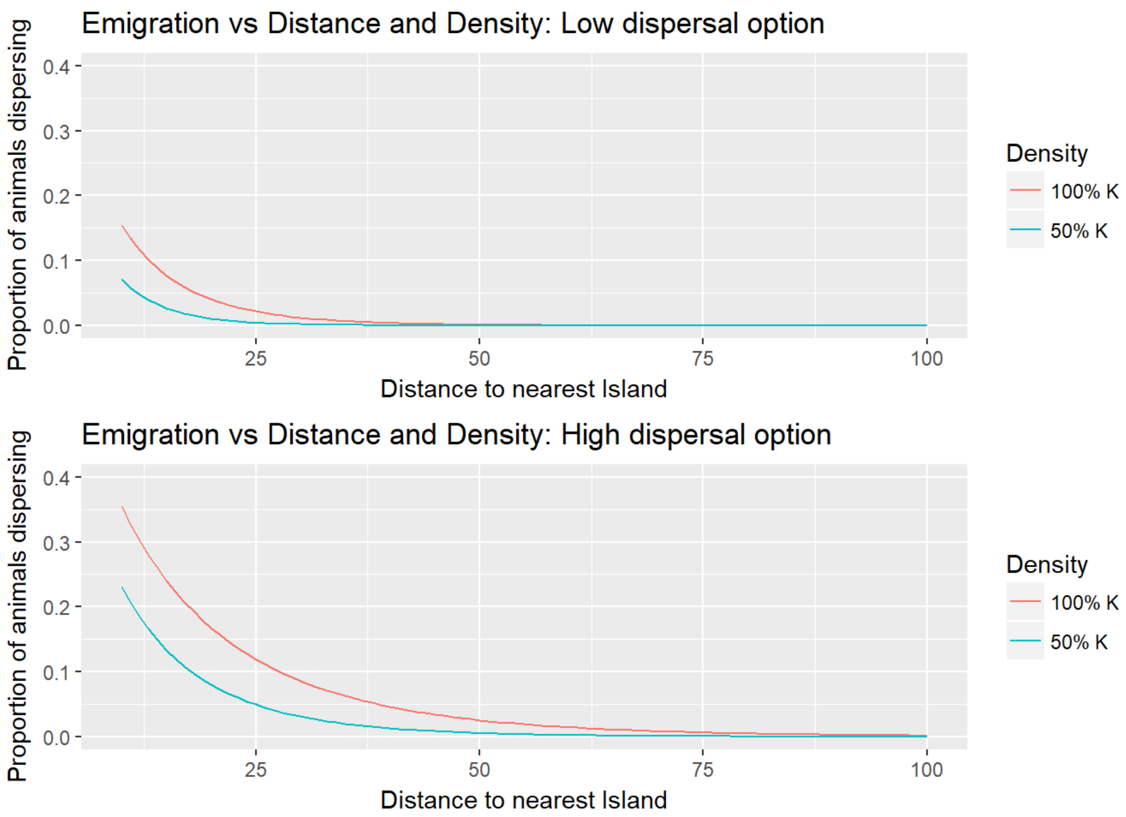


Figure 6 Dispersal rates (Ex,t) modeled as a function of relative population density (% of K) and distance from source island to the nearest neighboring island.

The actual number of dispersers each year from a particular island ($D_{x,t}$) was drawn randomly from a Poisson distribution with expected value $N_{x,t}*E_{x,t}$. For cases when $D_{x,t} > 0$, we used a multinomial distribution to randomly partition $D_{x,t}$ among age/sex classes, such that $\mathrm{S}d_{i,x,t} = D_{x,t}$ and dispersers were both male-biased (70:30) and juvenile-biased (60:40), based on published accounts of long distance movements by sea otters (Garshelis and Garshelis 1984, Jameson 1989, Ralls et al. 1996, Bodkin et al. 2000, Tinker et al. 2008). The recipient island for any dispersal event was also assigned randomly, with probabilities weighted by the relative proximities of all possible recipient islands (weightings were scaled by pairwise inverse distance squared, so dispersers were most likely to arrive at near-by islands).

For each management unit, we simulated 25 years of population dynamics. To capture the full range of uncertainty in simulation results (reflecting sampling error, model parameter uncertainty and environmental and demographic stochasticity), we ran 5000 simulations for a specified starting density, with all parameters and variables drawn randomly from the appropriate sampling distributions, as described above.

Estimation of Listing Thresholds

To determine appropriate uplisting threshold for the Western Aleutian management unit, the suite of 5000 simulations described above was repeated for 20 different starting densities. Initial densities evaluated ranged from 0.1% to 25% of regional K (where regional $K = \mathrm{S}K_x$) and at $t = 0$ we distributed the regional population across Islands by drawing from a multinomial distribution with probability values scaled to the proportional abundances for each Island in the most recent range-wide survey (year 2000). For each of the 20 starting densities, we tracked the proportion of simulations that went to quasi-extinction within a 25-year period, a value we designate as Ω. Quasi-extinction is defined as the point at which there are no remaining Islands with at least 5 adult females and at least 1 adult male (USFWS 2013). We fit a quadradic function to the log-transformed dataset of Ω vs. starting density (as this functional form resulted in an R^2 of >0.95) and using this function we solved for the density at which $\Omega = 0.05$; this value represents the starting density associated with ≥ 5% probability of quasi-extinction within a 25-year period. To account for uncertainty, we actually use the upper 95% prediction interval for this function to determine the critical density, Ω^{05}, which has been suggested as an appropriate value for the up-listing threshold, L^U (USFWS 2013). Note that if Ω^{05} is very low (less than 500), considerations such as maintenance of genetic diversity may be more important than demographic viability, and thus we suggest setting L^U to the maximum of 500 or Ω^{05}.

The full suite of simulations was then re-run for 20 different starting densities, exactly as described for the up-listing threshold. For each starting density we recorded ω, the proportion of simulations in which relative abundance drops below L^U (the suggested up-listing threshold). As before, we fit a function to the log-transformed dataset of ω vs starting density, and then solve for the starting density at which $\omega = 0.05$; above this density there is <5% probability of the population becoming endangered (dropping below L^U) within 25 years. To account for uncertainty, we use the upper 95% prediction interval for this function to determine the critical density, ω^{05}, which is suggested as an appropriate value for the de-listing threshold, L^D.

Results

Time Series Analysis: Age-independent Hazards

The state-space model used to estimate age-independent hazards (g) and environmental stochasticity (s_p) converged well: examination of trace plots and psrf values indicated excellent chain mixing (for all parameters psrf £1.01), and posterior distributions of all model parameters were unimodal and distinct from prior distributions (Figure 4). The baseline vital rates, combined with the density- and time-varying components of g (f and r, respectively), resulted in estimated trajectories at index islands that were in good agreement with the skiff survey trends at these Islands (Figure 5). The estimated value for f suggested that density-varying component of g was only important in the earliest years of the decline, when sea otters were still abundant; since then, elevated and variable values of r_t (Figure 6) have been primarily responsible for the continued decline and (more recently) for the failure of populations to recover post-decline. Interestingly, variation in r_t appears to exhibit cyclical behavior, with peaks in mortality occurring with a periodicity of approximately 7-9 years (Figure 6).

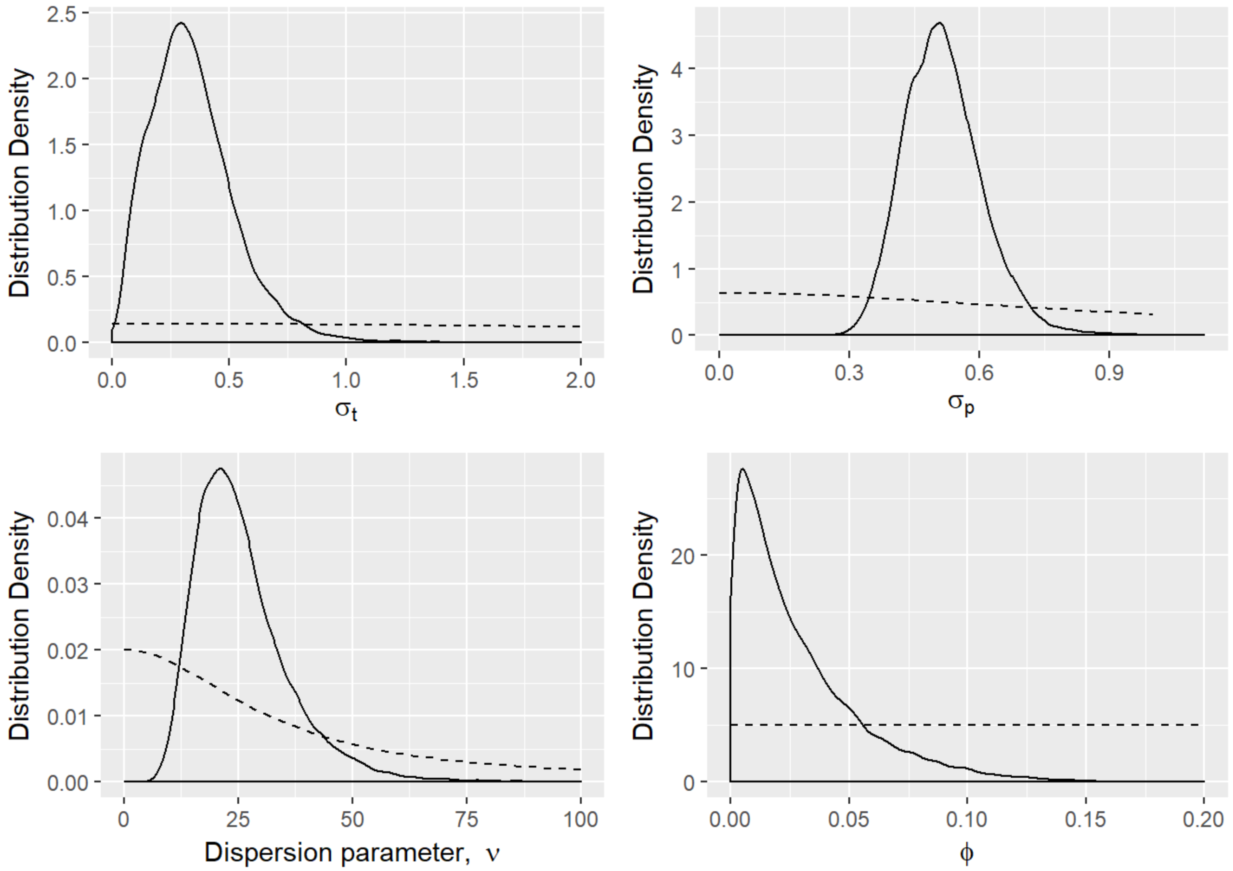


Figure 7 Posterior distribution plots for parameters of the Bayesian state-space model fit to time series of skiff survey counts for 9 index islands (or island groups) in the Aleutian archipelago. Prior density distributions are shown as dashed lines for comparison. Parameters shown include s_t (variance in instantaneous rate of AI hazards over time), s_p (variance in baseline hazards, or environmental stochasticity), the negative binomial dispersion parameter (n, which determines observer error in survey counts), and f, the parameter for density-dependent variation in AI hazards.

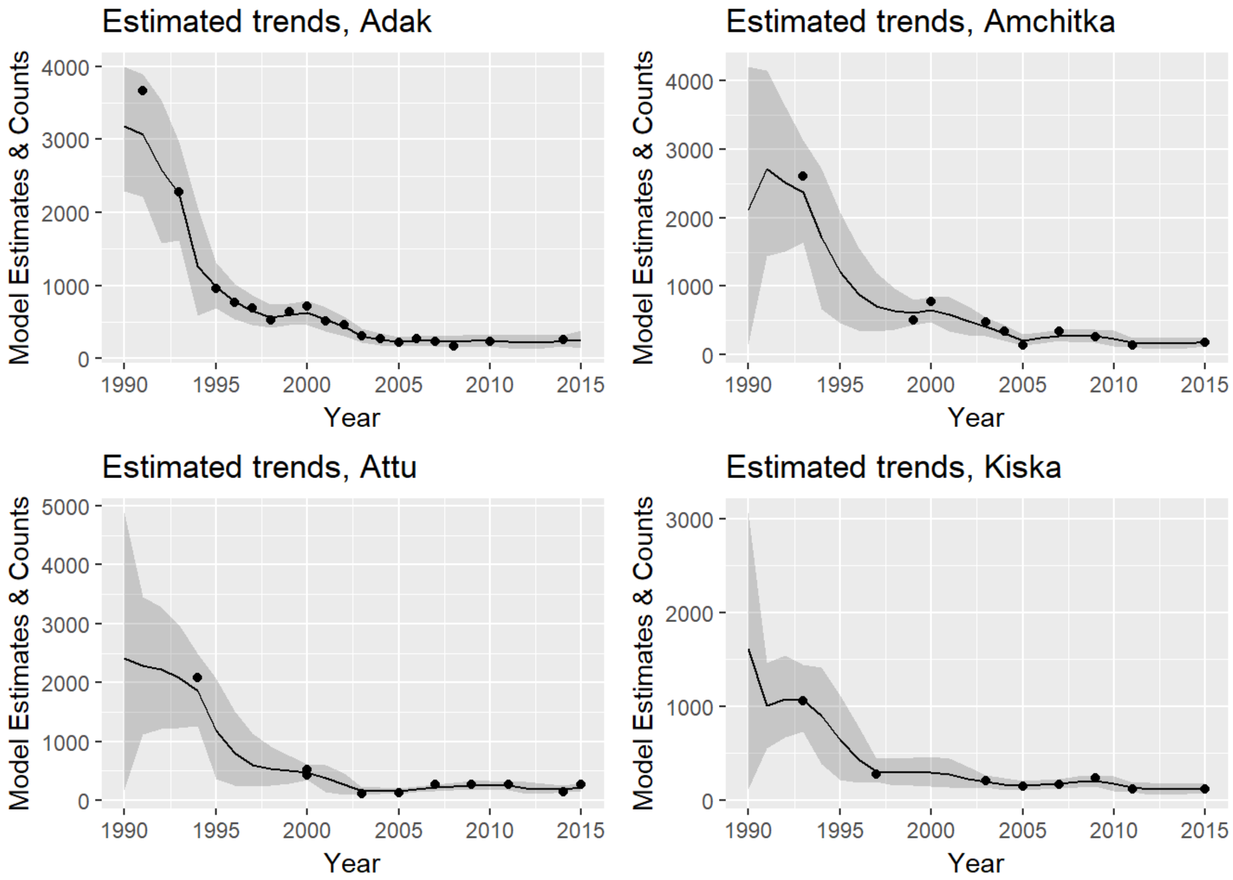


Figure 8 Plots of sea otter population trends at 4 index islands in the Aleutian archipelago. Solid lines show the inferred "true" relative abundance over time at each Island, while grey shaded bands indicate the 95% CI for relative abundance, and points indicate survey counts.

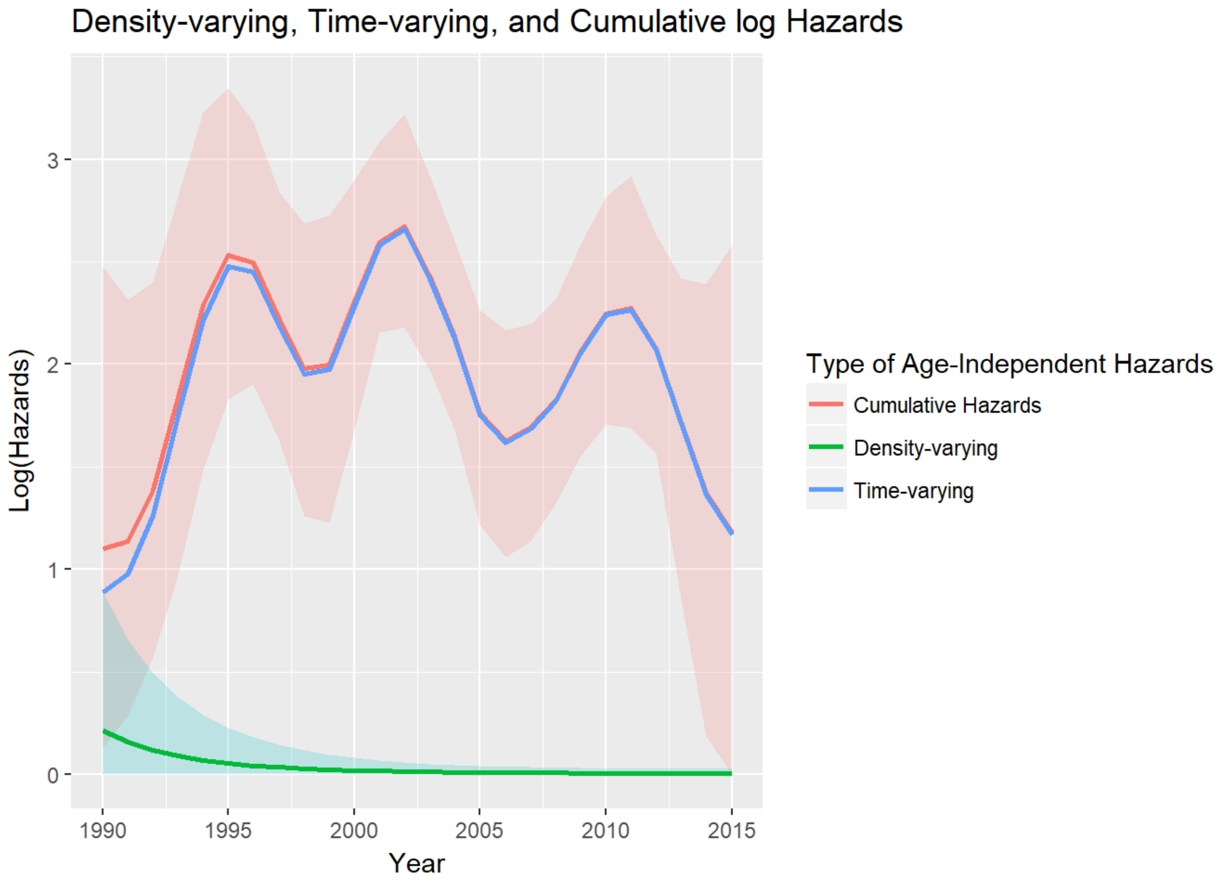


Figure 9 Plot showing temporal trends in estimated age-independent hazards (g) based on the results of a Bayesian state-space model fit to survey data at 9 index islands. Log-hazard values are shown for the density-varying component of g (as determined by parameter f) and for the time-varying component (r), as well as for the sum of these components, or cumulative hazards. Solid lines indicate mean estimated parameter values while shaded bands indicate 95% CI around these estimates.

PVA Simulations and Estimation of Listing Thresholds

PVA simulations for each island or island group resulted in a distribution of outcomes, with some trajectories going to extinction and some remaining approximately stable or even increasing over a 25-year period (e.g. Figure 7). The proportion of simulations going to regional quasi-extinction varied predictably as a function of the starting population density, a pattern that was used to determine critical thresholds for extinction or endangerment probability (Figure 8).

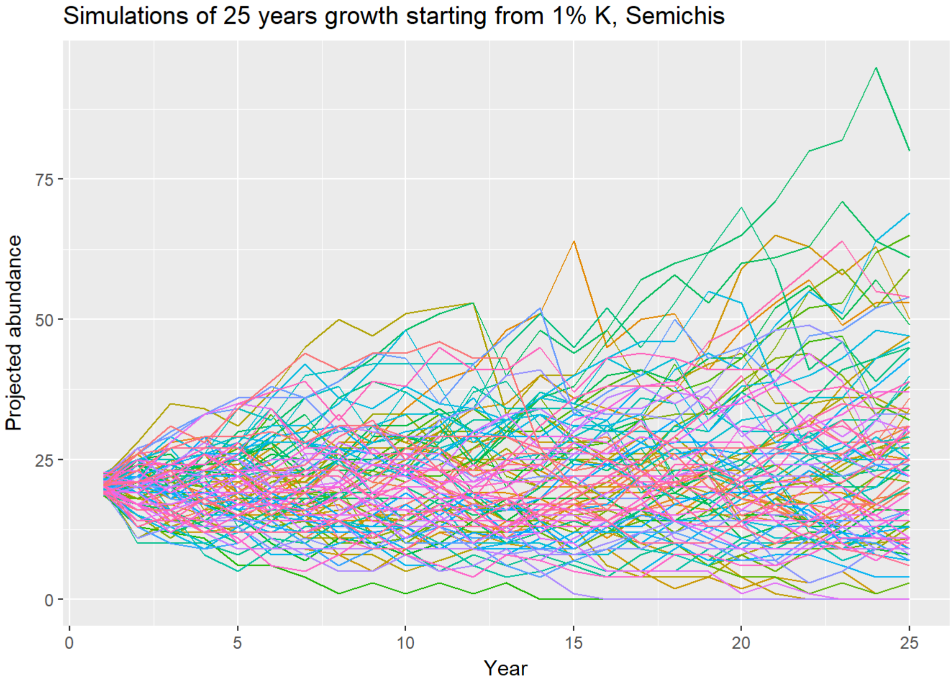
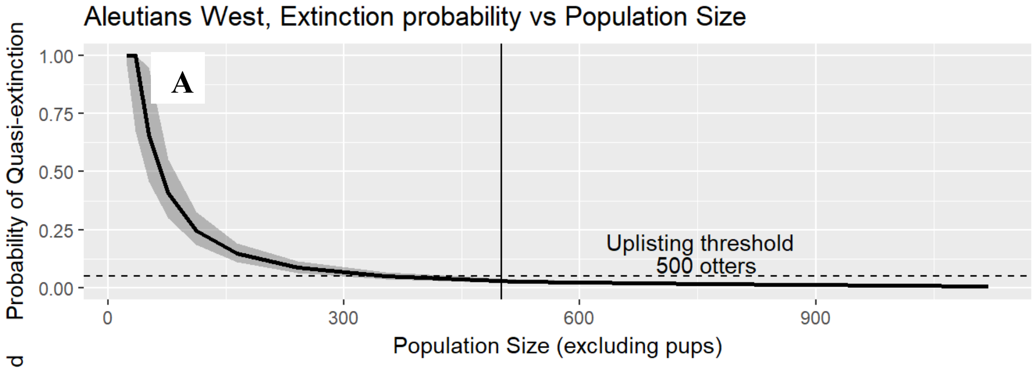
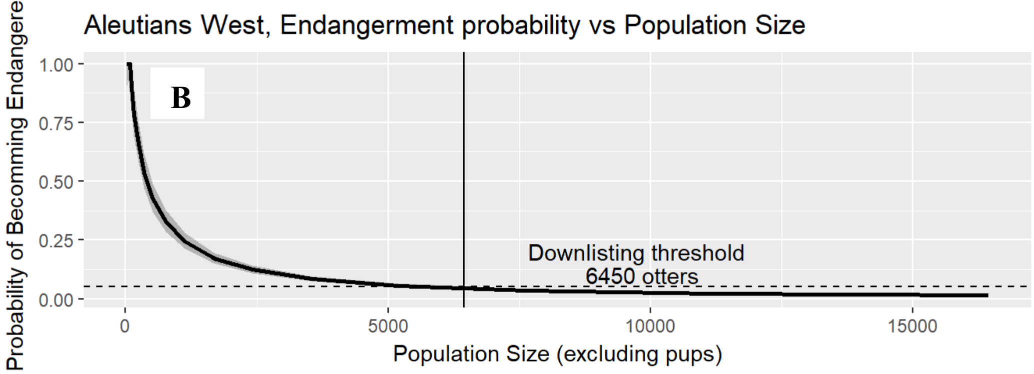


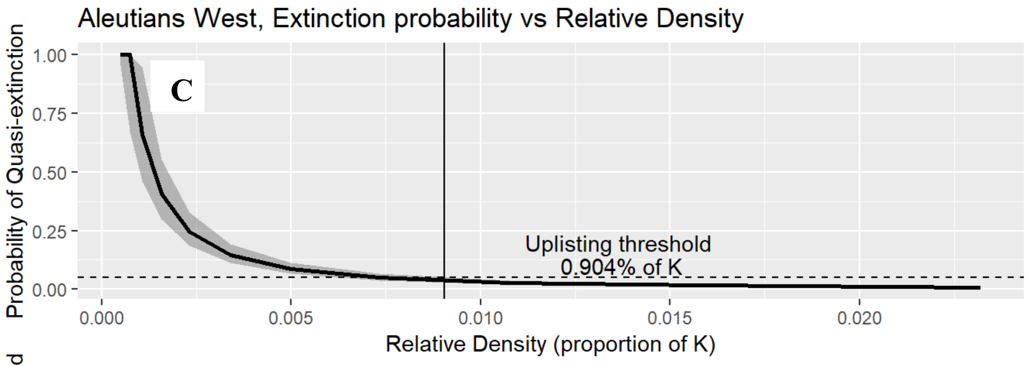
Figure 10. Plot of a sub-sample of results from 5000 iterated simulations of the PVA model for the Semichi Islands, illustrating the range of outcomes given stochasticity and parameter uncertainty. Starting abundance for this set of simulations was 20-24 independent otters, corresponding to the most recent skiff survey results.

For the Western Aleutians, the estimated risk of extinction (W) is >5% when there are fewer than 357 independent otters, with 95%CI 293 – 436. Since the upper 95%CI for Ω^{05} is less than 500 animals, it is suggested that the uplisting threshold (L^U) be set to 500 for the Western Aleutians (Figure 8a), corresponding to 0.9% of *K* (Figure 8c). Likewise, the risk of becoming endangered (w) is <5% when there are at least 5741 independent otters, with 95%CI 5129 – 6450. Thus, the suggested down-listing threshold for the Western Aleutians is 6450 independent otters (Figure 8b), which corresponds to 13.4 % of *K* (Figure 8d).

Until such a time as updated survey data are available (and thus the model run) for the other management units, it is recommended that the uplisting and down listing thresholds for these management units be set based on the results for the Western Aleutians. Specifically, the uplisting and down listing thresholds for these management units should be set to 1% and 14% of the estimated relative abundance at *K* for these management units.


Aleutians West, Extinction probability vs Population Size
A
Probability of Quasi-extinction
1.00
0.75
0.50
0.25
0.00
0
300
600
900
Population Size (excluding pups)
Uplisting threshold
500 otters


Aleutians West, Endangerment probability vs Population Size
B
Probability of Becomming Endangered
1.00
0.75
0.50
0.25
0.00
0
5000
10000
15000
Population Size (excluding pups)
Downlisting threshold
6450 otters


Aleutians West, Extinction probability vs Relative Density
C
Probability of Quasi-extinction
1.00
0.75
0.50
0.25
0.00
0.000
0.005
0.010
0.015
0.020
Relative Density (proportion of K)
Uplisting threshold
0.904% of K

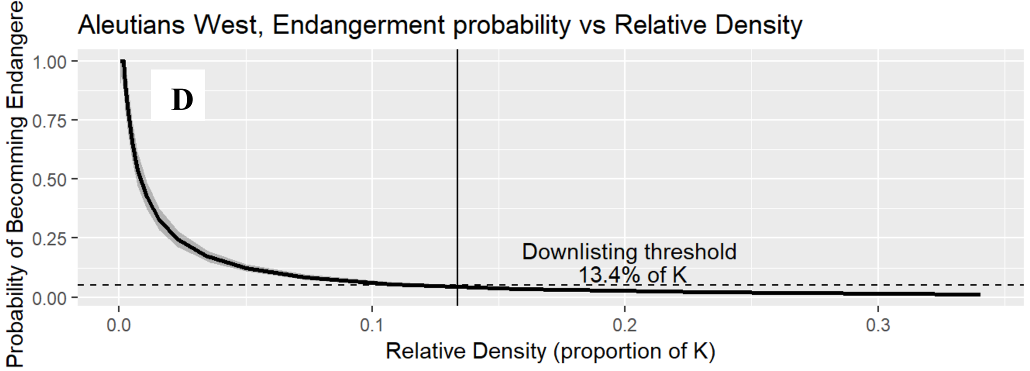

Aleutians West, Endangerment probability vs Relative Density
D
Probability of Becomming Endangered
1.00
0.75
0.50
0.25
0.00
0.0
0.1
0.2
0.3
Relative Density (proportion of K)
Downlisting threshold
13.4% of K

Figure 11. Plot of the functional relationship between the initial abundance of otters and the likelihood of extinction (panels A and C) and the likelihood of endangerment (panels B and D) over a 25-year period for the Western Aleutians (panels A and B) and Eastern Aleutians (panels C and D). Recommended uplisting and down-listing thresholds correspond to the points where the upper 95% CI for these functions drop below 5% probability (or, in the case of the uplisting threshold, 500 independent otters, whichever is greater).

Tables

Table 1. Summary of skiff survey data available for 9 index islands (or island groups) between 1991 and 2015. Counts and linear densities (otters per km coast surveyed) are shown for independent animals (non-pups) only.

	Adak			Agattu			Amchitka			Attu			Kagalaska			Kiska			Little Tanaga			Rat			Semichis		
Year	# Otters	Lng (km)	Ott/km	# Otters	Lng (km)	Ott/km	# Otters	Lng (km)	Ott/km	# Otters	Lng (km)	Ott/km	# Otters	Lng (km)	Ott/km	# Otters	Lng (km)	Ott/km	# Otters	Lng (km)	Ott/km	# Otters	Lng (km)	Ott/km	# Otters	Lng (km)	Ott/km
1991	1507	152.9	9.8542																								
1993	718	117.4	6.1164				641	49.4	12.982				191	88.8	2.1514	662	111.9	5.9161							74	15.6	4.7459
1994										2078	272.4	7.6297													186	52.6	3.5355
1995	929	359.6	2.5835																								
1996	725	354.0	2.0478																								
1997	688	372.3	1.8479										26	88.8	0.2929	85	56.1	1.5142									
1998	525	372.3	1.4101																								
1999	635	372.3	1.7056				356	141.3	2.519																		
2000	713	372.3	1.9151				117	30.3	3.8659	921	525.4	3.5174	43	88.8	0.4843				44	86.3	0.5098				110	103.2	2.1408
2001	515	372.3	1.3833																								
2002	461	372.3	1.2382																								
2003	306	372.3	0.8219	37	102.0	0.3629	235	98.9	2.3759	106	253.1	0.4189	11	88.8	0.1239	184	157.7	1.167	15	86.3	0.1738				19	50.0	0.38
2004	277	372.3	0.744				65	38.5	1.6862																		
2005	209	361.3	0.5785	36	102.0	0.3531	66	98.9	0.6673	118	253.1	0.4663				127	157.7	0.8055				19	37.2	0.5112			
2006	272	372.3	0.7306										11	88.8	0.1239				22	86.3	0.2549						
2007	231	372.3	0.6204	38	102.0	0.3727	171	98.9	1.7288	255	253.1	1.0077				149	157.7	0.945				17	37.2	0.4574	21	50.0	0.42
2008	158	353.4	0.447																								
2009				81	102.0	0.7945	127	98.9	1.284	254	253.1	1.0037				208	157.7	1.3192				9	37.2	0.2421	21	50.0	0.42
2010	224	357.8	0.626																								
2011				65	102.0	0.6376	72	98.9	0.7279	235	233.3	1.0072				103	157.7	0.6533				12	37.2	0.3228			
2014	249	357.8	0.6959							137	272.4	0.503													8	53.2	0.1503
2015				43	98.4	0.4371	185	200.7	0.9217	257	253.1	1.0156				110	177.7	0.619				9	25.7	0.3501	16	49.6	0.3226

Table 2. Parameter values for proportional hazards model used to describe survival and weaning success (pup survival).

Parameter	Value	Interpretation
z_0	-3.775	*log*(base hazards): specifies hazards common to all animals
z_j	0.7	*log*(hazard ratio for juveniles): additional hazards experienced by juveniles
z_m	0.5	*log*(hazard ratio for males): additional hazards experienced by juveniles
z_p	1.6	*log*(hazard ratio for pups): additional hazards experienced by pups
z_d	1.75	*log*(hazard ratio for density-dependent effects): additional hazards per unit increase in N/K

Table 3. Parameter values for dispersal function that describes variation in emigration rates as a function of distance to nearest neighboring Island and the population density relative to K (see Equation 10, Figure 3).

Parameter	Value	Interpretation
a_1	0.303	Determines overall magnitude of distance effect on dispersal probability
a_2	0.789	Determines rate at which dispersal decreases with distance
a_3	0.492	Determines overall magnitude of density effect on dispersal probability
a_4	0.554-1	Scaling parameter: varies emigration from high dispersal scenario (a_4 = 0.544) to low dispersal scenario (a_4 = 1)

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Supplementary Materials

The electronic files listed below can be found in an archive ("SeaOtterPVAmodel_files.zip") accompanying this report; these files are sufficient to run all the analyses described in methods, and to re-create the resulting statistics and summary plots. The first two files listed are the only files necessary for a user to run (as they call up all the other files): the r script "PVA_Shell.r" can be executed to run all components of the state-space model and PVA simulations (takes several hours, depending on computer speed), while the r markdown file "PVAmodel.rmd" is used to produce all statistical and graphical summaries. Further details are provided in the associated README file and in the "comments" sections at the top of all the r code and JAGS code files. Note that the last 3 files represent data files, which can be updated as more data are collected and the PVA re-run in future.

File list:

- **PVA_SHELL.r**
- **PVAmodel.rmd**
- README.docx
- FitDispFxn.r
- FitDisp.jags
- FitAiHaz.r
- FitHaz.jags
- somatrixHz.r
- somatrixHzDS.r
- PVA_sim_WestAleut.r
- PVA_thresholdExt.r
- PVA_thresholdThrt.r
- PVA_DispersPlots.r
- AiHazard_plots.r
- PVA_example_plot.r
- PVA_simplots.r

Data Files

- Survey_Sum_YEAR.xlsx (contains survey results)
- Aleutdata.xlsx (contains meta-data about islands)

Dispers_expected.xlsx (estimates of dispersal b