The Elakha Alliance

Our mission: To restore a healthy population of sea otters to the Oregon coast and to thereby make Oregon's marine and coastal ecosystem more robust and resilient.

Formed by tribal, nonprofit, and conservation leaders with a shared belief in a powerful vision: an Oregon coast 50 years from now where our children and grandchildren co-exist along with a thriving sea otter population and a robust and resilient marine ecosystem.

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ELAKHA ALLIANCE

Chapter 1: Introduction

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Background

The sea otter (*Enhydra lutris*) is one of the smallest of the world's marine mammals. As an apex carnivore in nearshore coastal marine habitats of the north Pacific Ocean it is recognized to play important functional roles in ecosystem structure and dynamics (Estes and Palmisano 1974, Riedman and Estes 1990, Tinker et al. 2017). During the international fur trade of the 18^{th} and 19^{th} century, sea otters were extirpated from the Oregon coast and indeed from most of the coast of the eastern North Pacific Ocean (Kenyon 1969).

At present there is no sea otter population in Oregon, although individual animals, thought to be mostly males making long-distance movements from populations to the north (Washington State) and south (central California), are observed from time to time.

In recent years there has been renewed interest in the possibility of reintroducing sea otters to Oregon, with several motivating objectives: 1) restoring the various ecological functions of a keystone species formerly present in Oregon's marine environment; 2) restoration of the cultural relations between sea otters and human residents along Oregon's coast; 3) increasing the capacity for the species overall to survive potentially catastrophic events, such as oil spills, through a broader distribution of sea otter populations on the Pacific Coast; and 4) improving the gene flow between northern sea otters on the Washington and British Columbia coasts and southern sea otters in California.

The Elakha Alliance, an Oregon non-profit organization, in cooperation with several partners, has supported the preparation of this Feasibility Study to determine whether existing habitat, source populations, and political, legal, economic, and social contexts are suitable for a successful reintroduction of sea otters to Oregon.

Reintroduction vs translocation

Wildlife reintroduction programs involve "the intentional movement and release of an organism inside its indigenous range from which it has disappeared", where the goal is "to re-establish a viable population of the focal species within its indigenous range" (IUCN 2013). Within this document we use the phrase "reintroduction" as defined in the previous sentence, although when specifically describing the process of moving animals from one location (e.g., a source population) to another location (e.g., a potential reintroduction site) we also use the related term "translocation".

Wildlife translocation and reintroduction as a conservation strategy has been used extensively over the past century, with well-known examples of successful reintroductions including golden lion tamarins in South America (Kleiman and Mallinson 1998), peregrine falcons in the mid-western United States and Canada (Tordoff and Redig 2001) and fisher populations in the Pacific northwestern United States (Lewis et al. 2012).

The translocation and reintroduction of sea otters to their former habitats along the west coast of North America (including southeast Alaska, British Columbia, Washington, and San Nicolas Island in southern

California) proved to be a successful management strategy for the recovery of this species from near extinction (Jameson et al. 1982, Bodkin 2015) (See Chapter 2, Prior Translocations).

In contrast to these success stories however, are the many reintroduction efforts that have failed to establish viable populations (Griffith et al. 1989, Wolf et al. 1996). In 1970 and 1971, nearly 100 sea otters from the Aleutian Islands were translocated to the southern Oregon coast (Jameson et al. 1982). Although post-release reproduction of this translocated population was documented and some animals persisted in Oregon for about five years, a permanent population was not established (Jameson 1975).

One cause of failed reintroductions is inadequate planning from a demographic and ecological perspective; for example, not including enough individuals of the appropriate age/sec classes, or selecting inappropriate habitats (Kleiman 1989, Wolf et al. 1998). However, another reason for failure includes a too-narrow focus on demographic and ecological factors and a lack of attention to other key elements such as social, economic and political considerations (Reading et al. 2002).

Reading et al. (2002) identify four main categories of considerations that should be addressed when considering the feasibility of a reintroduction program: 1) Biological and technical aspects (population ecology, habitat suitability, translocation and reintroduction techniques, etc.); 2) Organizational aspects (the personnel, bureaucratic structure and relationships between the various agencies and organizations involved); 3) Authority/Power aspects (legal and political considerations); and 4) Socio-economic aspects (including values, traditions, attitudes and economies of the affected communities). All these variables can play a role in the success or failure of a reintroduction program; thus, it is important to incorporate this broader suite of considerations into the initial assessments of feasibility of any reintroduction efforts under consideration.

The goal of the Feasibility Study

The overall goal of the Feasibility Study is to assist the Elakha Alliance, relevant state and federal agencies, stakeholders, and the public in identifying, understanding, evaluating, and addressing environmental, economic, social, legal and other factors relevant to restoring a population of sea otters on the Oregon coast. It is intended to provide the Elakha Alliance and all parties with the best available scientific, economic, and legal information and analyses to guide consideration of future steps toward restoration, in consideration of:

a) implications for the viability of source populations and newly established populations
b) suitability of habitat and the potential for positive and negative effects on ecosystems
c) social and economic impacts, both positive and negative
d) administrative and legal requirements
e) logistical constraints and steps for implementation

It is also important to emphasize what this report is not intended to be: specifically, it is NOT intended as a definitive statement about whether the reintroduction of sea otters to Oregon is advisable, or indeed whether it is practically feasible from all perspectives. Such decisions are left to others: the purpose of this report is to provide a comprehensive source of pertinent information, history, and best available science, which we believe will be useful for a wide range of stakeholders, resource managers and decision makers going forward.

At a superficial level, the question of whether reintroducing sea otters to Oregon is conceptually "feasible" is almost self-evident: successful sea otter reintroductions conducted previously (see Chapter 2), combined with historical documentation that sea otters were once abundant in coastal Oregon (see Chapter 4), would argue for feasibility in the broadest definition of that word.

This report is not intended to provide a yes or no answer to the question of whether reintroduction is advisable, nor is it designed to convince the reader of one opinion or another. Rather, it is our intent to amass and synthesize the relevant information that we believe that a person (or community of people) would need to make an informed decision about whether to proceed with a proposal to reintroduce sea otters to Oregon, and secondarily to provide guidance about what elements such a proposal should include.

Contents of this report

Twelve chapters (including this introductory chapter) focus on different considerations that are germane to a comprehensive assessment of the feasibility of a reintroduction of sea otters to coastal Oregon. A set of Appendices to this report contain more detailed documentation, maps and resources that are alluded to in various chapters.

Chapter 2, Prior Translocations, begins with an overview of the history of previous sea otter translocation and reintroduction efforts over the past century. By comparing the methods, goals, and outcomes of these previous efforts, we draw some basic inferences about the factors that seem to predict success or failure in sea otter reintroductions, as well as some of the key variables that need to be considered in any future reintroductions.

Chapter 3, Population and Demographic Considerations, assesses feasibility from the perspective of population biology, examining some of the demographic variables that can determine success of a reintroduction effort. A principal tool in this assessment is an Oregon Sea Otter Population Model (ORSO), a computerized population model built upon previously published population models for sea otters. This model provides a quantitative modeling framework for evaluating probable outcomes and associated uncertainty of various reintroduction scenarios. The model methods are explained in detail in an Appendix attached to the report, and a web-based user interface allows any interested user to explore the implications of different assumptions, variables, and alternative logistical strategies for the potential viability and likely future abundance and distribution of sea otters in Oregon.

The Oregon Sea Otter Population Model (ORSO) uses a stage-structured matrix model of sea otter demography to project future trends in abundance and changes in spatial distribution of reintroduced sea otter populations. The model is structured and parameterized based on extensive data from other sea otter populations and reintroduction outcomes, and incorporates density dependence, Allee effects, environmental and demographic stochasticity, and realistic dispersal and range expansion behavior. Thus, while any one simulation trajectory is unlikely to reliably predict future outcomes for a proposed reintroduction scenario, the range of projections over many model iterations will tend to encompass the most likely future outcomes.

Chapter 4, Genetic Considerations, explores the implications of a reintroduction of sea otters to Oregon from a genetic and historical perspective. This chapter provides an overview of the deep history of sea otters in North America, and Oregon in particular and summarizes published information on genetic diversity and relatedness of the extant sea otter populations. The chapter examines the implications of an Oregon reintroduction for genetic diversity and connectivity of sea otter populations overall.

Chapter 5, Ecosystem Effects, broadens the assessment from biologic and demographic to the ecosystem-level implications of a sea otter reintroduction. Sea otters are often considered to be a textbook example of a "keystone species", defined as a species that has disproportionately large effects on its ecosystem relative to its abundance (Paine 1969). As sea otters have been reintroduced or naturally recovered to other coastal areas in North America, they have caused substantial perturbations to the structure and dynamics of nearshore food webs. Some of these effects are perceived as beneficial for people and some are perceived as negative. This chapter provides a brief primer on the ecological concepts necessary to interpret the direct and indirect effects of sea otter recovery, reviews these effects and discuss their implications for nearshore ecosystems and human communities in coastal Oregon.

Chapter 6, Habitat Suitability, examines the corollary of sea otter effects on ecosystems: that is, the effect of ecosystems on sea otters. The chapter explores how different attributes of nearshore habitats in Oregon are likely to affect their potential to support sea otter populations in the future, an exercise often referred to as "habitat suitability analysis". This analysis is important for evaluating the potential viability of sea otters in different areas of Oregon, based on availability of critical habitat features. Such an analysis represents an important step in selecting prospective sites for any future reintroduction efforts, but also can be used to assess the areas where sea otters are most likely to concentrate in the future, and therefore where there is potential for conflicts with human activities.

Chapter 7, Socioeconomic Considerations, assesses socioeconomic considerations of a sea otter reintroduction. This assessment of socioeconomic impacts of sea otters begins with a broad overview of the existing literature and previous examples of sea otter socioeconomic impacts, then focuses on Oregon more specifically. This discussion of socioeconomic impacts is primarily conducted at a qualitative level, although a separate "Economic Impacts Assessment" document will provide a more quantitative examination.

Chapter 8, Legal Considerations, examines further the social dimensions of sea otter reintroduction with a review of the legal and policy considerations. As with any reintroduction effort there are many legal issues involved. The reintroduction of a marine mammal that is protected by international, federal, state, and tribal laws is especially complex, with multiple statutory and regulatory processes that need to be considered. Relevant laws and processes are listed and discussed with regard to differ applications depending on the reintroduction scenario, especially the selection of a source population.

Chapter 9, Logistics Considerations, discusses practical and logistical considerations of alternative reintroduction scenarios. The logistical issues considered include some of the topics addressed elsewhere in the report, such as selection of a source population and release site (or sites), as well as methodological issues such as how to capture, transport, release and monitor sea otters. While this chapter is in no way meant to represent a detailed proposal for a sea otter reintroduction, it does provide a useful overview of the topics that would need to be addressed in a detailed proposal.

Chapter 10, Health and Welfare Considerations, addresses a specific set of risks that are inherent in sea otter reintroductions, centered on sea otter health and welfare considerations. There is a rich and extensive literature on topics related to sea otter health, disease, and environmental threats; many of these previously reported diseases and threats could affect the success of a newly established sea otter population in Oregon. We provide a review of this literature, with discussion and interpretation tailored to the factors most likely to be relevant for a reintroduced population in Oregon.

Chapter 11, Stakeholder Concerns and Perspectives, provides a brief overview of the wide range of views and concerns associated with sea otters and sea otter reintroductions. This chapter is not intended to be an exhaustive analysis of all different views, but it is intended to help foster open and candid discussion about some of the societal-level challenges associated with sea otter recovery, and to encourage respect for the diverse and sometimes conflicting views about this subject.

Chapter 12, Conclusions, summarizes some of the key findings and points raised in all the previous chapters and provides some final thoughts about how these findings might be further explored or developed in any "next steps" that might occur.

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Chapter 2: History of Prior Sea Otter Translocations

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Introduction

Translocations or reintroductions of wildlife are often employed as a tool to mitigate the direct or indirect effects of human activities that result in the loss or reduction of species in all or parts of their historical habitat (Griffith et al. 1989, Seddon et al. 2014). Following a growing recognition of the important role that keystone species – often apex predators – can play in the structure and function of ecosystems (Paine 1966, Power et al. 1996), the goals or translocations and reintroductions have come to include the restoration of ecosystems (Moritz 1999, Hale and Koprowski 2018). Most recently, establishing genetic connectivity and recovery of genetic diversity within species and across habitats has become a desired attribute and explicit objective in the reintroduction of species, particularly those with a demonstrated loss of genetic diversity (Larson et al. 2015, Zimmerman et al. 2019). A rich history of sea otter recovery following the North Pacific maritime fur trade and translocations since the mid-19th century (Table 2.1 and Figure 2.1) provides powerful demonstration of each of these complementary benefits (Estes and Duggins 1995, Bodkin et al. 1999, Bodkin 2015, Hughes et al. 2019).

Translocation success often depends on a variety of recognized factors including an appropriate number and health of founding individuals, suitable habitat, adequate food resources, and realized reproductive potential and survival rates (Griffith et al. 1989). However, it is becoming evident that other, less well recognized factors, such as movements and behavior, can contribute to the success, or failure of reintroductions (Batson et al. 2015, Berger-Tal et al. 2020). The history of sea otter translocations and the knowledge gained from research during the process of recovery from depletion illustrates many of the biologic, ecologic and behavioral aspects that will play a role in the success of future translocations. Assessing the feasibility of reintroducing sea otters to the Oregon Coast will benefit from a comprehensive review of prior sea otter translocations and allow for evaluation of achieving specific translocation goals.

History of Sea Otter Translocations

The first documented translocation of sea otters was conducted in Russia, in 1937, when nine sea otters were captured at Medny Island, in the Commander Islands, for transport to the Murman coast in the southern Barents Sea, more than 5000 km from their natural distribution in the north Pacific (Barabash-Nikiforov 1947). The intent of the translocation was the establishment of an additional colony to supplement Russian fur production through captive and wild rearing and included developing techniques to hold sea otters in captivity prior to translocation. Although the Russian translocation was outside the historical range of the sea otter, we describe the effort here because it was the first recorded translocation of the species. Several aspects of this initial effort are particularly relevant in considering future translocations. The first is the recognition of the need for, and documentation of suitable environmental conditions and habitats with adequate and appropriate prey resources at the release site prior to translocation (Barabash-Nikiforov 1947). The second is that animal husbandry practices appropriate to the species are critical to translocation success, particularly while in transport. The third is that holding of animals in captivity is feasible, and acclimation of animals at release sites could contribute to translocation success. Unfortunately, only two males survived the long and complex journey, which occurred first by ship and then by train, but these two survivors lived in captivity and in the wild for more than four years, thus demonstrating the feasibility of translocating and long term holding of this species in captivity (Barabash-Nikiforov 1947).

Initial efforts to restore sea otter populations within their historic range along the coasts of North America began in 1951 (Kenyon and Spencer 1960, Kenyon 1969). Between 1951 and 1959 five attempts to translocate 86 sea otters (in groups from 5-35 individuals) from Amchitka Island in the central Aleutians (Figure 2.1) to the Pribilof Islands (total of 81) in the Bering Sea and Attu Island (total of 5) in the western Aleutians failed. Fifty-three of the animals captured in these early translocations died in captivity prior to transport and almost none of the animals released are known to have survived following their release. These early attempts at husbandry and translocation apparently failed due to several different factors (or combinations of factors), including inadequate holding facilities and husbandry practices prior to and during transport, long transport times by ship that resulted in high rates of mortality (in some cases up to 100%) and, in two cases (5 to Attu in 1956 and 6 to the Pribilof Islands in 1957), an inadequate number of individuals (Kenyon 1969). The 1959 relocation to the Pribilof Islands was novel in being comprised exclusively of tagged animals and being partially successful, as at least one of seven juveniles relocated in 1959 was sighted two years after release. It is also possible that the Pribilof Islands, lying near the northern extent of the sea otters' range, provided less than optimal habitat.

Concurrent with both the Russian and US early translocation attempts, work was undertaken to develop animal husbandry methods that might increase survival of sea otters in captivity (Barabash-Nikiforov 1947, Kenyon and Spencer 1960, Kenyon 1969). High mortality during holding and transport in both Russian and American initial attempts identified the critical need for sea otters to maintain the integrity of their fur to achieve thermal neutrality. Early husbandry practices also included inadequate quantities of food (< 10% of their body weight/day) and provisioning of atypical foods (e.g., meat of waterfowl and seal). Access to clean water and appropriate food and space while in holding and transport proved to be instrumental in reducing mortality prior to introduction and improving future translocation success. While early translocations resulted in high mortality and largely failed efforts, insights gained would eventually lead to what would become a highly successful marine conservation effort (Bodkin 2015).

The first successful North American translocation took place in 1965 when 41 sea otters were captured and moved by amphibious aircraft from Prince William Sound to southeast Alaska. Twenty- three of these animals survived to be released to Chichagof Island in southeast Alaska (Kenyon 1969). Although pre-release mortality was high (0.44) due to overheating in flight, possibly related to tranquilizing, at least some individuals were re-sighted in 1966. This was the beginning of 13 separate translocations of 708 individuals from Amchitka Island and Prince William Sound to various locations, between 1965 and 1972 (Jameson et al. 1982). Fifty-five individuals were moved to the Pribilof Islands in 1968; 389 to six release sites in southeast Alaska from 1965 to 1969; 89 to the west coast of Vancouver Island, British Columbia from 1969 to 1972, 59 to the Olympic coast of Washington from 1969 to 1971 and 93 (63 females and 30 males; 44 adults and 39 Juveniles, with 10 of unknown age) to two releases sites on the coast of Oregon in 1970-71 (Jameson 1975, Jameson et al. 1982).

The series of translocations and reintroductions between 1965 and 1972 had mixed success. Sea otters persisted in the Pribilof Islands for at least ten years, with sporadic observations of independent animals until at least 1976 (Schneider 1981), with some suggestion that their continued presence may have reflected immigration from otters reoccupying historic habitat along the north Alaskan Peninsula. In addition to the eventual failure of the Pribilof translocation, the other translocation that ultimately failed was to Oregon: surveys reported declining abundance from the initial 93 animals that were reintroduced, until only a single animal could be found by 1981 (Jameson et al. 1982). However, the presence of pups provided clear evidence of successful reproduction in the Oregon population during the decade after 1971. It seems likely that post-release mortality contributed to the failure of the Oregon translocated population to become established, but it is also likely that at least some of the Oregon animals dispersed north to Washington, thus contributing to the eventual success of the translocated Washington population and possibly even the British Columbia population (Jameson et al. 1982). The eventual failure of the Pribilof Islands and Oregon efforts highlight two key points: 1) the success or failure of reintroductions may take a decade or more to become manifest; and 2) frequent and systematic monitoring of post-release populations during the first decade could help inform management actions to influence successful establishment, perhaps through enhancements to survival, reductions to mortality, or augmenting abundance via supplementary introductions of additional animals.

The reintroductions to southeast Alaska, British Columbia and Washington clearly established the feasibility of reintroductions as a tool to enhance the recovery of sea across their range. In southeast Alaska, the 412 animals translocated by 1969, resulted in more than 25,000 by 2011/2012 (Bodkin 2015, Tinker et al. 2019). By 2013, nearly 7,000 individuals resided along British Columbia (Nichol et al. 2015), and more than 2,000 along the Washington coast in 2017 (Jeffries et al. 2017). Today it is likely that sea otter abundance from translocations alone exceeds 50,000 animals (based on observed recent rates of increase of about 10% annually), a number that may represent more than a third of the current overall number of sea otters in the North Pacific Ocean.

Between 1987 and 1990, the US Fish and Wildlife Service conducted the most recent translocation of 139 animals from the mainland central California coast to San Nicolas Island, 110 km off the coast of southern California (Rathbun et al. 2000). This was the first translocation to explicitly aid in the recovery of the ESA listed southern subspecies of sea otter. It was also the first translocation to rigorously evaluate the health of individuals, define specific age and sex of animals to be moved, and closely monitor the translocated animals post release. While plans and pens were constructed to acclimate animals at the release site with the intent to encourage retention (Ames et al. 1986, USFWS 1987), sea conditions compromised the safety of the penned animals and they were released within a few days of transport to the island. As with all previous translocations, the number of animals remaining at San Nicolas Island declined dramatically during the post-release population establishment phase – to just 16 animals by 1991 (Rathbun et al. 2000) – and reached a nadir in 1993 of 12 animals observed. However, counts of sea otters at SNI began to increase in the late 1990s (10 years after the translocation), and the most recent census reported a population of 121 animals in 2019, with a five-year average annual rate of increase of 0.10 (Hatfield et al. 2019). While not assured, the long-term viability of this latest translocation now seems likely.

The differences in outcomes of previous translocation events, as well as some of the similarities, suggest several key factors that may contribute to successful reintroductions. While adequate food resources are obviously essential to successful translocation, it is not clear that prey abundance was a factor in the failure of the Oregon effort, or any of the prior failures, or indeed to the delayed success of any of the successful translocations. Both the initial Russian and the San Nicolas translocation dedicated significant effort to assuring that suitable and abundant prey were available at release sites (Barabash-Nikiforov

1947, USFWS 1987). But while abundant prey resources do not ensure rapid and successful establishment of any introduced population, it would nonetheless be essential to assure that appropriate and adequate prey are available at and near the locations of any future sea otter reintroductions. Other considerations include a sufficient number of individuals of the appropriate age and sex classes; the existence of protected areas for resting and pup rearing (e.g., reliable kelp beds or protected bays/inlets); minimal levels of disturbance from human activities (e.g., commercial and recreational boat traffic or tourism activity); and low levels of threats such as toxins, fishing gear entanglement or disease vectors that could lead to elevated mortality during the establishment phase (see Chapter 6 on habitat suitability and Chapter 10 on health and welfare considerations).

Although not a reintroduction in the traditional sense of moving sea otters into unoccupied historic habitat, the most recent managed introduction of sea otters involved the release of captive-raised juvenile sea otters into a coastal estuary in central California. Between 2001 and 2017 a total of 37 stranded pups were raised in captivity at the Monterey Bay Aquarium, with older female sea otters acting as surrogate mothers (henceforth surrogates). Once these pups reached typical weaning age (6-8 months), they were transported and released into Elkhorn Slough, an estuary at the head of Monterey Bay, California (Mayer et al. 2019). Originally the selection of Elkhorn Slough was made based on logistical considerations, as it was easier to monitor the rehabilitated juveniles within the enclosed estuary and recapture them if they required supplementary care. A secondary objective of this reintroduction was to enhance the local sea otter population (Mayer et al. 2019). This effort is notable for several reasons. First, it engaged captive adult female surrogates in the rehabilitation and raising of stranded juvenile sea otters explicitly for release over time. Second, animals were held and raised in captivity for extended periods of time during their development, a step that may have facilitated socialization and development of bonds among the animals that would eventually be released. Third, in contrast to all prior translocation release sites that were in or near outer coastal rocky reef habitats, these animals were released into a sheltered, soft sediment estuarine environment. Also relevant is the fact that the juvenile sea otters were added to an area that already had been occupied by otters for at least two decades, although in limited numbers and primarily by males (no reproduction had occurred in the Slough prior to the reintroductions, and the first females observed with pups within the Slough were in fact rehabilitated females). Perhaps most importantly, this reintroduction process, although often requiring recapture of juveniles and further rehabilitation in captivity prior to subsequent re-release, did not incur the large-scale losses of individuals due to emigration or mortality that were ubiquitous in earlier translocations.

Methods of Sea Otter Translocation

In general, methods employed in all sea otter translocations consist of capture, holding, transport and release of individuals, either as a single group in early translocations, or more recently, in a series of individuals or groups over time. Various methods are employed to capture free ranging sea otters, including tangle nets set in water near where animals reside and using long handled dip nets on haul-outs or in open water when they are at rest. Most recently, specially designed diver operated traps (Wilson traps) are used to capture otters from under water (Ames et al. 1986, Monson et al. 2001). The capture of sea otters is highly regulated by federal and state/provincial governments and requires adherence to stringent permitting conditions. In the US, sea otter permits fall under the purview of the US Fish and Wildlife Service, Division of Management Authority. Acquisition of permits is predicated on demonstrating expertise in the safe and humane capture and handling of sea otters, meeting animal health and welfare requirements, and describing how proposed activities benefit the species' conservation and management. Obtaining necessary permits for a translocation will be dependent on the status of source population(s) and the proposed release sites, and may take several years.

Once captured by tangle net, dip net or scuba-operated Wilson traps, otters are transferred to specially designed boxes or kennels for transport to holding facilities where the animals are accumulated in pools and prepared for transport to the release site. Transport is usually accomplished by van or truck to either ship (in the earlier translocations) or aircraft (in translocations since 1965). Over time, methods of capture, handling, holding, transport, and release have been refined to the point where serious injury or death has become an exceedingly rare event, but even with the greatest care, some small rate of morbidity should be expected when handling large numbers of sea otters. Additional detail on current capture, holding, transport and release procedures can be found in Chapter 9 of this report (Logistical and Implementation Considerations) and in Ames et al. (1986).

Lessons Learned from Past Translocations

Over the past 80 years nearly 1,000 sea otters have been captured, held, transported, and released into unoccupied habitats to restore populations. It is evident from the earliest translocations that inadequate attention was given to the physiological needs for the sea otters to maintain the integrity of their pelage, and that high mortality resulted from poor animal husbandry practices during holding and transport (Barabash-Nikiforov 1947, Kirkpatrick et al. 1955, Kenyon 1969). Since there early efforts, improvements in capture, husbandry and transport have nearly eliminated pre-release mortality (Ames et al. 1986, Rathbun et al. 2000, Mayer et al. 2019). In all translocations for which there are data, the numbers of sea otters reintroduced appeared to have declined rapidly following release, and in most cases appeared to stabilize at 10-50% of the original number released. We have limited understanding of the causes behind this rapid diminishment following introductions, due to the limited follow-up surveys after most translocations. Post-translocation surveys and marking of individuals moved to San Nicolas Island provided new insight into this phenomenon. Intensive post-release surveys at San Nicolas and throughout California documented that at least 26% (36 of 139) of the translocated animals returned to their original capture locations (Rathbun et al. 2000, Carswell 2008). An additional but unknown number of animals may have perished during an attempt to return to their original home range (Carswell 2008), a phenomenon that may explain post-release movements and declines after other translocations (Jameson et al. 1982). This finding demonstrates the strong individual affinity in this species for their established home range, and the associated likelihood of post-release dispersal that occurred at San Nicolas despite its selection as an appropriate release site based on suitability of habitat and abundance of prey (Rathbun et al. 2000). Further, the decision to translocate predominantly subadult sea otters did not appear to prevent an initial loss of animals at San Nicolas (Rathbun and Benz 1991), although there is some indication that the youngest animals were less likely to disperse (Carswell 2008). This further indicates that factors other than prey can be important in determining the behavior of species being translocated, and suggests that social, behavioral, and cultural attributes should be considered carefully. These considerations may be particularly relevant for sea otters, as they occupy small home ranges (Tarjan and Tinker 2016), exhibit specialized prey preferences that may be learned or culturally transmitted from other sea otters (Estes et al. 2003, Tinker et al. 2008), and demonstrate long-term relations among individuals within shared ranges (USGS, unpublished data). Sea otters translocated into vacant habitats appear unlikely to remain where released, despite the general suitability of habitat and abundance of prey, because of their affinities for specific habitat features, prey preferences and social interactions associated with their original home ranges.

Systematic surveys of early translocated populations were rare, usually occurring only after populations became established, and this resulted in uncertainty about founding population sizes and early population growth rates (Bodkin et al. 1999). However, once fully established, translocated populations generally demonstrated growth rates that were at or near the maximum rates feasible for sea otters (Estes 1990), averaging ~20% per annum , and significantly greater than growth rates observed in remnant populations (~10%; Bodkin et al. 1999). One recent exception to this was the 1987 translocation to San Nicolas Island (Rathbun et al. 2000, Carswell 2008), where, following 3 years of consecutive translocations the founding population of 139 quickly declined to 16 individuals, and then remained essentially unchanged for almost a decade (Hatfield et al. 2019). The pattern of post-release decline at San Nicolas Island was similar to other successful translocations to southeast Alaska, British Columbia, and Washington, but while these earlier translocations soon achieved annual growth rates of 20% or more, the annual growth rate at San Nicolas from 1999-2009 was only 6%. Rates of reproduction appeared adequate to sustain growth (pup:adult ratios were as high or higher than the mainland California population), and adult survival rates of tagged animals were very high (Bentall 2005), suggesting that sub-adults were being lost from the population, either through emigration or, more likely, fishery-related mortality (Hatfield et al. 2011). Interestingly, after 2009 the annual rate of population growth at San Nicolas increased to ~12%.

The history of the San Nicolas translocation provided new and important information regarding factors important to translocation success. First, abundant habitat and prey resources are not by themselves sufficient to ensure high retention rates of introduced animals. Second, behavioral and cultural factors, likely related to familiarity with established home ranges and social relations, contribute to initial losses. Third, unanticipated sources of mortality (such as fishing gear entanglement) can adversely affect growth rates, particularly when population size is small. And lastly, one of the legal conditions imposed on the San Nicolas translocation was that an “otter free” zone would be maintained through the capture and removal of sea otters outside San Nicolas between Point Conception and the Mexican border on the California mainland. After many years of trying to comply, in 2012 the USFWS abolished this requirement by declaring the translocation a failure (USFWS 2012), thus demonstrating the difficulty in spatially managing the distribution of sea otters by non-lethal means.

Conclusions

Several lessons can be gained from past experiences with translocating sea otters to aid their conservation. First, the basic biology of the species is important to account for: early translocations were largely unsuccessful due to the lack of understanding of the basic physiology of sea otters and their dependence on maintaining a thermal balance through their pelage and an unusually high metabolic requirement.

Second, given suitable habitat, prey resources, and protection from human or other mortality sources, translocations have proved an important tool in sea otter conservation. Assuming consistent rates of change over the past decade, about 30% of the global sea otter abundance today can be attributed to the translocations to southeast Alaska, British Columbia, and Washington (Bodkin 2015).

Third, even successful reintroductions often undergo an establishment phase during which their ultimate success can be questionable. During this phase a variety of factors will tend to reduce the founding population to a small fraction of the initial number translocated. It appears that with sea otters, behavior may be more important than food in determining the retention rate at release sites. A careful consideration of the behavior and social structure within parent populations that may affect the probability of retention of individuals at a translocation site may aid in forecasting the success of future translocations. The success of recent reintroductions in Elkhorn Slough using stranded juveniles, raised with the aid of surrogate mothers (adult female otters) in captivity and released into protected estuarine habitats where recapture was practical, should encourage consideration of alternative approaches in future translocation proposals.

Finally, the role that translocations can play in restoring coastal marine ecosystem structure and function, from coastal rocky reefs to estuaries (Estes and Palmisano 1974, Hughes et al. 2013, Hughes et al. 2019), and in recovering genetic diversity and facilitating genetic connectivity among sea otter populations (Larson et al. 2015, and see Chapter 4 of this report), provide ample justification for considering future efforts to continue restoration of sea otters and coastal ecosystems.

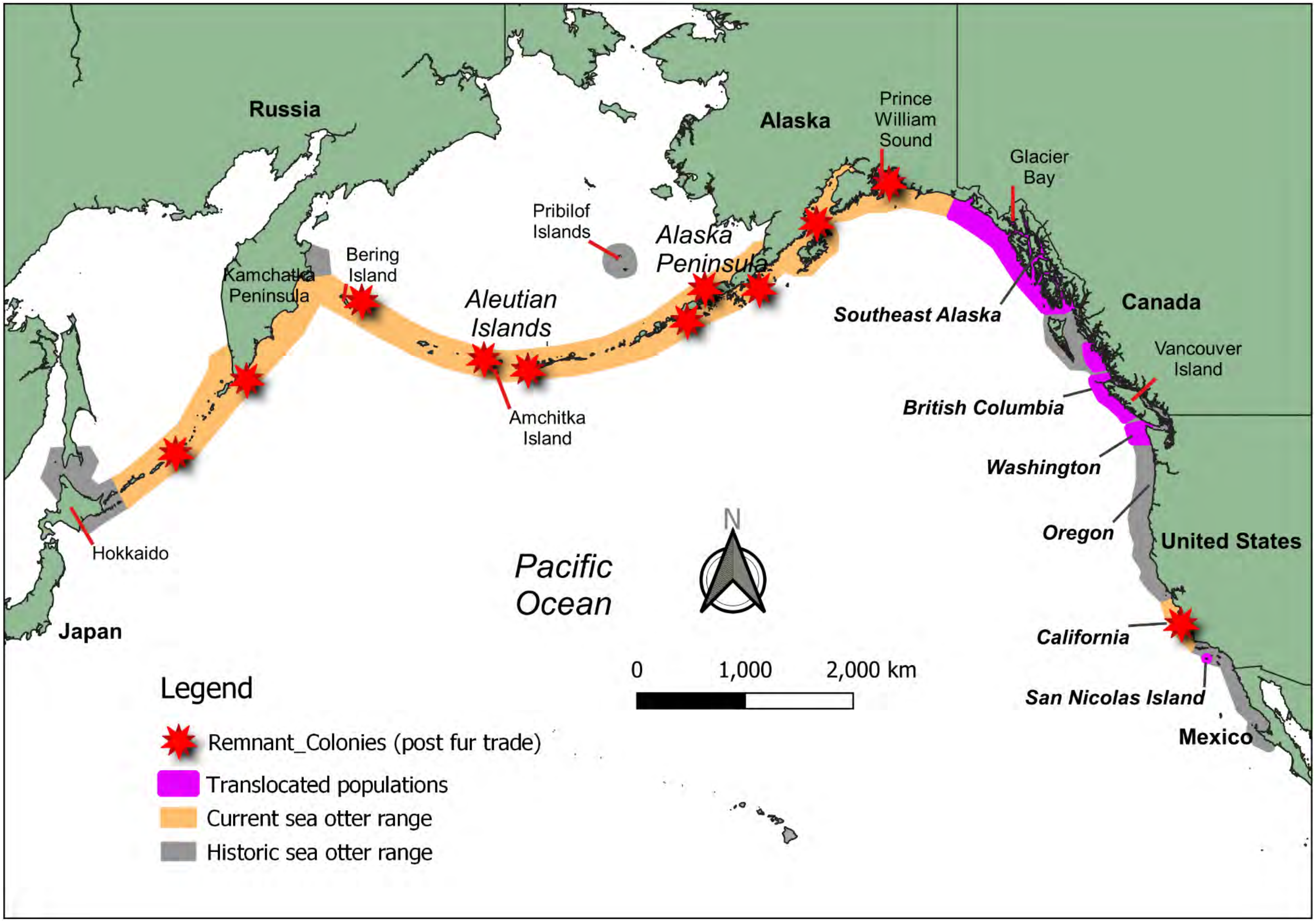

Figure 2.1. Map of the North Pacific showing historical and current sea otter range, the latter including translocated populations. Location of the remnant colonies left at the end of the fur trade (from which present-day populations are descended) are also shown.

Table 2.1 Summary statistics for ten previous sea otter translocation and reintroduction efforts.

Release Location	Year(s)	Source	Intended for release	Number released	Success	Approximate Founding number	Recent estimate
Murman Peninsula	1937	Bering Island, Russia	9	2	no	1	0
Pribilofs Is	1951	Amchitka, Alaska	35	0	no	0	0
	1955	Amchitka, Alaska	31	19	no	0	0
	1957	Amchitka, Alaska	8	0	no	0	0
	1959	Amchitka, Alaska	10	7	unknown	3	0
	1968	Amchitka, Alaska	55	55	temporary	unknown	0
Attu	1956	Amchitka, Alaska	5	5	no	0	NA
California	1969	California	17	17	no	NA	NA
North SE Alaska	1965-1969	Amchitka & Prince William Sound, Alaska	297	297	yes	100-150	11,600
Central SE Alaska	1968		51	51	yes	30	13,200
South SE Alaska	1968		55	55	yes	21	
		SE Alaska - TOTAL	**403**	**403**	**yes**	**150**	**>25,000**
British Columbia	1969-1972	Amchitka & Prince William Sound, Alaska	89	89	yes	28	7,000
Washington	1969-1970	Amchitka, Alaska	59	59	yes	10	>2,000
Oregon	1970-1971	Amchitka, Alaska	93	93	no	0	0
San Nicolas Is, CA	1987-1990	California	142	139	yes	12	121
Elkhorn Slough, CA	2002-2016	California	37	37	yes	37 + ~25 wild	120

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Chapter 3: Population and Demographic Considerations

M. Tim Tinker

While there are multiple reasons that resource managers may decide to reintroduce a wildlife species to a habitat from which it has been extirpated, the success of such an action will ultimately be determined in part on the performance of the population after the reintroduction. The key metrics of performance are thus evaluated at the population-level rather than the individual-level, or according to IUCN/SSC Guidelines:

> "*Conservation translocation is the deliberate movement of organisms from one site for release in another. It must be intended to yield a measurable conservation benefit at the levels of a population, species or ecosystem, and not only provide benefit to translocated individuals*." (IUCN 2013).

As a conservation tool, reintroductions are intended to restore viable populations of the focal species within their former ranges, and specifically to habitats from which they have previously been extirpated (Seddon et al. 2007). Given these underlying goals, a fundamental requirement for evaluating the feasibility of a reintroduction program is a realistic assessment of population and demographic considerations. If a proposed reintroduction is unlikely to result in a viable population within the recipient habitat, then it does not meet the most basic conservation criteria. Likewise, if the net impacts of the proposed reintroduction to overall species viability are likely to be negative (or not measurably positive), it cannot be considered successful from a conservation perspective. While these population and demographic considerations represent just one component of a broader suite of issues to be considered prior to initiating a reintroduction, including socioeconomic, political and organizational considerations (Reading et al. 2002), it is nonetheless a necessary step to examine carefully the likely population-level consequences of reintroduction. We consider these consequences with respect to the source populations, the recipient population (i.e., the prospective population that managers wish to establish), and the species overall.

Impacts of Reintroduction to Source Populations

For any wildlife reintroduction program, individuals must be taken from some source population for translocation to the new habitat. Because the removal of individuals will necessarily cause a reduction in population size, the question is not whether a source population will be negatively affected, but rather if these negative effects will be statistically or biologically significant. In the case of an Oregon reintroduction, there are several possible source populations (see Chapter 9 of this report), and the impacts are likely to vary among these potential sources. We consider three potential source populations here: SE Alaska, California, and aquarium-rehabilitated stranded juvenile sea otters from California. We selected these three populations because of the availability of recently completed population analyses that allow us to make a quantitative assessment of the impacts of removing animals from each of these sources. We do not explicitly consider a fourth possible source population, Washington, because a comparable population model is not available at this time; however, given the similarity in population sizes we believe the results from the California analysis will be relevant and provide guidance for potential use of the Washington population as a source. We note that a population model for Washington is currently in review at a journal (Hale et al. in review) and should be available soon for use in a similar assessment.

In SE Alaska, translocations of sea otters to multiple locations in the 1960s and 70s successfully established a growing meta-population which has now increased to over 25,000 animals (Esslinger and

Bodkin 2009, Tinker et al. 2019). A spatially-structured population model was recently developed for sea otters in this region (Tinker et al. 2019), and this model was then adapted for the purpose of evaluating the population impacts of Native Alaska subsistence harvest on sea otters (Raymond et al. 2019). Because the removal of sea otters for the purpose of translocating to a different region (Oregon) is, demographically speaking, identical to the lethal removal of animals during a harvest, we can use the results of these analyses to evaluate the demographic consequences of using SE Alaska as a source population for an Oregon reintroduction. The key results from the harvest impacts study were that the demographic consequences of harvest was negligible when annual removals were less than 10% of local population size (Raymond et al. 2019). For example, in the Maurelle Islands over 100 otters were frequently harvested in a single year, but because of the high number of otters in the Maurelle Islands this harvest rate represented less than 5% of the population, and effects on population trends were negligible. In Sitka Sound, harvest levels prior to 2005 were <10% in most years, and this level had only minor effects on population growth; however, after 2005 the annual harvest rate increased and levels frequently exceeded 10% of the local population (and sometimes >25%) resulting in substantial population impacts, with a >50% decline in abundance. These results highlight two important points: 1) the consequences to a source population of removing animals for the purpose of translocation should be assessed at a local scale (i.e., within 20-60 km of the site of capture) rather than at a regional scale; and 2) removals of animals that approach or exceed 10% of the local population are likely to have population-level consequences, but removals of less than this level may be sustainable. If we assume that 100 animals were to be captured for translocation to Oregon, there are several sub-regional population segments in SE Alaska identified by Tinker et al (2019) that could sustain this level of removal with minimal impacts (i.e., 100 animals would represent <<10% of local abundance), including Icy Straits and Glacier Bay in northern SE Alaska, or the Maurelle Islands, northwest Prince of Wales Island, and Kuiu Island in southern SE Alaska.

In California, a recent habitat-based estimate of sea otter carrying capacity (Tinker et al. 2021), combined with a comprehensive analysis of sea otter mortality patterns (Miller et al. 2020), has allowed for the development of a spatially structured integrated population model (IPM) for southern sea otters (Tinker et al. in press). The IPM model can be used to assess the population-level impacts of variation in cause-specific mortality, as well as reintroductions or removals of animals from specific locations within the range of sea otters in California. We therefore used this model to evaluate the impacts of a hypothetical removal of animals for translocation to Oregon. As with the SE Alaska model, we evaluated spatially explicit scenarios of the removal of up to 100 individuals. Specifically, we ran 50-year simulations of population dynamics in California, with 100 animals removed from one or more coastal segments in year 1 of the simulation, and we the assessed how much this removal would reduce population growth over the next 50 years as compared to an identical simulation without the removal. We found that a removal from the northern range periphery (the coastal area between Santa Cruz and Pigeon Pt) would result in a 4.9% reduction in projected abundance after 50 years (Figure 3.1a). In contrast, a similar removal of 100 sea otters from the range center (between Monterey and San Simeon), where local abundance is high and approximately at carrying capacity (*K*), resulted in only a 0.8% reduction in projected abundance after 50 years (Figure 3.1b). The first scenario resulted in greater impacts to the source population for two reasons: 1) the northern periphery is well below *K* and thus the removals would delay local recovery far more than would removals from an area already near *K*; and 2) a removal of animals near the range edge would tend to reduce or delay the potential for future range expansion into new habitats, while removal of animals from the range center would have no such effect.

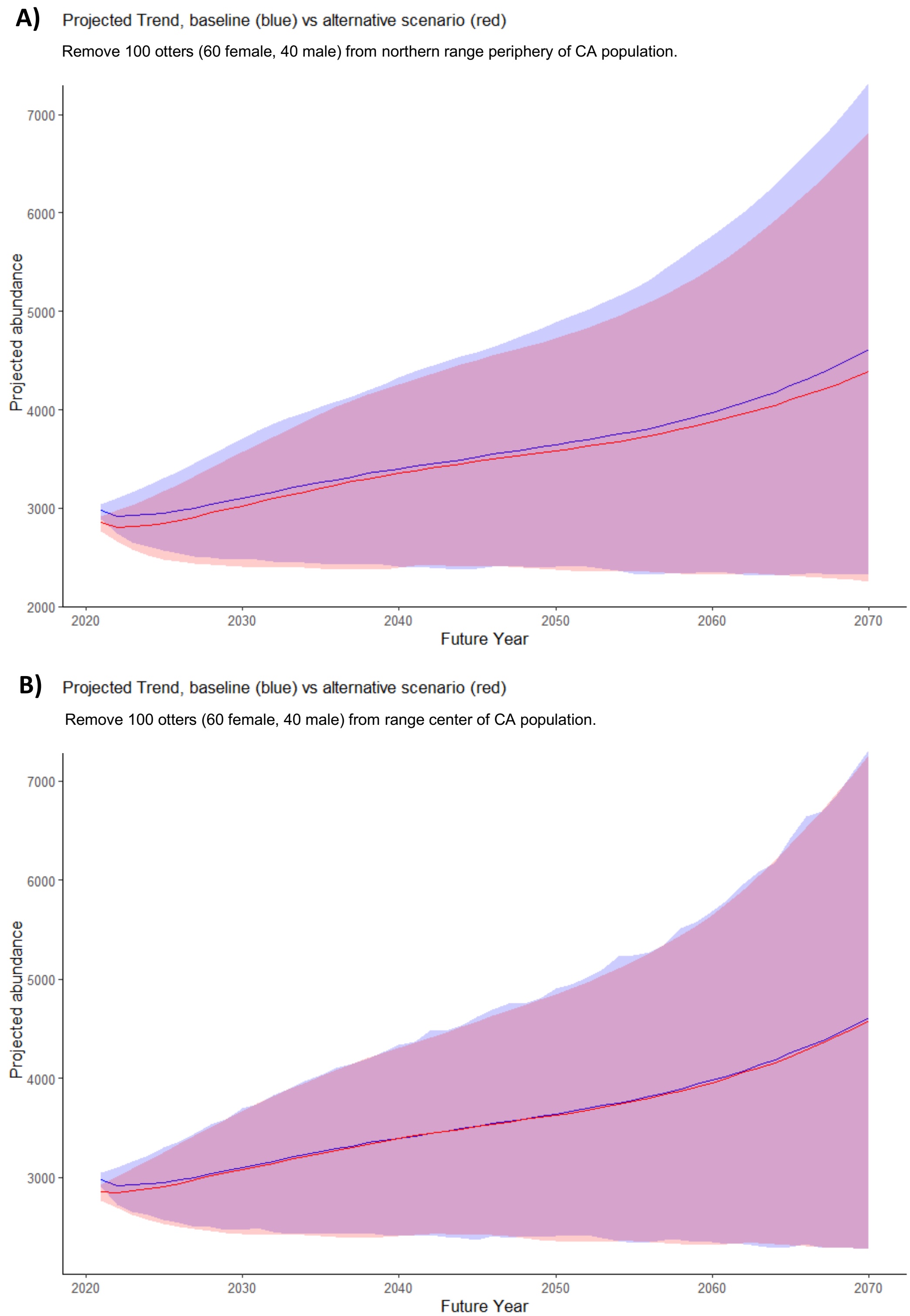


Figure 3.1. Population simulation results for an IPM model evaluated with and without the removal of animals for use in a translocation to Oregon. The blue line shows the baseline projected trend, while the red line shows the projected trend under the "alternative scenario" with 100 sea otters removed in year 1 of the simulation A) from the northern range periphery and B) from the range center.

Thus, when considering where sea otters might be taken from California (if it were to be used as a source population), it is important to consider local population status – areas near to *K* will be more resilient to removals than areas well below *K* – as well as the potential implications for future range expansion. Removing animals from areas near the edge of the range may be inadvisable, as it could have greater impacts on future recovery by reducing or delaying range expansion into new habitats.

A third potential source of animals for reintroduction to Oregon are juvenile animals in California that strand as pups, and are then rescued, rehabilitated and reared by "surrogate" mother sea otters in captivity (Nicholson et al. 2007). These rehabilitated juvenile animals have already been demonstrated to have potential to enhance population recovery in areas of low abundance (Estes and Tinker 2017, Mayer et al. 2019), and it has been suggested that similar methods might allow these animals to be used to establish a new population in California or Oregon (Mayer et al. 2019, Becker et al. 2020). A key advantage of this approach would be that the wild population in California would not be impacted at all, since the stranded animals are already effectively disconnected (demographically) from the wild population. Thus, at first glance this potential source population would seem to be ideal in terms of not negatively impacting a wild population. However, it is also true that the rehabilitated captive juvenile population is a highly limited resource: currently there are only a small number of animals that are successfully rescued, rehabilitated and available for release to a new area each year. If these animals were to be used as a source population for Oregon reintroduction, that would prohibit their use for establishment of new population centers within unoccupied habitats in California (or at least would reduce the numbers of animals available for reintroductions within California). Population simulations using the IPM have shown that the re-establishment of new population centers in un-occupied areas of California using rehabilitated animals could potentially have substantial impacts on future population growth, with projected increases of up to 50% (as compared to simulations without reintroductions) for a population established in the Channel Islands, and up to 100% for a population successfully established in San Francisco Bay (Tinker et al. in press). These projections are based on a great many assumptions (most importantly, that the establishment of new populations using rehabilitated animals would be successful) and thus should be interpreted cautiously. Nonetheless, these results do demonstrate that the use of rehabilitated sea otters for reintroduction in Oregon would come with a hidden opportunity cost: because they represent a limited resource, their use for reintroduction in one area will preclude their use in other areas, and thus the potential benefits (and costs) of this strategy should really be considered regionally, in both Oregon and California.

Impacts of Reintroduction to Recipient Population

In previous sea otter reintroduction efforts, the viability of the translocated populations has often been uncertain during the decades after reintroduction: a previous translocation to Oregon eventually resulted in failure (Jameson et al. 1982), and other translocated populations (such as San Nicolas Island in California) have dropped to very low population sizes before eventually beginning to increase (see Chapter 2 of this report for a more detailed review). Therefore, a realistic assessment of the likely viability of a proposed reintroduction, as well as an understanding of the factors that are likely to affect viability, is an important requirement for a feasibility study.

To help in our assessment of the likely viability of reintroduced sea otters in Oregon, we have developed an Oregon sea otter population model (ORSO). This model features a user-friendly interface, to help community members, stakeholders and managers explore possible sea otter recovery patterns after introduction. Full details of the rationale, analytical methods, and results of this model are provided in

Appendix XX. The ORSO model is intended to contribute to responsible stewardship of sea otters and other nearshore marine resources, by helping to anticipate the approximate magnitude of expected population growth and range spread of sea otters in coastal Oregon in the foreseeable future, under different scenarios of translocation/reintroduction. This information can help in evaluating management options and anticipating ecological and socio-economic impacts in a spatially and temporally explicit way. We caution, however, that experience from prior reintroductions demonstrates the difficulty in predicting where translocated animals will settle, how many will remain following release and how soon population growth will commence. The ORSO model is therefore not intended to predict specific outcomes, but rather to explore a range of outcomes that may be most likely, given an extensive range of model inputs and assumptions.

The ORSO model was developed using information from published reports and previous examples of sea otter introductions, population recovery and range expansion in the northeast Pacific. Data collected from areas of sea otter recovery in California, Washington and SE Alaska were used to inform our expectations for sea otter colonization and recovery in Oregon. The distinct habitats and differing historical contexts of these neighboring populations preclude a direct translation of expected dynamics; however, the data from studies of these populations can be used as the basis for developing a predictive model that is tailored to the habitat configuration of Oregon. ORSO incorporates demographic structure (age and sex), density-dependent variation in vital rates, habitat-based variation in population growth potential, dispersal, and immigration, and uses a spatial diffusion approach to model range expansion over time. The model structure and parameterization is based on similar models constructed for other sea otter populations in North America that have proved effective at predicting patterns of population recovery and range expansion in diverse habitats (Udevitz et al. 1996, Monson et al. 2000, Tinker et al. 2008, USFWS 2013, Tinker 2015, Tinker et al. 2019, Tinker et al. 2021). By building on these previously published model designs and incorporating locally relevant data on sea otter vital rates, movements, habitat quality and environmental parameters, we believe it is possible to define realistic boundaries for the expected patterns of population abundance and distributional changes over time.

Previous translocations and reintroductions of sea otters have shown that the years immediately after reintroduction can be a period of great uncertainty (Jameson et al. 1982, Bodkin et al. 1999, Carswell 2008, Bodkin 2015). During the population establishment phase there is generally limited population growth, and often a significant decline in abundance, associated with elevated mortality and dispersal of a substantial proportion of animals away from the release site. The likelihood of post-release dispersal is thought to be high, but may be less for younger sea otters that have not yet formed strong attachments to a specific home range (Carswell 2008), and releasing sea otters in estuaries may allow for better retention of animals near the release site (Mayer et al. 2019, Becker et al. 2020). Otters that do disperse from the introduction site may settle in other areas of suitable habitat within the region (as occurred in SE Alaska), return to their former home ranges if possible (as occurred at San Nicolas Island), or move entirely out of the region (as was suspected to have occurred for some animals in the Oregon translocation, believed to have moved north to join the Washington or BC populations), though in all cases there is likely to be significant mortality for both dispersing and non-dispersing animals. Thus, the "typical" patterns of density-dependent population growth, dispersal, and range expansion only emerge after this establishment phase, which may extend for 5-20 years after the initial translocation (Jameson et al. 1982, Bodkin et al. 1999, Carswell 2008, Bodkin 2015). The ORSO model accounts for these establishment phase dynamics and allows the user to adjust the relevant parameters: specifically, the expected duration of the establishment phase, the degree of elevated mortality during the establishment phase, the probability of dispersal away from the release site, and how this dispersal probability varies as a function of sea otter age class and whether the release site is in an estuary. While the “true” values of these parameters are impossible to determine at present, given available data, we provide appropriate ranges based on the results of past translocations: varying the parameters to explore their effects on population viability is perhaps the most appropriate way to move forward at this stage. Conducting small scale experimental reintroductions may be the only means of improving the accuracy and precision of these parameters.

Using the ORSO model to simulate population dynamics after a reintroduction provides several key insights into the factors affecting viability of the reintroduced population. First and foremost, the results reveal a great deal of uncertainty associated with model projections, as indicated by the width of the 95% confidence interval band around plotted trends over time (e.g., Figure 3.2). Projection uncertainty associated with ORSO model results reflects a combination of many separate sources of variation and uncertainty about population dynamics during and after a reintroduction project (see Appendix A for details). This uncertainty is important to factor into the decision-making process because it highlights the level of risk associated with any proposed reintroduction scenarios. It is prudent to make decisions not only to maximize the average expected outcome for any single variable (e.g., future population size), but also to minimize the possibility of failure.

A second insight is that all reintroduction scenarios are likely to involve a period of “population establishment”, during which population growth will be sluggish and very possibly negative (Figure 3.2a). This pattern is consistent with the post-release declines (and/or slow growth) observed after previous reintroductions, even when those reintroduced populations subsequently grew rapidly after the establishment phase (as with SE Alaska: see Chapter 2). To ensure a high probability that a reintroduced population does not go extinct, the results of the ORSO model suggest the following guidelines: 1) a sufficiently large number of individuals should be included in the initial reintroduction; 2) the release site should be carefully chosen (and post-release management conducted) to maximize the chance that animals remain near the release site; 3) supplementary introductions could be used (if possible) to enhance the probability of successful reintroduction (see Chapter 9 of this report). Supplementary introductions could consist of small numbers of rehabilitated juvenile animals added annually to the initial establishing population: this approach has been tested in Elkhorn Slough, CA (Mayer et al. 2019), and appears to be an effective means of improving population viability during the establishment phase (Figure 3.2b). In the absence of supplementary additions to enhance viability, the ORSO model results suggest that at least 120 animals would have to be included in an initial reintroduction to have a 90% probability of maintaining a population of at least 25 otters after 25 years (Figure 3.3).

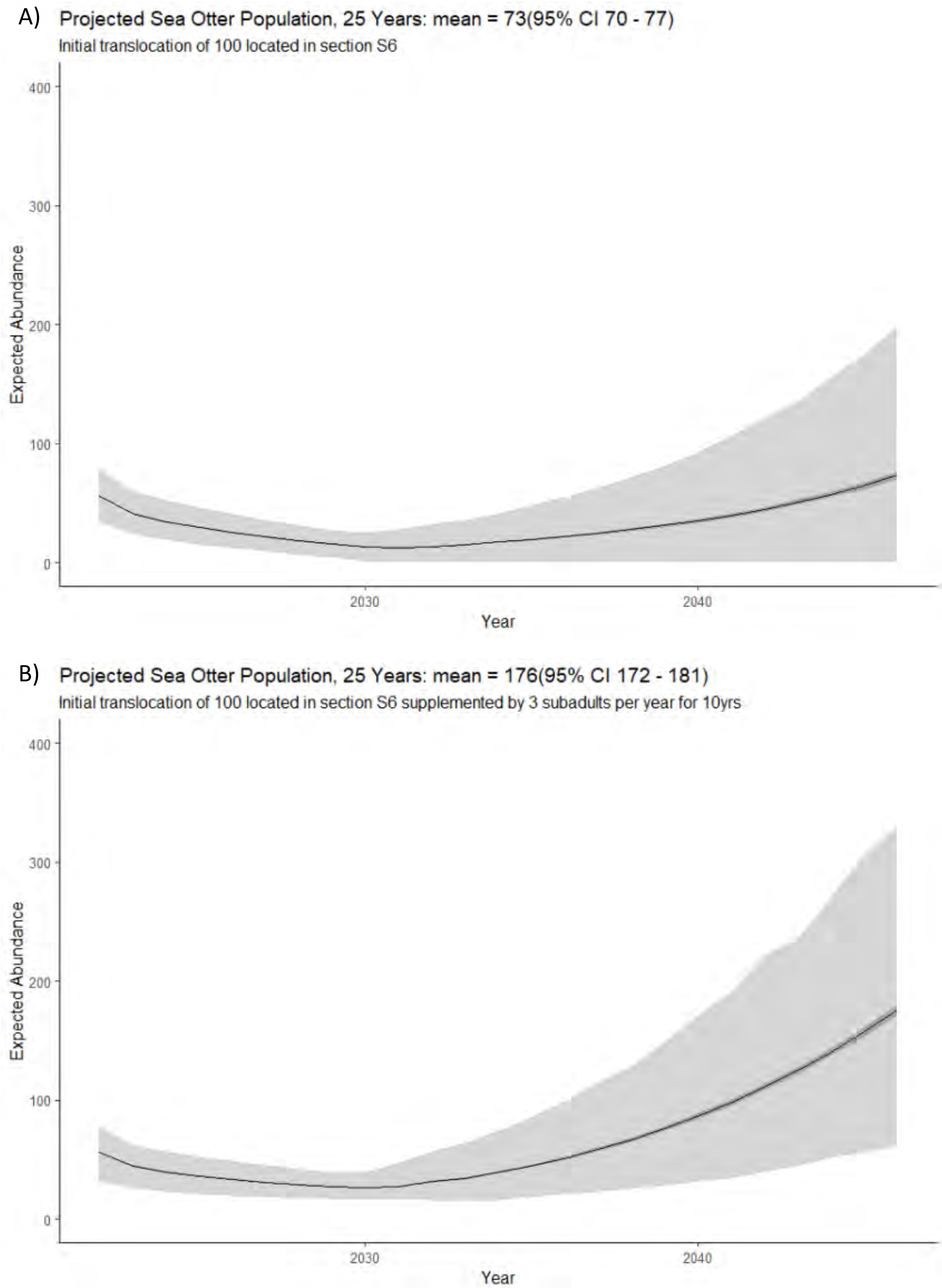


Figure 3.2. Expected trends in sea otter abundance after a reintroduction to coastal Oregon, based on projections using the ORSO model assuming A) 100 otters introduced to section S6, or B) 100 otters plus supplementaty additions of 3 subadults per year for 10 years. In both plots the solid line shows the mean expected trend and grey bands indicate 95% confidence intervals.

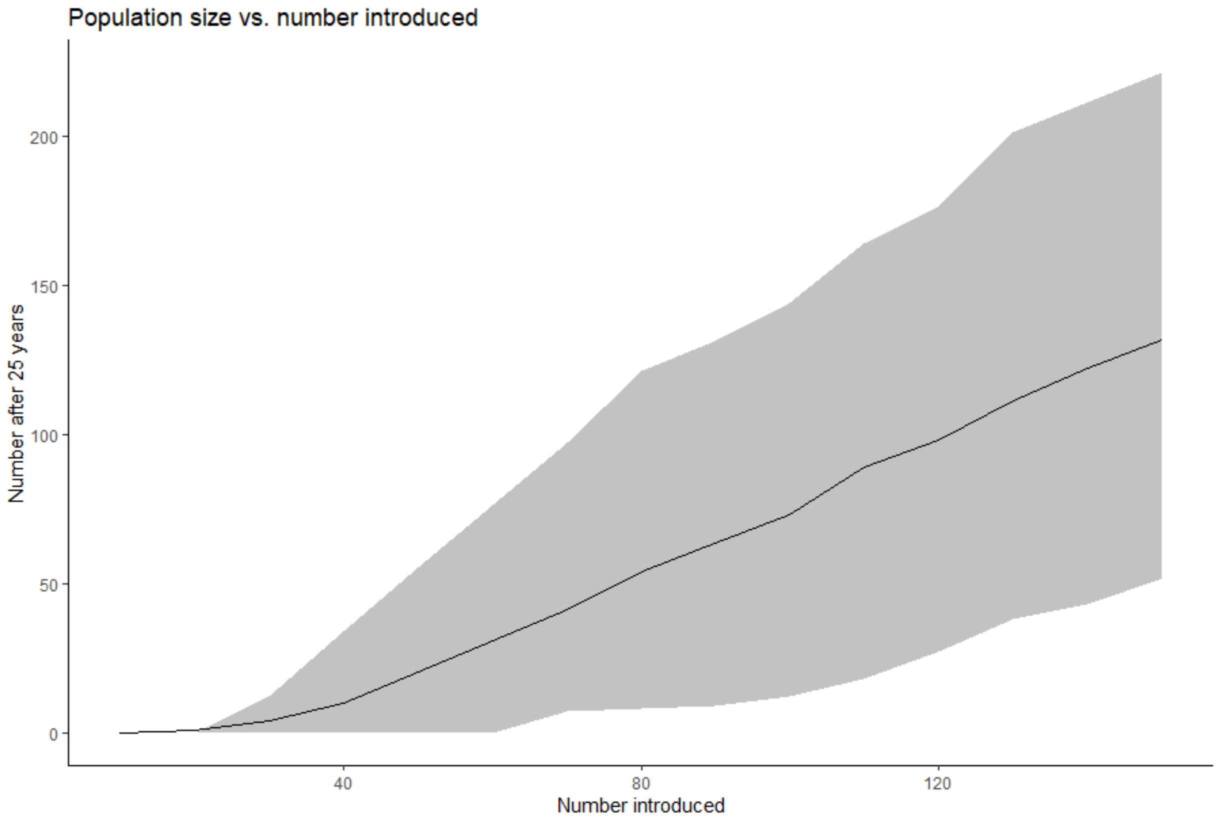


Figure 3.3. A plot of the relationship between the number of otters introducted to a release site in Oregon (coastal section S6 in this analysis) and the success of the reintriduction, as measured by the mean number of otters remaining after 25 years. The solid line indicates the mean expected value of all simulations, while the grey band represents the 80% confidence interval.

A third important insight from the ORSO model results is that spatial considerations and selection of a release site can have substantial implications for the outcomes of a reintroduction project. Spatial differences in the likelihood of population establishment and future growth are partially a reflection of suitability of the release site, but also reflect the spatial granularity of sea otter populations and density-dependent population regulation. Sea otters have relatively small lifetime home ranges (Breed et al. 2013, Tarjan and Tinker 2016) and thus tend to be limited by habitat quality and resource abundance at local rather than regional scales (Bodkin 2015, Tinker 2015, Tinker et al. 2019). Population growth potential depends on carrying capacity, which can vary at local scales based on the recruitment dynamics and productivity of invertebrate prey (Tinker et al. 2021). Furthermore, the small home ranges and limited movements of adult sea otters means that spatial extent of the population distribution tends to change slowly (as compared to invasion potential for more mobile mammals): the long-term rate of range spread along linear coastlines has been documented at 2-5 km/year (Lubina and Levin 1988, Tinker et al. 2008). Together, these fundamental properties suggest that the population performance of a reintroduced population will depend on the quality of habitat and productivity of prey resources in the *neighborhood* around a reintroduction site, and the results of the ORSO model are consistent with this prediction. A previous application of a habitat-based model of sea otter carrying capacity to the Oregon coast (Kone et al. 2021) indicates substantial variation in habitat quality (as measured by the expected density of sea otters at *K*) along the coastline (Figure 3.4). Based on ORSO simulations, spatial differences in the expected success of reintroductions (the number of otters remaining after 25 years) were consistent with these habitat differences: the highest growth potential occurred in coastal segments such as S6, SE2 or NE3 that encompass areas of high-quality habitat (Figure 3.5). In these high-quality habitat areas, a reintroduction of 70 sea otters (supplemented by 30 more over the next decade) would be expected to result in a successfully established population of >150 otters after 25 years, as compared to <50 otters for low quality areas.

A final key insight from the ORSO model results is that multiple release locations (resulting in multiple "seeds" of population growth) may be more effective than a single center, if logistically possible. There are two primary reasons why this is the case: first, from the perspective of risk management, two sites can add a degree of insurance against stochastic and un-predictable failure of a population to establish (if one re-introduced population fails, the other may persist). The second reason that two centers of growth can result in better performance is related to mathematical and demographic constraints of diffusion along a linear coastline. Because each population center is limited both by local density dependence and the rate of range spread to the north and south, the same number of animals divided between two centers will result in greater net growth than if they were combined into a single center (all else being equal and assuming that both populations are successfully established). A concrete example of this principle is provided by the SE Alaska translocation: one reason that sea otter numbers in SE Alaska are so high today is that the original 450 animals were divided among 6 release sites (see Chapter 2 of this report for details). Spatially distributed release sites in SE Alaska led to many separate population nodes, each growing exponentially and expanding outwards: the same number of animals introduced at a single release site would have resulted in a much smaller population with a more limited distribution (Tinker et al. 2019). Using the ORSO model to compare a reintroduction scenario of 100 animals introduced to a single site (S6) vs. a scenario of the same number of animals divided between two spatially distant sites (SE2 and CE4) resulted in almost 2x more animals after 25 years under the latter scenario (Figure 3.6). Comparing maps of the projected populations under the two scenarios reveals the reason for the difference: the two release sites resulted in two distinct population centers (Figure 3.7).

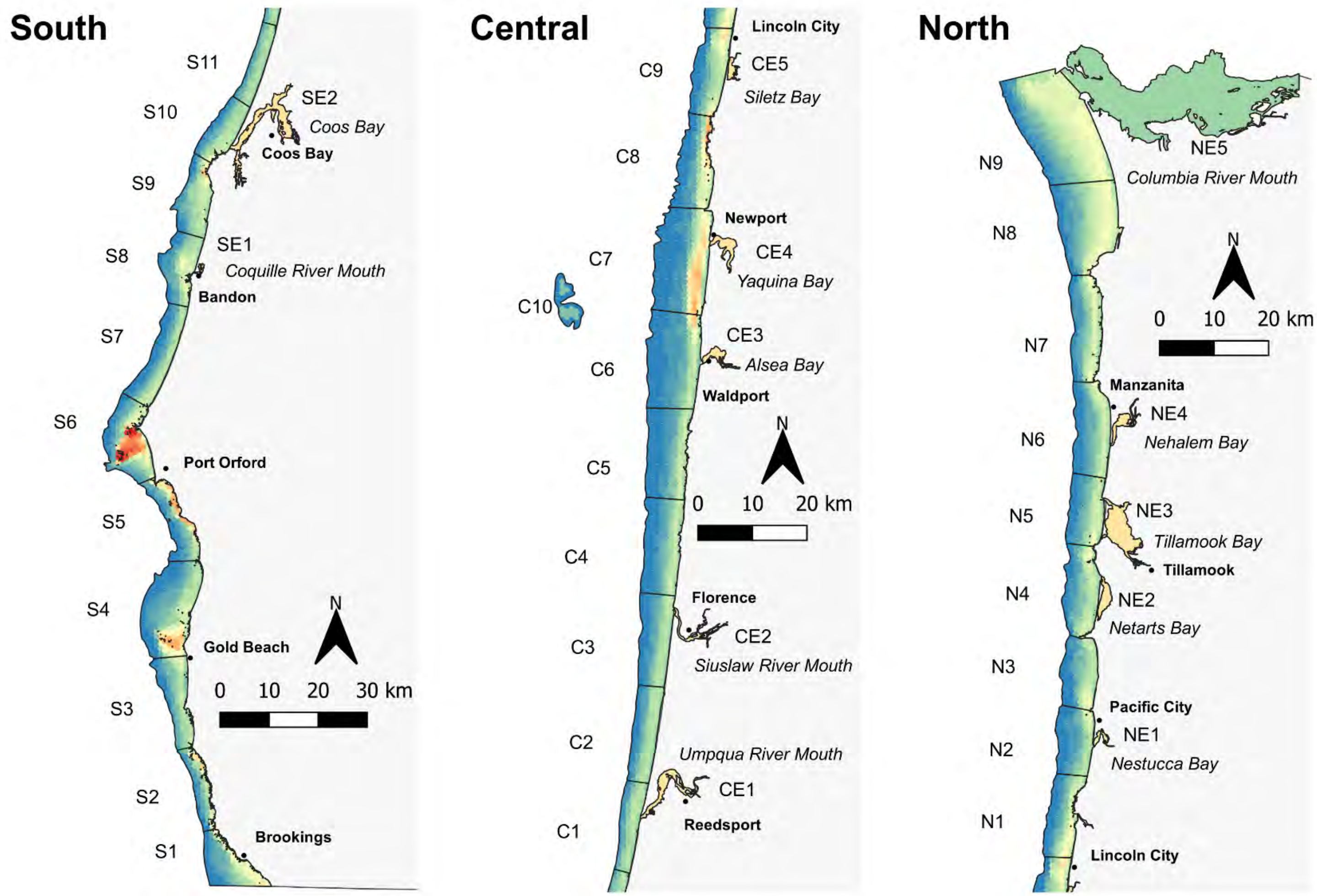


Figure 3.4 Results of a habitat-based model of sea otter carrying capacity to the Oregon coast (Kone et al. 2021), showing variation in the expected density of sea otters at K resulting from differences in habitat suitability.

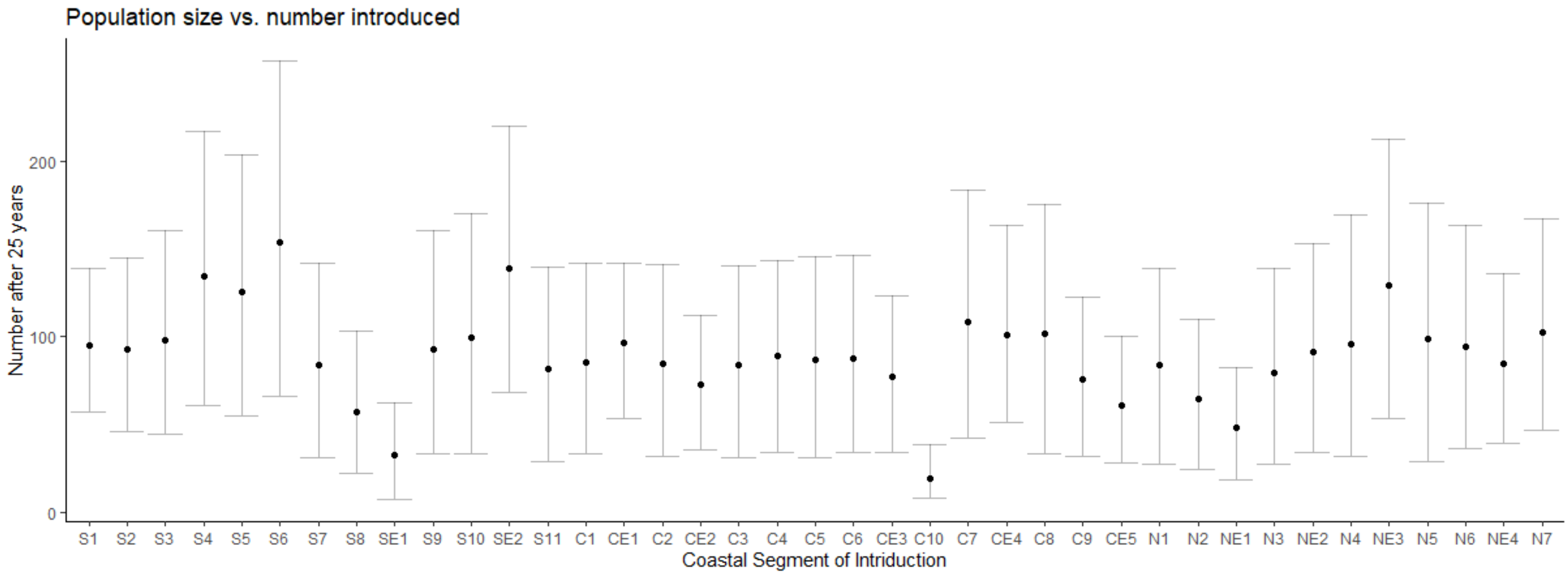
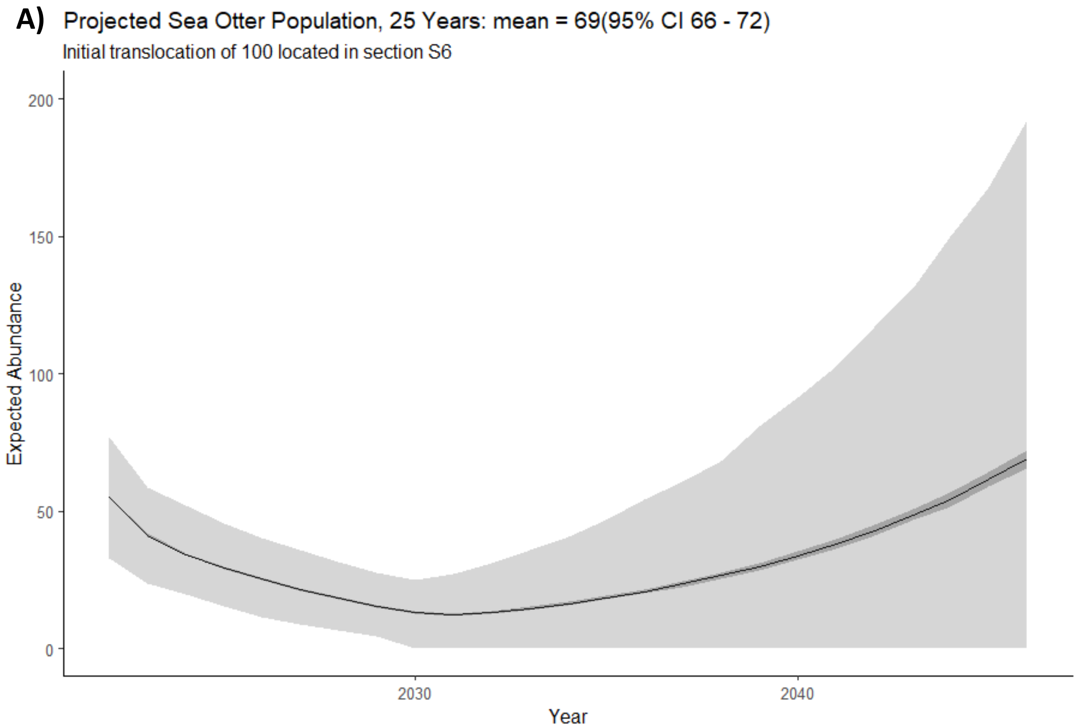


Figure 3.5. Comparison of expected number of sea otters after 25 years based on reintroductions of 100 sea otters to different coastal segments (see map, Figure 3.4). Each scenario consisted of an initial reintroduction of 70 animals, followed by supplementary additions of 3 otters per year for 10 years. The establishment phase was assumed to last for 10 years, with an elevated mortality rate of 0.14 during that period, and an average probability of post-introduction dispersal away from the translocation site of 75% for adults but only ½ that rate for sub-adults.

A)



B)

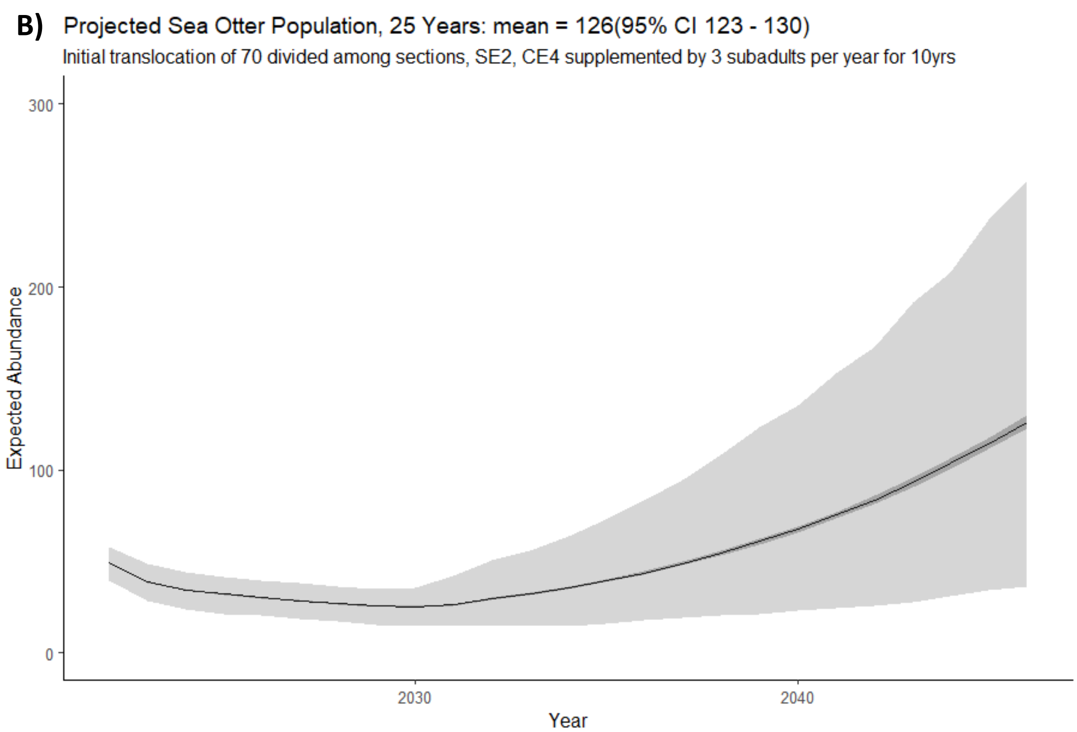


Figure 3.6 Comparison of projected sea otter trends after two reintrodiction scenarios: A) An initial translocation of 100 animals to a single coastal area (section S6 – see map in Figure 3.4) ; B) An initial translocation of 70 animals divided equally amongh two sections (SE2 and CE4), with supplemental additions of 3 subadults per year for 10 years (also divided equally between the two areas). Despite the fact that both scenarios involved reintroduciton of 100 animals, the second scenario resulted in an expected abundance after 25 years that was twice that of the first scenario. The difference reflects the benefits of multiple populaiton centers, as well as using supplementary additions of animals to improve viability of the population at a given release site.

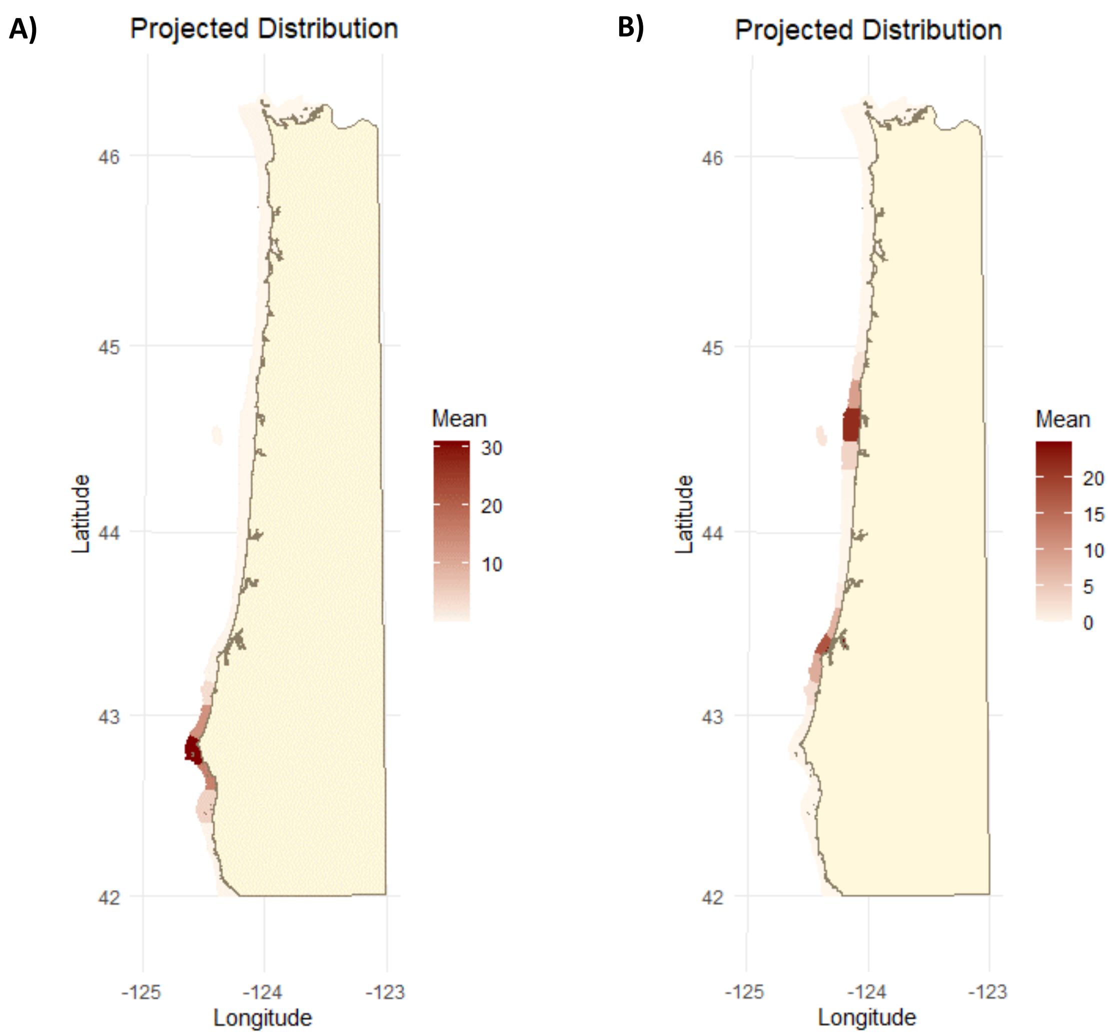


Figure 3.7. Comparison of projected sea otter distribution after 25 years for two reintrodiction scenarios (see Figure 3.6 for details): A) An initial translocation of 100 animals to a single coastal area (section S6 – see map in Figure 3.4) ; B) An initial translocation of 70 animals divided equally amongh two sections (SE2 and CE4), with supplemental additions of 3 subadults per year for 10 years (also divided equally between the two areas). The second scenario resulted in two spatially disjunct populaiton centers, and a net abundance that was approximately two times that of the first scenario.

In summary, the ORSO population model provides an easy-to-use tool for exploring the factors that may affect the future viability of re-introduced sea otter populations in Oregon. Broadly speaking, the take-home message is that a reintroduced population (or populations) of sea otters in Oregon could indeed be viable, but there is an unavoidable and high degree of uncertainty associated with the outcome of any one reintroduction scenario. A prudent approach would therefore be to use the model to consider a wide range of options with the goal of identifying an appropriate set of candidate scenarios for which the level of uncertainty (risk of failure) is "acceptable" to all stakeholders. Each of these candidate scenarios should also be evaluated through the lens of potential ecological effects on local ecosystems (see Chapter 5), local habitat suitability (see Chapter 6), possible socio-economic impacts (see Chapter 7), logistical constraints and considerations (see Chapter 9) and other potential risk factors (see Chapter 10). While this process may be time-consuming and labor intensive, it will almost certainly result in a greater chance of success and a lower likelihood of unintended and undesirable outcomes.

Implications of Reintroduction for the Species

One simple way to consider the net impacts of an Oregon sea otter reintroduction program for the species overall is to tabulate a ledger of negative consequences for the source population and positive consequences for the recipient location. Assuming that a reintroduction is successful, the analyses presented here suggest that it is highly likely that such a tabulation exercise will result in a net positive outcome: this is because the negative impacts to the viability of a source population are small (assuming that an appropriate source population is selected, following the above-described guidelines) relative to the positive impacts of growth in a new habitat. However, such a simple accounting exercise does not really capture the full species level implications of a reintroduction to Oregon. A more robust assessment needs to consider the historical biogeographic context of the current distribution of sea otters, and issues of demographic and genetic connectivity.

The north Pacific fur trade of the 18th and 19th centuries dealt a severe blow to sea otters, completely extirpating them from a vast stretch of their historical range in North America (Kenyon 1969). This event greatly increased susceptibility of the species to total extinction due to the demographic risks of small population size, as well as the genetic consequences of population reduction and fragmentation (see Chapter 4 of this report). Just as importantly, it eliminated their functional role as a keystone apex predator in nearshore ecosystems from Mexico to Alaska (Estes and Duggins 1995, Estes et al. 2004). One of the primary challenges faced by managers in facilitating the recovery of sea otters and restoration of their functional roles in coastal ecosystems is that natural range expansion is extremely slow in this species: as discussed above, this is due to inherent traits in sea otters of limited mobility and high site fidelity of reproductive adults. Because of these traits, natural recolonization of sea otters to all their former habitats in western North America from the remnant colonies in Alaska and California could have taken centuries. Instead, this process was greatly accelerated by translocations from SW Alaska to SE Alaska, British Columbia, and Washington (Jameson et al. 1982). However, there remains a sizable stretch of unoccupied coastline between the Washington population and California population, and given the relatively slow rate of range spread for both these populations, the point at which they converge naturally could be many decades away. From a species-level perspective, the significance of a managed reintroduction to Oregon would be acceleration of the return of the species to the entirety of its former range, restoration of its functional role in those habitats, and reestablishment of a near-continuous (albeit patchy) distribution along the west coast of North America. Restoring a near-continuous distribution is a necessary requirement for allowing pre-fur trade levels of gene flow (Larson et al. 2002, Wellman et al. 2020) and would also greatly enhance the potential for demographic “rescue effects” (the process by which natural dispersal from one area can “rescue” a neighbouring sub-population that has experienced decline from disease, predation or anthropogenic impacts like oil spills). When considering the species-level implications of an Oregon reintroduction, this biogeographic perspective is more relevant than is a simple tabulation of sea otter numbers.

Conclusions

An assessment of the population impacts of a species reintroduction must form a core part of any feasibility study because the restoration of a viable population within the former range is a fundamental objective of conservation-based reintroductions (Seddon et al. 2007, IUCN 2013). Population viability should be considered from the perspective of the source population (i.e., the population from which individuals will be taken for the reintroduction), the proposed recipient location, and the species overall. Here we have used quantitative approaches to assess the population-level impacts of removing animals from putative source populations, and to assess the likely viability of an established Oregon population under various reintroduction scenarios. The model framework we have developed for this assessment (the ORSO web app) can be easily used by managers and a wide range of stakeholders to explore potential outcomes of alternative reintroduction scenarios, assess the relative risks and implications for coastal ecosystems and socioeconomic activities, and evaluate the factors likely to determine success or failure of a reintroduction. We emphasize that biological considerations (i.e., population viability and ecological impacts) represent just one set of variables to be factored into decisions about reintroduction, and must be placed in a broader context of social and economic considerations, legal and administrative considerations, and logistical considerations (Reading et al. 2002). We believe the OSRO model can help in evaluating all these subject areas, as it provides a spatially and temporally explicit tool for visualizing the outcomes of sea otter reintroduction under different scenarios and assumptions. Finally, in thinking about the species-level implications of reintroduction, we encourage a broad perspective that considers the history and biogeography of past and current sea otter populations.

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Chapter 4: Genetic and Historical Consideration of Oregon Sea Otters

Shawn Larson and M. Tim Tinker

Historical Considerations

Sea otters have an extensive history of population extirpations and reductions by humans spanning thousands of years (Bodkin 2015, Salomon et al. 2015). Historically, sea otter populations were distributed along the North Pacific Rim from northern Japan in the northwestern Pacific to Baja California, Mexico in the eastern Pacific (Kenyon 1969). Prior to 1750, their abundance across this range has been estimated as 150,000 to 300,000 animals (Johnson 1982). The most well-known and widespread extirpation, as well as the most recent, was the commercial sea otter harvest conducted during the International maritime fur trade from the mid-1700s to 1910 (Kenyon 1969). During the height of the maritime fur trade in the 18th and 19th centuries, an estimated 99% of the sea otter population was extirpated from much of its original range, leaving only 13 small, isolated, and scattered populations, 11 of which survived as founders for the populations extant today (Lensink 1960, Kenyon 1969, Bodkin 2015). Refer to Figure 4.1 for a map of the historical and current sea otter range, including locations of fur trade remnant populations and those populations resulting from successful translocations.

Prior to the commercial fur trade extirpations, sea otters were hunted by the indigenous populations of North America (henceforth First Nations) for at least 10,000 years for food and ceremonial purposes, as well as for management of shellfish stocks (Simenstad et al. 1978, Salomon et al. 2015). According to oral historical accounts, sea otter hunting was a respected skill and an honored tradition among coastal First Nations communities and only certain people had the privilege to hunt, such as the chief or a hunter designated by the chief (Salomon et al. 2015). Like many coastal resources used by First Nations, it is believed that sea otters were managed spatially, with male rafts targeted more often than female dominated areas (i.e., areas used by reproductive females and territorial males and from which non-territorial males are mostly excluded). Spatial management practices likely reduced or excluded sea otters from some areas while leaving abundant populations in other areas, thus resulting in a patchwork of sea otter populations and sea otter exclusion areas, or an "ecological mosaic". Shellfish harvests could be optimized in areas from which sea otters were excluded, while the maintenance of healthy sea otter populations in other areas ensured their availability for ceremonial uses, as otter fur and teeth were highly valued and used to demonstrate high social status (Salomon et al. 2015). This scenario is supported by the fact that sea otter remains can still be found and investigated in curated First Nations middens (layers of discarded animal bone, shells, and other artifacts from historic human occupation) throughout the west coast of North America and that represent thousands of years of continuous occupation. First Nations subsistence hunting was thus sustainable in the sense that sea otter populations persisted throughout their North American range prior to the arrival of Europeans, although genetic analyses suggest one or more population bottlenecks (of unknown severity or duration) that potentially affected genetic diversity over this period (Aguilar et al. 2008, Beichman et al. 2019). Even though there were likely long term and widespread harvests of sea otters by First Nations people, the maritime fur trade remains accepted as the primary mechanism of sea otter population extinctions and reductions throughout their former range (Lensink 1960, Kenyon 1969, Jameson et al. 1982, Bodkin 2015).

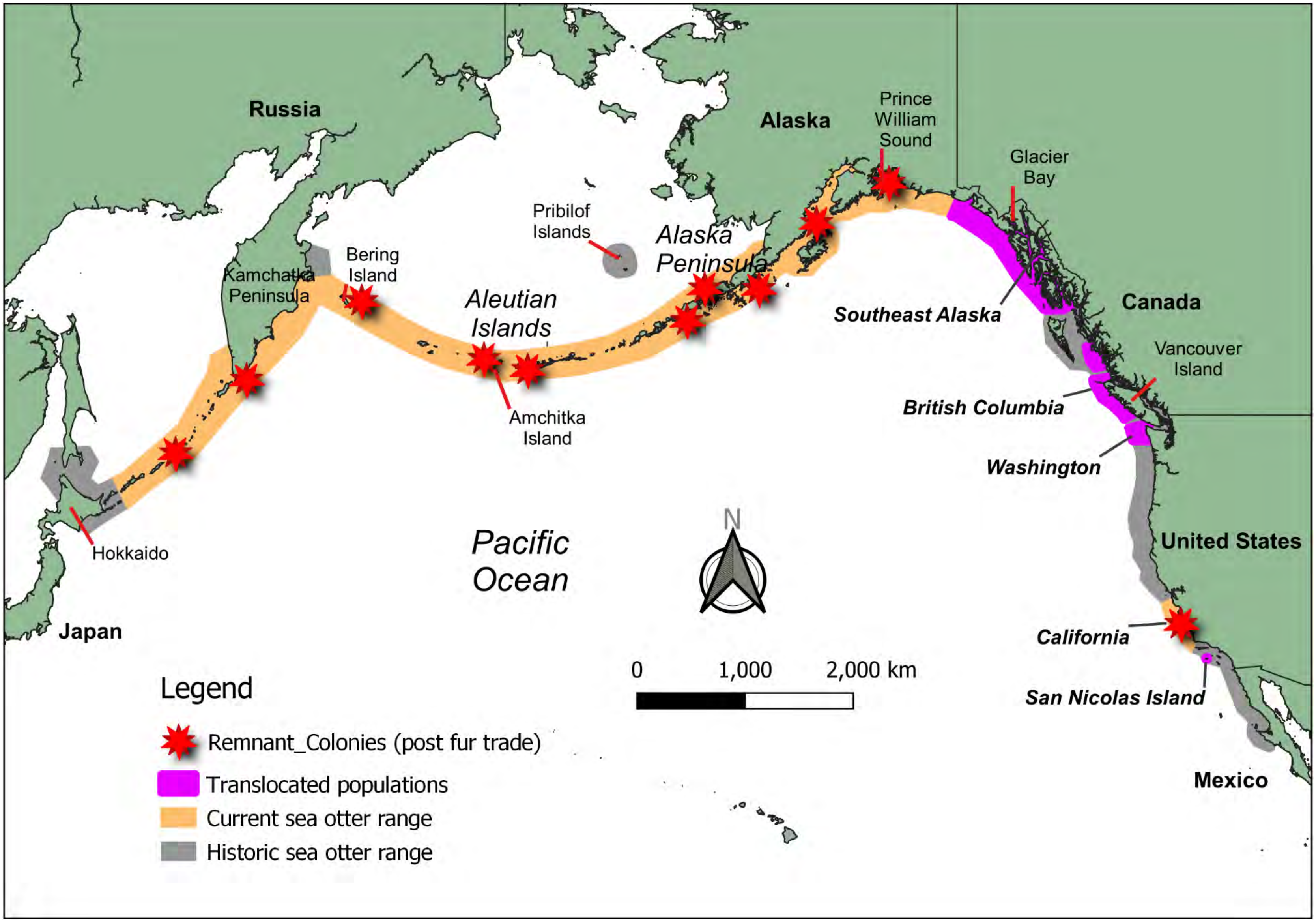

Figure 4.1 Map of the historical and current sea otter range, including locations of fur trade remnant populations and those populations resulting from successful translocations

Range expansion following fur trade extirpations in portions of the Aleutian Archipelago was relatively rapid due to the presence of several remnant populations and the relatively short distances between populations (10s of kms) which are well within the range of the sea otters movements in Alaska (Lensink 1960, Kenyon 1969, Garshelis and Garshelis 1984, Tinker and Estes 1996). However, even though some populations recovered relatively quickly, much of the historic sea otter habitat along the west coast of North America remained vacant, from the remnant population in Prince William Sound, Alaska, to the remnant California population centered around Big Sur (Kenyon 1969, Estes 1990). This situation changed rapidly in the 1960s and early 1970s, when state and federal agencies made several translocations of sea otters from the Aleutian Islands and Prince William Sound populations to vacant habitat along North Americas west coast (Chapter 2 of this report, and Jameson et al. 1982). Roughly 700 otters were captured at Amchitka Island in the Aleutian chain and in Prince William Sound, Alaska, and released into previously occupied habitats in Southeast Alaska, Vancouver Island in British Columbia, Washington, and Oregon. An important detail from a genetic standpoint is that the Southeast Alaska and Vancouver Island translocations were founded by animals from Amchitka and Prince William Sound, while the Washington and Oregon translocations were founded only by Amchitka animals (Jameson et al. 1982, Bacon 1994, Bodkin et al. 1999). All these translocations resulted in viable sea otter populations extant today except the one to Oregon, which failed for unknown reasons (Jameson et al. 1982), although there is speculation that the surviving otters eventually swam north to join the population in Washington (see Chapter 2 for details, and Figure 4.1 for a map of successful translocations).

In sum, it is clear that sea otters occupied Oregon prior to the fur trade, as evidence by First Nations oral histories, sea otter remains in Oregon's First Nations middens (Valentine et al. 2008, Hall 2009), and written accounts of sea otters by explorers such as Lewis and Clark and fur traders (La Follette and Deur 2021). However, a clear account of the density and distribution of otters throughout Oregon prior to the fur trade extirpation is missing. Studies of First Nations middens along Oregon's coast suggest that sea otters likely inhabited much of the coast (Figure 4.2) although actual numbers of individual otters in the se middens have not been analyzed. The Lewis and Clark expedition in the winter of 1805-1806 mentioned that sea otters were "plentiful" in the Northern Oregon Coast, yet also hard to kill (La Follette and Deur 2021). Some researchers have concluded that sea otters were less numerous in Oregon than they were to the north and south (Ogden 1941), as evidenced by the scarcity of sea otter harvest records during the fur trade, the fact that there were few international trading ships that could easily make port along Oregon's coast, and finally the observation that native Oregon sea otters had been hunted to extinction by the beginning of the 20th century despite the apparently limited harvest efforts (La Follette and Deur 2021).

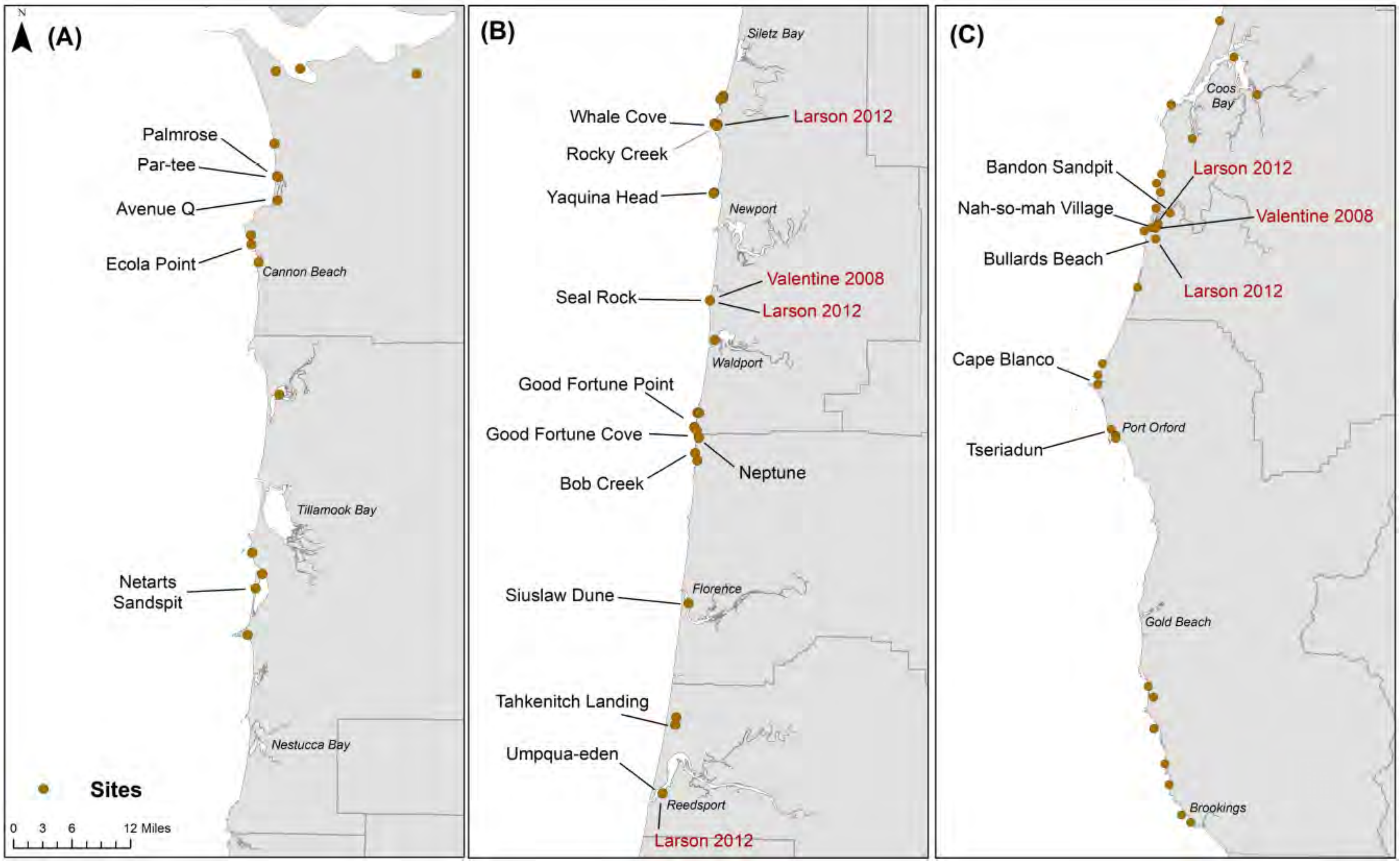

Figure 4.2. Coastal Oregon archaeological sites with known vertebrate faunal remains, plotted by region (A=North, B = Central and C = South). Labelled sites are know to have held sea otter remains, and sites that were previously sampled for genetic studies are labelled in red. Source of Figure: Curran, Kone and Wickizier 2019 – Appendix E

Genetic Considerations

Over this extensive history – from First Nations management for thousands of years, to the massive and extensive fur trade extirpations, to the translocations of small numbers of otters and subsequent population recovery – many extant sea otter populations are thought to have suffered from not just one but multiple reductions in population size over time (Larson et al. 2002a, Larson et al. 2002b, Aguilar et al. 2008, Beichman et al. 2019). Populations that suffer one or many severe reductions in population size and isolation due to reduced population connectivity are recognized to be at risk for loss of genetic diversity (Frankham 2005, Lankau and Strauss 2007, Ralls et al. 2018). Genetic studies focused on sea otters using a variety of variable nuclear genetic markers have demonstrated relatively low genetic diversity (average of 50% diversity within the genome) within all extant sea otter populations, as compared to mammals that have no known population bottlenecks that typically have diversity metrics between 70-80% diversity within the genome (Cronin et al. 1996, Scribner et al. 1997, Larson et al. 2002a, Larson et al. 2002b, Aguilar et al. 2008, Larson et al. 2012, Gagne et al. 2018). To estimate pre-exploitation sea otter genetic diversity, Larson et al. (2002*b*, 2012) used nuclear microsatellite markers and 600 to >10,000-year-old sea otter bones found in First Nations midden collections. These ancient sea otter samples had levels of genetic heterozygosity (a measure of genetic diversity) ranging from 62% in ancient California to 86% in ancient Alaska, indicting a loss of about 30-40% of pre-bottleneck heterozygosity (Larson et al. 2002b, Aguilar et al. 2008, Larson et al. 2012, Gagne et al. 2018). The sea otter populations with the highest measured levels of genetic diversity to date are from the translocated groups founded by more than one source population: Southeast Alaska (60%) and Vancouver Island, BC (54%), both founded by a combination of Amchitka Island and Prince William Sound otters. In addition, recent genetic evidence suggests that the Washington translocated population, which was originally founded by Amchitka animals, has been mixing genetically with the Vancouver BC population, thereby increasing its genetic diversity to 56% and approaching 80% of estimated pre-fur trade genetic diversity levels (Larson et al. 2012, Larson et al. 2021). The California sea otter population has the lowest genetic diversity, stabilizing over the past 40 years at 49% diversity, most likely because of past bottlenecks, relatively slow growth rates and continued isolation from other sea otter populations (Gagne et al. 2018).

The successful reintroductions of sea otters to Washington, Vancouver Island B.C., and Southeast Alaska were responsible for a combined abundance of approximately 50,000 animals as-of 2012 (Nichol et al. 2015, Jeffries et al. 2017, Tinker et al. 2019), representing approximately one third of the estimated 125,000 sea otters existing at that time (Bodkin 2015). In addition, as evidenced by new genetic migrant analyses, these reintroductions have been instrumental in increasing population connectivity, with evidence of migrants and thus geneflow between neighboring sea otter populations spanning from the Alaska Peninsula, to Prince William Sound to Southeast Alaska and down into British Columbia and Washington (Larson et al. 2021). These successful translocations have arguably been the most successful management tool employed to recover extirpated sea otter populations and their genetic diversity. However, because of the failure of the Oregon translocation there remains a large stretch (approximately 1,200 km) of unoccupied habitat from northern California to southern Washington. Re-colonization of this unoccupied stretch, either naturally or via managed reintroduction, would effectively complete the genetic connectivity of sea otters throughout their historical range. Current rates of natural range expansion in Washington and California have slowed or stalled in recent years (Jeffries et al. 2017, Tinker et al. 2017, Hatfield et al. 2019, Tinker et al. in press), so managed reintroduction would clearly accelerate the achievement of this goal. If such a management action were to be undertaken, a key question is which sea otter population should be used as a source population.

Selection of a source population for a new re-introduction to Oregon should take into consideration two factors from a genetic perspective: 1) maximization of genetic diversity, and 2) genetic consistency with the original pre-fur trade population in Oregon. The original sea otters native to Oregon have been analyzed genetically by three different researchers, to determine whether they more closely resembled southern sea otters, northern sea otters, or a mixture of both. Remains from pre-fur trade Oregon sea otters were sampled from First Nations midden sites. The actual number of individual sea otters in Oregon first nations middens remains unknown, but they were one of the most common marine mammals found along with Steller sea lions and harbor seals (Hall 2009). Valentine et al. (2008) sequenced a portion of the mitochondrial DNA (mtDNA) from ancient Oregon otter teeth at two separate locations, the Seal Rock (SR) location in north-central Oregon and the Nah-So-Mah Village (NV) location in southern Oregon near Bandon. They sequenced 16 mtDNA signatures or haplotypes matching both modern northern and southern sea otters as well as two new haplotyes not yet recorded. Valentine et al. (2008) found the dominant haplotype matching southern sea otters and suggested that one reason the translocation in mid-20th century to Oregon failed was because the founders from Amchitka weren't genetically suited to colonize the Oregon Coast. Larson et al. (2012) looked at nuclear genetics from ancient/historical sea otters sampled throughout the range. They sampled ancient/historical pre-fur trade Oregon sea otters from midden remains (bones) from five archaeological sites: Little Whale Cove (35-LNC-43) on the northern Oregon coast; near the mouth of the Umpqua River and near Seal Rock State Park on the central Oregon Coast, and two sites near the mouth of the Coquille River near Bandon on the southern Oregon Coast. They found that the ancient/historical Oregon samples were genetically similar to both ancient/historical California (southern sea otters) and Washington samples (northern sea otters). However, the majority of the ancient/historical Oregon samples were assigned to the group containing ancient/historical Washington samples, suggesting more gene flow moving northwards rather than in a southerly direction. This finding using nuclear markers contrasted with the earlier finding based on mitochondrial DNA (Valentine et al. 2008). Together these findings suggest a possible hybrid zone between southern and northern sea otters in Oregon, although the location and extent of such a hybrid zone is not clear. Finally, new research by Wellman et al. (2020) presents the results of a sequence of the complete mtDNA genome (the mitogenome) from 20 archaeological sea otter teeth: 10 from the Par-Tee site and 10 from the Palmrose site in northern Oregon. They also sequenced two teeth from historical otters collected near Port Orford in southern Oregon during the height of the fur trade in the mid-1800s. Wellman et al. (2020) found 10 archaeological Oregon haplotypes, six unique to single individuals and similar to other northern sea otters (specifically historical Washington and BC haplotypes) that were substantially different from California haplotypes. The two fur-trade era haplotypes from southern Oregon also clustered closely to northern haplotypes (Wellman et al. 2020). These results are perhaps not surprising (in light of the previous analyses) given that their archeological samples were exclusively from northern Oregon. Considering all the ancient Oregon archaeological studies to date, the results strongly point to genetic variation along a latitudinal cline and suggest that, prior to sea otter extirpation in the fur trade, the Oregon coast apparently served as a transitional zone between southern and northern sea otters and could serve a similar function in the future. Further investigation is required to increase the archaeological, historical and modern nuclear and mitogenome data sample size from locations throughout their former range.

Conclusion

The history of sea otters in western North America, including information from First Nations oral histories, archaeological remains and genetic studies, suggest that sea otters in Oregon represented a hybrid zone between southern and northern sea otter populations. Based on this evidence, an argument could be made that any future reintroduction effort might be designed with this history in mind, and thus aimed at recreating such a hybrid zone. This could be achieved in several ways: 1) using both southern and northern source populations for an Oregon reintroduction; 2) using northern sea otters as a source population for a northern Oregon release site, and southern sea otters as a source population for a southern Oregon release site; or 3) by pairing an Oregon reintroduction using a northern sea otter source population, with a northern California reintroduction using southern sea otters as a source population. In the latter scenario, hybridization of northern and southern sea otters would re-occur naturally. Any one of these strategies would further the recovery of genetic diversity by restoring mixing of northern and southern sea otters and restoring the potential for gene flow to the largest remaining gap in sea otter distribution within their current range.

Summary

Oregon's sea otter population was hunted to extinction during the international maritime fur trade with the last native sea otter thought to have been killed in the early 20th century. Sea otters are thought to have occupied most or all of the Oregon Coast, as evidence by sea otter remains in archaeological sites within First Nations middens. However, the historical population size remains unknown, and it is thought that the numbers may have been relatively low due to the scarcity of information documenting Oregon otters hunted during the fur trade. Three studies have been done using genetics to determine the most closely related sub-species, northern or southern sea otters, of Oregon's extinct sea otter population (Valentine et al. 2008; Larson et al. 2012 and Wellman et al., 2020). Valentine et al. (2008) looked at a portion of the mitochondrial DNA and found most of the ancient Oregon otters had genetic signatures similar to the southern sea otter subspecies. Larson et al. (2012) looked at 5 variable nuclear microsatellites and found evidence of both southern and northern sea otter subspecies in the ancient Oregon otters. Finally, Wellman et al. (2020) looked at the entire genetic sequence of the mitochondrial DNA and found most of the ancient Oregon otters belonged to the northern sea otter subspecies. Thus, we conclude that the original Oregon sea otters likely represented a hybrid zone, with ancestors that genetically resembled both southern and northern sea otters.

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Chapter 5. Ecosystem Effects of Sea Otters

J.A. Estes and M.T. Tinker

The interplay between sea otters and coastal marine ecosystems is a key point of interest and concern surrounding the possible repatriation of sea otters in Oregon. This interplay has two distinct dimensions: 1) as effects of the ecosystem on otters, and 2) as effects of otters on the ecosystem. These classes of effects intersect broadly with the science of ecology, a discipline that is complex and often opaque to non-specialists. We thus begin this chapter with a short primer of ecology's central concepts, goals, methods, and challenges (Box 5.1). The remainder of this chapter will consider the effects of sea otters on ecosystems. The effects of ecosystems on sea otters will be addressed elsewhere in this report (Chapter 6 on habitat suitability considerations and Chapter 10 on health and welfare considerations).

How do ecologists determine a species' effect on its associated ecosystem? The most compelling approach is from contrasts of otherwise similar habitats in which the species is present and absent. For some species this can be accomplished experimentally, but for many others (like sea otters) purposeful experiments are difficult or impossible to do. In these latter cases, the ecological effects of species have been inferred through what are often referred to as "natural experiments", wherein the contrasts are made opportunistically in space (i.e., between otherwise similar habitats with and without the species) or time (i.e., at some location wherein the species is appears, disappears or undergoes significant changes in abundance over time). Both the spatial and temporal approaches have been applied repeatedly to sea otters and their coastal marine ecosystems in various parts of the North Pacific rim, thereby providing what is arguably the most extensively studied and best-known example of ecological influence by any large-bodied predator in all of ecology.

The strength of this case results in large measure from six attributes of sea otters and their associated ecosystems. The *first* of these attributes is historical in nature. Sea otters were exploited to near extinction during the Pacific maritime fur trade, after which populations recovered in several areas with surviving remnant colonies but remained absent in nearby areas where they had been hunted to extinction. Half a century later, after many of the surviving remnant colonies had recovered from the fur trade, translocations were used to establish additional colonies. The ecological influences of sea otters were thus identified simply by comparing nearby areas in which the species was present or absent, and by observing change at specific locations as otter populations waxed or waned through time. The *second* important attribute of sea otters and coastal ecosystems is replication. The historical patterns have played out repeatedly across the sea otter's natural range, from the northern Japanese archipelago, across the Pacific Rim, to the central Pacific coast of Baja California, Mexico. The *third* important attribute of sea otters and coastal ecosystems is the tendency of individual otters to live their entire lives in relatively small areas. This feature of the species' natural history, which is unusual for large predators, prevented large-scale diffusion and mixing with population recovery from the fur trade, thereby maintaining high levels of spatial granularity in nearshore ecosystems with and without sea otters. The *fourth* and *fifth* important attributes of sea otters and coastal ecosystems are 1) the *ease* with which other key elements of the interaction web (e.g., macroalgae, benthic macroinvertebrates, reef fish, etc.) can be observed and measured and 2) the capacities of these species to recover quickly following pulse perturbations (i.e., the addition or removal of sea otters). A final attribute of the system is the sea otter's high rate of food consumption (Williams and Yeates 2004, Yeates et al. 2007). Our discussion of the significance of these attributes presupposes a familiarity with fundamental concepts in ecology: we have therefore provided a brief introductory review of key ecological concepts in Box 5.1. Readers already familiar with ecological concepts and terminology can skip Box 5.1 and go directly to the next section.

Box 1. A Primer of Ecology

This primer provides interested or unfamiliar readers with further background on those dimensions to the science of ecology that intersect intimately with our current understanding of the influences of sea otters on their associated ecosystems. Although we have tried to make this treatment understandable to non-specialists, the subject is admittedly both complex and often nuanced. We therefore refer those readers who may wish to obtain more detailed or additional understanding to the referenced literature.

The central goals of ecology are to understand, manage, and conserve the distribution and abundance of species (Krebs 1972). *Understanding* is the province of basic ecology whereas *conservation* and *management* are the provinces of applied ecology. Successful conservation and management usually rest on a foundation of science, which in the case of ecology has two dimensions--1) the description of pattern (i.e., which species occur where and in what numbers); and 2) the determination of causal process (i.e., knowing why the distribution and abundance of species is what it is). The description of pattern, while frequently tedious, is otherwise a relatively straightforward endeavor, attainable simply via “boots on the ground” observations and measurements. Understanding the processes that underlay these patterns, however, is more challenging because, in contrast with descriptions of pattern, processes are more complex and much more difficult to observe and measure.

This challenge, while daunting, can be brought into focus by recognizing that the multitude of processes that determine the distribution and abundance of any species is divisible into three broad categories—those stemming from 1) biogeography and evolution (i.e., history), 2) the current abiotic (i.e., physical and chemical) environment, and 3) the current biotic environment (i.e., species interactions). These categories of processes create a further dichotomy of perspective in describing and understanding the distribution of species, which is where any particular species ***can live*** (the species’ so-called *fundamental niche*) vs. where it actually ***does live*** (the species’ so-called *realized niche*). A species’ fundamental niche is largely determined by the abiotic environment and species interactions; it’s realized niche is further determined by the historical influences of biogeography.

Species interactions can be thought of most simply as the manner in which two species that co-occur in nature influence the respective distributions and abundances of one another. Such interactions play out in several ways, the most important of which are competition (i.e., the influence of each species on the other species is negative), mutualisms (i.e., the influence of each species on the other species is positive), and consumer-prey interactions (i.e., the influence of the prey on the consumer is positive whereas the influence of the consumer on the prey is negative). All three categories of interactions occur widely in nature although consumer-prey interactions are especially important because without them it would be impossible for any species (other than photosynthesizing plants and a few chemosynthetic autotrophs) to exist anywhere. The network of ***trophic linkages*** (interactions between consumers and prey) is known as a *food web* (Pimm 1982), and the scientific enterprise of understanding how this network of linkages influences the distribution and abundance of species is the province of *food web dynamics*.

The simple fact that consumers depend on the species that nourish them had a dominating impact on ecology through the 1950s. Until about that time, the distribution and abundance of species was believed to be determined by what are known as *bottom-up* forcing processes (Hunter and Price 1992), wherein the distribution and abundance of species is dictated by three essential resources (energy [sunlight/temperature], water, and nutrients) and the efficiencies by which these resources are extracted from the environment and transferred from prey (lower in the food web) to consumers (higher in the food web; hence the term *bottom-up forcing*). Further variation in the distribution and abundance of species at any one trophic level was attributed mainly to competition for these limiting resources.

Ecology's conceptual mindset broadened in the 1960s with Hairston et al.'s (1960) *Green World Hypothesis*. Hairston et al. (1960) argued that the distribution and abundance of species can also be limited by their consumers, and that most of our planet's terrestrial realm, when viewed from a distance, appears green because autotrophs are green and predators limit their herbivores, thus causing green plants to be more abundant than they otherwise would be. By this view, the distribution and abundance of species is influenced by what have come to be known as *top-down* forcing processes and the networks of consumer-prey interactions--from apex predators at the top of the food web to plants at the bottom--are known as ***trophic cascades*** (Paine 1980, Terborgh and Estes 2013, Ripple et al. 2016).

In this *top-down* view of ecological process, relatively rare species (e.g., apex predators) can have disproportionately strong influences on the distribution and abundance of other species. These comparatively rare but otherwise ecologically important species are known as ***keystones*** or more precisely, ***keystone species*** (Paine 1969, Power et al. 1996). Keystone species are often apex predators within their food webs. The processes that cause these predators to have such strong and wide-ranging effects on their ecosystems also are diverse and somewhat complex. Therefore, before reviewing the effects of sea otters on coastal ecosystems, we describe some of these general processes.

A more general construct for thinking about the functional dynamics of ecosystems is that of an ***interaction web***[1] (Menge and Sutherland 1987). The more widely known concept of a food web – a sort of road map to who is eaten by whom (Paine 1988) – is embedded in this more encompassing notion of the interaction web. We have chosen to frame our discussion of the ecological influences of sea otters in the context of interaction webs rather than food webs because some of the important ecological effects of sea otters are not exclusively trophic (although most are), and species interactions initiated by sea otters can feed back to influence the abiotic environment. We next discuss some of the more important structural features and properties of interaction webs.

Direct Versus Indirect Species Interactions

Linkages between any two species in a species interaction can be either direct (no intervening species) or indirect (one or more intervening species). If species A eats species B, and species B eats species C, then A-B and B-C are direct interactions and A-C is an indirect interaction. It is important to understand that the number of potential indirect interactions is vastly greater than the number of potential direct interactions in all but the simplest interaction webs (Estes et al. 2013). Moreover, indirect interactions can link up across numerous species to create long chain reactions across complex ecological pathways.

[1] the network of linkages (interactions) among species and between species and their physical environment

Drivers Versus Recipients

Many interactions among species and between species and the elements of their abiotic environments are asymmetrical, which means that one member of the interacting pair is the **driver** (i.e., its abundance is the primary determinant of pairwise dynamics) and the other the **recipient**. Adding or losing driver species from food webs affects ecosystem dynamics more strongly than adding or losing recipients.

Interaction Strength

The functional importance of a driver (D) in its interaction with any other species depends on the *interaction strength* (Berlow et al. 1999), commonly defined as the difference in abundance of the recipient species (R) when the driver is present (R_{dp}) versus when the driver is absent (R_{da}). Interaction strength is often calculated on a per capita basis, $(R_{dp} - R_{da})/D$, where D is driver abundance. When ($R_{dp} - R_{da}$) and D are both large, the driver is referred to as an ***ecological dominant***; when ($R_{dp} - R_{da}$) is large and D is small, the driver is referred to as a **keystone species** (Power et al. 1996). A keystone species is thus one that exerts inordinately large impacts on food web structure and dynamics, relative to its abundance.

Bottom-Up Versus Top-Down Forcing

Trophic interactions, which necessarily define much of an interaction web's structure and function (as explained above), vary fundamentally depending on which member of the consumer-prey pair is the main driver and which is the main recipient. When prey are the main drivers of the distribution and abundance of their consumers (through maintenance, growth, and reproduction), the interaction web is said to operate through ***bottom-up control***, thus implying that net primary production (NPP—defined as the amount of carbon fixed by autotrophs per area per time) and the efficiency of energy and material transport upward across trophic levels primarily control the distribution and abundance of species. Conversely, when consumers are the main drivers, the interaction web is said to operate through ***top-down control***, meaning that either mortality or behavioral effects imposed by the consumer on its prey are the most important controlling influences on the distribution and abundance of species. It is important to understand that all interaction webs operate, to a greater or lesser degree, through both bottom-up and top-down control.

Size-Selective Predation

All consumers must choose what to eat from an array of possibilities. The economics of consumer choice are driven by decisions that maximize consumer fitness. These decisions include where to feed, what prey species and their sizes to eat. Prey size matters a great deal in this behavioral calculus by consumers because of both benefit and risk effects. As a result, prey species typically are consumed in a strongly size-selective manner. In some cases small prey are avoided because they are not sufficiently valuable, while in other cases large prey are avoided because they are too energetically costly or too risky to pursue, capture, and consume. The scientific literature is full of examples of these kinds of consumer choice; one that is especially pertinent to this assessment is the tendency for sea otters to avoid the consumption of smaller individuals for many of their prey species.

Complex emergent properties of food webs

In ecosystems dominated by bottom-up control, the distribution and abundance of species are essentially predictable from two processes--primary production, and material/energy transfer efficiency across trophic levels. Under this condition, the qualitative relationship between consumers and prey is always the same, regardless of trophic status or food chain length. That is, prey are always the drivers and consumers are always the recipients, so that the nature of interactions upward across trophic levels has a neutral effect on the prey and a positive effect on the consumer. Variation in primary production thus has a uniform enhancing or reducing effect on all species, irrespective of trophic status or position in the interaction web.

In contrast, for ecosystems dominated by top-down control there are qualitative differences in species interactions depending on food chain length. For example, increasing food chain length by one trophic level via the addition of a new apex predator alters the nature of direct consumer-prey interactions throughout the food web, thus shifting the strength (from weak to strong, or vice versa) of all direct trophic interactions and the sign (from negative to positive, or vice versa) of all indirect trophic interactions (Fig. 5.1). Top-down influences by a species of high trophic status, downward through a food web is known as a ***trophic cascade*** (Paine 1980), which can also be thought of as the propagation of indirect effects of higher trophic-level consumers downward through a food web. Bottom-up forcing can also modulate the relative abundance of multiple prey species of a common predator through apparent competition (Holt 1977), whereby one prey species may be eliminated (or its abundance reduced) by a predator that is attracted to an alternative prey species that is also able to persist in the presence of the shared predator. Additional variation in food web structure based on indirect effects and directionality of forcing is discussed in greater detail by Schoener (1993) and Estes et al. (2013).

Scale

To observe and document the ecological influences of most large-bodied predators, one must measure dynamics at the spatial and temporal scales over which the important controlling processes operate. Large marine predators often are highly mobile animals, and even weakly motile or sedentary species of marine autotrophs and invertebrates which comprise coastal food webs often have dispersive life stages (Palumbi 1994). The size of the spatial area within which the predator's effects should be measured therefore depends on the individual mobility and home range size of the predator itself, as well as the scale at which its limiting resources (prey populations) vary in time and space. Failing to properly account for scale can lead to a misunderstanding of predator-prey interactions and predator effects.

Consumptive Versus Risk Effects

Consumers can influence their prey in two ways: via direct predation (also called consumptive effects) and via risk effects (also called ***trait-mediated***, or non-consumptive effects) (Werner and Peacor 2003, Creel and Christianson 2008). Consumptive effects obviously reduce prey numbers; however, the risk of predation can influence prey population sizes by inducing costly physiological or behavioral changes that affect access to food resources: this is a trait-mediated effect. Risk effects of consumers on prey behavior, and the knock-on effects[2] of these influences on the larger interaction web, have together become known as the ***ecology of fear*** (Brown et al. 1999). Importantly, trait-mediated effects may be strong even for prey species that are rarely successfully captured by a predator. Therefore, a particular predator does not have to be a primary mortality source for a given prey species and that prey species does not have to be common in the diet of the predator for strong top-down effects to occur in nature (Creel and Christianson 2008, Heithaus et al. 2008).

[2] Ripple et al. (2016) define knock-on effects of trophic cascades as indirect interactions that spin off the trophic cascade via qualitatively different sorts of species interactions (e.g., competition, mutualisms, or bottom-up forced consumer prey interactions).

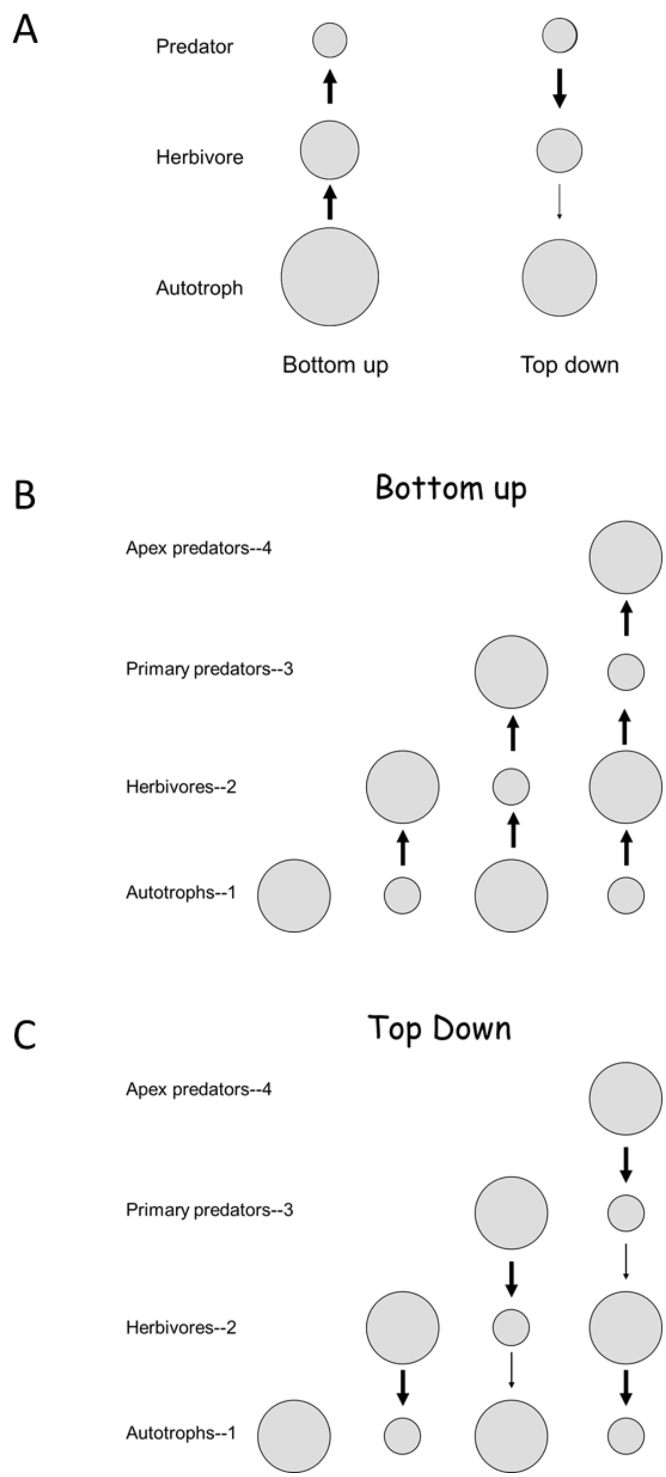

Figure 5.1. Depictions of how bottom up and top down forcing differ from one another (Panel A), and why these matter to the distribution and abundance of species (panels B and C). In all panels, the circles represent species, lines with arrows represent species interactions, arrows indicate direction of forcing, and arrow/line weight indicates interaction strength (thin [weak] vs. heavy [strong]). Differences in interaction strengths between odd and even numbered food chains under bottom up (panel B) and top down (panel C) forcing.

Functional Relationships

As ecological drivers, predators can affect their ecosystems in ways that might vary linearly or nonlinearly with predator population size. Nonlinear relationships, which growing evidence indicates are common in nature, occur when the magnitude of the ecological impacts of a per-capita change in predator abundance differs depending on how abundant the predator is. Non-linear interactions can cause abrupt ***phase shifts*** (a rapid shift between states of an ecosystem) and demonstrate ***hysteresis*** (the condition by which a functional relationship differs depending on whether the predator is increasing or decreasing). Non-linear interactions can also lead to the existence of ***alternative stable states*** in the composition of communities (Scheffer et al. 2001).

Generality and Variation

Although many of the above-described patterns and processes are recurrent among species, habitats, and ecosystems, nothing in ecology is invariant across these entities. This fundamental truth must be kept in mind in considering what can be reasonably predicted about the ecological, social, and economic consequences of repatriating Oregon's coastal ecosystem with sea otters.

Synopsis of Sea Otter Effects

Ecological effects

The ecological influences of sea otters on coastal ecosystems are probably the best documented and among the most widely known of those for any species of predator. These influences have been determined in accordance with the two-step procedure that is explained in the preceding primer—that is, by first describing the interaction web linkages leading outward from sea otters through coastal ecosystems, and then observing how the various species and physical/chemical environmental entities that define this network change as sea otter populations increase or decline in abundance. In all cases, the linkage pathways begin with the limiting effects of otters on the abundance, size, and/or behavior of their macroinvertebrate prey. Although the magnitudes of these limiting influences by sea otter predation (i.e., their interaction strengths) vary somewhat with environment and prey type, they are often large—in the realm of one to two orders of magnitude for sessile or weakly motile prey, like sea urchins and abalone, that live on the exposed seafloor in rocky reef systems. The resulting direct and indirect effects of sea otter predation have been chronicled in three main ecosystem types--rocky reefs, soft-sediments, and estuaries.

Sea otters commonly select the largest available individuals of a given prey species (Estes and Duggins 1995, Tinker et al. 2008), so in most areas it is the smaller individual prey that survive predation. Cracks and crevices in rocky substrate can also provide important refuges from sea otter predation for certain species such as abalone and sea urchins (Lowry and Pearse 1973, Hines and Pearse 1982, Raimondi et al. 2015, Lee et al. 2016). The limiting effects of otters on more mobile species, like lobsters and crabs, appears to be somewhat less, although these effects have not been as well quantified.

Kelp Forest Ecosystems

In kelp forest systems, the influences of trophic interactions between sea otters and their prey spread through the interaction web via several pathways. The most widely studied and well known of these pathways is from sea otters to herbivorous macroinvertebrates (primarily urchins) to kelp and other macroalgae (Estes and Palmisano 1974, Duggins 1980, Breen et al. 1982, Estes and Duggins 1995, Watson and Estes 2011, Burt et al. 2018). Other pathways are less-well documented but can also be important, such as a pathway from sea otters, to predatory sea stars, to the sea stars' invertebrate prey, such as mussels and barnacles (Vicknair and Estes 2012). The otter-herbivore-kelp pathway (a trophic cascade) occurs with varying sea otter density as an abrupt phase shift between lush algal forests and deforested barrens in many parts of Alaska and British Columbia (Steneck et al. 2002, Estes et al. 2010, Selkoe et al. 2015) whereas the response function may be more graded in California (Kenner and Tinker 2018, Smith et al. 2021). The population density of sea otters at which the phase shift occurs also differs among areas (from the Aleutian Islands through southeast Alaska and British Columbia) and with the direction of change. For example, rocky reef ecosystems in the Aleutian Islands remain in the urchin-dominated state after the repatriation of sea otters, until otter population density nears carrying capacity (*K*). In contrast, kelp-dominated systems containing high density otter populations that are in decline remain kelp-dominated until the sea otter population has reached about one-half carrying capacity (Estes et al. 2010). This dynamic ecosystem behavior, in which the functional relationship between a system and its driver differs with the directionality of change in driver intensity, is an example of *hysteresis* (see Box 5.1 primer). Reef systems in southeast Alaska and British Columbia also switch between kelp- and urchin-dominated states, although in this region the sea otter population densities at which these shifts occur are lower than they are in the Aleutian Islands (Estes and Duggins 1995). In California's more complex coastal food webs, other urchin predators may act to mitigate the strength or bi-phasic nature of the otter-urchin-kelp cascade (Foster and Schiel 1988), and indeed the addition of sea otters to a southern California kelp forest at San Nicolas Island has shown that community state transitions can be driven by factors other than sea otter predation; however, in spite of this complexity, sea otter predation at San Nicolas has shifted the subtidal community to a previously un-observed state featuring abundant kelp canopy understory algae and persistent low densities of urchins (Kenner and Tinker 2018). The relative abundance of other "complementary" predators, especially sunflower sea stars, mediates the strength and functional shape of the sea otter trophic cascade in British Columbia and central California (Burt et al. 2018, Smith et al. 2021).

Whether a reef ecosystem occurs in the forested or deforested state has numerous knock-on effects on other species and ecological processes. Perhaps the most important of these is the magnitude of biological production. Kelps and other macroalgae grow rapidly and so the abundance of kelp, as influenced by the abundance of otters, has an important influence on net primary production (NPP), which is elevated by several fold where or when sea otters are sufficiently abundant to force coastal ecosystems into the kelp-dominated state (Duggins et al. 1989). This elevated NPP in turn fuels elevated secondary production via bottom up forcing. Duggins et al. (1989) demonstrated this effect by out-planting newly recruited mussels and barnacles, from a common population source in the San Juan Islands, WA., to islands in the western and central Aleutian archipelago with and without sea otters. Growth rates of the out-planted mussels and barnacles were two- to three-fold greater in the otter-dominated (forested) compared with the otter-free (deforested) ecosystems. Isotopic analyses confirmed that inorganic carbon fixed via photosynthesis by kelp and other macroalgae contributed importantly to overall production in otter-dominated ecosystems (Simenstad et al. 1993). Kelp-based production has been shown elsewhere to propagate upwards through coastal food webs, affecting higher-level consumers such as nearshore rockfish (Markel and Shurin 2015, von Biela et al. 2015, von Biela et al. 2016).

Kelp affects coastal marine ecosystems via three other known pathways: i) structurally, as habitat for other species; ii) by attenuating waves and currents; and iii) by absorbing CO_2 from the surrounding seawater and overlying atmosphere (i.e., part of the supply side for increased NPP). These processes in turn have a range of important effects on both physical and biotic elements of the ecosystem. For example, microbes (bacteria) serve to cycle energy and materials, decompose detritus, and re-mineralize organic matter--processes that are especially important in marine ecosystems. Clasen and Shurin (2015) found that bacteria grew faster, were more abundant, and contributed more strongly to zooplankton grazing in areas where kelp forests had increased because of the otter-urchin-kelp trophic cascade.

Abundant kelp populations in ecosystems with sea otters draw down CO_2 from the overlying atmosphere, thus potentially influencing carbon sequestration (depending on the rate of organic carbon remineralization from kelp detritus and the extent to which kelp detritus is transported into the deep sea) and the CO_2--bicarbonate balance and pH in the surrounding sea water. Wilmers et al. (2012) used information on the areal extent of rocky reef habitat in the eastern North Pacific Ocean; kelp forest NPP; carbon concentration in living kelps; and kelp biomass density between coastlines with and without sea otters--from which they estimated a sea otter effect of 4.4 to 8.7 tera-gram carbon storage, a value that might be even larger depending on rates of remineralization and transport into the deep sea.

The effect of sea otters on kelp extends to other coastal marine species. For example, reef fish population densities are elevated by up to an order of magnitude by the otter-urchin-kelp trophic cascade (Reisewitz et al. 2006, Markel and Shurin 2015), an indirect effect of sea otters that probably occurs because of increased production and habitat complexity. Various species of piscivores (fish eaters) are influenced by this interaction by the knock-on effect of bottom up forcing. Irons et al. (1986), for example, demonstrated that Glaucous-winged Gulls (*Larus glaucescens*) in the Aleutian Islands switch from piscivory to invertebrate feeding when sea otters are lost from coastal ecosystems, and Anthony et al. (2008) reported similar dietary shifts by Bald Eagles (*Haliaeetus leucocephalus*)—in this case from a roughly even mix of marine mammals, fish, and seabirds where otters were abundant, to dominance by seabirds where otters were absent.

Indirect effects of sea otters on coastal ecosystems can also follow interaction wood web pathways other than the otter-urchin-kelp trophic cascade. For example, using a time series of information associated with the repatriation and growth of sea otters at Attu Island, in the western Aleutian archipelago, Vicknair and Estes (2012) found that sea otters preyed on predatory sea stars, thereby reducing sea star populations and associated mortality rates from sea star predation on filter-feeding mussels and barnacles (Vicknair and Estes 2012).

Although the preceding narrative summarizes a diverse array of indirect ecological influences from the otter-urchin-kelp trophic cascade (Fig. 5.2), the majority of such effects are unstudied, and thus are either uncertain or unknown. Some of these unknown interactions may have significant influences on human welfare. One such potential case involves Pacific herring (*Clupea pallasii*), which spawn on kelp, draw nourishment from coastal marine ecosystems, and thus are probably influenced by the otter-urchin-kelp trophic cascade. This interaction is potentially important because herring are prey (as forage fish) for numerous marine species (e.g., fish [including salmon], seabirds, pinnipeds, and cetaceans).

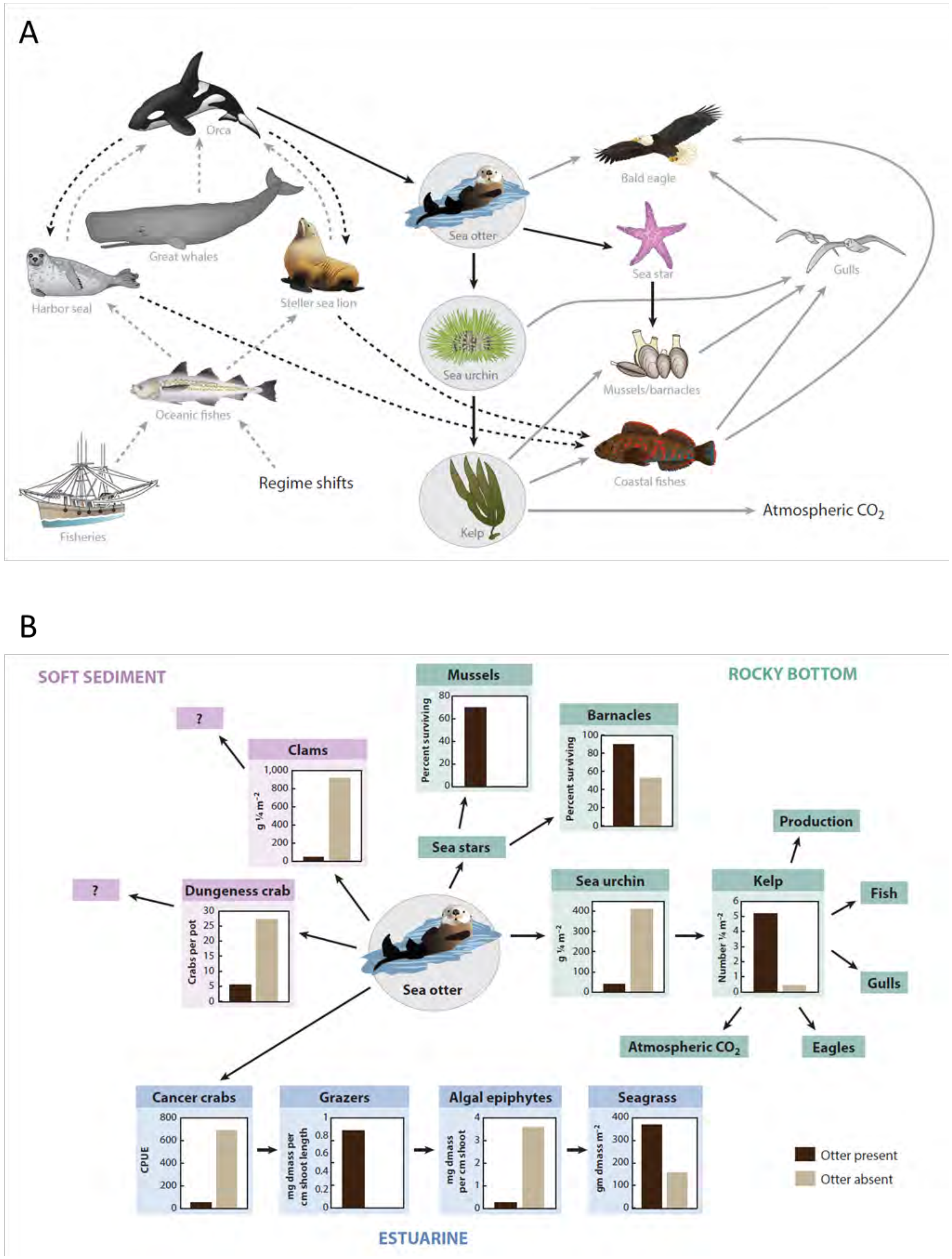

Figure 5.2. Some of the known or suspected linkages between sea otters and coastal marine ecosystems. See original source (Estes et al. 2016b) for further explanation and detail.

Estuarine/Seagrass Ecosystems

Sea otters have been shown to reduce the abundances of clams and crabs in soft-sediments and estuaries (Hughes et al. 2013, Grimes et al. 2020). Seagrass-dominated estuarine systems are also influenced by sea otters in various ways, some of which have important conservation implications for these valuable but threatened ecosystems. For example, anthropogenic inputs of nitrogen from agriculture and residential activities has enhanced the spread of epiphytic algae in many estuaries, leading to algal overgrowth, and ultimately reducing estuarine seagrass beds. In one nutrient impaired estuary in central California (Elkhorn Slough), this pattern of seagrass loss was reversed by the return of sea otters to the system. The unexpected positive effect resulted from a previously undescribed tropic cascade, involving top-down effects from sea otters consuming predatory decapods (crabs), which in turn feed on algivorous isopods and opisthobranch mollusks (sea hares), which graze epiphytic algae. Reestablishment of sea otters into Elkhorn Slough has substantially reduced the size and density of larger crabs (mostly *Cancer productus* and *Romaleon antennarium*), thereby releasing algivorous isopods and sea hares from limitation by crab predation, in turn thereby increasing removal rates of epiphytic algal overgrowth from seagrass blades and ultimately facilitating seagrass bed recovery (Hughes et al. 2013).

Oregon's large coastal estuaries are likely areas for both staging sea otter reintroductions and the habitats that reestablished populations will later occupy. Because of their shallow nature, the likelihood is high that estuarine crab populations and their associated fisheries will be negatively impacted—much as in Alaska (Garshelis et al. 1986) and Elkhorn Slough in central California (Hughes et al. 2013).

Oregon's extensive estuarine oyster farms are another potential concern for conflicts with a shellfishery, although in this case there is little known evidence for negative interactions between sea otters and oyster farming in areas of Alaska and British Columbia where the two co-occur. Nonetheless, oyster farming procedures differ somewhat between these regions and the possibility for conflicts therefore should not be ignored. Indirect positive effects of sea otters on Oregon's estuarine ecosystems, as shown by Hughes et al. (2013) in Elkhorn Slough, are also possible, although the nature of any such effects is presently largely unstudied and therefore uncertain.

Soft-sediment Ecosystems

The effects of sea otters result from consumption of numerous prey species, although the two prey groups that have been most well-studied in soft-sediment systems are infaunal bivalve mollusks (clams) and decapod crustaceans (crabs). Kvitek et al. (1992) reported reductions of one to two orders of magnitude in clam biomass density by sea otter predation in Alaska's Kodiak archipelago and (Garshelis et al. 1986) reported similarly strong limiting influences by sea otters on Dungeness crabs in eastern Prince William Sound. Similar limiting effects of sea otter predation on various clam species have been reported elsewhere (Miller et al. 1975, Kvitek and Oliver 1988, Groesbeck et al. 2014). The indirect knock-on effects to other species and processes in these soft-sediment systems, though probably important, are largely unstudied and thus unknown, but may include such factors as modification of substrate complexity and sediment turn-over, facilitating clam recruitment rates on shell debris, modifying accessibility of clams for other predators, and mediating bivalve filtration rates.

Where sea otter impacts on commercial crab species have been documented, the effects are highly variable. For example (as mentioned above), expansion of a growing sea otter population into eastern

Prince William Sound, Alaska, in the 1980s resulted in a substantial reduction in catch/effort and collapse of the commercial Dungeness crab fishery (Garshelis et al. 1986). In contrast, recreational and commercial Dungeness crab fisheries have persisted and even increased at the northern end of the sea otters' range in central California (Grimes et al. 2020, Boustany et al. 2021). This difference between Prince William Sound and central California may be the result of comparatively fewer otters in California (although sea otters have been present at high densities in commercial crab fishery areas for many decades). Another possible explanation for the difference is bathymetry, with the much deeper nearshore water at the edge of California's continental shelf potentially providing a depth refuge for adult crabs from sea otter predation. Although dive depths of up to 100 m have been documented by male sea otters, the cost of deep diving probably results in reduced foraging efficiency and the vast majority of foraging dives in this species are in <30m of water (Bodkin et al. 2004, Tinker et al. 2007, Thometz et al. 2016, Tinker et al. 2017). Yet another possible reason for differences between Prince William Sound and central California is variation in the strength and frequency of larval supply. Dungeness crab populations in Alaska's inner waters appear to be locally or self-recruiting whereas populations in northern California probably draw more extensively from vast larval pools in the offshore California Current ecosystem (Alan Shanks, personal communication). The situation for commercial crab fisheries in Oregon is more similar to that in California, although recreational crab fisheries in Oregon's extensive coastal estuaries may respond to sea otter predation more similarly to those in coastal Alaska. As a rule of thumb, the negative influences of sea otter predation on Oregon's Dungeness crab fisheries are expected to be strong in shallow water environments and weak to non-existent in deeper water habitats.

Generality and Variation

It is important to understand that all the above-described patterns and processes can vary among locations and at any given location through time. This is not to say that little or nothing can be predicted about how the reestablishment of sea otters will influence Oregon's diverse coastal ecosystems. For example, a reduction in sea urchins and the resulting expansion of kelp forests are likely consequences, based largely on the recurrent nature of this trophic cascade across Alaska, British Columbia, and Washington State. However, the precise details of these effects are unpredictable and wholesale surprises (Doak et al. 2008) are almost inevitable. Some of this variation is no doubt caused by spatial and temporal variation in the physical environment. However, several other features of sea otters and their ecosystems also contribution to this variation, some of which have already been alluded to. These include i) learned behavioral differences among individual sea otters, especially as they relate to dietary preferences; ii) variation in water depth; iii) variation in the regularity and strength of recruitment by species like fish, invertebrates, and macroalgae that are commonly characterized by complex life histories with spores or larvae, and iv) the presence or absence of other species of predators.

Evolutionary effects

The preceding synopsis shows many of the direct and indirect ecological influences of sea otters to be strong and diverse. This finding inevitably leads to questions of evolutionary consequence. Although describing and understanding the evolutionary consequences of sea otter predation have been less thoroughly studied than their ecological counterparts, there are nonetheless several suggestions of important evolutionary influence by sea otters in kelp forest and seagrass ecosystems.

The oldest and most well-known of these evolutionary studies is Steinberg et al.'s (1995) proposal for influences by sea otters on the co-evolution of kelp and herbivores via the otter-urchin-kelp trophic cascade. Steinberg et al.'s (1995) work was founded on two well-known processes—the decoupling effect of sea otters on the interaction strength between sea urchins and kelp, and the co-evolution of defenses (by plants) and resistance to those defenses (by herbivores) when the intensity of herbivory is strong. Steinberg et al. (1995) reasoned that an evolutionary history of weak herbivore-plant interactions in the North Pacific (stemming from the sea otter-urchin-kelp trophic cascade) should have led (via the lack of necessity on the one hand and an otherwise high evolutionary cost of defense/resistance on the other) to a poorly defended kelp flora and weakly-resistant herbivores. They tested this hypothesis via comparative and experimental studies of North Pacific and Australasian kelp forests, from which they discovered i) that Australasian kelps and their analogues were well defended by secondary metabolites whereas their North Pacific counterparts were not; ii) North Pacific herbivores were strongly deterred by these metabolites whereas their Australasian counterparts were not; and iii) kelps and herbivores lived in close association with one another in Australasian kelp forests whereas in North Pacific rocky reef systems they did not. These findings led Steinberg et al. (1995) to conclude that the lack of an effective predator on Australasian herbivores led to the co-evolution of defense and resistance in Australasian kelp forests whereas the presence of sea otters and their recent ancestors in the North Pacific reduced that potential. This evolutionary scenario is thought to have further promoted the radiation of Steller's sea cows (a kelp eating mammal) in the North Pacific (Estes et al. 2016a) and the evolution of unusually large body size in North Pacific abalones (Estes et al. 2005).

A final example of evolutionary influence by sea otters comes from recent work by Foster et al (in review) on disturbance, reproduction and genetics in eelgrass (*Zostera marina*) meadows of British Columbia. Eelgrass has two distinct life history variants—a long-lived form that propagates asexually via a rhizoidal root system, and a shorter-lived form that propagates via flowering, sexual reproduction, and seed set. The asexual form, which is genetically impoverished, is most successful in undisturbed habitats (lacking sea otters) because the resulting dense colonies compete strongly for space and inhibit successful seed set. The repatriation of sea otters (following reintroductions in the late 1960s—see Chapter 2 of this report) has resulted in sea otters digging for prey in these dense asexually clonal eelgrass stands as populations have increased and spread, thereby creating patches of open space on the seafloor for successful seed set, in turn increasing eelgrass genetic diversity. The positive effect of sea otter recovery on eelgrass genetic diversity appears to be substantial, greater than effects associated with more typical factors such as depth and size of eelgrass beds.

Conclusions

The influence of sea otters on coastal ecosystems is one of the most well-known and well-documented examples of a trophic cascade (the complex network of consumer-prey interactions, from apex predators at the top of the food web to plants at the bottom). The top-down effects of sea otters on coastal ecosystems result mostly from the direct limiting influences of sea otters on their macroinvertebrate (including many shellfish species) prey, and indirectly through knock-on effects on other species and ecological processes. The most extensively studied and well-known knock-on effect of sea otters occurs through their limiting influence on herbivorous sea urchins and the resulting enhancing effect on kelps and other groups of macroalgae, which in turn affects numerous other species and ecological processes (a phenomenon that has earned sea otters the reputation of being what ecologists refer to as a *keystone species*). In this chapter we have summarized these known direct and indirect ecological effects and their likely evolutionary consequences, drawing particular attention to many others that are either less well studied or entirely unknown. Although many of the patterns and processes we describe have been well documented, the details can vary substantially from place to place and through time. The sea otter's powerful and diverse ecological influences result in both costs and benefits to human societies, a topic that is taken up further in Chapter 7 of this report.

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Chapter 6: Habitat Suitability

J. Hodder, M.T. Tinker and J.L Bodkin

Although there are a wide range of human-caused species declines, conservation issues are often predicated on either 1) over exploitation of individuals of species (often large carnivores such as wolves, bears, lions etc.), or 2) the destruction or modification of habitats that are essential for species survival (e.g. polar bears and monarch butterflies). In the case of sea otters, conservation through protection from human harvest, and reintroductions into vacant habitat, has been successful in large part because much of their habitat has remained largely unaltered by human endeavors over the past century.

Sea otter occurrence in nearshore marine habitats is dependent on characteristics such as depth and slope, substrate composition, prey abundance and primary productivity, and coastal geography, as well as their behavior and social structure. All of these features contribute to the spatial variation in sea otter distribution and abundance (Tinker et al. 2021). Essentially, all coastal habitats within their geographic range (including latitude and bathymetry) can be considered “potentially suitable” habitat, given that there do not appear to be any coastal areas not used by sea otters in regions where they have fully recovered since the fur trade. However, it is also essential that we recognize not all nearshore habitats will support equal densities of sea otters: for example, in both California and southeast Alaska it was found that local equilibrium densities of sea otters varied more than 20-fold based on habitat differences (Tinker et al. 2019a, Tinker et al. 2021). In the following chapter we explore what we know, and what we don’t know, about how characteristics of sea otter habitat in Oregon might influence reintroduction efforts.

Critical Resources for Sea Otters

For sea otters, as with most high trophic level carnivores, the resource that is most critical for survival is access to sufficient and suitable prey. Sea otters are known to consume more than 150 species or prey, primarily bottom-dwelling marine invertebrates in the intertidal and sub-tidal zones (Riedman and Estes 1990, Estes and Bodkin 2002, Tinker et al. 2017), although in some areas of southwest Alaska and the Russian Commander Islands they are also known to consume some nearshore fish (Watt et al. 2000), and more rarely they may opportunistically consume episodically occurring oceanic invertebrates, fishes and marine birds. In general, the sea otter’s diet is determined largely by the type of habitats they forage in, which for simplicity can be classified into two categories, rocky reefs vs. unconsolidated substrate or “soft sediments” (Newsome et al. 2015, Davis and Bodkin in press). In rocky reef habitats, the diet consists mostly of species living on the surface of the seafloor (“epibenthic” invertebrates), including purple and red sea urchins, various marine snails, abalone, octopus, crabs, mussels, chitons, and other small invertebrates that attach to kelp or rocks (Riedman and Estes 1990, Tinker et al. 2008, Tinker et al. 2012). In the early stages of sea otter population establishment in rocky reef habitats, urchins almost always represent a core part of the diet (Wild and Ames 1974, Ostfeld 1982, Rathbun et al. 2000, Tinker et al. 2008, Rechsteiner et al. 2019). In contrast, where substrates consist of soft sediments, the diet is dominated by species dwelling within the sediment (“infuanal” invertebrates), including clams and worms, but also mussels and crabs (Kvitek and Oliver 1988, Dean et al. 2002, Hale et al. 2019). Soft sediment habitats can be further divided into outer coast areas vs. enclosed estuaries, with some differences in prey taxa occurring between these two ecosystems (Hughes et al. 2019). Based on the success of commercial, subsistence and recreational fisheries for many of the above-described species, as well as direct research and monitoring of Oregon’s coastal ecosystems (Huntington et al.

2015), it would appear that, broadly speaking, appropriate and sufficient sea otter prey species occur across the three habitats identified above (rocky reef, outer coast soft sediments and estuaries). While fisheries suggest the presence of suitable prey, they also suggest the potential for conflict with humans over valuable marine resources (see Chapter 7).

In addition to habitat with adequate prey, sea otters also display a range of behaviors that they exhibit most often when they are aggregated in groups, such as resting, grooming and social or reproductive behaviors (pup rearing), that can be facilitated by habitats protected from adverse environmental conditions such as high seas. Examples of such habitat features will include headlands, bays, reefs, islands, lagoons, estuaries, and sand bars, that provide sheltered waters. Where they occur, canopy forming kelp beds can also provide habitat for these behaviors and will often attract high densities of animals. Not all kelp beds are equivalent, however: certain species of kelp are more likely to be used as resting sites by aggregations of sea otters (referred to as “rafts”), and larger kelp beds tend to provide more protected and predictable resting areas. For example, in California it appears that *Macrocystis* (giant kelp) beds are more preferred than *Nereocystis* (bull kelp) beds, although both are used. The specific features that provide attraction to particular kelp beds or locations within specific habitats are poorly understood. It is believed that kelp beds provide a refuge from adverse environmental conditions such as high winds and seas, and also from potential marine predators such as killer whales or sharks (Nicholson et al. 2018). In addition to kelp beds, intertidal areas that become exposed on falling tides can provide resting and refuge habitats from both marine and terrestrial predators. The value of these intertidal habitats is not well known, in part because sea otters are difficult to observe when hauled out, and they may abandon these habitats when disturbed. In estuaries it has been shown that eelgrass beds and tidal creeks both may provide protected resting and nursery habitats for sea otters, perhaps replacing the function of kelp beds in these soft-sediment ecosystems (Eby et al. 2017, Espinosa 2018, Hughes et al. 2019). It should be noted, however, that high densities of sea otters can also be found in open coastal habitats chronically exposed to high seas and winds, that appear to offer little in the way of shelter. Examples include the Bering sea north of the Alaska Peninsula (Burn and Doroff 2005), and the southcentral coast of Washington, where large expanses of relatively shallow water extend for tens of km offshore (Jeffries et al. 2017). Thus, sheltering features appear to be used by otters when available, but may not be absolutely critical for otters to be supported in an area. Finally, while the role that social structure and behavior play in defining the spatial distribution and abundance of sea otters is recognized, it remains largely unexplored (Bodkin 2015, Tinker et al. 2019b).

The relative abundance and proximity to these two resources – concentrations of preferred prey and suitable sheltered habitats (although the former resource appears to be more limiting than the later) – will help determine the relative degree of habitat suitability for sea otters within their coastal habitats. Unfortunately, measuring these resources directly (especially prey availability) at spatial scales that are relevant for sea otters poses an enormous logistical challenge. In some regions the diets of sea otters are dominated by a single prey type, such as green urchins in the Aleutian Islands, and it has been possible to use scuba-based sub-tidal sampling methods to measure the relative availability of this prey species directly (Estes et al. 2010). In other regions, however, the diet is far more diverse, and often includes a high proportion of cryptic prey (such as crabs) that cannot be effectively measured by scuba-based methods at the appropriate scales. In such cases it may be possible to measure some proportion of prey taxa (e.g. Tinker et al. 2008), but an alternative approach is to utilize other indices of prey abundance (e.g. substrate characteristics) that can be more readily measured. A quantitative model of habitat suitability for sea otters (defined as the potential population density at equilibrium) was recently developed for California: this model indirectly reflects the quality of key resources using readily available GIS layers of abiotic and biotic features (Tinker et al. 2021). Nearshore coastal habitats in Oregon are, broadly speaking, fairly similar to coastal habitats in much of California (especially northern California), and all the basic habitat features used as predictor variables in the California model are also applicable to coastal Oregon. The California model was thus applied to the Oregon coast using the same GIS habitat layers (Kone et al. 2021). The results of this model (Figure 6.1) provide a useful starting point for understanding habitat suitability in Oregon.

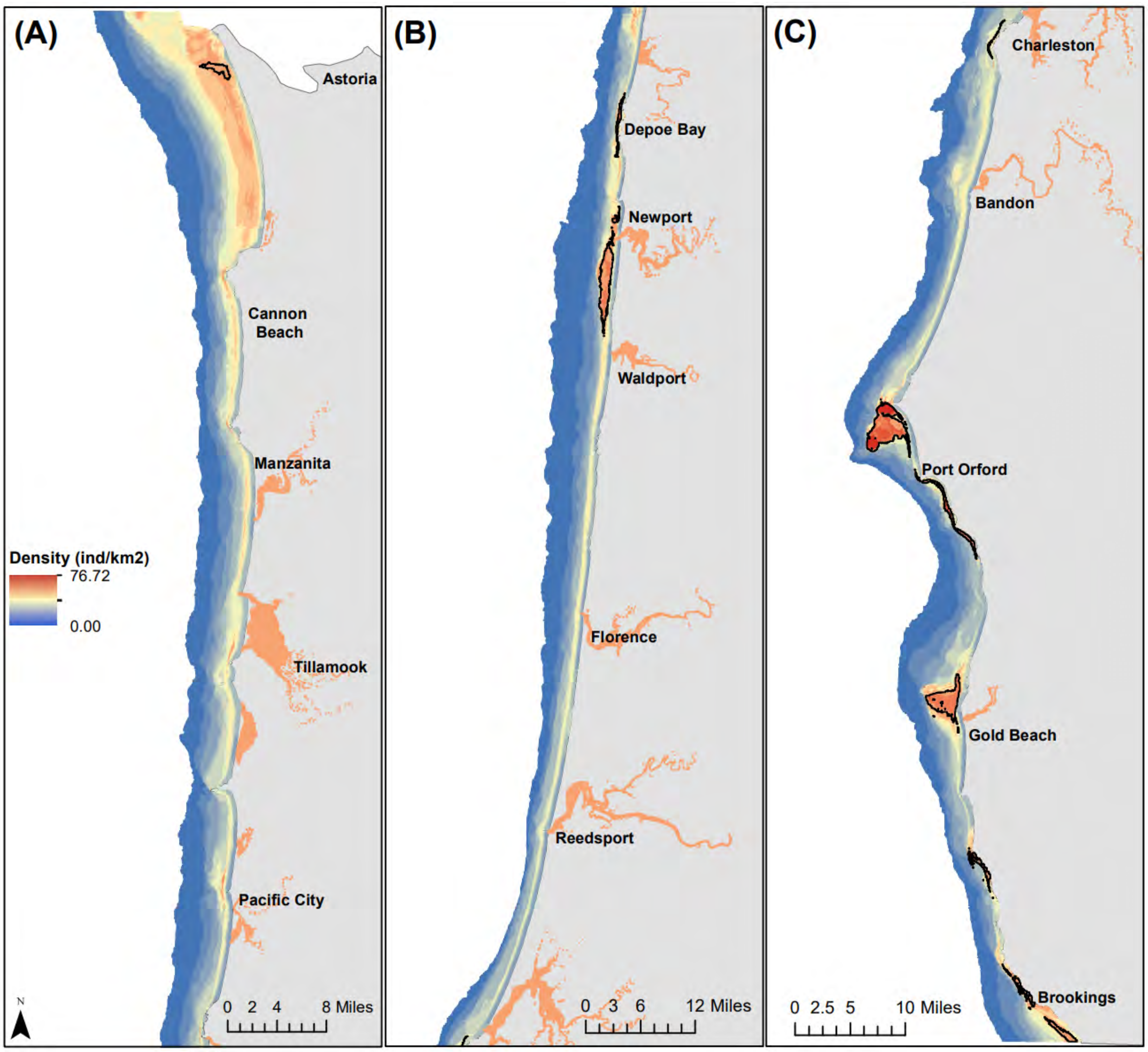

Figure 6.1. Estimated potential densities of sea otters at equilibrium (ie., assuming a population were to reach carrying capacity) along the outer coast and in estuaries of Oregon, for the north (A), central (B), and south (C) regions. Density values are visualized using natural breaks (Jenks) with 12 data classes. High-density habitat polygons are shown within black outlines and transposed over high-density values.

Habitat Suitability in Oregon: Overview

A detailed assessment of the suitability of potential habitat for sea otter reestablishment requires an understanding of several components of Oregon's coastal, nearshore and estuarine habitats. Most important is suitable substrate that supports a large enough prey base to allow sea otters to successfully colonize an area. Sea otters are typically found in highest densities in shallow (< 20m) rock-substrate habitats where canopy-forming kelps are present (Laidre et al. 2001, Tinker et al. 2021). Sea otters can also occur at high densities in certain soft-sediment habitats on the outer coast (Kvitek and Oliver 1988, Laidre et al. 2002, Bodkin et al. 2011, Jeffries et al. 2017) and within estuaries (Feinholz 1998, Hughes et al. 2019).

The Oregon habitat model presented by Kone et al. (2021) included bathymetry (depth and slope), distance to shore, substrate type, kelp cover over time and net primary productivity (NPP) to estimate sea otter population potential along the Oregon coast (Figure 6.1). Kone et al. (2021) identified eight high density polygons (outlined in black in Figure 6.1) that represent areas predicted to be capable of supporting the highest potential sea otter densities. Additionally, this model provides a graded scale of expected "equilibrium density" along the entire Oregon coast and within estuaries. Equilibrium density is defined as the density that would occur should a sea otter population increase to the point at which further population growth becomes limited by per-capita prey availability: at this point the death rate equals the birth rate, and abundance over the long term stabilizes at "*K*", the environmental carrying capacity. In the next sections we build on this model, using data from multiple sources to add more detail to potentially improve our understanding of the suitability of Oregon to support reintroduced sea otters. The topics covered include nearshore substrate, distribution of kelp, information on potential prey items, and biological resources in Oregon's estuaries.

Substrate

Oregon's nearshore subtidal consists of a mosaic of substrate ranging from rock reefs to mud plains. Oregon's Nearshore Strategy web site (https://oregonconservationstrategy.org/oregon-nearshore-strategy/habitats/) provides an overview of substrate for approximately 53% of Oregon's Territorial Sea[1] collected using high-resolution sonar technologies that outline this substrate mosaic. The maps (Figure 6.2) are based on the Coastal and Marine Ecological Classification Standard substrate classification and provide a starting point for assessing habitat suitable for supporting sea otter populations.

A more detailed habitat substrate characteristic for some of Oregon's coastal waters is available from the Active Tectonics and Seafloor Mapping Lab at Oregon State University (https://activetectonics.coas.oregonstate.edu). These data were gathered using side scan sonar. These maps (Appendix B) provide a more detailed picture of rock outcrops that, if at appropriate depths, may support kelp populations and thus provide suitable resting habitat for sea otters. They also indicate areas of the coast that are primarily soft sediment. The mapped distance to the coast varies in each case due to the weather conditions at the time of surveying and thus some maps do not have substrate details of the immediate coastline. Unfortunately, the three areas in the most southern portion of the State, shown on the inset map on the right-hand side of the figures, were not mapped as funds were not

[1] Oregon's territorial sea is defined as the waters and seabed extending three geographical miles seaward from the Pacific coastline.

available to complete the work. The Oregon Nearshore Strategy maps (Figure 6.2), however, show that there is considerable bedrock in this region of the State.

Another online resource for viewing physical habitat GIS layers in conjunction with mapping data on hydrographic, oceanographic, biological and human activities, is the “SeaSketch” online Oregon Ocean Planning tool:
https://www.seasketch.org/#projecthomepage/5c1001699112e049f68fc839

In addition to these state-wide maps, more detailed substrate characteristics of Oregon’s nearshore are available for the marine reserves and their comparison areas (ODFW Marine Reserves Program Data Dashboard: https://odfwmarinereserves.shinyapps.io/Marine_Reserves_Shiny_App_v7/). Only three of the five marine reserves contain any substantial rock substrate: Cascade Head, Otter Rock and Redfish Rocks. Maps from ODFW’s Data Dashboard for the substrate characteristics of these three marine reserves are included in Appendix C.

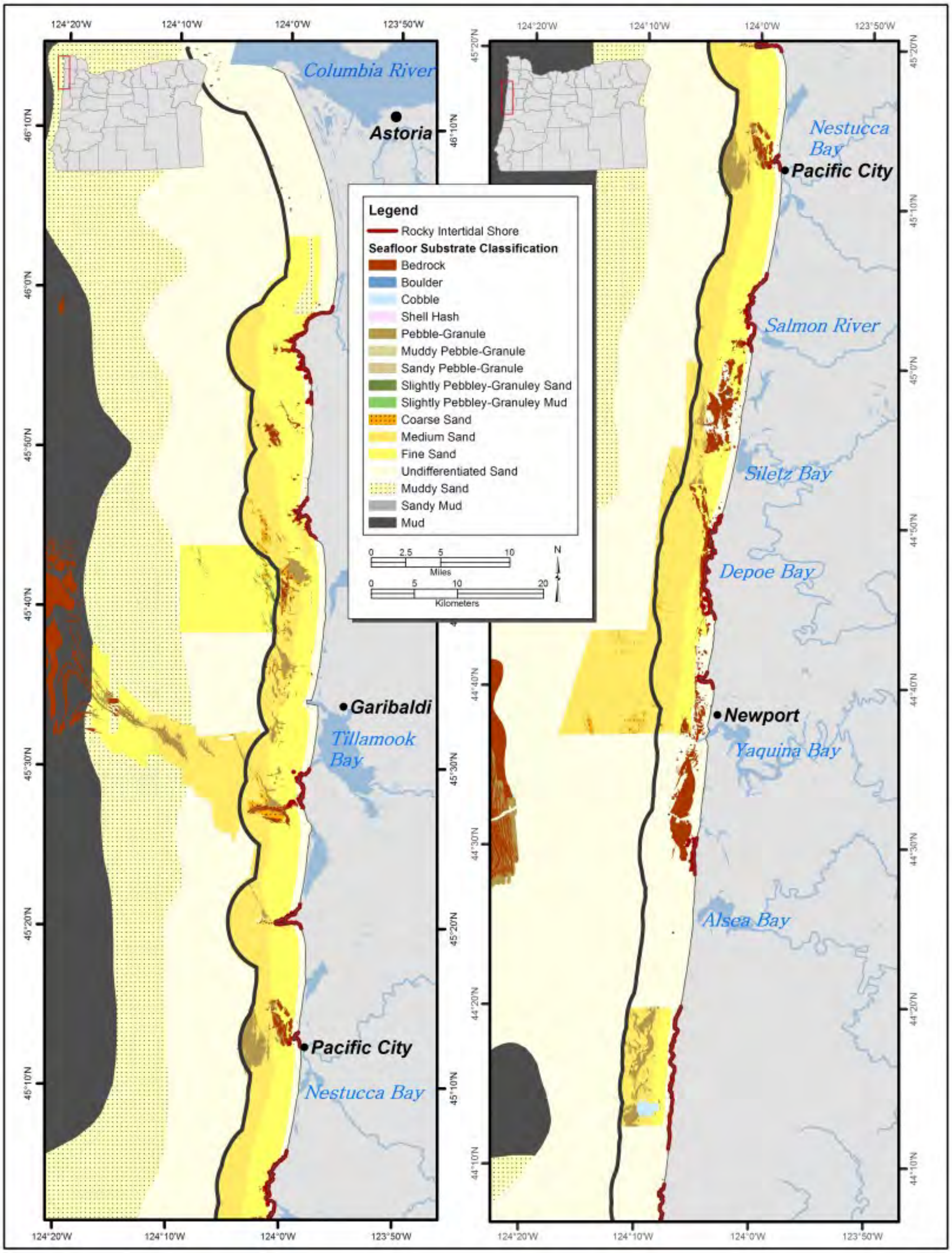

Figure 6.2a. Benthic substrate classification for the northern half of the Oregon coast

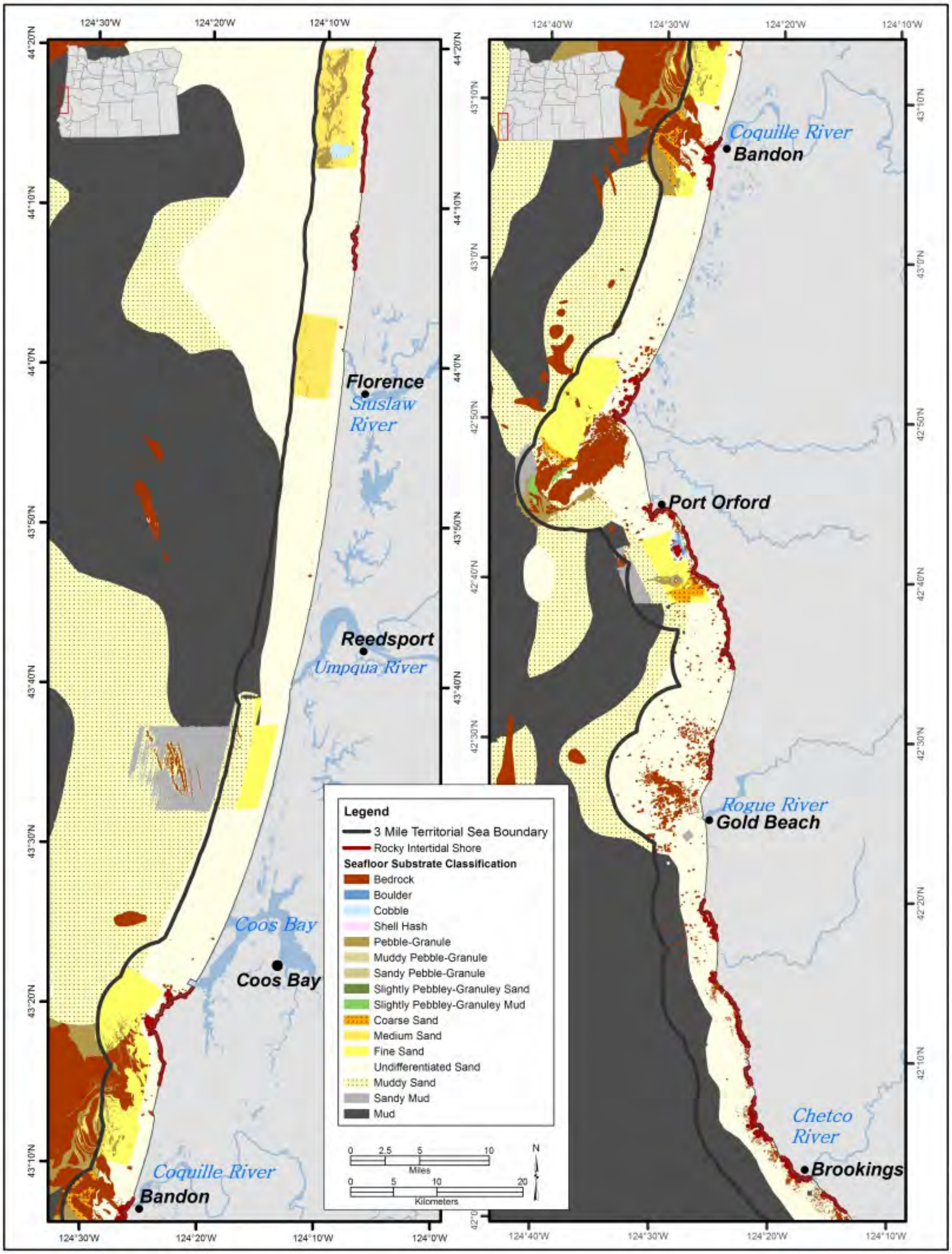

Figure 6.2b Benthic substrate classification for the southern half of the Oregon coast

Kelp Distribution

Substrate characteristic, particularly bedrock, provides some information on the suitability of habitat for sea otters with the presence of kelp beds perhaps adding to suitability. The vast majority of kelp beds in Oregon are composed of bull kelp, *Nereocystis luetkeana* which is the dominant canopy-forming kelp along the west coast of North America from northern California to Alaska (Springer et al. 2010). It has an annual life history, high fecundity (Springer et al. 2010), and flourishes in more wave-exposed environments than does giant kelp *Macrocystis pyrifera* (Dayton et al. 1984). The only known bed of *Macrocystis* in Oregon is located at the south end of Simpson's Reef in the North Cove of Cape Arago (Sanborn and Doty 1944), although *Macrocystis* occurs along open coasts north to the Gulf of Alaska. Interestingly, Simpson's Reef was one of the two core areas that sea otters settled during the original Oregon translocation, and where successful reproduction was documented (Jameson 1975), the other area being Blanco reef north of Port Orford. Several surveys of Oregon's kelp resource provide a picture of potential habitat suitability for sea otters and provide a further source to refine the model developed by Kone et al. (2021).

The earliest published survey of Oregon's kelp was conducted in 1954 by the Fish Commission of Oregon (Waldron 1955). Aerial photographs indicated possible kelp beds and observations from shore were made to verify presence. Only areas off Lincoln, Coos, and Curry counties proved to have kelp beds. No kelp beds were detected off Clatsop, Tillamook, Lane or Douglas counties. For areas where kelp was present the area of kelp was estimated, and the concentration of kelp was classified as thin, moderate or dense (Table 6.1). There were seven regions where there were more than 200 acres of kelp bed. They were:

- Boiler Bay – Whale Cove, Lincoln County
- Coos Bay - Cape Arago, Coos County
- Blanco Reef, Curry County
- Orford Reef, Port Orford, Curry County
- Humbug Mountain, Twin Rocks, Curry County
- Goat Island, Brookings, Curry County
- Chetco River – Red Point, Curry County

The spatial area of Oregon's kelp resources was again assessed in 1990, using sequential infra-red photographs taken from an airplane (Ecoscan_Resource_Data 1991). Unfortunately, the presence of coastal fog meant that data obtained south of Red Fish Rocks was obtained under less-than-ideal conditions. Table 6.2 shows the results of kelp canopy areas for 24 locations in Oregon. These data support the earlier findings (Waldron 1955) that locations in the southern portion of the coast have the highest abundance of kelp.

In 1995 the Oregon Department of Fish and Wildlife (ODFW) initiated a five-year study which included an estimation of kelp biomass using color-infrared aerial photographs to map the kelp canopy in the southern portion of the coast focusing on Blanco and Orford Reefs, Redfish Rocks, Humbug Mountain Reef and Rogue Reef (Fox et al. 1999). In 2011, ODFW produced a Kelp Canopy and Biomass Survey Report (https://www.dfw.state.or.us/MRP/publications/docs/2011_kelp_report_classicstyle.pdf) that utilized the 1990 and 1996, 1998 and 1999 survey information and supplemented it with data collected from 2011 aerial surveys of the southern coast of Oregon using a digital multi-spectral imaging system. Complete composite maps of kelp canopy extent from these surveys are provided in Appendix D.

Table 6.1. Location, acreage, concentration, and harvestability of kelp beds off the Oregon Coast, by County, 1954

AREA	CONCENTRATION (Acres)					HARVESTABILITY (Acres)		
	Not Confirmed	Thin	Moderate	Dense	Total	Unknown	Unharvestable	Harvestable
Lincoln County								
Delake	18	......	......	......	18	18	......	......
Boiler Bay-Whale Cove	......	57	222	65	344	......	......	344
Rocky Creek	......	14	......	......	14	......	14	......
Cape Foulweather-Otter Crest	......	9	36	32	77	......	77	......
Otter Rock	......	6	8	30	44	......	44	......
Gull Rock	......	......	3	6	9	......	9	......
Yaquina Head	......	......	5	......	5	......	5	......
Yaquina Bay State Park	......	......	100	9	109	......	......	109
Seal Rocks	......	1	4	......	5	......	5	......
Total	18	87	378	142	625	18	154	453
Coos County								
Coos Bay-Cape Arago	......	1	107	250	358	......	......	358
Fivemile Point	......	......	12	......	12	......	12	......
Total	......	1	119	250	370	0	12	358
Curry County								
Blanco Reef	......	30	130	63	223	......	......	223
Orford Reef	......	......	......	791	791	......	......	791
Port Orford-Humbug Mountain	......	167	23	11	201	......	201	......
Sisters Rocks	......	14	1	4	19	......	19	......
Rogue River Reef	61	......	......	......	61	61	......	......
Hunter Island	......	3	......	......	3	......	3	......
Crook Point	......	152	7	22	181	......	......	181
Yellow Rock	87	......	......	......	87	87	......	......
Burnt Point-Thomas Point	77	......	......	......	77	77	......	......
Whales Head	24	......	......	......	24	24	......	......
House Rock	......	16	......	......	16	......	16	......
Cape Ferello	124	......	......	......	124	124	......	......
Twin Rocks-Goat Island	117	87	......	......	204	......	204	......
Brookings	......	200	8	......	208	......	208	......
Chetco River-Red Point	......	300	......	......	300	......	300	......
Winchuck River	......	102	88	......	190	......	190	......
Total	490	1,071	257	891	2,709	373	1,141	1,195
Total for Lincoln, Coos, and Curry Counties	508	1,159	754	1,283	3,704	391	1,307	2,006

Note: Table copied from Fish Commission of Oregon Research Briefs (Waldron 1955)

Table 6.2. Oregon Coastal kelp resources: kelp canopy areas by Map Number. From Ecoscan Resources Data, 1991

MAP NUMBER	MAP NAME	KELP CANOPY AREA (ha.) N. leutkeana	KELP CANOPY AREA (ha.) M. integrifolia	TOTAL CANOPY AREA (Ha.) Both Species
1	Columbia River	0.00	0.00	0.00
2	Tillamook Head	0.00	0.00	0.00
3	Cape Falcon	0.00	0.00	0.00
4	Rockaway	0.00	0.00	0.00
5	Netarts Bay	0.00	0.00	0.00
6	Cape Lookout	5.03	0.00	5.03
7	Cascade Head	0.00	0.00	0.00
8	Lincoln City	9.39	0.00	9.39
9	Newport	50.31	0.00	50.31
10	Seal Rock	0.00	0.00	0.00
11	Waldport	0.00	0.00	0.00
12	Heceta Head	0.00	0.00	0.00
13	Florence	0.00	0.00	0.00
14	Tahkenitch Lake	0.00	0.00	0.00
15	Winchester Bay	0.00	0.00	0.00
16	Empire	0.00	0.00	0.00
17	Cape Arago	28.35	5.80	34.15
18	Bandon	0.00	0.00	0.00
19	Floras Lake	0.29	0.00	0.29
20	Port Orford	508.79	0.00	508.79
21	Sister Rocks	48.97	0.00	48.97
22	Gold Beach	86.60	0.00	86.60
23	Cape Sebastian	60.60	0.00	60.60
24	Brookings	38.32	0.00	38.32
TOTALS		836.64	5.80	842.44

More recently Hamilton et al. (2020) used 35 years of Landsat satellite imagery (1984 – 2018) to track the population size of *Nereocystis* in Oregon. Canopy-forming kelps, such as *Nereocystis*, float at the ocean's surface and can be detected in satellite imagery because photosynthetically active vegetation has a different spectral signature than seawater. The Landsat satellite image pixel size is 30m and thus can miss smaller kelp patches as well as kelp cover in the immediate nearshore. However, the method does provide a consistent methodology for evaluating temporal and spatial trends in kelp canopy cover. At the coast-wide scale, an evaluation of a time series of kelp canopy cover (Figure 6.3a) illustrates several key points: 1) there is considerable variability in kelp cover from year to year; 2) although there were several "peak years" of kelp cover prior to 1999, there have been no such banner years over the past two decades; 3) the total canopy area (after controlling for seasonal variation) has been surprisingly stable since approximately 2008. As with previous surveys, Hamilton et al. (2020) found the majority (95% of the median) of kelp canopy in Oregon is present in the southern region of the state (Figures 6.3b, 6.4 and 6.5), with 76% of the median summer canopy area contained in just five locations: Depoe Bay, Cape Arago, Orford Reef, Redfish Rocks (Port Oxford-Humbug Mountain area in Table 6.1) and Rogue Reef (Figure 6.4). Some areas (e.g., Cape Arago near Coos Bay) have been remarkably stable over time while others (e.g., Rogue Reef) have been more variable.

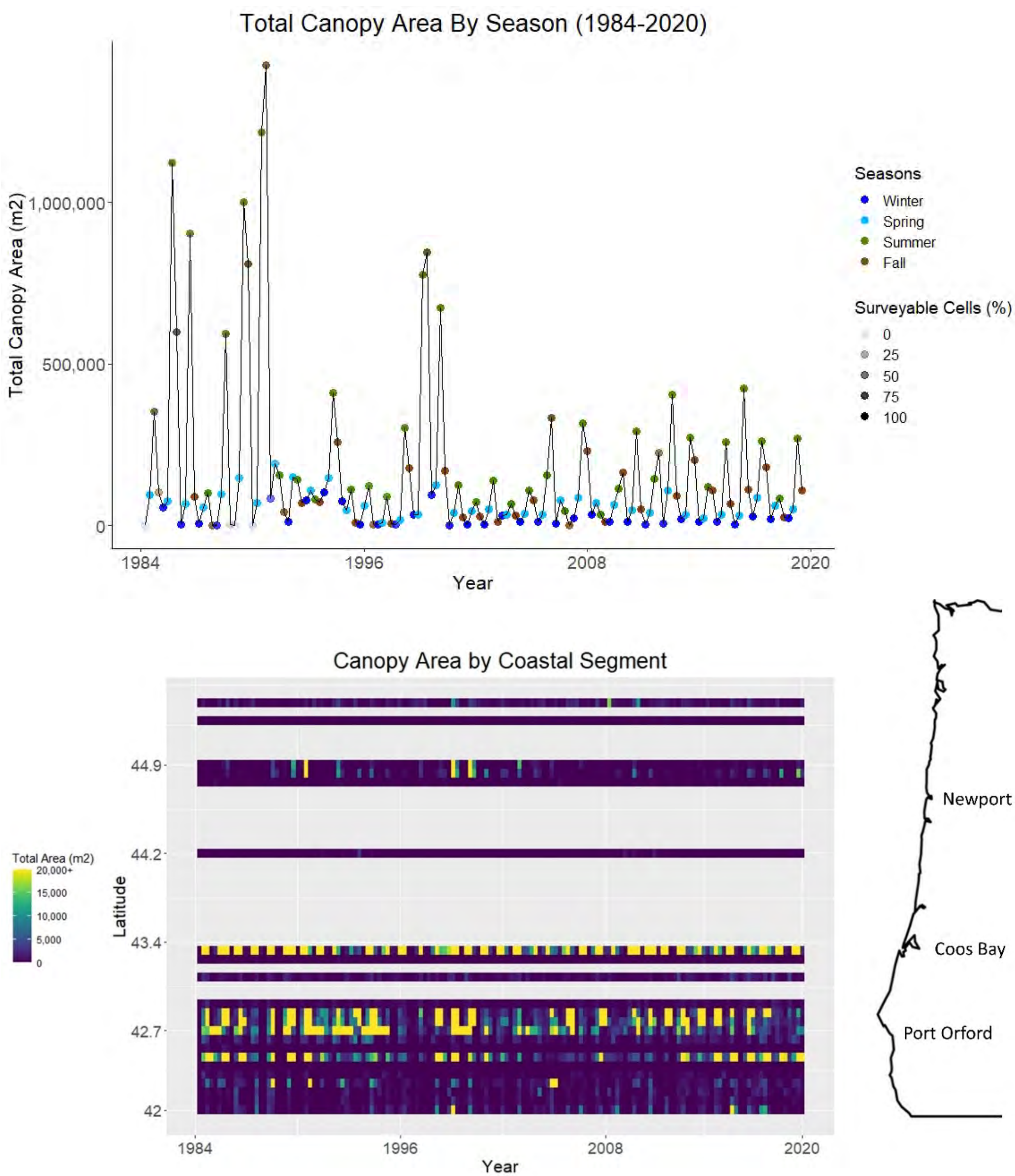

Figure 6.3. A) Total kelp canopy area across Oregon for every quarter from 1984 - 2020. Quarters are displayed as 'seasons' using colors and the transparency of the point indicates the percentages of all Oregon kelp pixels that were able to be surveyed during that quarter. B) Total kelp canopy area for every quarter from 1984 – 2020 displayed across latitude (the map at right shows approximate locations along the coast). The state's coastline was split into 60 segments of equal latitude and total canopy area summed for each quarter in each segment. Source: Sara Hamilton, personal communication.

At the scale of individual reefs, Hamilton et al. (2020) found no consistent trend in the *Nereocystis* canopy area or population trajectory over the last 35 years (Figure 6.5). Canopy area varied dramatically among years, although all five sites had what was described as “permanent canopy” in that it was present in 80% of the summers for which a Landsat image was available (Hamilton et al. 2020). The spatial variability of kelp canopy area over time is evident in the differences between the five sites. Three of the largest sites (Cape Arago, Redfish Rocks, and Rogue Reef; Figure 6.4) have remained within historically normal levels, with Rogue Reef reaching its greatest canopy area in 2018 (Figure 6.5). In contrast, Depoe Bay has experienced sustained low populations levels for the past 15 years.

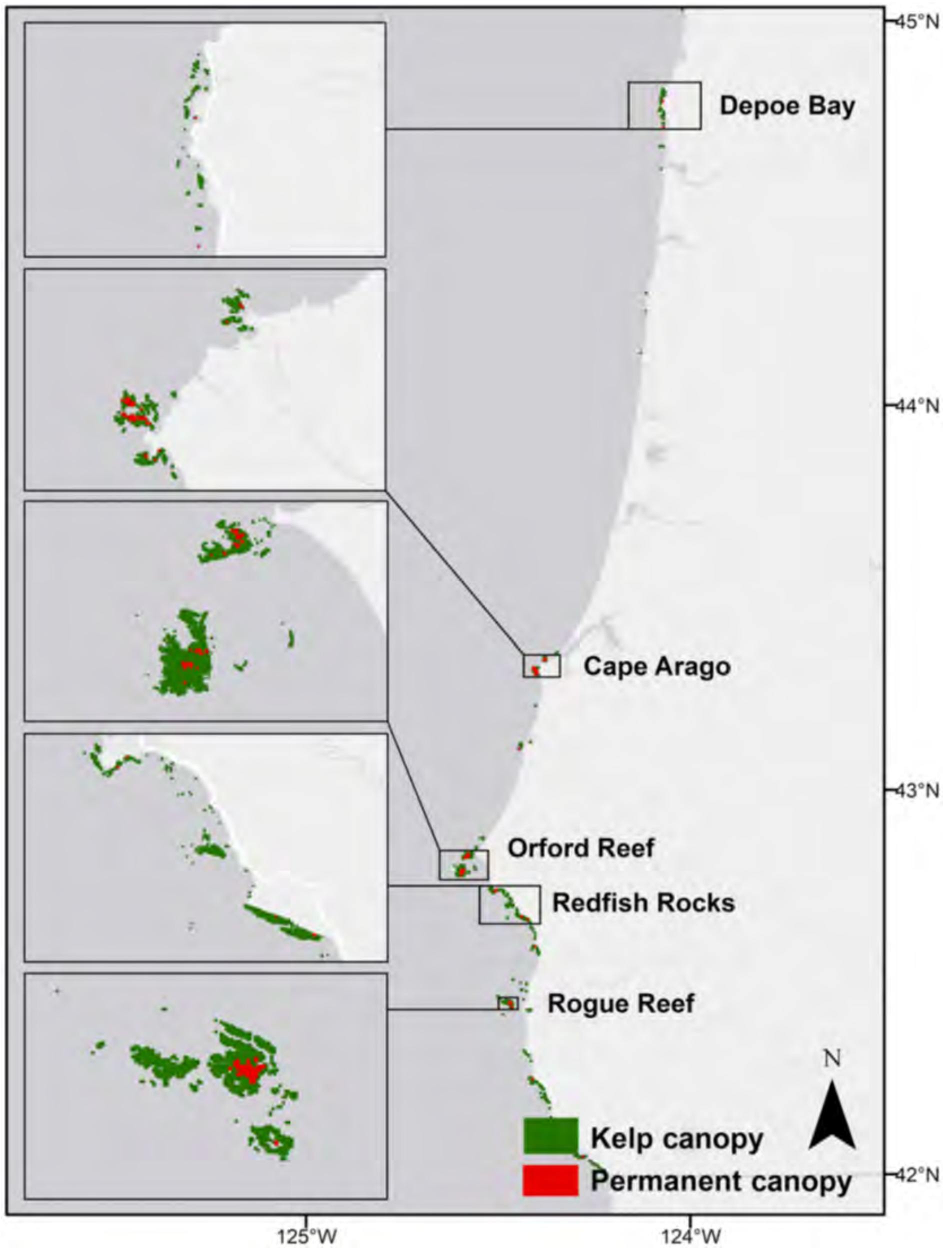

Figure 6.4. Map of all kelp detected in Oregon in at least 1% of the available Landsat images (green) and all "permanent" canopy (red), which is defined as being present in 80% of the summers for which a Landsat image was available. The five largest reefs in Oregon are labeled. From Hamilton et al. (2020).

A notable example of variation is from Orford Reef where the estimated maximum summer canopy extent in 1987 was 0.7% of the area present in 1986. Over the last 20 years, Orford Reef has shifted to somewhat smaller, less variable population (Figure 6.5).

Hamilton et al. (2020) ran linear models of canopy extent against a number of variables including year. Two time periods were modelled: 1984 to 2018 and 1996 to 2018. At Depoe Bay and Orford Reef, there was a small negative correlation between year and canopy size in the 1984 to 2018 model, indicating declining populations over the last 35 years. However, the 1996 to 2018 model did not show this correlation, suggesting that the decline occurred earlier and that there was lower variability at these two sites in more recent times. At Rogue Reef, canopy extent was positively related to year in the 1996 –2018 model, indicating a recent increasing trend in canopy cover. At Cape Arago and Redfish Rocks there was no relationship with year. At both sites, population sizes over the last 5 years were within the range of sizes seen regularly over the last 35 years (Figure 6.5).

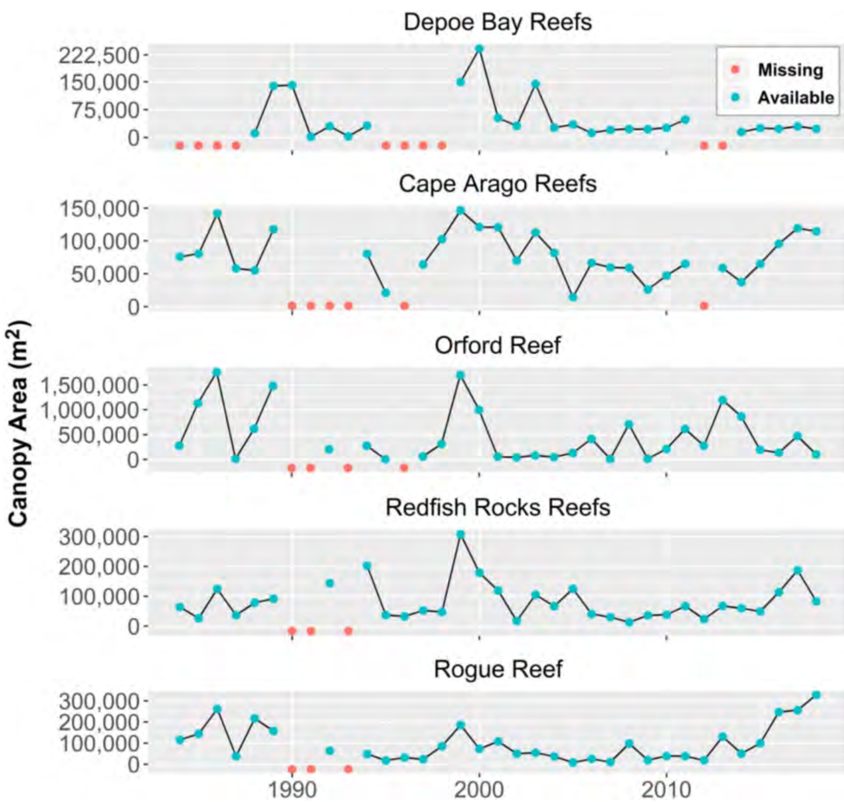

Figure 6.5. Time series of maximum detected summer kelp canopy area (m2) for the five largest reefs in Oregon from 1984 to 2018. Note that the y-axis scale varies between reefs. Blue (pink) points represent summers when canopy area could (could not) be estimated, usually because of lack of cloud-free Landsat imagery or imagery taken at high tide. From Hamilton et al. (2020)

Hamilton et al. (2020) also looked at whether Oregon *Nereocystis* population sizes responded to a 2014 marine heat wave, which in northern California was accompanied by a large decline in the *Nereocystis* populations, and a substantial increase in urchin densities. This pattern was not evident in Oregon. At Depoe Bay and Orford Reef, there were no changes in maximum summer canopy area for 2015–2018 as compared to the prior 10 years. At Cape Arago, Redfish Rocks, and Rogue Reef, kelp area increased in 2015–2018 as compared to the previous decade. During the 2014 marine heat wave, maximum monthly sea surface temperature in northern California was roughly 16°C, whereas in Oregon it was only 14.5°C.

In general, these data suggest that the presence of canopy forming kelp is greatest in the southern third of the coast (from Coos Bay south) and thus more likely to provide seasonable resting habitat for sea otters. Canopy cover in more northern areas may be less abundant and thus potentially lower quality habitat for sea otters than in the south.

Sea otter prey

Intertidal invertebrates

There are limited data for many of the potential sea otter prey items that are not commercially harvested in Oregon. Some intertidal sites have regular monitoring as part of groups such as the Partnership for Interdisciplinary Study of Coastal Oceans (http://www.piscoweb.org/about-us-0) or the Multi-Agency Rocky Intertidal Network https://marine.ucsc.edu/overview/index.html, but for many species that could be potential sea otter prey items based on the sea otter's diet in California (Tinker et al. 2008, Tinker et al. 2012), such as black turban snails, *Tegula* sp., top shells, *Calliostoma* sp., mussels, and cancroid crabs, there are few data other than short-term studies in localized areas. Some information, however, does exist for those species that are part of recreational harvests. In some of the south coast's rocky intertidal areas, native littleneck clams (*Leukoma staminea*) and butter clams (*Saxidomus giganteus*) are found under rocks and amongst gravel. ODFW conducts irregular surveys for these species at two sites south of Port Orford (Ainsworth et al. 2012). Few butter clams were found, but for littleneck clams there were an average of 3 – 5/m^2 in surveys conducted in 2010 and 2013.

Subtidal Invertebrates

For the majority of potential subtidal prey species of sea otters there are no consistent monitoring efforts. As with intertidal prey, a few prey species are included in subtidal monitoring by Partnership for Interdisciplinary Study of Coastal Oceans (http://www.piscoweb.org/about-us-0). Subtidal invertebrate surveys are also a standard part of monitoring efforts at Oregon's marine reserves and their control sites, and data from these surveys (https://odfwmarinereserves.shinyapps.io/Marine_Reserves_Shiny_App_v7/) are updated regularly and include information for urchins, sea cucumbers and sea stars.

Two species of sea otter invertebrate prey are also the basis of commercial fisheries in Oregon – red sea urchin and Dungeness crab – resulting in more extensive data available for these species, summarized below. Two other taxa monitored by ODFW for which there are not current fisheries, but which are potentially commercially important, include abalone (*Haliotis sp.*) and rock scallops (*Crassadoma gigantean*).

Red sea urchins

Both purple urchins (*Strongylocentrotus purpuratus*) and red urchins (*Mesocentrotus franciscanus*) are common in Oregon, with dive fisheries for the latter. Kone et al. (2021) evaluated the overlap between red sea urchin harvest areas and 8 portions of the coast predicted to potentially support higher than average density sea otter populations (Figure 6.6). This analysis indicated abundant red urchins (as indicated by fisheries landings) in many of the areas predicted to support high densities of sea otters, especially in the southern portion of the state (Figure 6.6C). A more detailed analysis of urchin fisheries landings is provided in Chapter 7.

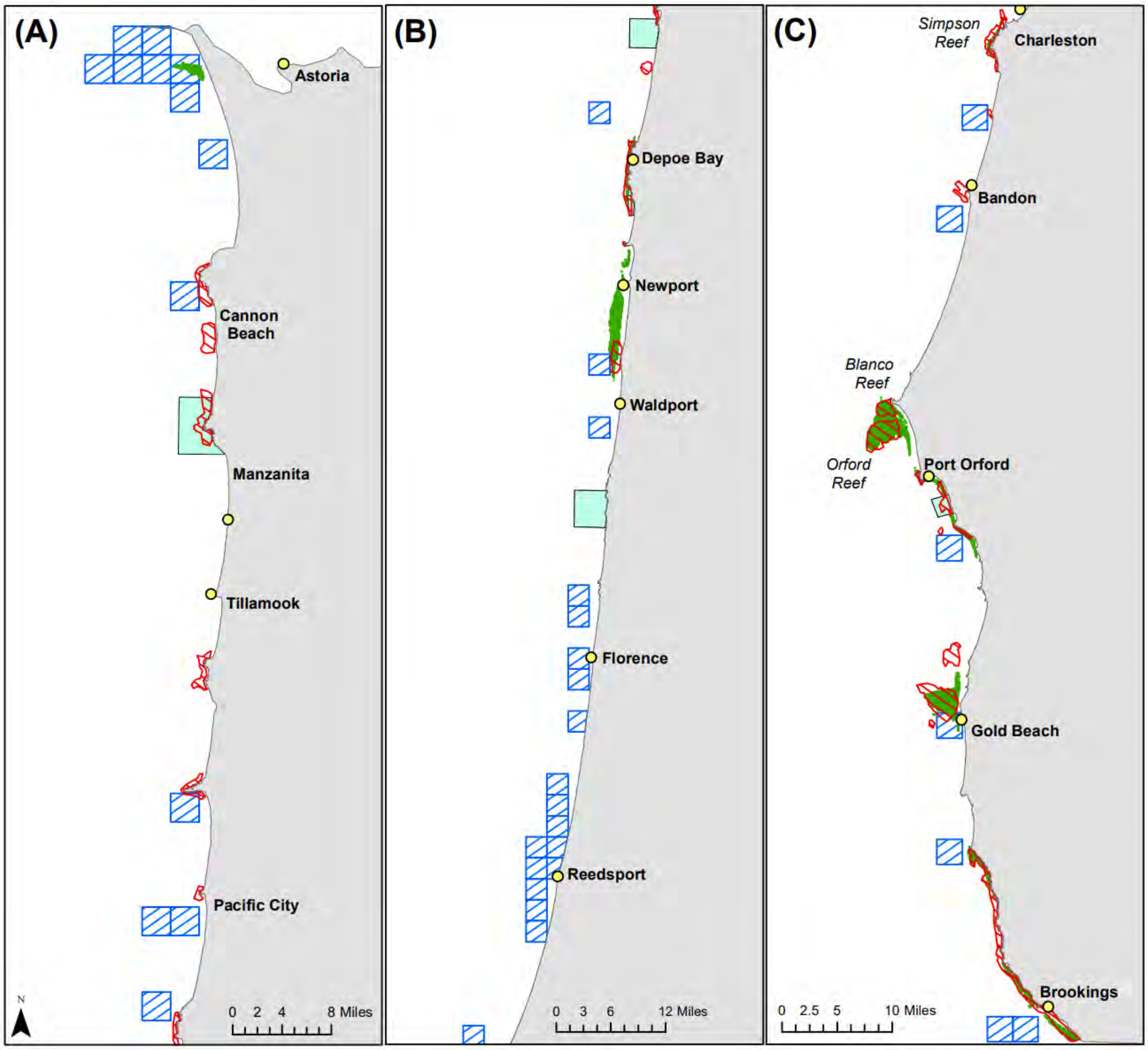

Figure 6.6. Spatial location of predicted high-density sea otter habitat (green polygons) along the outer coast and the potential overlap with and proximity of these areas to high-catch crabbing grounds (blue hatched grid cells; data from 2007 - 2017), sea urchin harvest areas (red hatched polygons; data from 2009 - 2018), fishing ports (yellow dots; data from 2011), and marine reserves (turquoise polygons; data from 2010) across regions (A = North, B = Central, C = South) in Oregon. From Kone et al. (2021)

Dungeness crab

As with urchin landings, Kone et al. (2021) evaluated the overlap between Dungeness crab fishing areas and 8 portions of the coast predicted to potentially support higher than average density sea otter populations (Figure 6.6). This analysis suggests that Dungeness crab are abundant throughout the state, including near to some of the areas predicted to support high densities of sea otters, but also in many of the areas where high sea otter densities are not predicted. A more detailed analysis of crab fisheries landings is provided in Chapter 7.

Abalone

Three species of abalone occur in Oregon. Red abalone, *Haliotis rufescens,* are limited to a few small areas and occur only from Cape Arago south. There was a short-lived commercial fishery from 1960-

1962 and a recreational fishery from 1953-2017. Both were closed because of the concerns for depletion and surveys for red abalone conducted by ODFW in 2015 showed that there were only 0.03 individuals/m^2 (ODFW report to the ODFW fish commission Sept 13, 2019). Flat abalone, *Haliotis walallensis*, are found in vegetated rock reefs throughout Oregon. They were commercially harvested from 2001-2008. There are no data on current population levels, but it is likely to be small as the closure was the result of conservation concerns about the population's status. Pinto abalone, *Haliotis kamtschatkana*, is a small species which ranges from Baja to Alaska, but this species is extremely rare in Oregon. There is no current commercial or recreational take of any abalone species in Oregon.

Rock Scallops

ODFW requires a special permit and reporting card for recreational harvest of rock scallops, *Crassadoma gigantean*. Figure 6.7 indicates that for the years 2013 – 2019 the annual recreational take ranged from 669 – 1154 scallops. The number of individuals participating in the fishery, based on permit returns, ranged from 58 -195/year. 50% of the take was returned to the ports of Charleston, Port Orford and Brookings indicating they were collected along the southern Oregon coast (pers comm Scott Groth, ODFW February 12, 2012).

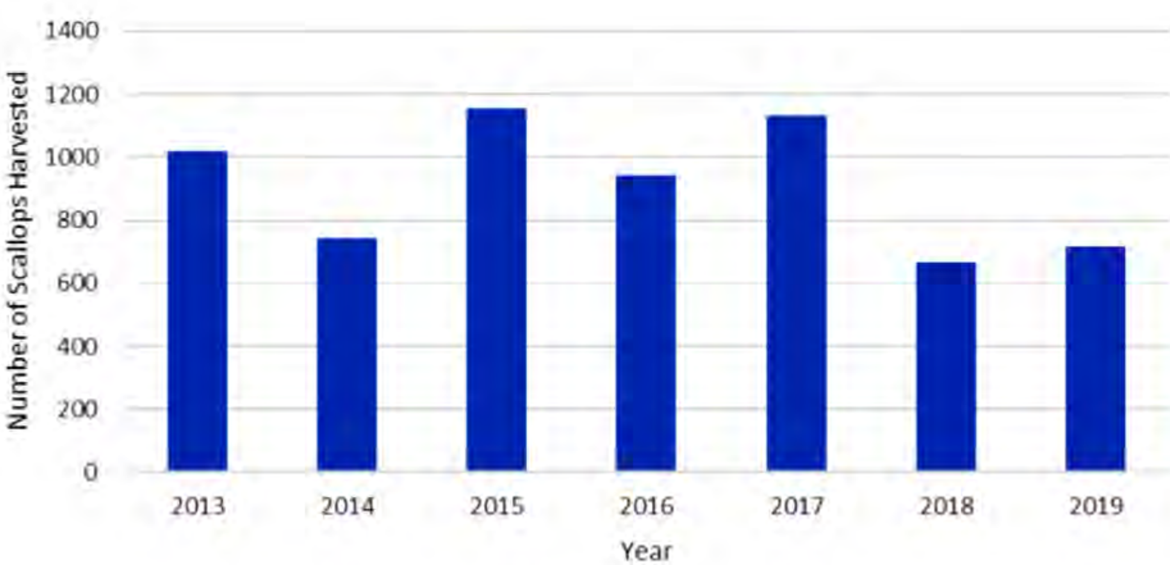

Figure 6.7. Number of rock scallops (Crassadoma gigantean) harvested recreationally by year in Oregon.

Coastal soft sediment areas

In addition to their use of rocky reef areas, sea otters are known to feed in soft sediment habitats in coastal areas (Kvitek and Oliver 1988, Dean et al. 2002, Hale et al. 2019). The habitat substrate maps from the Active Tectonics and Seafloor Mapping Lab at Oregon State University (Appendix B) provide details on where sand and mud substrates occur along the Oregon coast. Potential prey items in these substrates could include clams, cancroid crabs, and sand or mole crabs (*Emerita analoga*). There is a paucity of information about subtidal invertebrate species in Oregon, particularly from nearshore soft sediment habitats. McCrae and Daniels (1998) indicate that both gaper calms (*Tresus capax*) and cockles (*Clinocardium nuttallii*) occur in soft sediment areas of the outer coast, though in smaller numbers than are found in estuaries. Razor clams, another common prey species for sea otters, are found in sandy substrates both sub-tidally and in the low intertidal (McCrae and Daniels 1998) and are most common in northern Oregon from the mouth of the Columbia to Seaside, but also occur at lower densities throughout the coast. ODFW surveys the intertidal populations of razor clams along 18 miles of beaches in Clatsop County (Figure 6.8), but there are no comparable data on subtidal razor clam populations elsewhere in Oregon. Worth noting is that domoic acid levels toxic to humans commonly result in closures of commercial and recreational harvests of crabs and razor clams in Oregon: refer to Chapter 10 for a discussion of domoic acid effects on sea otter health.

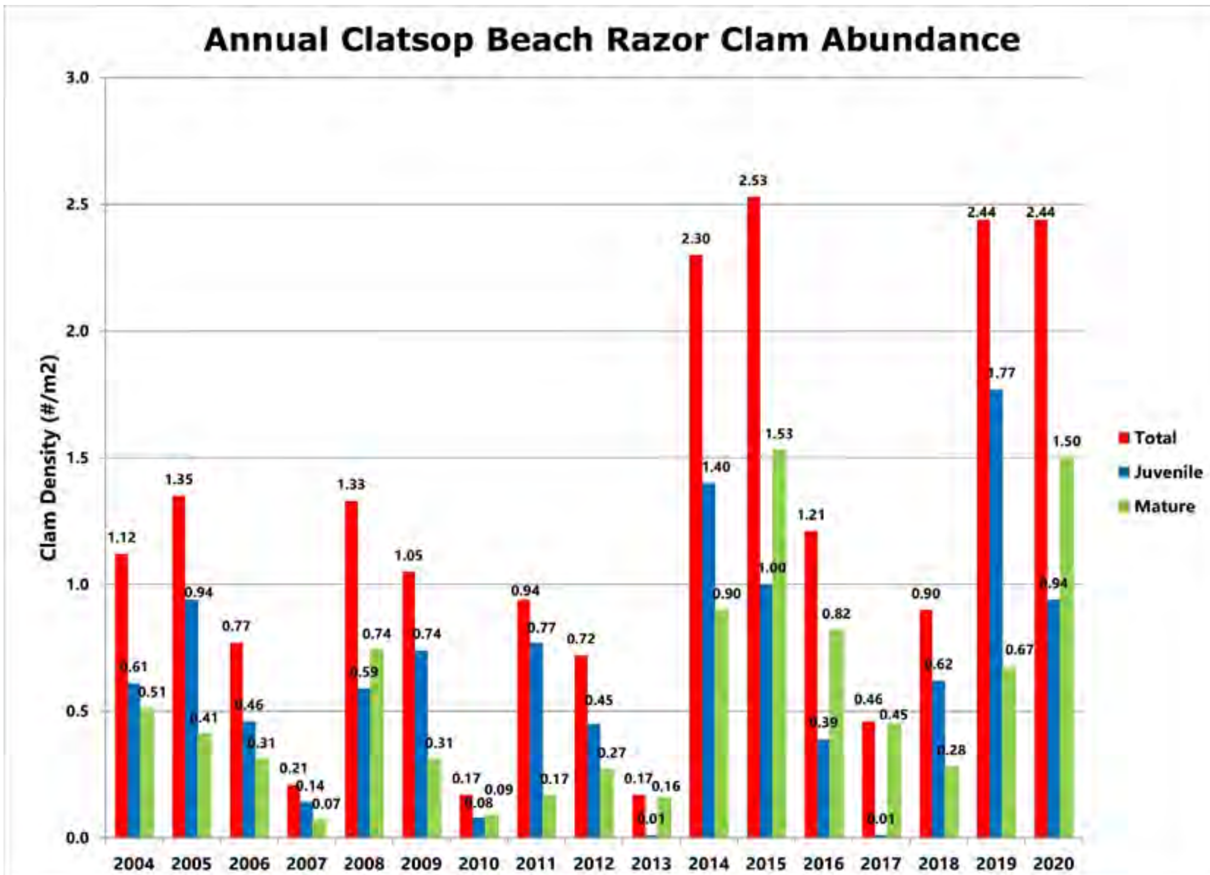

Figure 6.8. Data on annual abundance of intertidal razor clams in Clatsop County.

Estuaries

Throughout their present and historically occupied range, sea otters use (or have used) estuarine habitats in high and persistent densities. Notable examples in Alaska include Izembeck Lagoon, Kachemak Bay, Prince William Sound and Orca Inlet and Glacier Bay. In California, sea otters are also known to have historically occurred at high densities in estuarine habitats such as San Francisco Bay (Silliman et al. 2018, Hughes et al. 2019). At the present time, estuarine use by sea otters in California is limited to Elkhorn Slough and Morro Bay (Hatfield et al. 2019, Grimes et al. 2020, Tinker et al. 2021) because their distribution does not yet overlap with other estuaries such as San Francisco Bay. Within Elkhorn Slough, sea otters occur at very high densities (Tinker et al. 2021) and the presence of sea otters has had a significant positive impact on the extent and stability of the eelgrass community (Hughes et al. 2013): refer to Chapter 5 for more information on ecological impacts of sea otters in estuaries. In British Columbia, sea otters have been documented to forage in estuarine eelgrass habitats, although in most cases these otters also had ready access to kelp beds (Hessing-Lewis et al. 2018). The diet of BC sea otters contained far more urchins and clams than crabs (Rechsteiner et al. 2019), and the trophic cascade evident in Elkhorn Slough was not observed in BC eelgrass habitats (Hessing-Lewis et al. 2018).

The model for estimating sea otter population potential in Oregon (Kone et al. 2021) allowed for potential sea otter utilization of estuaries; however, due to data limitations, this model did not attempt to differentiate between estuaries based on specific characteristics, and thus treated the population potential in all estuaries exactly the same (Figure 6.1). In this section we summarize additional data sets to provide more details on Oregon's estuaries relative to their potential importance to sea otters, to better inform decisions about which estuaries in Oregon could potentially support sea otter populations.

Oregon's estuaries are diverse, ranging from those whose rivers start in the Cascade mountains to some that have such limited freshwater input that they are essentially saltwater lagoons. Several estuaries, however, encompass large areas that could provide suitable habitat for sea otters. Some of these larger estuaries have significant areas of eelgrass that can provide resting habitat for sea otters (and is also an indicator of good estuarine water quality), and rich invertebrate prey resources. South of Bandon (Figure 6.1C) the estuaries are generally small with little tideland and no significant eelgrass.

Eelgrass in Estuaries

Both *Zostera marina* and *Zostera japonica* are present in Oregon's estuaries. The non-native *Z. japonica* occurs intertidally at higher elevations than *Z. marina*. *Zostera marina* also occurs sub-tidally. There is little current information in Oregon about the extent of eelgrass in estuaries and even less about change over time. ODFW conducted a ShoreZone inventory in Oregon that included a presence/absence notation for both eelgrass and surf grass, *Phyllospadix* spp. (Harper et al. 2011). Based on the 2014 Shorezone report, a map of the distribution of eelgrass in coastal estuaries is provided in Figure 6.9.

The first surveys documenting estimates of historical eelgrass extent in Oregon were made in 1972–1973 and are summarized in the Estuary Plan Book (Cortright et al. 1987). The Estuary Plan Book identified eelgrass (*Zostera* spp.) in 13 estuaries in Oregon. An update to the Estuary Plan Book was made in the 1980's (Sherman and DeBruyckere 2018) and provided a limited synopsis of the extent of eelgrass in Oregon's estuaries, as summarized in Table 6.3.

Figure 6.9. Distribution of seagrass biobands: Eelgrass (ZOS) and Surfgrass (SUR) in the Oregon study area. From 2014 ShoreZone report (Harper et al. 2011).

Table 6.3. Timeline of data collection depicting the current and historic extent of eelgrass in estuaries in Oregon. Green boxes indicate the presence of eelgrass and survey year, or range of years. Yellow boxes indicate absence of eelgrass and survey year or range or years. Empty boxes indicate no available data. Adapted from Table 2 in (Sherman and DeBruyckere 2018).

PMEP Estuary (with eelgrass present)	**Regional Eelgrass Extent Summary Datasets**					**Other Local Data Sources**	**Literature Only**
	EPB	**NOAA ESI**	**EPA**	**ODFW (SEACOR)**	**Shorezone (OR & WA)**	**Estuary Specific Extent Data Source**	**Historic Extent Observations**
Nehalem River	1978				2011		1980
Tillamook Bay	1978		2007	2010-2011	2011	Tillamook Estuary Partnership 1995**	1980
Netarts Bay	1978			2013-2014	2011		
Sand Lake	1978				2011		
Nestucca Bay	1978		2004		2011		1980
Salmon River	1978		2004		2011		
Siletz Bay	1978			2013-2015	2011		1980
Yaquina Bay	1978		2007	2012	2011		1980
Alsea Bay	1978		2004	2013-2015	2011		1980
Siuslaw River	1978				2011		
Umpqua River	1978		2005		2011		1980
Coos Bay	1978		2005		2011	South Slough National Estuarine Research Reserve 2016	1980
Coquille River	1978				2011		1980
Sixes River					2011		1980
Rogue River	1978				2011		1980
Pistol River					2011		1980
Chetco River	1978				2011		1980

The United States Environmental Protection Agency (USEPA) characterized the seagrass intertidal populations of seven Oregon estuaries in 2009 using remote sensing and ground truthing techniques (Lee II and Brown 2009). The lateral extent of the study area ranged from the ocean entrance to the upriver termination of the reported distribution of intertidal *Z. marina* in that system. It was found that only the tidally dominated estuaries of Coos, Yaquina and Tillamook had substantial native eelgrass populations (Table 6.4). These data are supported by information in two on-line resources curated by the Pacific Marine and Estuarine Fish Habitat Partnership (https://estuaries.pacificfishhabitat.org/):
1.) The West Coast Data Explorer of Estuaries, and
2). the West Coast Eelgrass Maximum Observed Extent layer.

Each of these online resources used a different data source, but there was a common conclusion that Coos, Yaquina and Tillamook Bays have the most substantial eel grass resources, and that most other Oregon estuaries either are devoid of eelgrass or have only limited amounts.

Table 6.4. Seagrass abundance in seven Oregon estuaries. Sampling occurred between 2004-2006, with Coos estuary sampling occurring exclusively in 2005. Sample size is roughly 100 for all estuaries, with the most extensive sampling occurring in Alsea (109 sites) and the least in Tillamook (97 sites). A total of 101 sites were sampled in the Coos estuary. (Lee II and Brown 2009)

	Native seagrass (*Z. marina*)		Non-native seagrass (*Z. japonica*)	
	Presence	Coverage	Presence	Coverage
Estuary	(# of sites with Z. marina)	(% of total intertidal area)	(# of sites with Z. japonica)	(% of total intertidal area)
Alsea	0	0	0	0
Coos	12	11.7	17	19.4
Nestucca	0	0	19	23.4
Salmon	0	0	3	3.6
Tillamook	28	34.2	9	10.5
Umpqua	8	5.5	22	20.7
Yaquina	11	17.4	18	11.9

The Oregon Department of Fish and Wildlife SEACOR dataset (2010 - 2015) surveyed five estuaries for recreational clam populations and in some cases eelgrass distribution. There are clam species occurrence maps for six estuaries: Tillamook Bay, Netarts Bay, Yaquina Bay, Siletz and Alsea Bays and Coos Bay (https://www.dfw.state.or.us/mrp/shellfish/seacor/maps_publications.asp). For Coos Bay, data are presented in an interactive map of substrate, clam abundance and eelgrass cover (Figure 6.10).

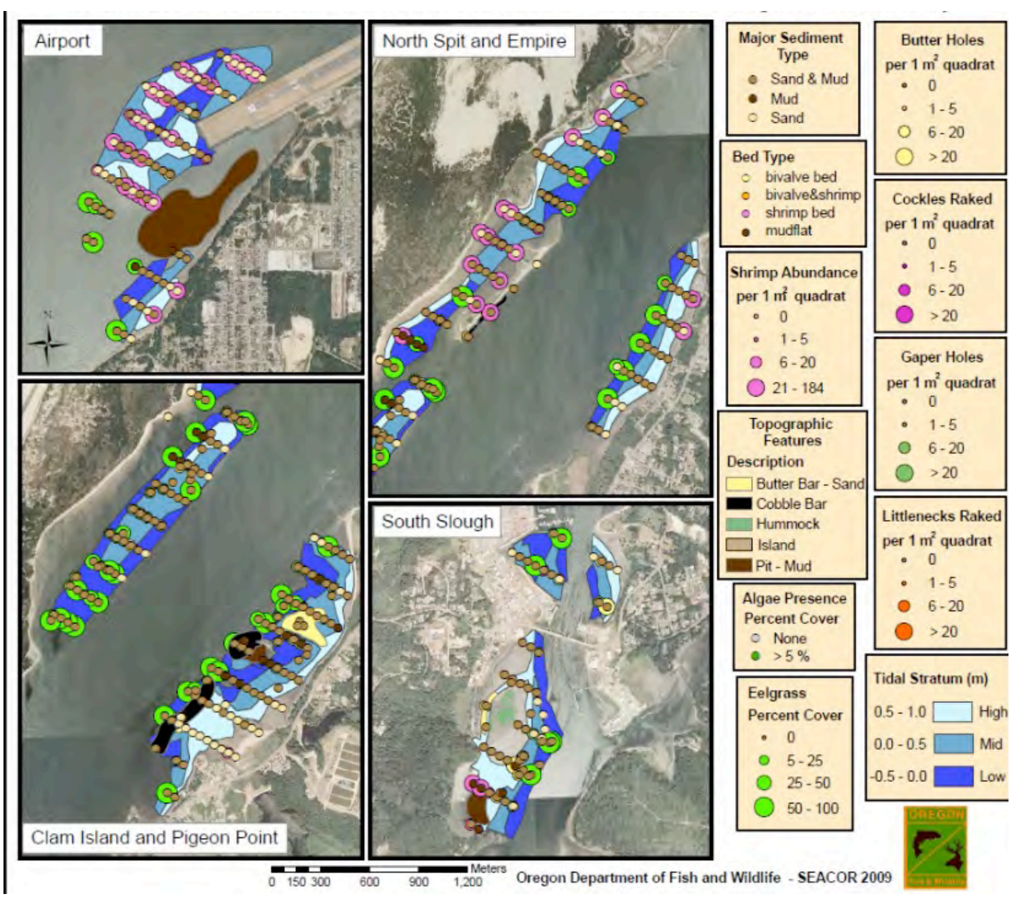

Figure 6.10 Substrate, clam abundance and eelgrass cover in Coos Bay

The Partnership for Coastal watersheds (https://www.partnershipforcoastalwatersheds.org/vegetation-aquatic/) provides additional information on the extent of eelgrass in Coos Bay, with the caveat that the data set may not be complete or up to date. These data are shown in Figure 6.11.

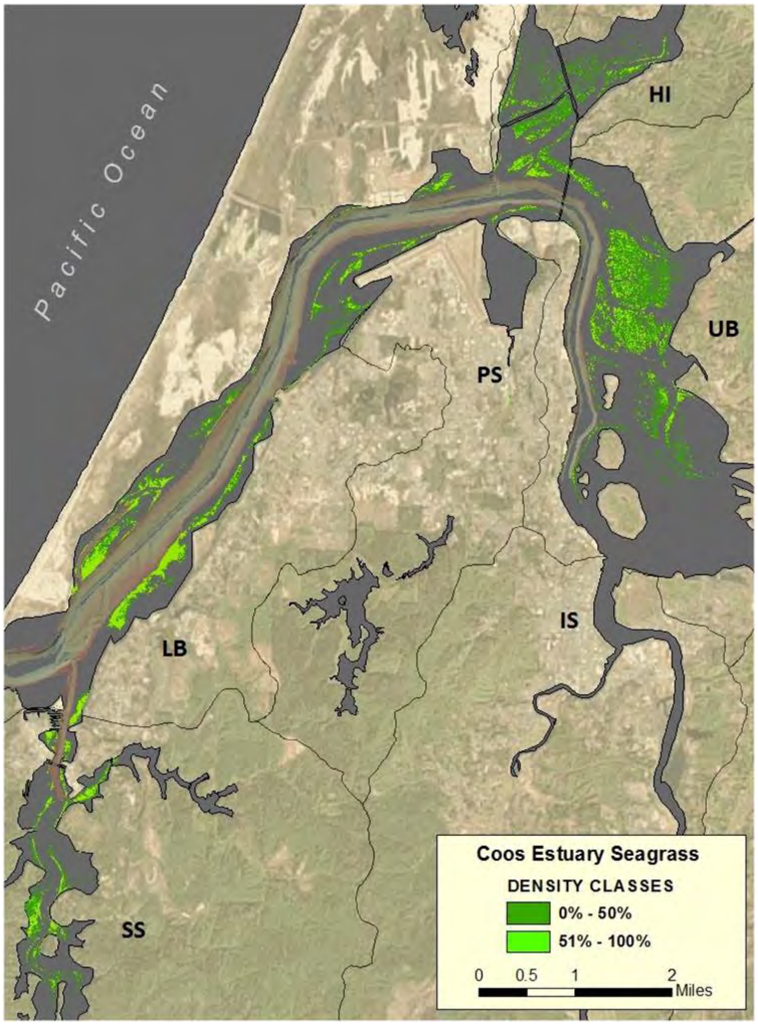

Figure 6.11. Eelgrass extent in Coos Bay, based on data from the Partnership for Coastal watersheds, https://www.partnershipforcoastalwatersheds.org/vegetation-aquatic/

There is a common understanding that, because of multiple anthropogenic stressors (including nutrient inputs, warming, disturbance, and sea level rise), eelgrass is declining in Oregon's estuaries. Unfortunately, data to document this decline are unavailable for all but a few estuaries. Sherman and DeBruyckere (2018) document an example of eelgrass decline in Yaquina Bay, comparing the maximum observed extent of eelgrass (based on the West Coast Eelgrass Maximum Observed Extent layer (https://estuaries.pacificfishhabitat.org/) with the Oregon Department of Fish and Wildlife SEACOR dataset (Figure 6.12). This comparison documents a dramatic reduction in the extent of eelgrass beds in Yaquina Bay.

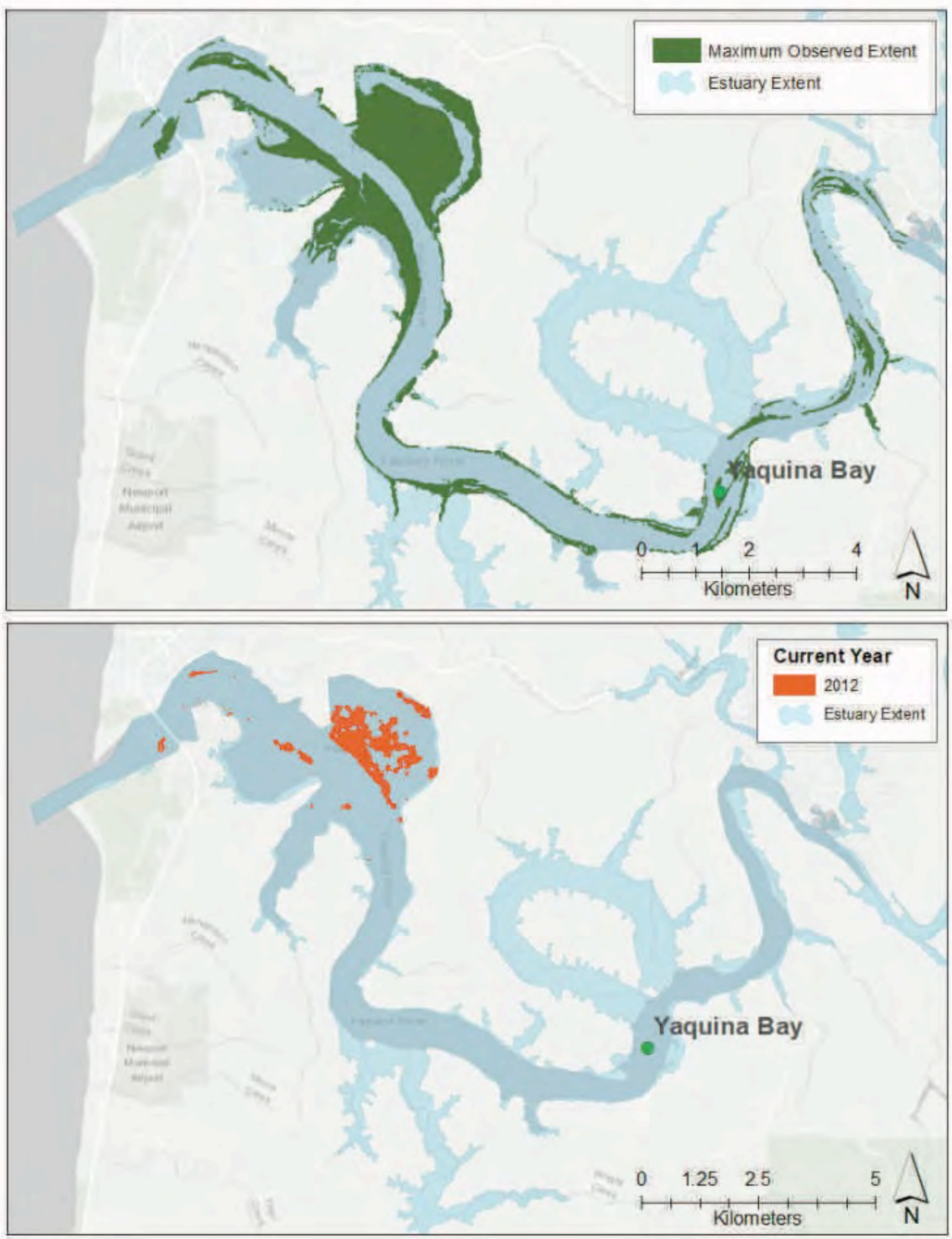

Figure 6.12. Comparison of current eelgrass extent to maximum extent for Yaquina Bay, OR. (Sherman and DeBruyckere 2018)

In Coos Bay there is an available time series of eelgrass abundance that allows for another examination of temporal trends in extent. The South Slough National Estuarine Research Reserve has monitored eelgrass density at four sites within the Reserve from 2004 – 2020 (personal communication, Allie Helms, Dec 2021). For reasons that are not yet clear, eelgrass has declined dramatically in recent years (Figure 6.13). This drastic decline is not bay wide, although little data are available to assess eelgrass abundance outside of the Reserve. In lower Coos Bay a recent increase in non-migratory Canada Geese feeding on eelgrass in the fall has impacted the seasonal production of drift eelgrass. The geese feed on the eelgrass and discard substantial quantities at a time where historically no eelgrass-feeding birds would be present. The impact of this feeding on the eelgrass population is unknown.

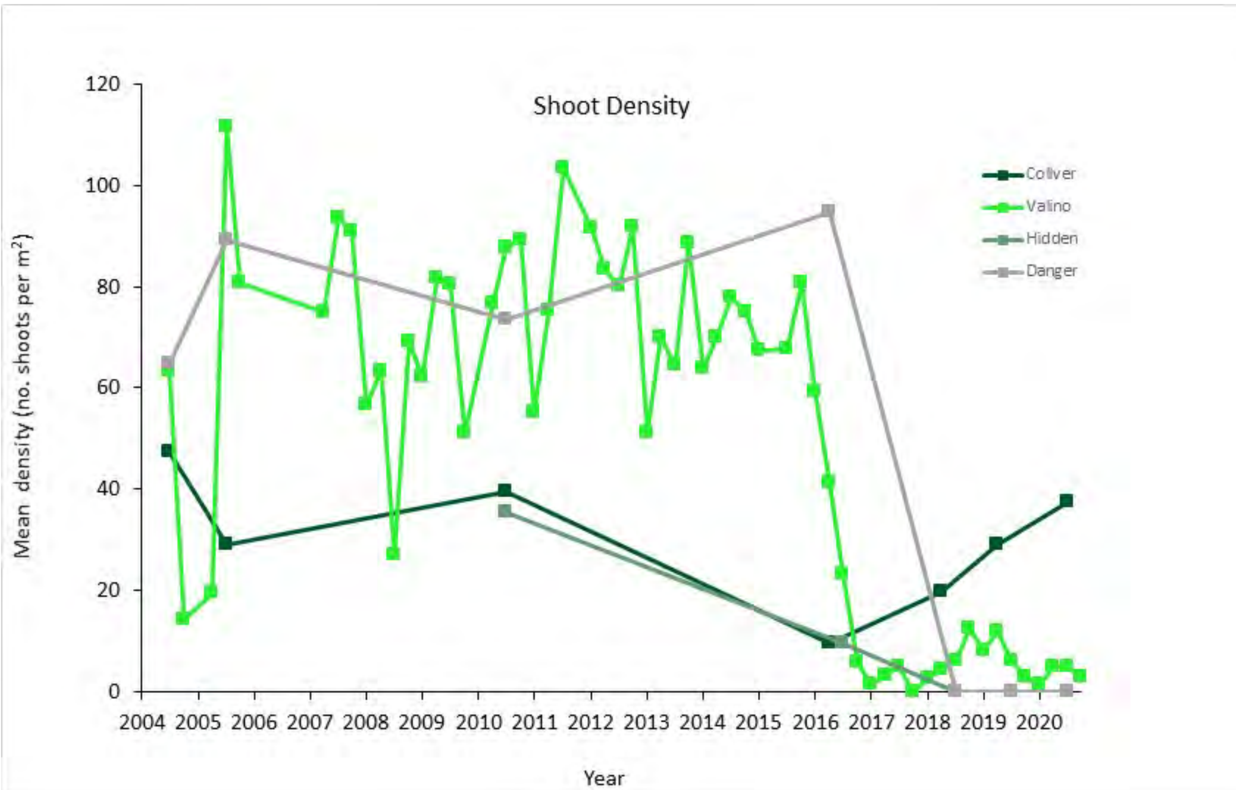

Figure 6.13. Shoot density of eelgrass from four sites in the South Slough National Estuarine Research Reserve (data provided via personal communication with Allie Helms, South Slough National Estuarine Research Reserve, Dec 2021)

Based on all the above data on eelgrass distribution, relative abundance, and trends, we can summarize the relative suitability of 5 major estuaries in Oregon in terms of their potential quality as sea otter habitat. This assessment is based on characteristics of eelgrass beds, which provide habitat for resting and reproductive behavior of sea otters, as well as adjacency of the estuaries to nearby kelp habitats (Table 6.5).

Table 6.5. Characteristics of eelgrass vegetation in 5 major estuaries in Oregon

Estuary	Size of estuary (acres)	Sites w/eelgrass*	% of intertidal*	Max observed eelgrass extent (acres)**	Adjacent to kelp beds
Tillamook	14,028	28	34.2	667	No
Yaquina Bay	6,649	11	17.4	162	Yes
Alsea Bay	3,562	"low to moderate percent of eelgrass" ***	unknown	325	No
Umpqua	12,419	8	5.5	99	No
Coos Bay	20,566	12	11.7	619	Yes

** From (Lee II and Brown 2009).*
*** From Pacific Marine and Estuarine Fish Habitat Partnership: https://estuaries.pacificfishhabitat.org/*
**** From (Phillips 1984)*

Invertebrate Prey Resources in Estuaries

Assessing habitat suitability for sea otters in estuaries also requires an understanding of the dynamics of their potential prey populations. Invertebrates occurring in Oregon estuaries that are likely to be eaten by sea otters include various crab, clam, and worm species. Recreational clamming and crabbing activities occur in many of Oregon's estuaries. ODFW's SEACOR program surveys (https://www.dfw.state.or.us/MRP/shellfish/Seacor/maps_publications.asp) provide data on clam presence and abundance in the six estuaries where significant recreational clamming occurs (from north to south: Tillamook, Netarts, Siletz, Yaquina, Alsea, and Coos Bay). Commercially exploited bay clams (cockle, gaper, butter, and native littleneck clams) are present in Tillamook, Netarts, Yaquina and Coos Bay (Figure 6.10), with variation in harvest levels over time (Figure 6.14). Only in Tillamook Bay is there a significant commercial harvest (Mitch Vance, ODFW, personal communication, 1/11/2021).

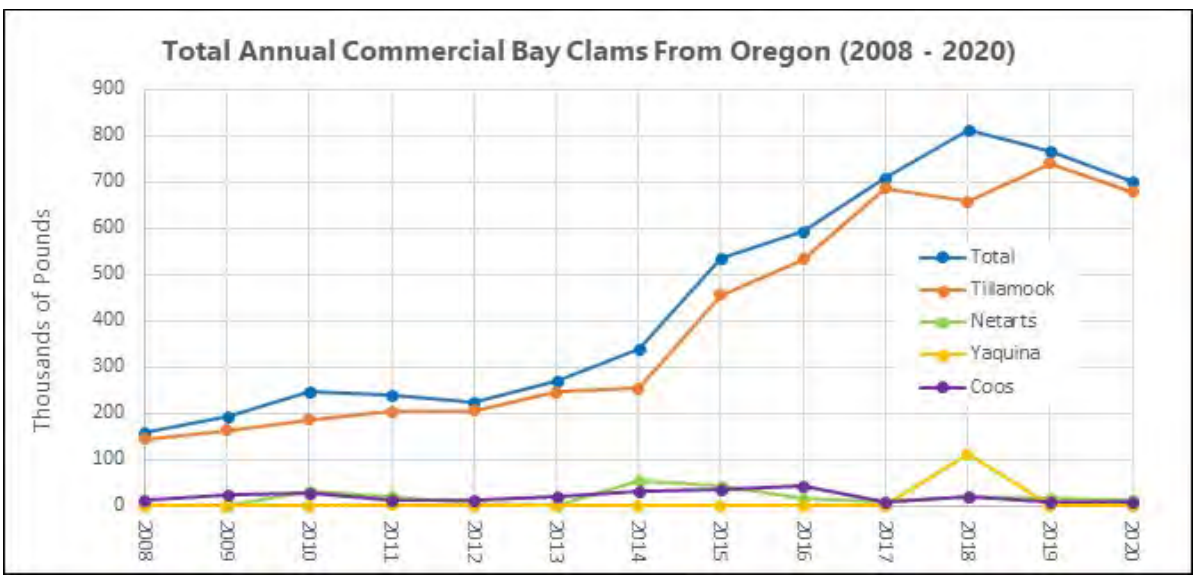

Figure 6.14. Commercial harvest of bay clams from four Oregon estuaries 2008-2020

Oregon's estuaries are also important habitat for juvenile and adult Dungeness crab *Metacarcinus magister*. Recreational crabbing occurs in all bays where this species is present. A much smaller number of red rock crabs (*Cancer productus)* are harvested. Ainsworth et al. (2012) provides the most comprehensive information on recreational crabbing in Oregon. Annually recreational harvest accounts for ~5% of the commercial harvest. The European green crab (*Carcinus maenas*) has been present in Oregon's estuaries since the late 1990s and has increased in abundance in the Tillamook, Netarts, Yaquina and Coos Bay estuaries since 2016 (Behrens Yamada et al. 2020).

Several of Oregon's estuaries (Tillamook Bay, Netarts, Yaquina Bay, and Coos Bay) support commercial oyster (*Crassostrea gigas*) farms. The majority of oysters in Oregon are grown directly on the estuarine bottom rather than by rack or hanging culture, as is often seen in other areas. Native oysters (*Ostrea lurida*) were once abundant in Netarts, Yaquina and Coos Bays but have been depleted or noted as absent since the late 1800s. Restoration projects in these three estuaries are currently underway spearheaded by The Nature Conservancy, the Confederated Tribes of Siletz, and South Slough National Estuarine Research Reserve (https://www.dfw.state.or.us/mrp/shellfish/bayclams/about_oysters.asp). Neither types of oysters are subject to recreational harvest. There is little published information about whether sea otters consume commercial or native oysters. Based on anecdotal reports, in areas where sea otters and commercial oyster operations overlap in Alaska there have been minimal interactions, however unlike the Oregon fishery the Alaskan commercial oyster operations utilize hanging bags or enclosures that may discourage sea otter interactions.

Estuary Summary

Based on all the data summarized above, we provide a summary of characteristics for select estuaries that may be relevant for their assessment as potential sites for a sea otter reintroduction (Table 6.6). The size of the estuary and the presence of an eelgrass community gives an indication of the availability of resting habitat for otters. The existence of commercial or recreational fishing activities can be viewed as a positive indicator of the potential for prey availability; however, these fisheries, and the presence of oyster farming activities, also represent a potential for human-otter conflicts in the case of sea otter recolonization.

Table 6.6 Summary of variables related to prey availability, threats, and eelgrass resting habitat for select estuaries in Oregon

Estuary	Area >1000 ha	Commercial shipping	Commercial fisheries activity	Recreational clamming and crabbing	Commercial clamming	Oyster farming	Eelgrass presence
Tillamook	Yes	Limited	Moderate	High	High	Yes	High
Netarts	Yes	No	Limited	High	Limited	Yes	Medium
Siletz	No	No	No	Limited	No	No	Low
Yaquina	Yes	Moderate	High	High	Limited	Yes	High
Alsea	Yes	No	No	Limited	No	No	Low
Umpqua	Yes	No	Limited	Limited	No	Yes	Low
Coos	Yes	High	High	High	Limited	Yes	High
Coquille	No	No	Limited	Limited	No	No	Low

Conclusions

Based on the existing abundance and distribution of sea otter populations in coastal habitats around the north Pacific, it seems likely that all of coastal Oregon (including estuaries) represents potentially suitable sea otter habitat. However, the preceding sections make clear that there is considerable variation in habitat features throughout the state – including benthic substrate (and associated invertebrate prey communities), kelp canopy cover along the outer coast, and eelgrass beds in estuaries – which would suggest that certain areas may provide higher quality habitat for sea otters (Figure 6.1). In terms of outer coast habitats, we suggest that areas in the southern half of the state appear to have a higher abundance of preferred habitat features and prey populations (especially urchins): in particular, the reef complexes near Port Orford (Blanco Reef, Orford Reef and Redfish Rocks) and Cape Arago (Simpson reef), and in the central part of the state Depoe Bay/Yaquina Head. In terms of estuarine habitats, there are three larger estuaries that appear to have an optimal combination of prey resources (clams, crabs) and resting habitats (eelgrass beds and tidal creeks) which suggest they could potentially support viable sea otter populations: Tillamook Bay, Yaquina Bay, and Coos Bay. Of these, the latter two have the additional advantage of proximity to outer coast reefs and kelp beds that could provide alternative habitats for establishing sea otter populations.

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Chapter 7: Socioeconomic Considerations

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Introduction

Sea otters have a wide array of strong direct and indirect effects on coastal ecosystems of the North Pacific Ocean and southern Bering Sea (see Chapter 5 for an overview). Accordingly, the nearshore coastal ecosystems within this region that now lack sea otters are qualitatively different from what they would have looked like prior to the extirpation of otters during the fur trade. And, by the same token, the repatriation of sea otters into such areas will cause these ecosystems to change again from what they now are. In this chapter we discuss some of the likely social and economic implications of these ecological changes for people.

The Pacific maritime fur trade drove once-abundant sea otter populations across the Pacific rim to the brink of extinction by the late 19th century (Kenyon 1969). Modern human societies in the Pacific northwest therefore developed for the most part in an environment without otters. People often perceive these otter-free systems as the “pristine” or “natural” state because that is the world they grew up in and became familiar with. Human perceptions and values have developed accordingly (Pauly 2019). Understanding and measuring these values is central to this socioeconomic analysis.

The value of anything can defined in terms of its “*desirability*, often in respect of some property such as usefulness or exchangeability, worth, merit, or importance” [1]. Value comes in an array of forms (or currencies). The most universally recognized and widely used of these currencies is money. Money is the foundation of modern capitalism[2] and capitalism is the socioeconomic structure in which most of today’s globalized social/political system operates. However, humans also use other currencies (e.g., existence, emotional, cultural) to assign or experience value. While it is important to include these various currencies in any socioeconomic analysis of the potential effects of repatriating sea otters to Oregon, doing so involves a number of daunting challenges. One such challenge is the assembly of a fair and reasonably thorough array of relevant currencies. Another challenge lies with the comparative weighting of these different currencies. Economists sometimes attempt to do this through a process of ‘value equivalency’ (e.g., establishing a person’s willingness to pay [in monetary terms] for something of non-monetary value [e.g., the opportunity to see a sea otter in nature or to partake in recreational shellfisheries]). Moreover, the available options may not be determinable solely in terms of economics, but also as constrained by law.

Regardless of currency, human existence in a world with or without sea otters has various costs and benefits. Until recently, these socioeconomic effects were seen largely as costs associated

[1] From the online free dictionary.

[2] an economic system characterized by private or corporate ownership of capital goods, by investments that are determined by private decision, and by prices, production, and the distribution of goods that are determined mainly by competition in a free market (Merriam-Webster).

with the negative effects of sea otters on shellfisheries. This perspective surfaced in the mid-1960s with concern over the long-term viability of California's commercial abalone fishery (Lowry and Pearse 1973, Wendell 1994). Like many of the sea otter's macroinvertebrate prey, North Pacific abalones probably increased greatly in size and abundance following the post-fur trade ecological extinction of sea otters (Watson 2000, Estes et al. 2005). The hyper-abundant abalones subsequently became the foundation for various commercial and subsistence fisheries. Many of these fisheries may not have been sustainable, even in the absence of sea otters (Tegner 2000). Regardless, the end came quickly as predation by the growing sea otter population in central California reduced remaining abalone stocks, thus leading to a conflict between commercial/recreational abalone fishers and sea otters (Wendell 1994). The currencies of this conflict were money (e.g., reduced ex-vessel landing values to the fishers and various associated businesses) and lifestyle (e.g., the ability to make a living and to enjoy doing so in accordance with family traditions and values). As sea otter populations continued to recover from the fur trade in the eastern North Pacific Ocean, similar conflicts have developed for other shellfish species in other areas (Pitcher 1989, Larson et al. 2013, Carswell et al. 2015).

The early socioeconomic perception of sea otters was largely negative, owing to lost revenues and lifestyles associated with the *direct effects* of sea otter predation on shellfisheries (Estes and VanBlaricom 1985). This perception broadened as the *indirect effects* of sea otters became better known and people began to realize that some of these indirect effects could have associated economic costs and benefits (Estes et al. 2004). Most recently, a comprehensive analysis of economic costs and benefits, including both direct and indirect effects, was completed for British Columbia (Gregr et al. 2020). Another review of some of the potential direct and indirect effects of sea otter recovery was also completed for the Oregon coast (Kone et al. 2021). Here, we draw upon these previously published analyses and other sources to explore the direct and indirect effects of sea otters that are important to consider prior to the species' reestablishment in Oregon. This includes a synopsis of some of the specific commercial activities in Oregon that may be affected. We also note that a more comprehensive Economic Impacts Assessment of potential return of sea otters to Oregon is currently underway and will be available as a companion piece to this Feasibility Study report.

Direct Effects

Sea otters are predators and as such their main direct effect is via prey limitation. In such cases wherein the sea otter's macroinvertebrate prey are consumed and valued by humans, one cost of living with sea otters is the reduction or elimination of shellfisheries. Although such direct negative impacts of sea otter predation have influenced various mollusk, crustacean, and echinoderm fisheries from Alaska to California, the magnitude of these impacts varies considerably among species and locations. The strong negative effects of sea otters on urchin dive fisheries have been quite consistent (Johnson 1982, Carswell et al. 2015), and in Oregon there is a high potential for recovering sea otters to impact urchin fisheries, as most of the same areas where sea otters are likely to recover (see Chapter 3) are also areas where urchin fishing activity is highest (Kone et al. 2021). Negative impacts on existing commercial clam fisheries are another common feature of sea otter recovery, including pismo clams in California (Kvitek and Oliver 1988) and geoduck clams in SE Alaska (Kvitek et al. 1993, Hoyt 2015). The magnitude and timing of this negative effect will depend on the pattern and rate of sea otter recovery and the relative availability of alternative (non-commercial) prey species (Hoyt 2015). Another related direct effect involves not just fisheries, but the conservation status of affected shellfish species. The best-known example is that of abalone, which for some species are themselves listed under the ESA as threatened or endangered. The imperiled status of these species and stocks could be exacerbated by further losses to sea otter predation. It is possible, however, that these species and stocks might be enhanced via the otter-urchin-kelp trophic cascade (see Chapter 5, and below).

For other shellfisheries, the nature and magnitude of direct effects by sea otters has been less consistent. Sea otters have had a strong negative effect on commercially valuable sea cucumbers in SE Alaska (Larson et al. 2013) , but this effect has not been described elsewhere. Similarly, the expanding sea otter population in eastern Prince William Sound clearly reduced Dungeness crab populations, causing local crab fisheries to collapse (Garshelis et al. 1986), and similar declines were observed in SE Alaska (Hoyt 2015). In contrast, crab fisheries in California appear to have been largely unaffected by recovering sea otters (Grimes et al. 2020, Boustany et al. 2021), probably owing to nuanced features of the behavior and natural history of otters and crabs combined with differences in coastal bathymetry. Regional differences in the impact of sea otters on Dungeness crab fisheries seems to be related to an interaction between bathymetry (water depth) and size selectivity by foraging sea otters.

Sea otters are size-selective predators and avoid the consumption of smaller bodied prey almost entirely. For example, although sea otters in the Aleutian Islands prey on (and strongly limit) sea urchins, they seldom consume urchins less than about 2cm in test diameter (Estes and Duggins 1995), thereby potentially increasing the production of this segment of the urchin population by reducing intraspecific competition between the smaller recruits and larger adults. Size selectivity patterns have also been reported for sea otters foraging on urchins in BC (Burt et al. 2018) and California (Smith et al. 2021) and on *Cancrid* crabs in California (Grimes et al. 2020). It is possible that this size selectivity, combined with intraspecific competition among size classes, may modulate the impact of sea otter predation on Dungeness crab populations in central California. Like many marine invertebrates, Dungeness crabs have dispersive early life stages (larvae) that develop and grow at sea. These larvae return to coastal zones via transport by internal waves, where they settle and are recruited into adult populations but are also limited by intraspecific competition with larger adults. The addition of otters to estuaries reduces the abundance of adult crabs (Hughes et al. 2013) but not these smaller recruits, thereby potentially enhancing juvenile crab population productivity (Grimes et al. 2020). Moreover, adult crabs, because of their mobility, spend much of their lives in deeper water, near or even beyond the break of the continental shelf, where they realize a depth refuge from predation by sea otters. Sea otter predation therefore exerts little cost on, and may even confer a benefit to, Dungeness crab fisheries in some areas (Grimes et al. 2020, Boustany et al. 2021). The relative costs and benefits of sea otter predation on Dungeness crabs depend largely on water depth and the frequency and intensity of larval recruitment. In Oregon, the coastal areas where most commercial crab fishing occurs do not overlap with areas that are likely to support higher densities of sea otters (Kone et al. 2021), and like California these areas have bathymetric profiles that should confer depth refuges for adult Dungeness crab: thus, it is reasonable to conclude that effects of sea otter recovery on commercial Dungeness crab fisheries in Oregon will more closely resemble the California example (little to no significant effects) than the Alaskan examples (moderate to substantial effects). However, given the economic and social importance of this industry, more research on this subject is clearly warranted.

Positive effects of sea otters have also been noted for black abalone in central California (Raimondi et al. 2015). The mechanisms underlying this pattern are not entirely clear, although they may relate to complex responses by abalones to sea otter predation that result from nutritional benefits (i.e., increased production and food because of the otter-urchin-kelp trophic cascade—see Chapter 5) and reduced vulnerability to human exploitation because abalones seek refuge from foraging otters in cryptic habitats (Lowry and Pearse 1973). Similarly, in British Columbia, there was an overall decrease in abundance of northern abalone in response to the return of sea otters; however, abalone in cryptic habitats actually increased in abundance after the recovery of sea otters (Lee et al. 2016). Because cryptic abalone are not readily available to human harvesters, the net effect of sea otters on abalone fisheries is likely to be negative in most cases, however the impacts of sea otters on abalone population health and viability is not necessarily negative and may even be positive in some cases (Raimondi et al. 2015).

Indirect Effects

While the direct effects of otters on shellfisheries are largely negative (i.e., depressing), the indirect effects of otters on other coastal resources are often positive (i.e., enhancing). Positive effects occur primarily through the enhancing effects of otters on primary producers, especially kelp (i.e., the otter-urchin-kelp trophic cascade), and the knock-on effects of kelp via increased production and habitat provisioning (see Chapter 5). Significant increases in the abundance of several commercially or recreationally valuable finfish species (e.g., rockfishes, greenlings and ling cod) have been shown to occur following sea otter recovery, with these increases explained by the increased productivity and habitat structure associated with the kelp forests that flourished after sea otter recovery (Reisewitz et al. 2006, Markel and Shurin 2015). The effects of sea otter recovery on other finfish and their associated fisheries, while likely significant, remain poorly documented. For example, kelp can have a positive impact on Pacific herring populations because herring spawn on kelp, and the positive effect of sea otters on kelp increases the production of the coastal water column ecosystem in which herring live and feed.

A similar indirect effect of otters may occur within estuaries. In Oregon estuaries such as Coos and Yaquina Bay, herring spawn on eelgrass. Currently, eelgrass abundance in estuaries is in decline in Oregon (see Chapter 6), but a case study from a California estuary where sea otters have recovered (Elkhorn Slough) shows that the return of sea otters to estuaries can have a positive indirect effect on the extent and stability of the eelgrass community (Hughes et al. 2013), via complex trophic interactions. In contrast, in British Columbia where sea otters foraged in eelgrass habitats but also had ready access to kelp beds, their impact on eelgrass habitat was not as evident (Hessing-Lewis et al. 2018). These examples suggest that, while the outcome is not certain, there is the potential for positive indirect effects of sea otters on eelgrass and thereby on the various invertebrate and fish species (including herring) that use eelgrass as nursery habitat. Herring in turn are of value to people as the direct target of fisheries, and indirectly as forage fish that support numerous other species (e.g., salmon and whales) that people also value.

Kelp and eelgrass can influence human welfare via other ecosystem pathways: for example, by sequestering atmospheric carbon dioxide ($C0_2$) (Wilmers et al. 2012) or reducing wave energy and thus stabilizing and protecting shorelines (Pinsky et al. 2013, Nicholson et al. 2018). Sea otters can also impact human welfare through wildlife viewing opportunities and the benefits that imparts on the ecotourism industry (Gregr et al. 2020, Martone et al. 2020).

Although the negative and positive socioeconomic influences of sea otters through their direct and indirect effects on other species and ecological processes have long been recognized, the first comprehensive effort to measure these effects in monetary terms was done by Gregr et al. (2020), who considered the following four ecosystem services—shellfisheries, finfisheries, carbon sequestration, and ecotourism. Gregr et al.'s (2020) findings, which were specific to Vancouver Island in British Columbia, indicated that the repatriation of sea otters to this particular area resulted in 37% more annual ecosystem biomass; increases of 9.4 million, 2.2 million, and 42.0 million CA$ from fin fisheries, carbon sequestration, and ecotourism, respectively; and a -7.3 million CA$ loss from shellfisheries.

Non-monetary Effects

Although Gregr et al.'s (2020) analysis of sea otter economic impacts in British Columbia was both unprecedented and transformative, it also involves an extraordinarily complex issue that was beset by at least two limitations. One of these limitations is the incomplete breadth of indirect effects that were used in the ecological and cost assessments. The impacts of sea otters in coastal ecosystems extend to numerous species via diverse pathways, most of which either remain unrecognized, or simply are not yet well enough understood to be included in such an analysis (the aforementioned possible effects on herring, salmon and whales is a case in point). The other limitation to Gregr et al. (2020) is the singular currency (i.e., monetary value) used in the analysis. This is not a weakness, as monetary value is tangible, measurable, and broadly important to most people. However, money is not the only commodity that matters to people, especially when people are considered as individuals or special interest groups. Burt et al. (2020) made this point for British Columbia's First Nations peoples, who value shellfisheries for both cultural reasons and food security. Indeed, there is growing evidence that aboriginal maritime peoples in the Northeast Pacific Ocean limited sea otters in some areas (Simenstad et al. 1978, Groesbeck et al. 2014, Salomon et al. 2015, Slade et al. in press) thereby enhancing shellfish availability, although the extent to which these prehistoric effects were the purposeful consequence of shellfisheries management, or fortuitous epiphenomena of sea otter population reductions from overhunting, remains uncertain. In any case, any assessment of socioeconomic impacts of sea otter recovery must provide a comprehensive accounting of the social values of the relevant communities, including both monetary and non-monetary variables.

Synopsis of Direct and Indirect Effects

The socioeconomic consequences of repatriating sea otters to Oregon, while germane and important, are difficult to assess, in part because of uncertainties over details of the ecological effects of sea otters, in part because of the differing currencies by which people value the resulting natural resources, and in part because of differences in the way different people embrace these differing values. While the use of a monetary value system is the single most common way of conducting such a socioeconomic analysis, it is important to keep in mind the non-monetary values and recognize there may be no obvious way forward that all or even most parties will find completely fair and reasonable. We acknowledge that these complex issues are largely outside the realm of expertise of the authors of this report. Some of the differing views and values of various stakeholders are discussed in Chapter 11. However, these issues will be taken up separately by more qualified experts in the areas of resource economics and the social sciences.

Potentially Affected Oregon Fisheries

Although Oregon's coastal fisheries are identifiable, a detailed assessment of the impacts of sea otters on these fisheries is beyond the scope of this chapter (although we note that a full economic impacts assessment is underway). Both direct and indirect effects are likely to occur. Direct effects are via predation, and the majority of these influences on prey populations will be negative, although there are exceptions (see above) and the magnitude of impact varies strongly among species and habitats (see above). Most of the indirect effects will probably be positive, although here too one should recognize the likely variation among species, ecosystem types, and specific areas. In Oregon, the invertebrate species which are fished commercially and taken by recreational harvesters, and which potentially would be affected by sea otter recovery, include: Dungeness crab, red rock crab, razor clams, butter clams, Gaper clams, littleneck clams, cockles, mussels, ghost shrimp, and red and purple sea urchins. We do not further consider finfisheries and the potential indirect effects of sea otters on these fisheries in this document, though we emphasize that such effects are likely to occur and, in most cases, will be positive (Reisewitz et al. 2006, Markel and Shurin 2015, Gregr et al. 2020).

Commercial Invertebrate Coastal Fisheries

Oregon has consistently been one of the largest producers of Dungeness crab on the U.S. west coast, harvesting a long-term average (20 years) of 17.3 million pounds of crab per season (Figure 7.1). Most of the catch is from the open ocean, and landings are made at all Oregon ports. Red sea urchins were first harvested commercially in Oregon in Port Orford in 1986, and landings quickly escalated and peaked at 9.3 million pounds in 1990. Virgin stocks were quickly reduced, and by 1996 the urchin fishery boom was over: from 1996 to 2015 the urchin fishery landings stabilized at a much lower level (Figure 7.2.). Red sea urchins are harvested exclusively from kelp beds, and most of Oregon's kelp beds occur south of Charleston, where about 90% of the harvest occurs. The most important harvest areas are Orford reef, just northwest of Port Orford (~50% of harvest) and Rogue reef, just northwest of Gold Beach (~25% of harvest). It is notable that both these areas have been identified as potential habitat for sea otter recovery (Chapters 3 and 6 of this report, and Kone et al. 2021). Nearshore areas of Brookings, Cape Arago, and reefs off of Depoe Bay account for the remaining 25% of harvest. Purple sea urchins account for less than 1% of the 43 million pounds of sea urchins which have been harvested from Oregon since 1986. California sea cucumbers are also covered by an urchin permit, though harvest of this species has been minimal. Data from ODFW landing statistics for invertebrates, not including oysters, at the eight major ports in Oregon provide insights into the current extent of commercial activity. These data are summarized below (Tables 7.1 – 7.8) based on data from: [https://www.dfw.state.or.us/fish/commercial/landing_stats/2019/index.asp.](https://www.dfw.state.or.us/fish/commercial/landing_stats/2019/index.asp) Although shrimp (*Pandalus jordani)* is included in these tables, the fishery for this species occurs at depths of 40 to 125 fathoms (240 to 750 feet) in areas of mud or sand, and the species is only rarely consumed by sea otters. In recent years a market squid (*Doryteuthis opalescens*) fishery has developed in Oregon coastal waters. All other species in the Tables 7.1 – 7.8 are harvested in estuaries.

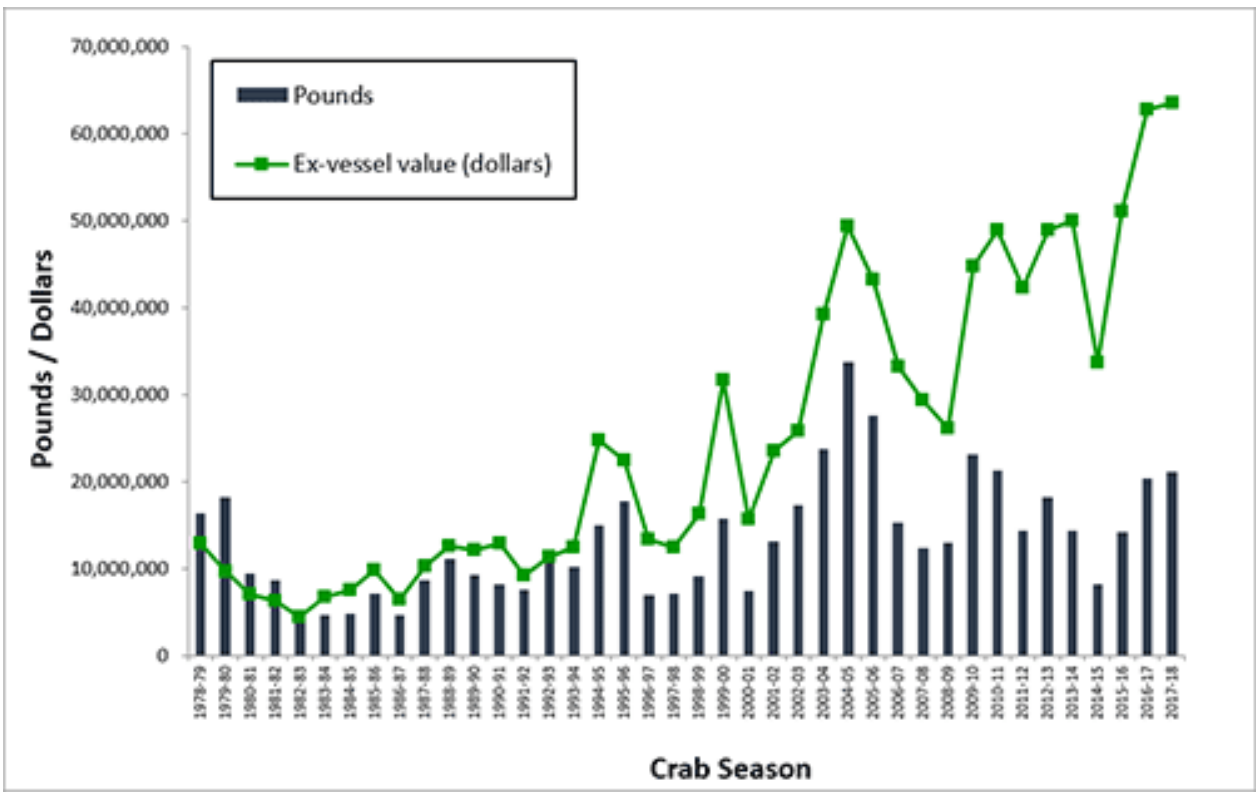

Figure 7.1. Annual Dungeness crab landings in Oregon over time. Data from: https://www.dfw.state.or.us/MRP/shellfish/commercial/crab/landings.asp

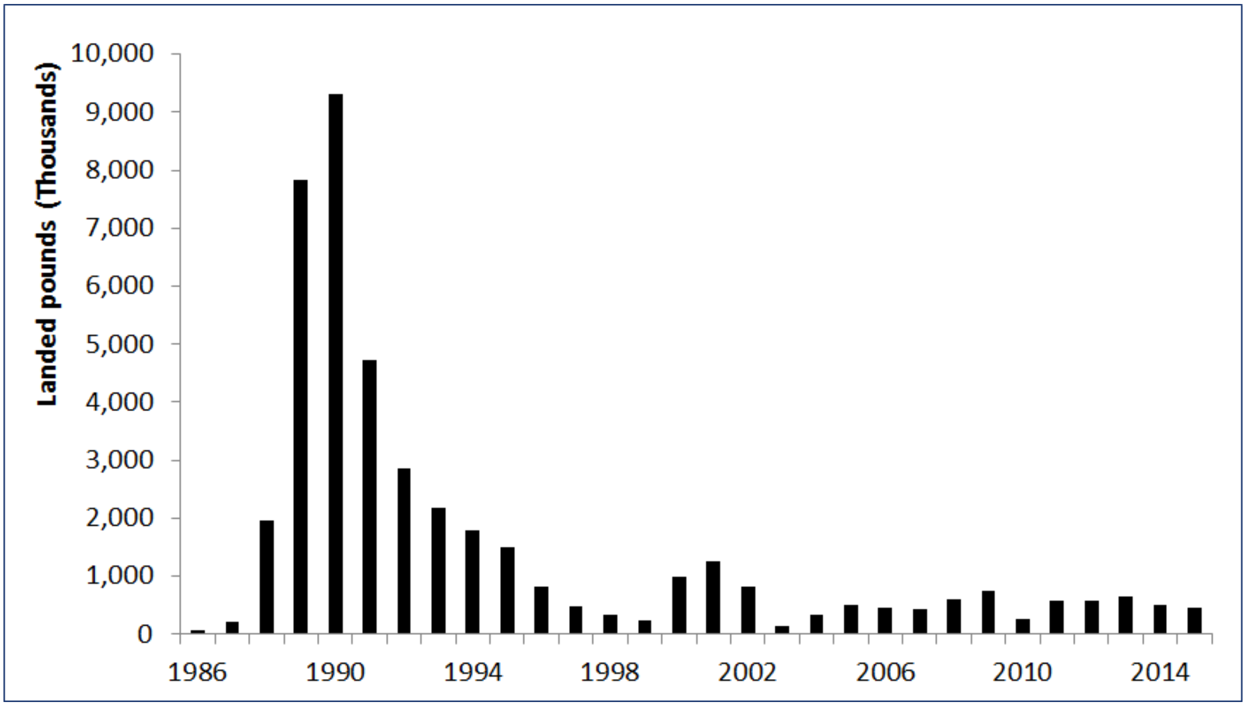

Figure 7.2. Annual urchin landings in Oregon over time. Data from:
https://www.dfw.state.or.us/mrp/shellfish/commercial/urchin/index.asp

Table 7.1 Commercial Catch statistics for ASTORIA (Columbia River Mouth)

2019 FINAL

POUNDS AND VALUES OF COMMERCIALLY CAUGHT FISH AND SHELLFISH LANDED IN OREGON - ASTORIA

		January	February	March	April	May	June	July	August	September	October	November	December	Total
Crustaceans	#	2,750,269	429,965	148,577	1,131,990	2,073,900	1,589,975	2,163,850	877,896	260,337	182,069	1,018	22,953	11,632,799
	$	8,353,683	1,757,282	656,774	1,029,353	1,756,119	1,236,897	1,510,418	657,987	213,775	137,086	1,000	68,501	17,378,875
Crab, box	#						1							1
	$						0							0
Crab, Dungeness, bay	#										206	200		406
	$										1,330	1,000		2,330
Crab, Dungeness, ocean	#	2,750,269	429,965	148,577	35,752	20,050	6,889	3,108	253	2	1	818	22,953	3,418,637
	$	8,353,683	1,757,282	656,774	179,121	126,638	32,931	14,383	980	0	0	0	68,501	11,190,293
Shrimp, pink	#				1,096,238	2,053,850	1,583,085	2,160,742	877,643	260,335	181,862			8,213,755
	$				850,232	1,629,481	1,203,966	1,496,035	657,007	213,775	135,756			6,186,252

Table 7.2 Commercial Catch statistics for SEASIDE to NEHALEM BAY. Note that razor clams are harvested commercially from the intertidal of Clatsop beaches and account for an estimated 15% of the total razor clam harvest, the remaining harvest is recreational and is not represented in these landing statistics. The bay clams come mostly from Tillamook and Netarts Bays.

2019 FINAL

POUNDS AND VALUES OF COMMERCIALLY CAUGHT FISH AND SHELLFISH LANDED IN OREGON - GEARHART-SEASIDE-CANON BEACH-GARIBALDI-NEHALEM BAY

		January	February	March	April	May	June	July	August	September	October	November	December	Total
	$	1,723,509	454,268	281,928	161,195	142,885	68,136	52,394	18,439	3,980	3,183	5,408	907	2,916,232
Barnacle, gooseneck	#						33	47	60	43	41	20	15	259
	$						330	430	510	391	335	158	105	2,259
Crab, Dungeness, bay	#									554	476	866		1,896
	$									3,244	2,644	4,814		10,702
Crab, Dungeness, ocean	#	533,515	106,735	60,438	23,705	19,395	11,931	10,861	3,786			403	797	771,566
	$	1,723,504	454,265	281,900	161,185	142,834	67,762	51,937	17,888			403	797	2,902,475
Crab, rock	#									107	49	14		170
	$									321	147	28		496
Shrimp, ghost	#	3	2	17	6	34	28	18	27	16	38	3	3	195
	$	5	3	28	10	51	44	27	41	24	57	5	5	300
lolluscs	#	89,902	66,388	90,433	28,236	33,533	33,065	342,898	29,074	12,515	18,364	21,120	20,196	785,514
	$	116,729	82,048	118,895	45,192	67,298	60,086	313,659	23,270	7,868	17,985	17,271	14,079	884,380
Clams, butter	#	8,023	13,537	11,288	3,770	1,671	2,146	6,490	4,187	7,712	13,519	19,392	19,712	111,447
	$	6,590	10,083	8,300	3,016	1,374	1,717	5,185	2,987	5,171	8,265	12,392	12,619	77,699
Clams, cockle	#	81,681	52,345	78,142	18,928	16,123	18,841	26,704	16,528	1,707	41			311,040
	$	110,000	71,541	108,491	25,261	18,346	22,832	23,425	15,870	935	78			396,779
Clams, gaper	#	198	506	413	158	374	46	302,372	8,323	3,063	2,204	131		317,788
	$	139	424	344	126	507	37	264,600	4,377	1,729	1,873	105		274,261
Clams, razor	#			590	5,380	15,365	12,032	7,078			2,571	1,594	474	45,084
	$			1,760	16,789	47,071	35,500	20,368			7,740	4,771	1,460	135,459
Mussels, bay	#							54	36	33	18	3		144
	$							81	36	33	18	3		171
Octopus	#										11			11
	$										11			11
Total	#	624,036	174,832	157,873	56,172	66,517	56,112	383,320	290,157	62,446	99,435	27,161	22,730	2,019,793
	$	1,841,641	540,041	417,646	217,393	254,044	167,598	477,548	508,813	103,732	167,266	34,006	19,340	4,749,068

Table 7.3 Commercial Catch statistics for PACIFIC CITY to DEPOE BAY. Note that the urchins would have been harvested close to Depoe Bay

2019 FINAL

POUNDS AND VALUES OF COMMERCIALLY CAUGHT FISH AND SHELLFISH LANDED IN OREGON - NETARTS - PACIFIC CITY - SILETZ - SALMON RIVER - DEPOE BAY

		January	February	March	April	May	June	July	August	September	October	November	December	Total
	$			1,802										1,802
Sea urchin, purple	#			1,500										1,500
	$			1,500										1,500
Sea urchin, red	#			302										302
	$			302										302
Total	#	13,321	2,543	9,494	12,783	16,335	14,436	16,895	9,329	6,832	11,670	10,494	2,416	126,548
	$	41,464	6,741	26,581	35,278	36,104	24,646	57,394	24,064	12,550	35,400	30,815	7,148	338,185
Crustaceans	#	11,787	1,434	3,551	1,083	2,594	1,510	2,102	1,690	608	2,636	2,499	229	31,723
	$	37,930	4,398	15,481	4,510	13,092	6,474	10,970	8,512	1,023	12,389	10,687	351	125,817
Crab, Dungeness, bay	#									18	1,781	1,980		3,779
	$									108	11,051	9,879		21,038
Crab, Dungeness, ocean	#	11,393	1,024	3,038	700	1,633	938	1,653	1,264					21,643
	$	37,327	3,773	14,700	3,929	11,640	5,600	10,277	7,850					95,096
Crab, rock	#										18	5		23
	$										54	15		69
Shrimp, ghost	#	394	410	513	383	961	572	449	422	590	837	514	229	6,274
	$	603	625	781	581	1,452	874	693	654	915	1,284	793	351	9,606
Shrimp, mud	#								4					4
	$								8					8
Molluscs	#				2,888	6,093	7,677					871		17,529
	$				1,444	3,453	4,929					697		10,523
Clams, butter	#											871		871
	$											697		697
Clams, cockle	#				2,888	6,093	7,677							16,658
	$				1,444	3,453	4,929							9,826
Other Invertebrates	#			1,802										1,802

Data As of 4/14/2020 3:21:11 PM | http://fwhqreports.odfw.int/ReportServer FTR205 Note: All pounds round 2 of 3

Table 7.4 Commercial Catch statistics for NEWPORT

2019 FINAL

POUNDS AND VALUES OF COMMERCIALLY CAUGHT FISH AND SHELLFISH LANDED IN OREGON - NEWPORT

		January	February	March	April	May	June	July	August	September	October	November	December	Total
Crustaceans	#	5,212,577	1,090,296	365,302	115,574	1,503,130	3,144,434	1,786,150	1,324,137	895,387	349,073	17,106	61,121	15,864,287
	$	16,684,187	4,815,565	1,725,540	795,031	1,426,082	2,400,229	1,457,341	1,092,437	847,344	306,853	16,420	183,423	31,750,452
Barnacle, gooseneck	#									15	57			72
	$									60	228			288
Crab, box	#		8											8
	$		8											8
Crab, Dungeness, bay	#									4	101	1,138		1,243
	$									16	808	5,218		6,042
Crab, Dungeness, ocean	#	5,212,577	1,090,288	365,302	115,570	47,102	19,271	11,154	3,404	19		2,852	61,121	6,928,660
	$	16,684,187	4,815,557	1,725,540	795,027	369,676	122,864	72,481	24,235	0		0	183,423	24,792,990
Crab, rock	#				4							82		86
	$				4							123		127

Table 7.5 Commercial Catch statistics for YACHATS to WINCHESTER BAY. Note: Ghost shrimp are harvested for bait in the intertidal of bays.

2019 FINAL

POUNDS AND VALUES OF COMMERCIALLY CAUGHT FISH AND SHELLFISH LANDED IN OREGON - WALDPORT - YACHATS - FLORENCE - WINCHESTER BAY

		January	February	March	April	May	June	July	August	September	October	November	December	Total
Crustaceans	#	500,790	172,008	72,370	28,923	19,796	9,832	5,262	2,987	3,067	10,897	18,162	2,035	846,129
	$	1,758,512	752,955	337,684	185,711	139,926	50,022	23,571	13,121	8,320	43,378	83,542	3,817	3,400,559
Crab, box	#				257									257
	$				900									900
Crab, Dungeness, bay	#										7,659	17,091		24,750
	$										34,845	80,418		115,263
Crab, Dungeness, ocean	#	499,276	170,487	69,810	26,286	16,349	7,585	3,372	1,609				969	795,743
	$	1,754,393	748,777	330,492	177,589	130,661	44,218	18,290	9,163				555	3,214,138
Shrimp, ghost	#	1,514	1,521	2,560	2,380	3,447	2,247	1,890	1,378	3,067	3,238	1,071	1,066	25,379
	$	4,119	4,178	7,192	7,222	9,265	5,804	5,281	3,958	8,320	8,533	3,124	3,262	70,258

Table 7.6. Commercial Catch statistics for CHARLESTON (Coos Bay)

2019 FINAL

POUNDS AND VALUES OF COMMERCIALLY CAUGHT FISH AND SHELLFISH LANDED IN OREGON - CHARLESTON

		January	February	March	April	May	June	July	August	September	October	November	December	Total
Crab, box	#					6								6
	$					12								12
Crab, Dungeness, bay	#										926	1,801		2,727
	$										4,017	7,638		11,655
Crab, Dungeness, ocean	#	2,282,972	1,565,359	287,609	121,259	55,257	19,059	10,735	2,210	19		1,840	63,405	4,409,724
	$	7,109,328	6,056,058	1,197,934	809,955	432,775	107,911	52,583	12,924	0		0	186,584	15,966,052
Crab, mole	#					3								3
	$					3								3
Shrimp, ghost	#		42	110	66	283	434	192	90	111	157	144	113	1,742
	$		84	220	132	566	868	384	180	209	312	285	226	3,466
Shrimp, pink	#					1,061,690	1,952,869	1,137,086	1,128,881	387,417	78,612	625		5,747,180
	$					754,268	1,368,010	759,637	835,997	302,611	71,276	531		4,092,330
Mollusos	#		903	2,433	2,289	125,984	186,873	96,218	1,212,196	497,151	44	203	706	2,125,000
	$		1,180	3,317	3,312	68,751	94,780	49,709	706,057	297,884	55	278	929	1,226,252
Clams, butter	#		255	703		91	199	59						1,307
	$		290	778		91	239	59						1,457
Clams, cockle	#		648	1,730	2,246	63	77	1,569				95	134	6,562
	$		890	2,539	3,247	95	116	2,354				143	201	9,585
Clams, gaper	#										44	108	520	672
	$										55	135	650	840
Octopus	#				43			25					52	120
	$				65			13					78	156
Squid, Market	#					125,830	186,597	94,565	1,212,196	497,151				2,116,339
	$					68,565	94,425	47,283	706,057	297,884				1,214,214
Other Invertebrates	#					13	2,014	9,277						11,304
	$					0	3,497	13,545						17,042
Jellyfish	#					2	15							17
	$					0	0							0
Sand dollars	#					11	1							12
	$					0	0							0
Sea urchin, red	#						1,998	9,277						11,275
	$						3,497	13,545						17,042

Table 7.7 Commercial Catch statistics for BANDON/PORT ORFORD. Note: the majority of these landings would have been from Port Orford

2019 FINAL

POUNDS AND VALUES OF COMMERCIALLY CAUGHT FISH AND SHELLFISH LANDED IN OREGON - BANDON - PORT ORFORD

		January	February	March	April	May	June	July	August	September	October	November	December	Total
Crustaceans	#	1,206	555,476	83,219	30,063	30,418	17,602	15,520	7,364		67	268	66,121	807,324
	$	0	1,851,104	334,093	150,928	167,306	96,295	63,906	30,793		335	0	196,554	2,891,314
Crab, Dungeness, bay	#										67			67
	$										335			335
Crab, Dungeness, ocean	#	1,206	555,476	83,219	30,063	30,418	17,602	15,520	7,364			268	66,121	807,257
	$	0	1,851,104	334,093	150,928	167,306	96,295	63,906	30,793			0	196,554	2,890,979
Molluscs	#		689	1,103	154	117	95		24				31	2,213
	$		456	671	99	69	98		12				16	1,421
Octopus	#		689	1,103	154	117	95		24				31	2,213
	$		456	671	99	69	98		12				16	1,421
Other Invertebrates	#	18,213			4,073	1,184							14,052	37,522
	$	64,122			8,545	4,736							59,310	136,713
Sea cucumber, California	#				566	1,184								1,750
	$				2,264	4,736								7,000
Sea urchin, purple	#				66									66
	$				66									66
Sea urchin, red	#	18,213			3,441								14,052	35,706
	$	64,122			6,215								59,310	129,647

Table 7.8. Commercial Catch statistics for GOLD BEACH/BROOKINGS. Note: the majority of these landings would have been in Brookings

2019 FINAL

POUNDS AND VALUES OF COMMERCIALLY CAUGHT FISH AND SHELLFISH LANDED IN OREGON - GOLD BEACH - BROOKINGS

		January	February	March	April	May	June	July	August	September	October	November	December	Total
Crab, Dungeness, ocean	#		1,508,179	166,088	36,501	18,150	8,940	3,014	1,123			253	106,955	1,847,203
	$		5,251,980	665,809	213,825	106,731	37,938	15,599	6,288			0	321,780	6,619,948
Sea urchin, red	#	15,498	11,943	21,099		23,755	22,708				16,455	21,965		133,423
	$	55,193	43,651	69,966		60,897	58,161				55,778	79,698		423,342

The commercial landings summarized in Tables 7.1-7.8 are somewhat reflective of where the catch occurs, although this is not always certain. For example, depending on weather and where they have put their pots, bigger boats from Charleston might sell crab in Newport. Commercial in-bay crabbing for Dungeness crab is permitted from Labor Day through December 31, while ocean crabbing season is December 1 – August 14.

Commercial Harvests in Estuaries

The landings data presented above (Tables 7.1-7.8) show that there is a small commercial take of Dungeness crab from estuaries landed in most ports, and it accounts for less than 5% of total crab landings. Ghost shrimp (*Neotrypaea californiensis)* are harvested from estuaries for bait. There is a commercial bay clam harvest in four of Oregon's estuaries (Figure 7.3). Bay clam species commonly harvested include Gaper (*Tresus capax*), butter (*Saxidomus giganteus*), cockle (*Clinocardium nuttallii*), littleneck (*Leukoma staminea*), softshell (*Mya arenaria*) and purple varnish clams (*Nuttallia obscurata*), all of which have been documented as prey items for sea otters (Estes and Bodkin 2002, Tinker et al. 2012).

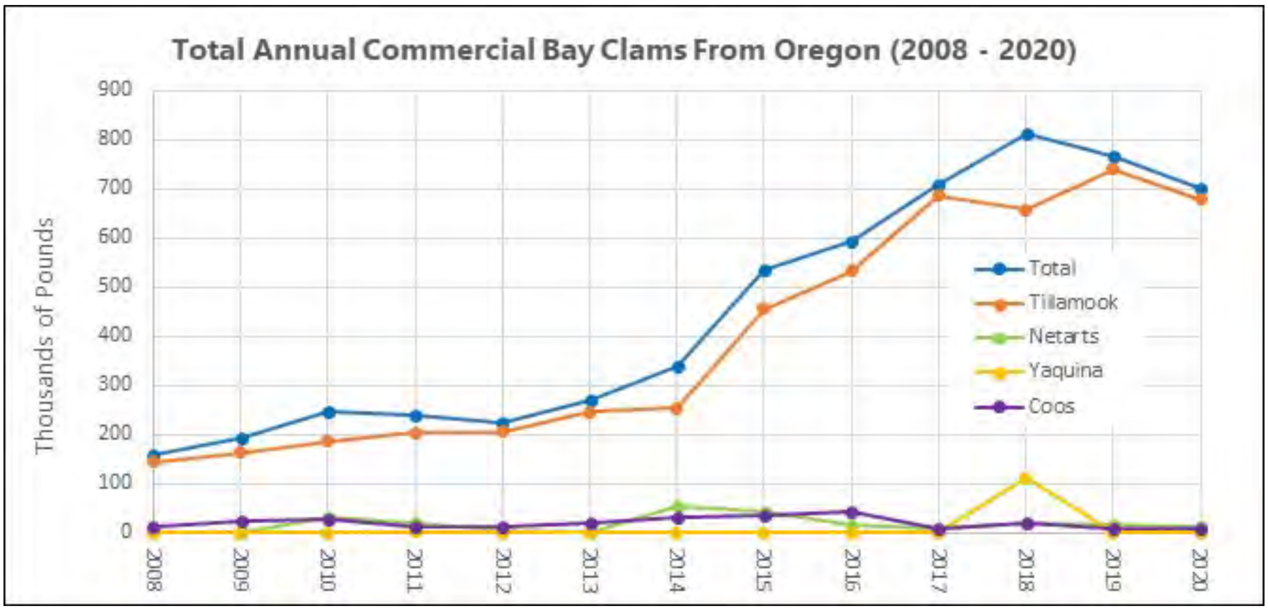

Figure 7.3. Summary of fisheries landings for commercially harvested bay clams in Oregon estuaries

The subtidal clam dive fishery is limited entry (15 permits statewide). The intertidal clam fishery is an open access fishery with generally between 30 to 60 permits sold each year. Of those, only about 20-30 license holders make significant landings in a given year. The intertidal harvesters focus primarily on cockles and most of this fishery happens in Tillamook Bay. The 2020 landings at Gearhart / Seaside / Cannon Beach / Garibaldi / Nehalem Bay, which represents the Tillamook harvest, are shown in Table 7.9. Cockles are the only species shown in landings reported from Netarts / Pacific City / Siletz Bay / Salmon River / Depoe Bay and from Charleston (Table 7.10). Oysters are harvested commercially in five of Oregon's estuaries (Table 7.11). Oyster harvest is regulated by the Oregon Department of Agriculture on estuarine bottom lands leased from the state, or in the case of some regions in Coos Bay, owned by the Port or Coos County.

Table 7.9. Summary of 2020 landings of clams from Tillamook bay estuary and nearby areas. Data from: https://www.dfw.state.or.us/fish/commercial/statistics.asp

Clam species	No. of lbs.	Value ($)
Butter clam	189,217	130,577
Cockle	329,113	406,823
Gaper clam	237,073	174,041

Table 7.10 Summary of 2020 landings of clams from Netarts / Pacific City / Siletz Bay / Salmon River / Depoe Bay and from Charleston. Data from: https://www.dfw.state.or.us/fish/commercial/statistics.asp

Port	No of lbs.	Value($)
Netarts etc.	14,519	8,277
Charleston	11,462	10,554

Table 7.11. 2020 Commercial oyster production on Oregon state leased lands in five estuaries.

ESTUARY	ACRES LEASED*	GALLONS SHUCKED	BUSHELS RAW**	TOTAL PRODUCTION***	PRODUCTION VALUE****	LEASE/FEES COLLECTED
South Slough	240.13	245.00	8,218.17	8,463.17	$507,790.00	$4,093.83
Netarts Bay	425.22	38.00	5,514.17	5,552.17	$333,130.00	$6,605.53
Tillamook Bay	2,605.14	2,833.75	27,943.00	30,826.75	$1,849,605.00	$36,961.92
Umpqua River	60.00	0.00	28.83	28.83	$1,730.00	$843.46
Yaquina Bay	517.00	5,805.00	3053.55	8,858.55	$531,513.00	$7,164.71
Totals	**3,847.49**	**8,971.75**	**44,757.72**	**53,729.47**	**$3,223,768.00**	**$55,669.45**

Source: Oregon Department of Agriculture, Food Safety Program

N.B. South Slough is the State leased land in Coos Bay. Additional oyster production occurs on Port and County lands in upper Coos Bay that is not accounted for in these data.

Recreational Harvest in Estuaries

Recreational crabbing for Dungeness crab occurs in all estuaries or bays where this species is present. Annually, recreational harvest in estuaries is about 5% the size of the commercial harvest. A much smaller number of red rock crabs (*Cancer productus)* are harvested. Ainsworth et al. (2012) provides the most comprehensive information on recreational crabbing in Oregon estuaries. From 2007 through 2011 ODFW collected data on boat-based crabbing effort and catch in Oregon in the bays and open ocean. For the purpose of this report, we have included the estimates of number of recreational crabbing trips and the estimates of number of crabs harvested in five estuaries: Tillamook, Netarts, Yaquina, Alsea and Coos (Figures 7.4 – 7.8).

Recreational crabbing in the open ocean is increasingly popular as people purchase larger boats with more reliable engines. There is limited data on this activity, but a report by Ainsworth et al. (2012) shows the number of trips taken from Oregon ports to the open ocean in 2007 – 2011 (Figure 7.9).

Estimated monthly recreational crabbing trips in Tillamook Bay (NS = not sampled).

	2008	2009	2010	2011
April	89	663	451	320
May	229	1,108	814	641
June	378	479	630	203
July	575	1,958	788	631
August	1,373	1,721	1,589	1,330
September	1,426	1,536	1,531	2,512
October	2,370	NS	1,276	NS
Total (95% conf. interval)	6,440 (4,635-8,245)	7,465 (5,829-9,102)	7,080 (5,503-8,657)	5,637 (4,355-6,919)

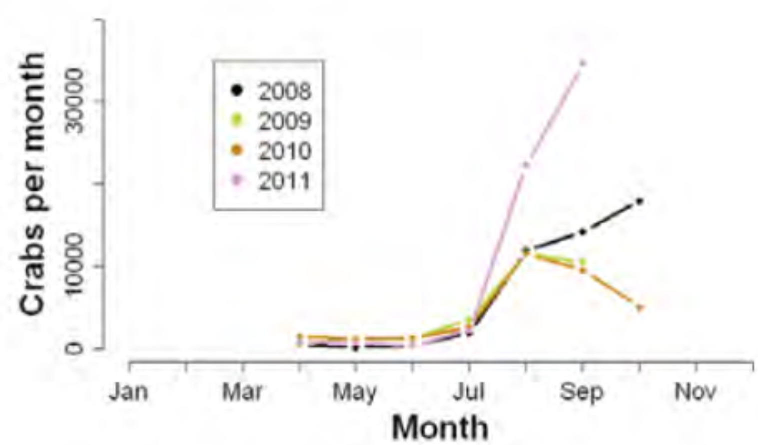

Figure 7.4. Estimated number of crabs harvested recreationally, by month and year from 2008-11, for TILLAMOOK BAY. Adapted from (Ainsworth et al. 2012)

. *Estimated monthly recreational crabbing trips in Netarts Bay (NS = not sampled).*

	2008	2009	2010	2011
April	299	333	434	553
May	406	559	467	694
June	285	267	455	510
July	360	1,928	1,240	1,042
August	801	1,612	2,745	1,297
September	930	1,664	2,767	1,924
October	1,871	NS	2,140	NS
Total (95% con. interval)	4,951 (3,485-6,418)	6,363 (5,001-7,724)	10,248 (8,131-12,364)	6,020 (4,666-7,375)

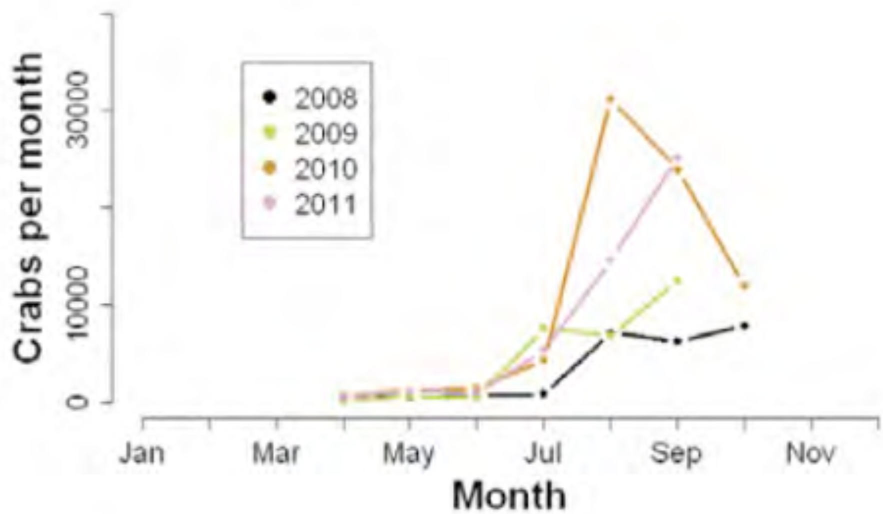

Figure 7.5 Estimated number of crabs harvested recreationally, by month and year from 2008-11, for NETARTS BAY. Adapted from (Ainsworth et al. 2012)

Estimated monthly recreational crabbing trips in Yaquina Bay.

	2007	2008	2009	2010	2011
Jan.	927	251	1,435	656	684
Feb.	923	644	1,127	1,397	645
Mar.	1,264	658	1,031	1,054	578
April	738	601	1,061	1,154	423
May	1,181	1,040	869	497	853
June	1,301	976	1,084	1,311	716
July	4,210	2,599	1,817	2,307	2,169
Aug.	2,617	2,285	1,966	2,240	1,927
Sept.	1,356	3,658	2,572	2,144	2,065
Oct.	4,038	3,506	2,161	3,730	2,125
Nov.	972	3,390	1,335	695	596
Dec.	406	474	1,126	566	936
Total (95% conf. inter-val.)	19,934 (13,879 - 25,988)	20,081 (15,628 - 24,535)	17,586 (13,851 - 21,321)	17,752 (13,927 - 21,577)	13,716 (10,648 - 16,748)

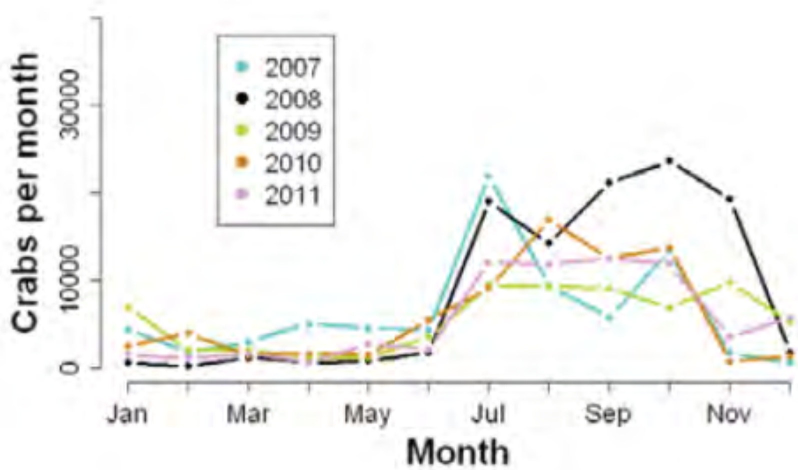

Figure 7.6. Estimated number of crabs harvested recreationally, by month and year from 2008-11, for YAQUINA BAY. Adapted from (Ainsworth et al. 2012)

Estimated monthly recreational crabbing trips in Alsea Bay.

	2007	2008	2009	2010	2011
Jan.	300	169	553	54	252
Feb.	400	163	275	295	90
Mar.	286	276	209	48	80
April	180	133	168	99	64
May	292	145	500	191	497
June	460	437	380	161	299
July	2,519	1,455	1,462	1,077	1,312
Aug.	2,613	3,724	2,109	2,721	2,055
Sept.	3,296	3,715	3,363	2,913	2,136
Oct.	3,077	3,306	2,821	1,719	2,503
Nov.	901	2,418	1,314	896	1,048
Dec.	486	675	773	577	1,221
Total (95% conf. inter-val.)	14,810 (9,698 - 19,923)	16,615 (13,059 - 20,171)	13,929 (10,775 - 17,082)	10,752 (8,318 - 13,186)	11,558 (8,951 - 14,269

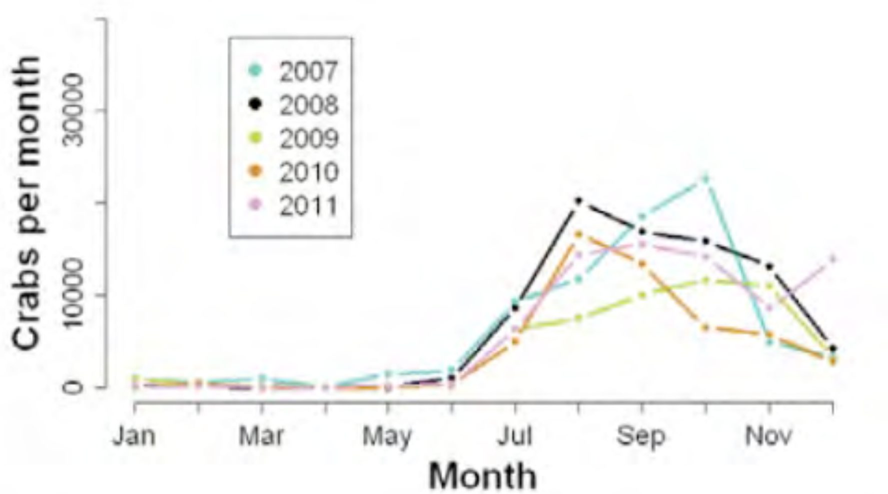

Figure 7.7. Estimated number of crabs harvested recreationally, by month and year from 2008-11, for ALSEA BAY. Adapted from (Ainsworth et al. 2012)

Estimated monthly recreational crabbing trips in Coos Bay (NS = not sampled).

	2008	2009	2010	2011
Jan.	NS	1,845	NS	1,530
Feb.	NS	NS	NS	NS
Mar.	351	1,329	319	928
April	683	1,143	359	375
May	877	864	1,000	920
June	638	663	1,153	874
July	1,834	2,033	2,021	2,000
Aug.	6,155	2,136	3,085	2,481
Sept.	3,468	2,572	2,476	2,671
Oct.	3,616	NS	2,126	2,431
Nov.	1,886	NS	NS	NS
Dec.	NS	NS	NS	NS
Total (95% conf. inter-val.)	19,507 (14,076 - 24,939)	12,584 (8,264 - 17,106)	12,540 (8,657 - 16,422)	14,209 (10,337 - 18,081)

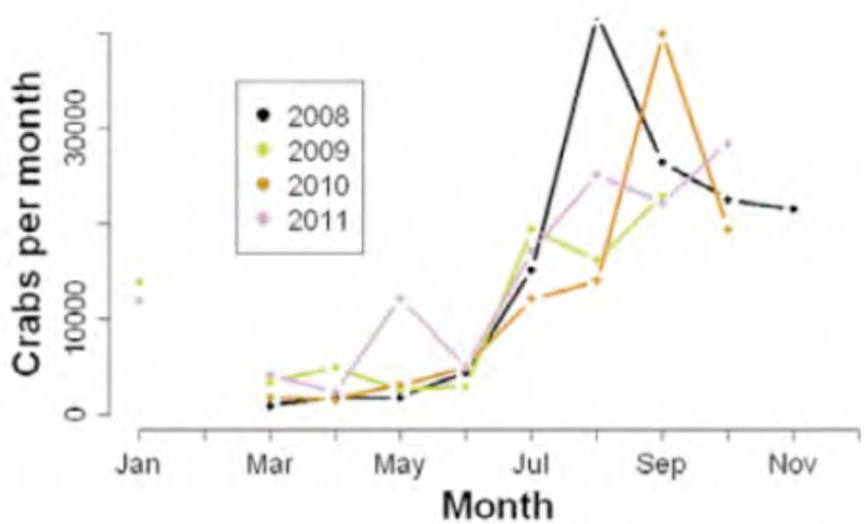

Figure 7.8. Estimated number of crabs harvested recreationally, by month and year from 2008-11, for COOS BAY. Adapted from (Ainsworth et al. 2012)

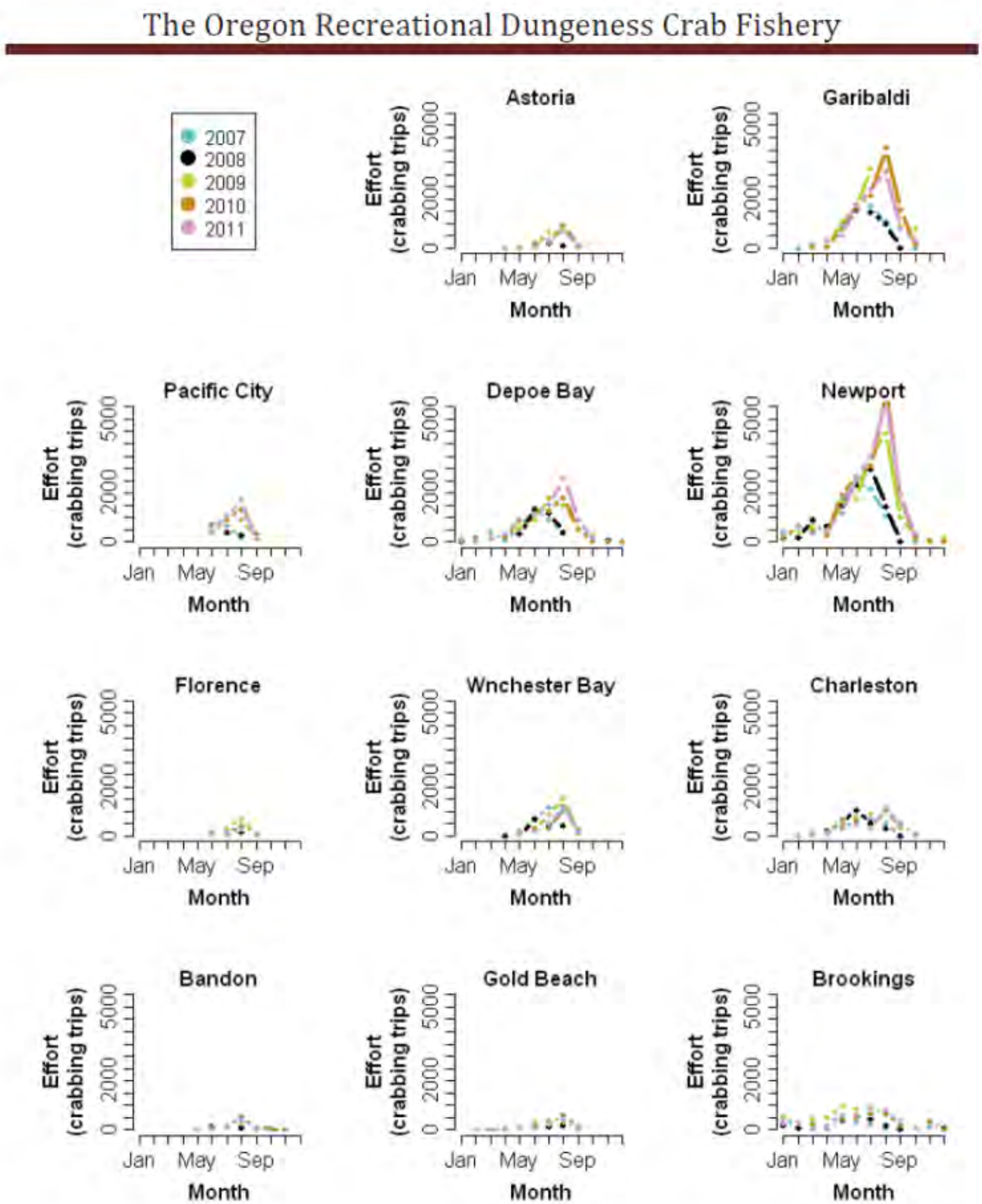

Figure 7.9. Estimated monthly recreational ocean crabbing trips, including charter and private boats (Ainsworth et al. 2012).

Recreational clamming is also a popular activity in Oregon estuaries. ODFW's SEACOR surveys (https://www.dfw.state.or.us/mrp/shellfish/seacor/maps_publications.asp) provide data on clam species presence and abundance for six estuaries (Tillamook, Netarts, Siletz, Yaquina, Alsea, and Coos) where significant recreational clamming occurs. From 2008 – 2012, ODFW conducted surveys of the number of recreational clam-digging trips to these bays with the exception of Alsea Bay (Table 7.11). The time periods covered for each bay differs. Surveys in Tillamook took place from April to August. Those in Netarts averaged a mean of 32% days annually. Yaquina Bay surveys started as early as January or February in some years and lasted through August. Coos Bay clammers were surveyed during the spring and summer, with an average of 33% of the potential survey days sampled.

Table 7.11. Number of recreational clam-digging trips for each of 4 estuaries in Oregon, 2008-2012. Data from ODFW's SEACOR program.

BAY	2008	2009	2010	2011	2012
Tillamook	9,832	9,818	6,207	6,134	11,018
Netarts	12,081	23,262	11,177	9,786	13,653
Yaquina	6,114	13,002	11,961	7,363	7,052
Coos Bay	13,598	15,428	13,030	11,113	9,729

The 2019 – 2023 Oregon Outdoor Recreation Plan ("Outdoor Recreation in Oregon: Responding to Demographic and Societal Change", https://www.oregon.gov/oprd/PRP/Documents/SCORP-2019-2023-Final.pdf) contains the results of a survey of 3,069 randomly selected Oregonians to assess their participation in outdoor recreation activities. Crabbing and clamming are included as a recreational activity, and an estimate of their economic value is included in Table 7.12.

Table 7.12. Estimate of the economic value of recreational crabbing and clamming activity in Oregon. Note: User occasions are the number of times individuals participated in outdoor recreation activities in 2017. An activity day is defined as one person recreating for some portion of a day. RUVD is the Recreation Use Values Database which is based on an extensive review of recreation economic value studies spanning 1958 to 2015 conducted in the United States and Canada

SCORP Activity	RUVD Activity	2017 SCORP User Occasions (million)	Activity Days per User Occasion	2017 Activity Days (million)	MRA RUVD Value/Person /Activity Day ($; 2018 USD)	Total Net Economic Value ($million; 2018 USD)
Crabbing	Shellfishing	1.858	2.496	4.638	$49.88	$231.324
Shellfishing / clamming	Shellfishing	1.012	2.496	2.527	$49.88	$126.057

Summary

As a keystone species, sea otters have inordinately large effects on marine ecosystems, which means that the socioeconomic impacts of sea otter recovery are correspondingly large. These effects are often disruptive to existing social and economic activities, although previous examples of sea otter recovery include both positive and negative impacts. The full range of effects are diverse; however, they can generally be classified into direct effects of sea otter predation (which are generally negative from a human perspective insomuch as they involve shellfish species that are harvested commercially, recreationally or as part of subsistence fisheries) and indirect effects that result from food web interaction pathways. Direct effects of sea otter predation are relatively easy to quantify and are often the first to be documented, in part because sea otter diets have the highest proportion of commercially valuable species during initial stages of recovery. In Oregon, invertebrate species which are fished commercially or recreationally, and which potentially would be affected by sea otter recovery, include: Dungeness crab, red rock crab, razor clams, butter clams, Gaper clams, littleneck clams, cockles, mussels, ghost shrimp, and red and purple sea urchins. Some of these fisheries represent hundreds of thousands of dollars annually, or even (in the case of Dungeness crab) tens of millions of dollars, thus the potential economic impacts of even a small reduction due to sea otter recovery are consequential. However, while for some of fisheries (e.g., urchin dive fisheries) there is good reason to project a substantial negative impact of sea otter recovery, in the case of others (e.g. crab, shrimp) it is far from clear whether there would be a negative impact, or how substantial such an effect would be. In the case of Dungeness crab, negative impacts were found to be associated with sea otter recovery in Alaska, while in California there were no measurable impacts associated with sea otter recovery, and in fact there was a positive correlation between sea otter recovery and crab landings.

Indirect effects are often more difficult to measure than direct effects as they involve complex suites of interactions with other species. In cases where indirect effects have been measured, they are often associated with reductions in herbivores and corresponding increases in primary producers (plants), which in coastal marine ecosystems include kelp and sea grass. Because kelp forests and eelgrass beds support many other species (including commercially valuable finfish species) and provide a variety of ecosystem services for people, these indirect effects of sea otter recovery are generally considered positive from a human perspective. In addition to supporting a variety of other fauna, kelp and eelgrass can influence human welfare by sequestering atmospheric carbon dioxide or reducing wave energy and thus stabilizing and protecting shorelines. Sea otters can also impact human welfare through wildlife viewing opportunities and the benefits that imparts on the ecotourism industry. Finally, it is important to recognize that monetary considerations are not the only way of measuring human values. Communities based around fishing activity provide many important non-monetary values to people. In the case of First Nations peoples, subsistence shellfisheries often provide cultural as well as economic value, while the return of sea otters to the ecosystem may also have cultural importance. Any assessment of socioeconomic impacts of sea otter recovery should therefore provide a comprehensive accounting of the social values of the relevant communities, including both monetary and non-monetary variables.

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Chapter 8: Administrative and Legal Considerations

Shawn Larson and M. Tim Tinker

Sea otters once occupied the Oregon Coast but have been absent from Oregon's nearshore for more than 100 years. The Elakha Alliance and others are actively working toward and anticipating the return of Oregon's sea otters. This is not only to restore sea otter populations into previously occupied habitat to increase connectivity of existing sea otter populations in Northern California and Southern Washington, but also to restore Oregon's nearshore coastal ecosystem functioning. However, reintroducing a marine mammal that is protected by international, federal, state, and tribal laws is not a trivial task and many statutory and regulatory processes would apply to such an effort. We present a summary of the related laws and processes below, with the caveat that any future reintroduction effort will ultimately fall within the jurisdiction of the relevant management authorities and be subject to the laws in place at that time. A more detailed description of Federal legal requirements and procedures has also been compiled by the US Fish and Wildlife Service (Zwartjes 2020), and should also be consulted. All relevant regulations must be followed, and approvals obtained from the relevant agencies prior to any actual reintroduction of sea otters to the Oregon Coast.

International protections

Sea otter populations have varied levels of protections, triggering different legal considerations. At the international level, the sea otter is listed as Endangered by the International Union for the Conservation of Nature (IUCN) due to decreasing populations in portions of its range and unknown effects of climate change (Doroff and Burdin 2015). The purpose of the IUCN Red List (IUCN 2020) is "to provide information and analyses on the status, trends, and threats to species in order to inform and catalyze action for biodiversity conservation." Sea otters are also managed internationally by the Convention on International Trade of Endangered Species (CITES), which specifies requirements for permits for international trade. Sea otters are classified taxonomically into three subspecies based on skull morphometric variation: the Russian sea otter found in Japan and Russia, *Enhydra lutris lutris*; The northern sea otter found throughout Alaska, British Columbia and Washington, *E. l. kenyoni*; and the southern sea otter found in California, *E. l. nereis* (Wilson et al. 1991). There are no behavioral or ecological differences between the subspecies nor is there genetic data supporting subspecies to date (Cronin et al. 1996; and Larson, unpublished data). However, there are three distinct genetic stocks in Alaska as recognized under the Marine Mammal Protection Act (MMPA, 1972): a Southwest stock (SW) including the Aleutian Islands, the Alaska Peninsula, the Katmai peninsula, and Kodiak Island; a Southcentral (SC) stock including Prince William Sound, the Kenai Peninsula, and Cordova; and a Southeastern (SE) stock including the Alexander Archipelago (USFWS 2013) (See Table 1).

The southern sea otter is a CITES Appendix-I list species that lists the most endangered species among CITES-listed animals and plants (https://cites.org/sites/default/files/eng/app/2020/E-Appendices-2020-08-28.pdf). Species on CITES Appendix-I are described as "threatened with extinction" and CITES prohibits international trade in specimens of Appendix-I species except when the purpose of the import is not commercial, including for scientific research. In the case of research, international trade may take place provided it is authorized by the granting of both an import permit and an export permit (https://cites.org/eng/app/index.php). The northern sea otter and the Russian sea otter are Appendix-II list species that are listed as "not threatened with extinction now but that may become so unless trade is closely controlled". International trade in specimens of Appendix-II species may be authorized by the granting of an export permit with no import permit required. Permits or certificates will only be granted if the relevant authorities are satisfied that certain conditions are met, above all, that trade will not be detrimental to the survival of the species in the wild. A CITES permit would only be required if the founders for an Oregon reintroduction were internationally sourced from outside of the United States (for example, if animals were proposed for translocation from Canada to Oregon). CITES would not apply if sea otters were moved between States (Alaska, Washington, Oregon, and California), although other permits and authorities would apply, as described below.

Federal management and protections

Sea otters are managed in the United States at the federal level by the United States Fish and Wildlife Service (USFWS), along with the other nearshore marine mammals such as polar bears, walruses, manatees, and dugongs. The more pelagic marine mammals, such as seals and sea lions (pinnipeds) and all whales and dolphins (cetaceans), are federally managed by the National Oceanic and Atmospheric Association (NOAA). The MMPA protects all sea otters on the high seas and in waters or on lands under the jurisdiction of the United States. In addition, Endangered Species Act ((ESA) 1973, 16 U.S.C. 1531 et seq.) protections apply to the southern sea otter subspecies in California, (listed as threatened under the ESA in 1977; 42 Federal Register 2965) and to the Southwestern Alaskan Distinct Population Segment (DPS) of the northern sea otter in southwest Alaska (SW stock listed as threatened under the ESA in 2005;70 Federal Register 46366). Further details about listing status for each of these threatened populations or stocks of sea otters can be found in the recovery plan documents for the southern sea otter (USFWS 2003) and the SW Alaska stock (USFWS 2013).

The MMPA applies to all marine mammals and those protections remain in place regardless of whether the animal is listed under the ESA. Any species of marine mammal that is listed under the ESA has the protections of that statute in addition to those provided by the MMPA, but those ESA protections remain in place only if the stock is listed. In considering the reintroduction of sea otters to Oregon, the ESA would come into play only if an ESA-listed subspecies or DPS (southern sea otter or SW Alaska stock of sea otters) were to be involved as a possible source population, as described below.

MMPA

The MMPA prohibits, with certain exceptions, the "take" of marine mammals by any person, vessel, or other conveyance on the high seas, or in waters or on lands under the jurisdiction of the United States, and the importation of marine mammals and marine mammal products into the US. “Take” under the MMPA is defined as “to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal.”

Take that is incidental to an otherwise lawful activity (“incidental take”) may be allowable in certain situations, provided that the MMPA’s requirements are met. For example, Section 118 of the MMPA governs the taking of most marine mammal species incidental to commercial fishing operations. However, Sections 101(a)(5)(E)(vi) and 118(a)(4) of the MMPA specifically prohibit the incidental taking of southern sea otters for the purpose of commercial fishing, regardless of where those otters occur or their listing status. Under the current provisions of the MMPA, if southern sea otters were translocated to Oregon, there would be no exemption for incidental take through commercial fishing operations. States may not enact or enforce any law that attempts to override protection of marine mammals under the MMPA within the State (16 USC 1379: “(a) State enforcement of State laws or regulations prohibited without transfer to State of management authority by Secretary"). Finally, a permit would be required under the MMPA to take sea otters out of the wild, or to handle, transport, and reintroduce sea otters, regardless of origin (e.g., from a rehabilitation facility) (MMPA 3-200-43). The reintroduction of sea otters to the Oregon coast could be eligible for a permit if it would "enhance the survival or recovery of a species," in accordance with subsection 104(c) of the MMPA. These permits are issued by the USFWS Division of Management Authority.

One of the goals of the MMPA is to ensure that "stocks" of marine mammals occurring in waters under the jurisdiction of the United States do not have a level of human-caused mortality and serious injury that is likely to cause the stock to be reduced below its optimum sustainable population (see Chapter 3). Section 117 of the MMPA provides for the development of stock assessment reports (SARs), which are used to evaluate the progress of commercial fisheries towards achieving the goal of zero mortality and serious injury to marine mammals. There are four recognized stocks of sea otters under the jurisdiction of the USFWS, the southern sea otter and three stocks of northern sea otter (see Table 1). If a stock is listed under the ESA, it is also considered a "depleted" stock as well as a "strategic" stock under the MMPA (16 U.S.C. 1362, Sec. 3(1)).

NEPA

Any permit issued by a Federal agency requires an evaluation under the National Environmental Policy Act of 1969 (NEPA). NEPA requires that Federal agencies assess the environmental effects of their proposed actions prior to making decisions and is required for any Federal action that has the potential to significantly affect the quality of the human environment (and "human environment" is interpreted very broadly). In some cases, such permits are covered under a standard "categorical exclusion" provision, because they are routine and not likely to result in any significant effects. In this case, the issuance of a permit by USFWS for the reintroduction of sea otters under the MMPA (and possibly the ESA as well) would trigger a more rigorous evaluation under NEPA. The USFWS would prepare either an Environmental Assessment (EA) or an Environmental Impact Statement (EIS) under NEPA due to the potentially significant effects of the action on the environment, including ecosystem changes that co-occur with a healthy and sustainable sea otter population (Chapter 5) based on scientific knowledge from past sea otter population expansions and reintroductions (Chapter 2). The EA or EIS would evaluate the environmental and related social and economic effects of a reintroduction of sea otters into Oregon (e.g. Chapter 7) and provide opportunities for public involvement[1].

ESA

The selection of an ESA-listed population as a source of individuals for a reintroduction would involve some additional legal considerations. One requirement that would come with the ESA is a recovery and interstate commerce permit, issued by the USFWS under section 10(a)(1)(A) of the ESA (this permit allows for" take" as part of activities intended to foster the recovery of listed species, and allows for transport of listed species across state lines). This permit would be required for the capture, handling,

[1] The NEPA process involves several steps: 1) scoping, which identifies the issues to be addressed in the review and can be accomplished through a public comment period and/or public information meetings or hearings; 2) draft EA or EIS, followed by public comment; and 3) final EA or EIS, followed by a Record of Decision If significant changes are made between the draft and final stages, a supplemental EA or EIS may be required.

and transport of any individuals of a listed species during the translocation and any follow-up veterinary care or monitoring.

Section 7(a)(2) of the ESA requires federal agencies to consult with USFWS and/or NMFS to ensure that any action they authorize, fund, or carry out is not likely to jeopardize the continued existence of an ESA-listed species or result in the destruction or adverse modification of designated critical habitat. For example, the issuance of any permits by the USFWS would be authorizing an action and would thus be subject to Section 7 consultation requirements. In this case, the USFWS would have to determine whether reintroducing sea otters into a specific area will affect other listed species or critical habitat, and if so, whether it will jeopardize the continued existence of those species or adversely affect critical habitat. In cases where it is determined that an adverse effect is likely, a biological opinion would be required under section 7(a)(2) of the ESA prior to any action. If an ESA-listed population of sea otters were under consideration as a source for reintroductions, then this consultation requirement would apply to that population as well (the USFWS would have to complete an intra-Service consultation to ensure that removing individuals from that listed population would not jeopardize its continued existence).

If a reintroduction of sea otters to Oregon involved a source population that was listed under the ESA (e.g., southern sea otters), public apprehension about any regulatory restrictions that might come along with such an action could be addressed through the designation of the newly established population as a “non-essential, experimental” population. This designation requires a regulatory rulemaking, which would begin with a proposed rule to establish an experimental population of sea otters under Section 10(j) of the ESA. Section 10(j) of the ESA provides that the USFWS may authorize the release of an endangered species or a threatened species outside its current range, but within its historical range, upon a finding that the release will further the conservation of the species. The experimental population must be wholly separate geographically from non-experimental populations of the same species. The establishment of an experimental, nonessential population means that there is added flexibility for “take” prohibitions, which can be tailored to the conservation needs of the population. In most cases, such rules provide that legal incidental (accidental) take of the species would not be considered a violation of the ESA.

NEPA compliance is also required for the establishment of an experimental population under section 10(j) of the ESA, as it is a Federal action with the potential to significantly affect the quality of the human environment. If listed animals are contemplated as part of the reintroduction, a single NEPA process, as described above, can include consideration of both the reintroduction and the establishment of a nonessential experimental population. NEPA will also need to take into account potential impacts on the source populations.

CZMA

Finally, at the federal level, there is the Coastal Zone Management Act of 1972 (“CZMA”; 16 U.S.C. 1451) The CZMA states that it is national policy to preserve, protect, develop, and where possible, to restore or enhance, the resources of the national’s coastal zone for this and succeeding generations. The CZMA also provides for the development of State coastal zone management plans. Section 307 of the CZMA calls for consistency between Federal activities and State management programs and requires that each Federal agency activity within or outside the coastal zone that affects any land or water use or natural resources of the coastal zone shall be carried out in a manner which is consistent to the maximum extent practicable with the enforceable policies of approved State management programs. The Federal agency must provide a "consistency determination" in the form of a certification that the proposed action is consistent with any such enforceable policies to the relevant State agency; this applies to any applicant for a required Federal permit or license that may affect any land or water use or natural resource of the coastal zone (e.g., an application for a permit under MMPA). The certification is made available for public notice and comment, and the State must notify the Federal agency if it concurs with or objects to the applicant's certification.

State management and protections

Three states in the USA have sea otter populations that could be used as source populations for the Oregon translocation: Alaska, Washington, and California. Each has different management considerations.

Alaska – All sea otter pups brought into rehabilitation facilities from the wild are immediately deemed non-releasable by USFWS as there is no facility in Alaska that currently has the capability to rear and release stranded pups; thus, they cannot be considered as a potential source for reintroductions. Permission to capture and transport adult sea otters from Southeast (SE) Alaska, which supports a large and rapidly growing sea otter population (the largest in the United States) would be required via a USFWS permit, as discussed above. Strictly speaking, the State of Alaska does not have management authority over sea otters, but the USFWS and the State would likely work together coordinating any potential removal of sea otters from Alaska. Other sea otter populations such as those in Prince William Sound and the Katmai and Kenai Peninsulas could also be potential sources for translocations; however, their populations are not as large as that in SE Alaska and a translocation might cause a greater impact to the source population (see Chapter 3). As discussed above, the SW Alaska stock of northern sea otters is listed under the ESA as threatened and continues to experience severe declines, thus it is unlikely to serve as a viable source of animals for translocation.

Washington – Washington has a growing translocated population that spans the central and northern portions of the outer coast. The population is co-managed by USFWS and the state and is not federally listed under the ESA but is listed as threatened by the State of Washington. The population growth rate has averaged approximately 9% per year (Jeffries et al. 2017) and is thought to be mixing genetically with the Vancouver BC population (Larson et al. 2021). However, the Washington population is still believed to be well below its potential carrying capacity (Hale et al. in review), and there are large areas of unoccupied habitat in the southern Washington Coast. Thus, the demographic impacts of removing animals from this population would need to be considered carefully (Chapter 3).

California – There are two potential ways that California sea otters could be utilized as a source for an Oregon reintroduction. The first is that wild animals could be captured from the mainland population, as was done for the San Nicolas translocation (Rathbun et al. 2000); however, given that this population is listed under the ESA as threatened, this would entail some additional administrative hurdles (as described above) and could negatively impact the population (Chapter 3). The second way California could serve as a source population is via surrogate-raised juveniles (i.e., live-stranded pups raised by captive females), as those animals are deemed releasable, and their use would not affect the wild population. However, using source otters from California would still entail ESA permits/restrictions, although employment of section 10(j) of the ESA (establishing an experimental population, as described above) could relax some of these restrictions. Sea otters in California are also listed as a "Fully Protected

Species" under State Law, and thus consultation with the California Department of Fish and Wildlife (CDFW) would also be required.

Oregon – The Oregon Department of Agriculture Animal Health Unit would require an entry permit for any sea otter brought into Oregon's waters: specifically, a health certificate would be a prerequisite for each animal (Oregon Administrative Rules 603-011-0382). Under current State law (Oregon Administrative Rules 635-062-0020) the rehabilitation of marine mammals is expressly prohibited (unless specifically authorized by the USFWS or NOAA NMFS). Thus, the rehabilitation of stranded sea otters would be technically prohibited under State law. This could be addressed through either a change to the language of Division 62 of the Oregon Administrative Rules, creating a special exception for sea otters, or by pursuing the avenue of "specific authorization" under the existing law. The sea otter is listed as threatened under the Oregon State Endangered Species Act (Oregon Revised Statutes 496.171-496.192) although sea otters do not currently occur on the Oregon coast.

Tribal law considerations

Each tribal government within the range of a potential reintroduced population should be consulted as to their specific laws or policies governing the reintroduction and management of sea otters in and adjacent to Tribal lands and waters.

Table 1-International and federal protections of recognized sea otter subspecies and stocks

Common Name	**Subspecies**	**Stock (MMPA) or DPS (ESA)**	**CITES**	**MMPA**	**ESA**
Russian Sea Otter	*E.l. lutris*	NA	Appendix II[1]	Protected	--
Northern Sea Otter	*E.l. kenyoni*		Appendix II[1]	Protected	--
		Southwest Alaska Stock/DPS		Protected/Strategic Stock	Threatened DPS
		Southcentral Alaska Stock		Protected/Non-Strategic Stock	--
		Southeast Alaska Stock		Protected/Non-Strategic Stock	--
Southern Sea Otter	*E.l. nereis*	Southern Sea Otter	Appendix I[2]	Protected Strategic Stock	Threatened Subspecies

[1]Appendix II – International trade is controlled

[2]Appendix I – International trade is prohibited, unless under certain circumstances for research

Conclusions

Reintroducing a marine mammal that is protected by international, federal, state, and tribal laws requires careful consideration, planning and documentation of legislation including acquisition of multiple permits. Internationally there are CITES permits required for trade between countries. In the USA sea otters are managed at the federal level by the USFWS and are protected under the MMPA. The southern sea otter subspecies and the southwestern stock of the northern sea otter subspecies are listed as threatened under the ESA and thus are further protected requiring more federal permits and regulations. A reintroduction of sea otters from non-ESA listed stocks within the United States, such as sea otters in southeast Alaska or Washington, would require the least regulatory oversight and legal/permitting complexities; however, even for these non-ESA listed source populations, a reintroduction would still require extensive documentation and permits under federal law, as well as careful adherence to state laws and regulations as well as local ordinances and First Nations tribal laws. Thus, any future reintroduction proposal should factor in the necessary effort and time required for consultation and permit acquisition.

Information Resources

Convention on International Trade in Threatened and Endangered Species (CITES)
http://www.cites.org/

Federal Register Notice: Termination of San Nicolas Island Sea Otter Translocation Program
https://www.fws.gov/ventura/docs/frnotices/77%20FR%2075266.pdf

Endangered Species Act of 1973
https://www.fws.gov/endangered/esa-library/pdf/ESAall.pdf

Marine Mammal Protection Act of 1973
https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-protection-act

Marine Mammal Protection Act – Permits
https://www.fws.gov/international/animals/marine-mammals.html

NEPA flowcharts
https://www.usbr.gov/gp/nkao/ainsworth/flowcharts.pdf

Oregon Administrative Rules 635-062-0020
https://oregon.public.law/rules/oar_635-062-0020

Oregon Coastal Zone Management Plan – enforceable policies
https://www.oregon.gov/lcd/ocmp/pages/enforceable-policies.aspx?utm_source=LCD&utm_medium=egov_redirect&utm_campaign=https%3A%2F%2Foregon.gov%2Flcd%2Focmp%2Fpages%2Focmp_enforceable-policies.aspx

Oregon Department of Agriculture Animal Health Unit
https://www.oregon.gov/ODA/programs/AnimalHealthFeedsLivestockID/Pages/AnimalImportExport.aspx

Public Law 99-625
https://www.govinfo.gov/content/pkg/STATUTE-100/pdf/STATUTE-100-Pg3500.pdf

Secretarial Order No. 3355
https://www.doi.gov/sites/doi.gov/files/uploads/3355_-_streamlining_national_environmental_policy_reviews_and_implementatio.pdf

Threatened and Endangered Species Permits
https://www.fws.gov/endangered/permits/index.html

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Chapter 9: Implementation and Logistical Considerations

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Introduction

Based on a review of the history of sea otter translocations (Chapter 2), and our current combined knowledge and experience with the capture, holding and transport of sea otters, we have prepared an analysis of two general strategies for the reintroduction of sea otters to the waters of Oregon. One follows the strategy employed by all but one historic reintroduction and consists of the simultaneous release of groups of animals into vacant, but previously occupied exposed or semi protected coastal habitats (Jameson et al. 1982). The other strategy follows a recently-described procedure of sequential reintroduction of single or small groups of sea otters over several years into an estuary (Mayer et al. 2019)[1]. We wish to emphasize that these two strategies are not mutually exclusive, and a combination of the two may be most appropriate. For each strategy we provide the underlying rational and discuss the pros and cons. The presentation of alternative strategies is intended to provide a broad range of possibilities to consider. We begin by describing factors that should be considered when selecting a release site, followed by a review of alternatives for selection of source or donor populations. Depending on release strategies and source population alternatives, the capture/holding and transport, and to some extent, release and monitoring protocols may differ. Those differences and similarities will be presented and discussed in each release strategy and source population alternative.

Various factors require consideration in evaluating the potential suitability of release sites for successfully reintroducing sea otters into Oregon, either along the open coast or into estuarine habitats. These include: 1) suitable and appropriate habitats, 2) availability of appropriate and sufficient prey, 3) access to suitable resting habitats, either protected waters or canopy forming kelps, and 4) refuge from disturbance or sources of injury or mortality. We will briefly consider each of these habitat requirements in the discussion below, as is related to potential sea otter release strategies: a more comprehensive assessment of habitat suitability is provided in Chapter 6 of this report.

The present distribution and abundance of sea otters in the coastal north Pacific suggests that all coastal habitat types less than about 50 m in depth represent potential habitats for sea otters, but also that all habitat types do not support equal densities of sea otters. It has generally been regarded that exposed rocky reef habitats support greater densities than open coast sand coastlines (Kenyon 1969, Riedman and Estes 1990), with reported densities in rocky habitats in California more than 5 times greater than along sandy shoreline (Laidre et al. 2001, Tinker et al. 2021). However, relatively high densities of sea otters can be found in mixed substrate habitats, particularly along complex shorelines that provide sheltered habitats, including bays, lagoons, sounds and estuaries. Examples of such include Kachemak Bay, Prince William Sound, Izembek Lagoon, and Glacier Bay in Alaska, and Barkley Sound in British Columbia (Bodkin 2015). Sea otter densities along high energy, sandy shores typical of much of Oregon and Washington are generally lower than densities in other coastal habitats (Kone et al. 2021, Tinker et al. 2021), and may represent a less-preferred habitat type. It should be recognized that even in these less-preferred habitats, high sea otter densities may be achieved during the process of colonization

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[1] The published example of estuarine release was Elkhorn Slough, an estuarine habitat in California that was already occupied by sea otters (although these were mostly male otters and at a density well below the local carrying capacity), and which therefore might reflect a different outcome than a similar release to an unoccupied estuary in Oregon.

resulting from elevated prey abundances achieved during the otters' absence, but that otter densities may subsequently become reduced as the highest quality prey become depleted. It is also worth noting that there is historical evidence from the fur harvest records that sea otters may have been relatively less abundant along the Oregon coast than either further north or south (Ogden 1941), although a more recent analysis by Kone et al (2021) suggests that Oregon coastal habitats could still support over 4000 sea otters.

Our primary goal in this Chapter is to identify options for reintroduction of sea otters to Oregon that will maximize the potential for the successful establishment of a self-sustaining population (Chapter 3) while minimizing potential conflicts with humans over competition with sea otters for marine resources (Chapter 7) and potential threats from human activities.

General Strategies

Open Coast. Traditional open coast release site(s) with on site, short-term holding pens.

Historically, most sea otter reintroductions were comprised of animals captured, transported, and released into exposed or semi-protected ocean coastal habitats where sea otters had occurred historically but had been absent for decades to a century or more (see Chapter 2). In part, this approach resulted from the fact that the only sea otters that survived the maritime fur harvest occurred in small groups along open exposed coastlines where human harvest may have been somewhat restricted. This strategy of exposed capture locations in early reintroductions was thus largely predicated on where surviving populations persisted, which created the perception of sea otters as an "exposed open coast" species. The rational used to determine exactly where translocated sea otters would be released is less clear from historical information and published accounts. In most, if not all cases, logistics based on methods of transport would appear to have dictated feasible release locations.

Despite the failure of the initial reintroduction of sea otters to Oregon, suitable habitat for sea otters exists over much of the Oregon coast, although not all habitats in Oregon should be considered equivalent (Jameson 1975, Kone et al. 2021). Much of the north coast of Oregon consists of exposed sandy beach habitats that are likely to support low densities of sea otters. Prevailing thought and literature consider rocky reefs with canopy forming kelps as preferred habitats, supporting relatively high densities (4 - 6 otters per km2) of sea otters (Laidre et al. 2001, Tinker et al. 2021). Additional habitats include exposed unconsolidated substrates (sand or cobble shores) and protected estuarine habitats. Kone et al. (2021) suggest that the Oregon coast could support about 4,500 sea otters (range 1742 – 8976), with most of those along the outer coast in rocky reef habitats, but with more than 650 occurring in estuaries. Spatial and temporal variation in the potential densities of otters that could be supported in each area is likely related to differences in prey availability and productivity, as well as differences in access to sheltered habitat (e.g., kelp beds, nearby estuaries) for resting and pup rearing. Based on other reintroductions and examples of sea otter recovery, achieving carrying capacity in Oregon will be a prolonged process as sea otters demonstrate high fidelity to small home ranges and affinity to conspecifics. More detailed analyses are provided elsewhere in this report of the dynamics of population growth and recovery (Chapter 3) and habitat suitability along the Oregon coast (Chapter 6).

Perhaps the primary lesson to be learned from the history of past reintroductions is that a relatively small percentage of sea otters are likely to stay or become quickly established near where they are released (see Chapter 2). This was the case in the initial Oregon release, but also in all other open coast release attempts (excepting perhaps portions of southeast Alaska), despite the presence of abundant and preferred prey and proximity to established kelp beds. It may be possible to improve retention of sea otters near release sites through temporary holding in large anchored net pens, although this technique has not been fully demonstrated. Animals at San Nicolas were initially held in anchored net pens, in an attempt to achieve improved retention, but deteriorating sea condition required premature release. Any open-coast "soft release" of sea otters using net pens is likely to be exposed to harsh and unpredictable sea conditions, and thus should be carefully considered.

It also seems likely that prior reintroductions to outer rocky coasts consisted of animals that had strong affinities to the home range they were removed from, although there is little data on age and sex composition in most reintroductions. This is evident from the rapid diminishment in abundance post release, and the resighting of marked animals that returned to original capture locations in an experimental relocation within California (Odemar and Wilson 1969) and again later during and following the San Nicolas Island translocation (Rathbun and Benz 1991, Rathbun et al. 2000, Carswell 2008). Evidence of a similar trend of post-release movements presented in Southeast Alaska, where southern reintroductions diminished in numbers while in the north numbers increased and population growth occurred shortly after the final reintroduction (Pitcher 1989, Esslinger and Bodkin 2009). It may be possible to improve retention through the selection of juvenile sea otters before they establish home ranges or establish long term social bonds. Such an approach has proven feasible in estuarine habitat through the surrogate rearing of stranded pups in California (Mayer et al. 2019), but has not been tested in open coastal or unoccupied habitats.

The general strategy that has proven most successful in establishing open coast populations of sea otters has been the release of large numbers of individuals at multiple release sites over several years. This is best exemplified in the reintroduction of 403 sea otters over 5 years into 6 separate areas of southeast Alaska (Esslinger and Bodkin 2009) that ultimately resulted in 3 or possibly 4 distinct populations across coastal Southeast Alaska. Annual rates of increase by 1987-88, about 20 years after the final reintroduction, averaged about 20% per year, and total abundance had approached 5,000 sea otters (Pitcher 1989, Tinker et al. 2019a). It is possible that the loss rate to emigration or mortality in the southeast Alaska reintroductions may have been less than in the more southern efforts, as animals dispersing from one release site may have encountered otters from another release. It is also possible that high reproductive output of animals at some release sites compensated for lower survival at others, thus explaining early increases in regional abundance. Unfortunately, lack of detailed post-release tracking of animals in southeast Alaska makes it impossible to assess either of these hypotheses with certainty.

Estuarine. Longer term temporary estuarine holding facility at release site

Broadly defined, estuaries are partially enclosed and protected bodies of water that interface the oceans sea water, with the fresh water that drains the continents. Such habitats occur throughout the sea otters' range in the North Pacific. Because no populations that occupied estuaries survived the fur harvest, early work describing sea otter habitats (Barabash-Nikiforov 1947, Kenyon 1969) focused on open coast habitats, largely failing to recognize estuaries as important to sea otters. However, archeological evidence obtained from estuaries in Oregon and Washington (Moss and Losey 2011) and San Francisco Bay (Broughton 1994) identify sea otter as a predominant marine mammal remain in estuarine habitats, thus establishing estuaries as suitable and historically important habitats (Silliman et al. 2018). As sea otters have expanded their distribution through recolonization and translocation, we find they have occupied such habitats as they are encountered (Kvitek and Oliver 1988). These include small estuaries, such as Clam lagoon on Adak Island in the Aleutian archipelago (Tinker and Estes 1996), Izembek Lagoon, one of Alaska's largest estuaries (384 km^2) on the Alaska Peninsula, Orca Inlet in Prince William Sound (Bodkin et al. 2002, Coletti 2006), and Glacier Bay in SE Alaska, which supports in excess of 10,000 sea otters (Tinker et al. 2019a). As sea otters have expanded their range in California, they too have occupied the estuaries in Morro Bay and Elkhorn slough (Hughes et al. 2019), and Hughes et al. (2013) describe the role of sea otters in restoring the health of eelgrass beds in this estuary. Most recently, the Monterey Bay Aquarium with assistance from collaborators merged the complementary objectives of the rescue and rehabilitation of stranded juvenile sea otters, with the reintroduction of those animals into under-utilized habitat into the Elkhorn Slough within Monterey Bay (Mayer et al. 2019). This work in Elkhorn slough provides example of a previously unused strategy for release of reintroduced sea otters that potentially increases the low retention rate observed in most open coast releases.

Estuarine habitats clearly can provide suitable and abundant prey as well as adequate resting and pupping habitats (Eby et al. 2017, Espinosa 2018, Hughes et al. 2019). In addition, in some situations they can provide refuge from some large marine predators, such as killer whales (Estes et al. 1998) and possibly large sharks (Tinker et al. 2016). The recognition of estuaries as important sea otter habitat, and the success in supplementing an estuarine population using small numbers of rehabilitated juveniles, should be considered in reintroducing sea otter to the coast of Oregon. The details of the Elkhorn Slough reintroduction are important and distinctions from open coast releases require consideration. First, Elkhorn Slough had already been occupied by sea otters for several decades at the time that the reintroduction of juveniles began, although in numbers that were well-below carrying capacity (Tinker et al. 2021), and mostly by males with no intrinsic reproduction (Mayer et al. 2019). This example suggests that the presence of sea otters where releases occur may provide incentive for newly released individuals to remain. If this is true, then efforts to establish some presence of sea otters at a proposed release site may be facilitated by the enclosed nature of the estuary compared to the open coast, perhaps using net pens or other enclosures as a temporary measure to encourage residence. Second, it must be noted that the success of the Elkhorn Slough reintroduction required the recapture of most animals, for health or behavior reasons, some up to 4 times (Mayer et al. 2019). Thus, the ability to recapture animals that display stress or aberrant behaviors may be essential when translocating surrogate raised pups. Recapture is much more feasible in the protected waters of an estuary compared to the open coast. It may be possible that a captive population in a large, enclosed area within an estuary might mimic this situation.

Demographic considerations

Establishing the number and source of sea otters, as well as their age and sex composition and release sites in Oregon, will be critical in formulating a reintroduction plan. A web-based tool for evaluating many of these variables has been developed as part of this feasibility study (ORSO, Oregon Sea Otter Model), and is described in Chapter 3 (and see Appendix A). To demonstrate the feasibility of a proposed reintroduction plan, we somewhat arbitrarily consider a target of achieving an average population abundance of 200 animals after 30 years, with a 90% probability of at least 50 individuals by this time. Using the ORSO web app, we show that this might be achieved using a strategy of two release sites – one open coast site near Port Orford and one estuary site in Coos Bay – with an initial introduction of 50 animals near Port Orford and 25 individuals in Coos Bay, and supplementary additions of 3 juveniles per year for 10 years following the initial release. Another possible release strategy could entail successive reintroductions with close monitoring of numbers, movements and age and sex composition to determine when and where subsequent release occur, until the desired founding population size, distribution, and growth rate is achieved. Such a strategy could (and should) incorporate a range of inputs and considerations from a broad base of relevant stakeholders and community groups.

We note that there are several demographic and logistical considerations that should factor into a decision of one vs. multiple release locations. Clearly there would be greater logistical and financial costs associated with multiple release sites, which argues in favor of a single location. On the other hand, multiple release sites might act as an insurance policy against failure of one of the releases, thereby reducing the overall failure risk of the reintroduction program. Perhaps more importantly for the long-term success of a reintroduction is the fact that having two or more “nodes” of population growth can greatly increase the overall rate of population recovery, due to the combination of local density-dependent population regulation and the limited potential for range expansion in sea otters (Tinker 2015). This phenomenon is perhaps most clearly demonstrated by the rapid rate of recovery in southeast Alaska, which was facilitated by having several spatially distinct nodes of population growth, resulting from multiple release sites (see Chapters 2 and 3 of this report, and Bodkin 2015, Tinker et al. 2019a). The demographic consequences of multiple nodes of population growth may be even more dramatic in the case of a narrow, “one-dimensional” coastline such as Oregon or California, where the rate of population growth and range expansion is constrained by the linear configuration of habitat (Tinker 2015). At the same time, the potential for more rapid growth and colonization must be weighed against the potential social and economic impacts at the different prospective release locations (see Chapter 7 of this report).

Source population considerations

Several options for source populations for reintroduction to Oregon exist, including Southeast Alaska, Washington, and California. Each of these, singularly or in combination, will entail consideration of existing state and federal law (Chapter 8), implications for source populations and their management (Chapter 3), population genetics (Chapter 4), as well as logistical factors. In the following paragraphs we consider primarily the logistical considerations but include relevant information on history and biology of source populations wherever beneficial. Note that, because of legal complexities associated with transporting sea otters across international boundaries, we do not consider British Columbia sea otters as a likely source population, despite their abundance (> 8,000) and proximity to Oregon. Other than these administrative challenges, we note that sea otters from British Columbia would seem to be highly suitable as a source for reintroduction to Oregon.

Sea otters that reside in Washington would appear to provide the most immediate source for the open coast reintroduction to Oregon, based on their abundance, proximity, and state protected status, and under the assumption that the state of Washington and the USFWS would be cooperative. Washington sea otters currently number approximately 3,000 individuals and occupy about 100 km of coastline south of Cape Flattery. Their long-term rate of change is approximately 10% annually (Jeffries et al. 2017), a rate reduced from the early years of recolonization (Bodkin et al. 1999) but continuously positive. Annual removals of 100 individuals would represent approximately 3% of the population and 33% of the annual growth increment in the Washington population, sufficient to have a measurable impact on growth but probably not sufficient to cause a decline (see Chapter 3 for a more in-depth analysis). Transportation of animals captured in Washington would be relatively straight forward and consist primarily of transport by air-conditioned vans or trucks from a port such as La Push to temporary holding facilities in Oregon (see below) via interstate highway. It is also likely that the habitats occupied by sea otters in Washington most closely resemble those that sea otters will experience in Oregon. However, sea otters in Washington presently occupy habitats that are often exposed to sea surface conditions that render capture difficult and possibly hazardous to both otters and humans. This could result in a prolonged effort to capture the targeted number of animals. In addition, the proximity of a release site to animals captured in Washington may serve to encourage sea otters to return to their home range. The potential for this latter eventuality is speculative, but suggested by some prior translocation efforts within their established range in California (Odemar and Wilson 1969).

It is also possible that the state of Alaska would be a willing donor of sea otters to a reintroduction effort into Oregon. Southeast Alaska likely supports 30 - 40 thousand sea otters in 2020, occupying 1000's of km of coastline (Tinker et al. 2019a): annual removals of 100 animals would have no measurable effect on population viability at the regional scale, and would also be sustainable at a sub-regional scale depending on specific locations of captures (see Chapter 3). Transporting a large number of sea otters to Oregon from Alaska would entail additional effort requiring the use of air transport, and thus additional costs. However, the abundance of sea otters and protected nature of the habitat occupied in Southeast Alaska would likely entail reduced capture effort and risks, possibly offsetting higher transportation costs. It may also be possible, based on population abundance and distribution, to target and capture mostly subadult sea otters in Southeast Alaska from habitats that are qualitatively similar to the habitats at proposed release sites in Oregon, thereby maximizing the potential for retention of animals near release sites. Further, the state of Alaska may be more likely to support sea otter removals to support the Oregon effort if they help achieve local resource management objectives (e.g., removing sea otters from localized areas that support valuable shellfish resources for subsistence or commercial fisheries). If so, a multi-state collaboration could increase availability of crucial resources needed to implement the capture and translocation of animals.

Animals residing in Washington and Southeast Alaska appear to have readily adapted to the habitats, prey assemblages and environments along those coastlines, based on long term positive rates of increase in abundance. It is expected that animals from either source would encounter similar conditions in Oregon, although Oregon and Washington share more similar, open coastlines with relatively little coastline complexity compared to Southeast Alaska. One additional difference between Washington and southeast Alaska, is that southeast Alaska (and British Columbia) originated from two donor populations, Amchitka Island and Prince William Sound, in the Gulf of Alaska. This mixing of donors resulted in increased genetic diversity, the highest measured for any extant sea otter population (Larson et al. 2002, Larson et al. 2012), to some extent restoring genetic diversity lost as a consequence of the population bottlenecks induced by the Maritime fur trade (Bodkin et al. 1999, Larson et al. 2015). Thus, the use of southeast Alaska as a source population might best achieve goals of maximizing genetic diversity near the southern end of the sea otter's distribution (Chapter 4).

Given the ESA listing and demographic status of sea otters in California, it seems likely that taking a large number of animals annually (~ 100) from the population adequate to establish a viable population in Oregon would likely have measurable negative impacts on the conservation and recovery of the California population, depending on where the captures were conducted (see Chapter 3). However, depending on the preferred release strategy, a case could be made for inclusion of some sea otters from California based on at least two considerations. First, sea otters that resided historically in Oregon, or at least the southern half of the state, appear to have been more closely related genetically to southern sea otters (see Chapter 4). As a result, including a genetic component of California sea otters into Oregon would likely aid in the recovery of lost genetic diversity that resulted from the Maritime fur trade. This would theoretically provide future benefit to sea otters in both California and those further north, as Oregon could become a bridge that would reunite the long-fragmented sea otter species (Larson et al. 2012, Larson et al. 2015, Wellman et al. 2020). In turn this may eventually benefit sea otters isolated in California by restoring some portion of their lost genetic diversity. Inserting a California genetic component into an Oregon reintroduction could be accomplished through a relatively small number of animals contributing to an Oregon reintroduction. On the other hand, mixing source populations would also add considerable legal and administrative complications (refer to Chapter 8). It is perhaps worth noting here that a regionally coordinated strategy that might achieve the same genetic benefits while avoiding some of the legal complications could involve pairing an Oregon reintroduction using northern sea otter source with a northern California reintroduction using a southern sea otter source, thereby allowing for future mixing of these genetic stocks.

The second consideration relates to the potential inclusion of surrogate raised stranded pups into a Oregon reintroduction strategy. Such a strategy would depend in part on the number of stranded sea otter pups that can be accommodated in existing long-term facilities in California and Oregon. Assuming that the methods described in Mayer et al. (2019) of using surrogate females to rehabilitate and prepare stranded sea otters for release into the wild would achieve similar success in Oregon, using such juveniles could relieve the strain of surplus stranding's in California, that at times requires sea otter pups and juveniles to be euthanized. If an estuarine release strategy is employed in all, or in part, in Oregon, those surrogate reared and rehabilitated pups would accomplish; 1) reducing euthanasia of sea otter in California, 2) demonstrating a mechanism for stranded pups in other US and possibly Canadian populations to contribute to the Oregon population, 3) aiding in the recovery of lost genetic diversity within sea otters, potentially across much of their range in the eastern Pacific, and 4) potentially improving the retention of rate of reintroduced sea otters to Oregon beyond that expected based on past translocation efforts.

In the following text we will present options for the capture, transport, holding and release of animals into the coastal waters of Oregon. This would require a sizeable, but not insurmountable level of effort and cooperation from state and federal governments and their agencies that have management responsibility for sea otters. It would also require consideration of the many potential and reasonably anticipated implications to source populations, and the social, economic, cultural, and ecological effects in Oregon that are considered elsewhere in this study.

Capture

There are three different methods used to capture living sea otters: 1) with handheld dip nets on land or in water, 2) with tangle nets that are set near concentrations of sea otters, and 3) with diver operated traps from below the sea surface (Wild and Ames 1974, Ames et al. 1986). We will discuss the benefits and liabilities associated with each of these methods. It should be recognized that the capture of sea otters is highly regulated requiring federal and in some cases state permits. Permittees are required to establish knowledge, skill and experience in the safe capture and handling of sea otters. The potential for injury or death exists to the sea otter during capture although probability varies among methods (discussed below). Additionally, capture and handling presents potential serious injury to those involved in capturing sea otters. No one should attempt to capture or handle a sea otter without appropriate training, experience and permitting.

Dip Nets: Large, commercially available dip nets can be used to capture sea otters either hauled out on land (rare) or on the sea surface. In general, capturing of sea otters on the water is restricted to naïve, juvenile sea otters that fail to evade capture. Capture is usually attempted from a small (17-20') skiff with a 50-100 hp outboard motor, with a team of two persons, one operating the vessel, and another on the bow with the long-handled dip net. Because juveniles occasionally loosely aggregate in open water, individuals can be rapidly approached and occasionally simply dipped out of the water before they dive. If they do dive, and the sea surface is relatively calm, they can be followed as they swim underwater either visually, or by tracking the air bubbles that are released as they descend, that float to the surface (this is a technique developed by Aleuts to hunt the sea otter, although without the outboard motor). If the otter does not dive too deep, they may be followed visually, or as they ascend while swimming to gain a breath. Once an animal is captured, they are brought aboard the vessel and placed in a net bag within a "capture" box that can be used for transport (Figure 9.1). This technique has been successfully used to capture sea otters for research purposes as well in the recent translocation to San Nicolas Island. One advantage to dip-netting is that the equipment is rather simple and requires only 2 persons. It may also have the advantage of targeting relatively young sea otters, that may be more likely to remain near their translocation site. In California and Alaska, typical weights of dip-netted sea otters were approximately 15-25 lbs. (often recently weaned pups), and if juvenile sea otters are a

Figure 9.1. Capture box used for the short-term holding and transport of sea otters to and from the capture site

target age group, some individuals may be captured this way. There are at least three potential disadvantages to dip netting. One is that catch rate can be relatively low, perhaps 0-4 animals/d per team under good conditions; the second is the method can be stressful to the otter if pursued for more than a few minutes and, in rare circumstances, collisions with the capture vessel may occur, with serious injury or death possible; and third, the method requires relatively calm seas and clear waters where resting sea otters can be observed from afar and followed underwater while being chased.

Tangle Nets: Floating tangle nets represent the tool most likely responsible for a large majority of sea otter captures during translocations and for research in the 20th century. Tangle nets are typically 330’ in length, about 9-15’ in depth, constructed of #15 mono-filament line with a 9 1/4” stretch mesh size, commonly adapted from commercial king salmon fishing gear. Nets are kept afloat with a “cork-less” foam core float-line of 1 ½” diameter along the length of the net and a #20 lead core lead-line. It is important that the “lead” line be heavy enough to sink and light enough so that a sea otter that becomes tangled below the surface can easily return to and remain at the surface. Research Nets Inc. of Redmond Washington has made, most if not all, of the nets made in the past 30 years used in sea otter capture work. The nets are set in proximity to aggregations of sea otter at rest, or in areas where sea otters are known to forage or travel between resting and foraging locations. Typically, from 1 to 3 nets are set at a time, depending on the density and distribution of otters, the types of habitats and sea conditions, and the number of people available to tend the nets. Nets are typically anchored at one end with a scope of 3-5 to 1 with a chain and line rode, with a large float on one, or both ends, and usually in waters from 20-60’ depth and often in, or just adjacent to canopy forming kelp beds where sea otters are known to rest (Figure 9.2). In some instances where tide and current dictate, the net may be anchored at both ends, but with consideration of tidal change to permit the net to continuously float.

Figure 9.2 Illustration of the deployment of a tangle net for sea otter capture

Where sea otters are abundant nets might be deployed only during daylight hours and be watched continuously by a shore-based observer(s) with telescope. Where densities are low and sea conditions allow, nets may be allowed to remain overnight, but should still be checked periodically.

Tangle nets can be highly efficient in capturing sea otters under conditions where they are abundant. It might be expected under the right conditions to safely capture 5-10 sea otters per net per day. However, where they are in low density, one might go days without capturing a single animal. It is important to have local knowledge of the abundance, distribution, and behavior of sea otters in areas where nets will be deployed; reconnaissance is essential for efficiency and for safety of both the otters and the capturers. While nets can be highly effective under a range of conditions, they also present several risks. Foremost is the ability to safely access and remove animals that become entangled. There have been instances where adverse sea conditions have prevented researchers from getting to their nets and animals have remained entangled for extended periods. Often more than one animal becomes entangled at a time and multiple animals entangled may act aggressively toward one another. Occasionally, an animal that is free may behave aggressively toward an animal that is entangled. It is therefore essential that the nets be monitored continuously, and that the net tending crew are able to access their nets rapidly, at any time. Another potential hazard lies in the net or lead line becoming entangled with the bottom or some other feature that prevents an animal that becomes tangled from coming to the surface. In this case the animal is likely to drown within a few minutes. High current areas provide yet another opportunity for tangled sea otters to drown in a net that remains submerged because the current is stretching and holding the net below the surface. Yet another potential for hazard in the use of nets is un-expected encumbrance of the net with debris, algae, or other substances. In a protected bay in Prince William Sound, a tangle net became so saturated with diatoms that much of it sank. Only because the crew was in close proximity were they able to bring the net to the surface and release an animal that was submerged for several minutes. It usually takes a crew of three to operate 1-3 nets when they are deployed and retrieved daily. However, it is not unusual for these nets to become laden with seagrass or kelps that may take many hours to clean and prepare for re-setting, and there is also the risk of by-catch of fishes, birds, and other mammals. These incidences can result in injury or death to the bycatch, with potential serious injury to those tending the nets when a sea lion or fur seal is tangled. For the reasons stated above, only those with extensive experience with floating tangle nets should employ these to capture sea otters, and even then, not all risk can be eliminated. Compared to southeast Alaska, or British Columbia, the Washington coast probably provides the least amenable habitat, environment, and access to capturing sea otters with tangle nets.

Wilson Traps: In large part because of the risk presented by floating tangle nets, the state of California in 1972 experimented with a diver held device, to capture sea otters from below in what would come to be known as the Wilson Trap (Figure 9.3). The original device consisted of a large, lightweight aluminum frame into which a net, opened at one end was attached with a purse line (Ames et al. 1986). The frame and net were attached to a long pole that a team of divers carried as they swam to a position beneath a resting sea otter. They would then swim up to the otter whose initial reaction to disturbance would be to dive into the trap, that would immediately be closed by the purse string, entrapping the otter, that would soon be picked up by the dive tender. While early efforts with the trap proved feasible, in many cases the otter would be disturbed by the divers' exhaust bubbles and easily avoid capture. Over the years several modifications and improvements have been made to the Wilson trap technique, making this in many cases the preferred method of capture. These improvements include: a shift to oxygen rebreathers (a closed-circuit scuba system) that remove the scent and disturbance created by divers' bubbles; waterproof vhf radios that allow spotters to communicate with the divers; and the replacement of the wooden rod with a battery powered underwater propulsion devise that extends the range and speed of the divers. Under average to good capture conditions of abundant animals, clear and calm seas, expected capture rates by a team of 3-4 should approximate 3-6 animals/day.

Figure 9.3 Scuba diver operating an underwater propulsion device with Wilson trap

Regardless of the method of sea otter capture, it is essential that once a sea otter is captured that it be placed in a container that will restrain escape, protect captors from injury and provide a safe environment for transport and temporary holding. Over the years a “capture” box designed to hold any sea otter, has been proven to meet these needs (Figure 9.1). It is constructed of marine grade plywood, with a sliding lid, holes for drainage and air or water exchange and can hold ice to keep animals cool. A frame of tubular PVC can be placed on the bottom to keep the sea otter off the bottom of the box, thereby reducing potential for soiling of fur. If animals are required to be held for any period of time prior to or during transport, the capture boxes can be placed in the water and secured to a vessel or platform, allowing for an adequate breathing area above the waterline for the otter to float, so that water can flow through the drainage holes. An otter in a capture box that has been set in this “soaking” position has ample room to rest or groom inside the box, thus aiding in thermoregulation and maintenance of pelage integrity.

Transport and Holding

Planes, trains, boats (from large ships to small skiffs), trucks, helicopters and humans have all been used to transport sea otters for reintroductions, with runways, rail tracks, roads and anchorages playing a role in determining where they might be released. Transport, beyond capture, will be dependent on location, distances, and available logistics. In the following we will discuss the advantages and disadvantages of the modes of transport likely to be used in a translocation. Small, trailered skiffs, 5-7m in length, are required for each of the capture methods described above. Solid-hull and rigid-hull inflatables, powered by 50-150 hp outboard motors and generally center consoled, are typically employed. Adequate room is needed for 2-4 persons and capture equipment that might include nets, dive equipment and at least 2 capture boxes. The 17’ and 20’ center console Boston Whaler skiffs have been used for much sea otter research requiring capture using each of the methods described above, as have the extremely seaworthy rigid hull inflatables available today. These capture skiffs will provide initial transport of captured animals to shore or designated transport skiffs for further transport. Early efforts at sea otter translocation revealed the critical need throughout holding and transport for captured animals to be kept cool and to retain the ability to maintain the thermal integrity of their fur. Aboard the capture or transport vessels, this can be accomplished by periodically placing the capture box (with the otter inside) into the water, while the box is secured to the side of the vessel and ensuring there is room in the box for the otter to groom its fur at the surface (this is often referred to as “soaking” the captured animal). Extended travel, beyond an hour or two, may require individual sea otters to be moved into a standard large animal kennel, with a raised platform that aids the sea otter in maintaining a clean pelage. It is critical that the sea otter retain the ability to thermoregulate body temperature throughout holding and transport. Ice is often added to the holding container to aid in thermoregulation, and close monitoring of animal health status and body temperature during transport (by a qualified veterinarian or animal husbandry specialist) is strongly recommended. For some recent captures, tiny subcutaneous Passive Integrated Transponders (“PIT tags”) with thermal recording capability have been implanted into animals after capture; these allow veterinary staff to obtain an internal temperature reading from an animal from a few meters away using a PIT tag reader. Transport from initial holding facilities to release site facilities will be by truck and aircraft or vessel, depending on distances and logistics.

Holding facility requirements will be dependent on release strategies. If sea otters are to be accumulated for group release, they will require holding facilities capable of supporting the intended number of animals for each release. In the San Nicolas Island translocation several days to weeks were required to capture the desired number of animals, which were transported from the capture location by air-conditioned van to holding facilities at the Monterey Bay Aquarium. Adequate holding facilities will be required, either near capture or release locations, or possibly both. If sea otters are to be held at the release site, large floating net pens suitable for holding the number to be held with platforms above water level suitable for hauling out will be required (See Figure 9.4).

A surrogate raised rehabilitation strategy will require holding and acclimatization facilities at either capture or release locations. Ideally, a long-term holding facility at the release site will aid in raising the retention of released individuals and facilitate recapture of sea otters when needed. It may be advisable to acquire the capacity to hold adult female sea otters at the release site for the purpose or rearing juvenile sea otters under rehabilitation for release.

Figure 9.4. Photos of floating Net pens for holding sea otters at release site. TOP: view of a floating net pen deployed for testing in Monterey Bay; BOTTOM: releasing captured sea otter into floating net pen deployed at San Nicolas Island. Photos courtesy Colleen Young (CDFW) and Mike Kenner (USGS).

Release

Based on evidence from the earliest (Barabash-Nikiforov 1947) and latest (Mayer et al. 2019) reintroduction case studies, it may be possible to increase retention near the release site by providing for prolonged acclimatization to the habitat and prey populations, and this may be facilitated by allowing for recapture and holding of individuals as necessary. It appears likely that the development of socialization and relations among individuals could be important for achieving some level of cohesion between animals that will likely improve retention rates at or near the release site. If stranded, rehabilitated sea otters form a component or the core of a reintroduction in Oregon, this will necessitate a release strategy of single or small groups of individuals that may come from one or more captive sea otter institutions and require a holding facility at (or near) the release site to provide local acclimatization and bond development between individuals from different sources. Such a strategy may also require the capacity to recapture animals as needed, most likely using dip nets.

Monitoring

Post-release monitoring of reintroduced sea otters has proved to be a critical component of success in recent reintroductions (Rathbun et al. 2000, Carswell 2008, Mayer et al. 2019, Becker et al. 2020). Monitoring can be increasingly challenging the further that animals move from the release site, and the more erratic those movements. However, the use of remote sensing tags to each individual can help in locating animals that move even long distances. Implanted VHF telemetry tags (Williams and Siniff 1983) have a long history of use for tracking sea otters, although these tags are costly and relatively invasive to apply. GPS-enabled flipper tags are currently under development by USGS/NASA (J. Tomoleoni, personal communication) and may provide a less-invasive and cheaper alternative in the near future. In addition to telemetric monitoring, visual monitoring is valuable as it allows for assessments of individual health and status (e.g., determining if animal pelage looks well groomed), but visual monitoring may be more difficult for animals that are released on the open coast as compared to those released in estuaries (assuming that animals stay within the estuary). Frequent monitoring, daily or multiple times per day, can improve success of the reintroduction, particularly if recapture is required. Full-time teams of 2-4 trained and experienced observers may be required for initial monitoring. Depending on movements and degree of retention near release sites, intensive monitoring capabilities may be required throughout the duration of releases. On-call aircraft with VHF tracking capabilities, and staff capable of VHF and visual tracking from vehicle-accessible coastal locations, will likely be required if reintroduced animals move as expected. Note that there is a well-developed methodology and extensive literature on VHF tracking of tagged sea otters in coastal environments (Ralls and Siniff 1990, Siniff and Ralls 1991, Ralls et al. 1995, Bodkin and Ballachey 1996, Tinker et al. 2006, Tinker et al. 2019b, Becker et al. 2020). Aerial tracking is effective especially if some animals cannot be accounted for by ground-based teams and are believed to have moved greater distances. Aerial tracking of marine species is expensive and does entail safety considerations, and float-equipped aircraft may provide increased margins of safety for pilots and observers if tracking occurs more than a few km offshore.

Data Needs

The primary data need prior to a reintroduction will be the assessment of appropriate and adequate food and habitat resources (see Chapter 6). Such assessments will be dependent on the habitat available, and where sea otters become established (which may or may not be close to the area they are released). Although it is prudent to assess food resources and resting habitat in the area around the release site, the possibility that otters may move to a different location must be recognized, and so rapid assessments of food/habitat at new locations may need to be made. It is likely that recreational and commercial fisheries will provide some data on prey species availability for various, clam, sea urchin, and crab species that are also part of sea otter diets. However, much of the otters' diet will include taxa that are not part of any commercial fishery, including species such as shore crabs, kelp crabs, other echinoderms, snails, worms, chitons, and limpets. Habitat resources can also be assessed using geospatial (GIS) data layers including bathymetry, substrate type, kelp canopy cover, and shoreline contours (to identify areas of complexity that may offer shelter and high-quality prey habitat). Published and unpublished research may provide further data on habitat and community level data important in evaluating the potential to support sea otter populations (e.g., Kone et al. 2021, Tinker et al. 2021).

Another data need relates to the status of the ecosystem before and after the reintroduction, to allow for informed assessments of ecological and socioeconomic impacts (Chapters 5 and 7). Previous translocations and natural recolonizations provide extensive examples of the power of experimental manipulation, or before-after contrasts, in understanding the effects of reestablishing sea otters into their historically occupied habitats (e.g., Estes and Palmisano 1974, Duggins 1980, Estes et al. 1982, Estes and Duggins 1995, Bodkin et al. 1999, Watson and Estes 2011, Hughes et al. 2013, Markel and Shurin 2015, Burt et al. 2018). To the extent possible, pre-treatment sampling of biological communities at or near selected reintroduction sites, should be carefully designed and considered for implementation. Existing monitoring programs should be leveraged wherever possible. Some examples might include description of communities, species and ecological relations expected to be influenced by the reintroduction of a long absent predator. Other studies might consider using data from established or recolonizing sea otter populations, in terms of behavior, physiology or population dynamics in the context of a space for time substitution.

Summary and Conclusion

Several strategies can be considered regarding the implementation of reintroducing sea otters to the Oregon Coast. These include options for both source populations, release locations and specific animal attributes. Likely source populations of sufficient numbers include Washington and Southeast Alaska. Sea otters from California may be considered to supplement animals from northern populations that would potentially benefit the conservation and recovery of southern sea otters as well as establish a genetic bridge between California and northern sub-species. Evidence from historic reintroductions suggest multiple introductions may improve the probability of establishing a successful population.

Although sea otters can be expected to eventually occupy all nearshore habitats within their range, not all habitats will support equivalent densities. In general, shallow, high relief rocky habitats that support canopy forming kelp canopies may be preferred. High densities of sea otters also occur in many estuarine and shallow soft sediment habitats throughout their range. Selection of release locations should take into consideration habitat preferences, but sites that allow for access to both exposed and sheltered shorelines (or estuaries) may increase potential for success. It is critical to realize that in past translocations sea otters have often not remained where they were released but have become established many km from release sites.

Although not explicitly demonstrated, the sex and age composition of reintroduced sea otters may be important to success. There is reason to suspect that younger animals may not have well established home ranges they will try to return to, and so may be more likely to become established at or near the release site. It is also possible that a sex ratio biased toward females will contribute to the reproductive potential of the founding population.

A variety of capture methods are available that can contribute to achieving the desired abundance and age/sex composition. These include dip nets, tangle nets and scuba-operated Wilson traps. Appropriate care and monitoring of the health status of captured animals during transport and holding is critically important, and intensive post-release monitoring of animals will also help ensure success.

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Chapter 10: Animal Health and Welfare Considerations

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The purpose of this section of the feasibility study is to provide information on the potential health and welfare hazards which may negatively impact the success of the reintroduction of sea otters to the Oregon coast. The information will be subdivided into two major sections, animal health (or its converse, disease) and animal welfare. For the purpose of this discussion disease will include both infectious diseases, such as parasitic infections, and non-infectious disease, such as domoic acid intoxication. There may also be circumstances in which a differentiation between northern sea otters (*Enhydra lutris kenyoni*) and southern sea otters (*E. l. nereis*) is made.

The animal welfare section of this chapter will be more subjective and speculative in nature. While animal welfare is becoming more science-based, it is an evaluation of an animal's state at any one point in time, is described on a continuum from good to poor, and will vary, often dramatically, within a group of animals and over time. The subject will be addressed through the lens of a modified list of the five freedoms described by Britain's Farm Animal Welfare Council in 1965 and subsequently released in 1979 (https://webarchive.nationalarchives.gov.uk/20121010012427/http://www.fawc.org.uk/freedoms.htm) and the Association of Zoos & Aquariums' Five Opportunities outlined in their accreditation standards (https://assets.speakcdn.com/assets/2332/aza-accreditation-standards.pdf): 1) nutritionally complete diets (quantity, familiarity, safety, accessibility); 2) comfortable habitat (appropriate for species, ability to rest, haul out opportunity, anthropogenic risk); 3) health (known disease risk, live stranding response, carcass recovery & processing, potential rehabilitation opportunities); 4) chronic stressors (boat traffic, ecotourism disturbance, adequate refugia, inter-species interactions); 5) social structure (group size, sex ratio, age range, site fidelity).

Lastly, a discussion of health and welfare would be incomplete without the inclusion of animal transportation and post-arrival conditioning. There are a number of federal agencies with regulatory oversight for interstate transportation of animals, and the list becomes longer, albeit less specific when dealing with wildlife, especially marine mammals. Regardless of the source population, the transport will be several hours long, and the potential for transport-related stress and loss of pelage conditioning is high. Some degree of post-arrival recovery and conditioning will likely be a critical component in the maintenance of the otters' health and well-being.

Animal Health

As previously described, animal health will include both infectious and non-infectious diseases. For the purposes of this chapter, a rather stringent definition of infectious disease will be applied. Infectious diseases are those that are caused by a living organism (i.e., viruses, bacteria, fungi, protozoa, or metazoan parasites) under normal (natural) circumstances. It is important to note that the definition does not include or describe modes of transmission. Diseases that are transmitted directly between animals will be described as transmissible, communicable, contagious, or transmitted horizontally. An exception to that definition are the diseases which are known to be transmitted *in utero*, such as Toxoplasmosis, for which transplacental or vertical transmission will be used. While many infectious diseases are transmitted directly between animals, not all are. Examples include both Toxoplasmosis (excepting the vertical transmitted between dam and fetus) and Sarcocystosis. Both are caused by living organisms, protozoa, but they cannot be transmitted directly to other otters (or humans) through normal mechanisms. Theoretically, they may be transmitted directly if an uninfected otter ate an infected one, but that is not a normal activity.

This document will be selective in its inclusion of non-infectious diseases. An attempt will be made to address those that are considered to potentially impact the success of a sea otter re-introduction program at a population level and are typically considered more as an individual animal malady. Of the eleven major groups of non-infectious diseases (degenerative, allergic, autoimmune, metabolic, neoplastic, nutritional infectious, immunological, toxic, traumatic, and genetic) only four (infectious, toxic, traumatic, and genetic) are salient to this discussion. The reader is referred to Chapter 4 for further information on genetics and disease.

Aspects of this discussion will be necessarily speculative. Information provided will be based upon a combination of published data, work in progress, personal communication with colleagues, and the author's experience in clinical sea otter medicine. In addition. Inference will be drawn from other members of the family, *Muistelidae*, for which a fair bit of information is known about infectious and non-infectious diseases.

Infectious Disease

Morbillivirus

Of the list of viral diseases affecting sea otters, morbillivirus is undoubtedly the most concerning. A member of the *Paramyxoviridae* family, the genus *Morbillivirus* contains two species of significant concern to sea otters, canine distemper and phocine morbillivirus. Prior to 2001, all sea otters tested for morbillivirus were sero-negative (Hanni et al. 2003, Thomas et al. 2020). Live otters from Washington State (henceforth, Washington) were tested in 2001-2002 following the 2000 mortality event and 80% were sero-positive (Brancato et al. 2009). A retrospective evaluation of tissue from 18 deceased otters sampled between 2000 and 2010 using immune-histochemistry and RT-PCR identified canine distemper virus as the cause of either infection (12/18) or disease (6/12) (Thomas et al. 2020). Evidence collected suggests that canine distemper virus was the cause of the 2000 mass mortality event.

Phocine morbillivirus was first associated with a mass mortality event affecting seals in the North Atlantic in 1988. Since then, a second event has occurred, and sporadic deaths are reported. Serologic evaluation of live-captured sea otters in the eastern Aleutians and Kodiak archipelago in 2004-2005 identified 40% sero-positivity to phocine morbillivirus (Goldstein et al. 2009).

The incidence of morbillivirus in southern sea otters appears to be low. A recent compilation of southern sea otter necropsies from 1998-2012 identified three cases of putative morbillivirus infection (3/560) as primary cause of death (COD) and five (5/560) as contributing COD (Miller et al. 2020). In nearly 1000 live strandings seen at the Monterey Bay Aquarium, no cases of morbillivirus have been identified.

Despite the fact that morbillivirus has been associated with marine mammal die offs in the North Atlantic, Gulf of Mexico, and Mediterranean Sea, the only morbillivirus-associated mass die-off affecting sea otters was the 2000 event off the Washington coast. That being said, however, the potential exposure to canine distemper virus to naïve sea otters from terrestrial carnivores, such as canids and raccoons, as well as marine-foraging river otters, cannot be ignored. Additionally, the ongoing loss of sea ice and opening of the Northwest Passage may facilitate movement of phocine morbillivirus by carrier seals. Once established in the Pacific, the potential exposure of sea otters becomes significantly greater.

Influenza virus.

Mustelids are well known as being susceptible to influenza virus infection, so much so that the domestic ferret is often used as an animal model for studying the disease. Marine mammals, particularly pinnipeds, are considered wildlife reservoirs for the virus. Northern sea otters captured in 2011 were evaluated for antibodies to influenza virus H1N1 (LI 2014). Of the 30 otters tested, 70% (21/30) were sero-positive. The source of the infection was unclear, however serologic evidence supported the notion that the source of infection to the sea otter was the northern elephant seal (*Mirounga angustirostris*).

While the mortality associated with influenza virus in sea otters is uncertain, that fact that virus transmission can occur through shared haul out areas is notable. Additionally, the addition of the sea otter as a wildlife reservoir for influenza A virus may have some public health significance.

Bacterial diseases.

Morbidity and mortality associated with bacterial infections is not uncommon in the sea otter. Bacterial infections were the primary COD in 33/560 and 35/560 contributing cause of death in southern sea otters, 1998-2012 (Miller et al. 2020). The examined death assemblage from the 2002-2015 evaluation of Washington State otters identified 14/93 cases of bacterial infection (including 6 cases of Leptospirosis) (White et al. 2018).

Recent sea otter mortality studies have lumped bacteria-caused mortality into a single group, bacterial infection. It is unclear whether the bacterial species is considered a primary or secondary (opportunistic) pathogen. Review of the list of 15+ species recovered at necropsy (Brownstein et al. 2011) suggests that the vast majority of bacterial species are, in fact, opportunistic relying on a breach of the host's intrinsic immune system (skin, mucus membranes), immunosuppression, or co-infection with a primary pathogen to gain access to the body. It is notable that several of the pathogens identified have significant zoonotic potential and may pose a public health risk; *Brucella spp, Coxiella brunettii, Bartonella spp, Erysipelothrix spp, Leptospira spp,* and *Salmonella spp.* Most are likely opportunistic in nature.

Streptococcus phocae, one of the more commonly identified opportunistic pathogens, is frequently recovered from deceased sea otters. A true secondary pathogen, the organism requires damaged skin as a portal of entry. It has been recovered from shark bite wounds, breeding-related wounds to the muzzle and nasal pad, and a myriad of bite wound likely associated with intra-specific aggression. Once the organism is established, it often causes abscesses or septicemia (Bartlett et al. 2016).

Recent studies have demonstrated that several sea otter prey species, bay mussels (*Mytilus trossulus*), butter clams (*Saxidomus giganteus*), Dungeness crab (*Metacarcinus magister*), and black turban snails (*Tegula funebralis*), are capable of bio-accumulating *S. phocae* (Rouse et al. 2021). It is not clear whether this bacterium is capable of breaching the gastro-intestinal mucosa or if food-borne exposure requires a pre-existing break in the GI tract, such as an ulceration or wound associated with prey handling.

Other beta-Streptococcus species, *Streptococcus bovis/equinus* and *Streptococcus infantarius* subsp *coli* have been strongly associated with vegetative valvular endocarditis, a proliferative disease of the heart valves. While the exact pathogenesis remains unclear, some attribute the unusual mortality event declared in 2006 in Kachemak Bay to be partially or entirely caused by one or both of these Strep species (Carrasco et al. 2014).

Bordetella bronchiseptica is a common primary and secondary pathogen affecting domestic dogs; one of several organisms associated with “kennel cough.” The organism was first identified as a sea otter pathogen affecting the respiratory tract (Staveley et al. 2003). In the sea otter it is considered to be a secondary pathogen and may be associated with morbillivirus infections. This organism may become significant during post-transport holding and acclimation. The stress-mediated immunosuppression of capture, transport, abnormal social structures, and behaviorally-induced inappetence may result in opportunistic infections with this contagious pathogen.

Leptospirosis has historically been an uncommon disease of sea otters. A study of otters in Washington had a sero-positivity rate of 1/30 in 2001 (Brancato et al. 2009); 5/103 in California in 2003 (Hanni et al. 2003); and 3/161 in Alaska and Russia in 2004-2006 (Goldstein et al. 2011). In 2002, six beach cast sea otter carcasses were evaluated and COD attributed to leptospirosis (Knowles et al. 2020). While the incidence seems to remain low, there may be some degree of concern for transfer of infection from terrestrial wildlife. A study of peri-urban wildlife in Northern California identified six species associated with significant risk factors for infection: western gray squirrel, coyote, striped skunk, raccoon, gray fox, and mountain lion (Straub and Foley 2020). Their presence in and around potential sea otter haul outs may pose some degree of inter-species transmission on the Oregon coast.

Overall, bacterial infections are unlikely to pose a significant, population-level threat to a re-introduced sea otter population along the Oregon coast. Recent mortality studies of southern and Washington sea otters identified 68/560 (12%) and 14/93 (15%) cases in which bacterial infections were the primary or secondary COD, respectively (White et al. 2018, Miller et al. 2020).

Fungal diseases.

There is only one fungal disease warranting discussion within this venue, coccidioidomycosis or Valley Fever, a disseminated fungal infection caused by *Coccidioides immitus*. While it is an infectious disease, it is not easily transmitted from one otter to another, and therefore should not be considered communicable. The infectious fungal spores have a limited range, and the primary risk to sea otters is associated with adjacency to the San Joaquin Valley (Figure 10.1). No cases were reported in northern sea otters, and 9/560 were identified by Miller, et al; all of which were found at the southern end of the sea otter range (Miller et al. 2020).

Interestingly, the incidence of Valley fever has increased dramatically in humans at the northern end of the southern sea otter range from 7.3 cases per 100,000 population in 2008 to 54.7 cases per 100,000 in 2018 (https://www.co.monterey.ca.us/government/departments-a-h/health/diseases/coccidioidomycosis-valley-fever/coccidioidomycosis-local-data). Some have theorized that the sea otter cases are associated with construction and other disturbances to the topsoil in the valley associated with eastern winds.

At this point there is no evidence of a population-level threat being posed by coccidioidomycosis to the sea otter re-introduction. That being said, however, a map of prevalence (Figure 10.1) demonstrates the proximity of the fungus to coastal and central Oregon. Given the weather and other impacts associated with climate change, assuming that infection is impossible is probably not wise.

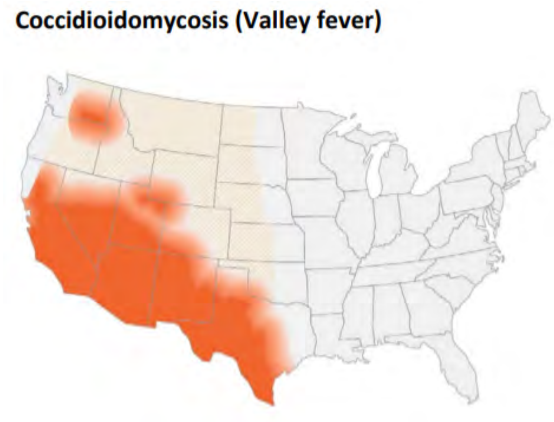

Figure 10.1. Map of distribution of Valley Fever in the U.S. https://www.cdc.gov/fungal/pdf/more-information-about-fungal-maps-508.pdf

Parasitic diseases

Unlike parasitic disease in many other wildlife species, the majority of the parasites reported in sea otters tend not to be easily transmitted horizontally. Four of the five parasitic diseases reported to be primary or contributing causes of death in recent studies (White et al. 2018, Miller et al. 2020) are not communicable, and in fact, the sea otter is an aberrant host for three of four infections, protozoal infection (*Sarcocystis, Toxoplasma*), acanthocephalid peritonitis, and larval migrans (*Baylisascaris, Paragonimus*).

<u>Sarcocystosis</u>

Sarcocystosis is caused by a sporozoan protozoa, *Sarcocystis neurona*. It has a rather complicated life cycle, employing a number of endotherms, including dogs, cats, raccoons, and sea otters, as intermediate hosts, in which it forms tissue cysts. The definitive host, the species in which sexual reproduction occurs and oocysts and produced and shed, is the Virginia opossum, *Didelphis virginiana*.

In the sea otter, positive antibody titres are more common than clinical disease. It is suspected that encysted parasites may not cause significant symptoms. The 2002-2015 Washington State study found Sarcocytosis to account for 28/93 primary causes of death (White et al. 2018), while the California study identified protozoal infection (*Sarcocystis* and *Toxoplasma*) accounting for 50/560 and 58/560 as primary and contributing COD, respectively. While numbers were not provided, Sarcocystosis outnumber Toxoplasmosis as a primary COD by a factor of five (Miller et al. 2020). The 2004 mass mortality event in Morro Bay, CA was attributed to Sarcocystosis as the primary COD in 15/16 animals (Miller et al. 2010a).

Sarcocystis infections have been identified in California, Washington, British Columbia, and Alaska with spatial clustering most common in California and Washington. There has been a strong association of infection, as defined by positive antibody titres, with terrestrial features (wetlands, croplands, and high human-unit density), soft sediment substrate, and predominance of clams in the diet (Burgess et al. 2020).

A transmission pathway has been proposed, in which oocysts accumulate overtime, remaining viable in the environment for months to years. Freshwater runoff into the nearshore system allows concentration by the local marine habitat features, ocean physical processes, and subsequent invertebrate bio-accumulation. Benthic invertebrates, such as bivalve mollusks (e.g. razor clams), are then consumed by the sea otter, resulting in infection.

In California, there is good alignment between the dominant freshwater outflows occurring in late winter and early fall followed by a disease peak in sea otters in spring and early summer. This tends to confirm the land-sea transmission epidemiology of Sarcocystosis (Miller et al. 2010a). In addition, disease hot spots have been identified in association with localized oceanic conditions and terrestrial features that affect run-off (Burgess et al. 2020).

Sarcocystosis is of significantly more concern than the other diseases mentioned previously in this chapter. Evidence points to *Sarcocystis* being a more virulent parasite than other apicomplexan parasites. The Virginia opossum is a very well-adapted, non-native mammal introduced into Oregon in 1910-1921, therefore oocyst shedding is likely along the extent of the Oregon coast. Infective stages are shed into the environment and remain infective for extended time periods. The method of transmission from land to sea is now well understood, as is the bio-concentration of the parasite within a normal food item without causing disease in the vector.

Toxoplasmosis.
A second sporozoan (spore-producing) protozoan, *Toxoplasma gondii*, is a significant pathogen in sea otters (Thomas and Cole 1996, Miller et al. 2007). This parasite is found throughout the sea otter's range. There are several serotypes that have been identified with Type II and Type X dominating in sea otters. Type X is the genotype most often associated with fatal disease in sea otters, and Type II, while causing sero-conversion, rarely causes significant, if any, clinical disease (Miller et al. 2008b, Shapiro et al. 2019). Type X has been identified not only in sea otters, but also in domestic cats, bobcats, and mountain lions. Toxoplasmosis is not an uncommon disease in humans, generally associated with undercooked meat, particularly pork. In pregnant women, serious disease in the unborn fetus is possible.

As with for *Sarcocystis*, the sea otter is not the definitive host for the parasite. In the case of *Toxoplasma*, the only known definitive host is a felid, either domestic or wild. Vertical transmission of the parasite is possible, with abortion or peri-natal death as likely outcomes (Miller et al. 2008a, Shapiro et al. 2016).

When evaluated at a large spatial scale, the risk of infection is greatest in areas with higher human population density or high proportion of human-dominated land use, such as impervious surfaces and cropping land. It is thought that this effect is the result of an increased presence of a felid definitive host (Burgess et al. 2018).

At smaller spatial scales, the risk of infection positively correlates to increasing age, sex (male), and prey choice (Burgess et al. 2018). Diets dominated by marine snails are more commonly associated with toxoplasmosis than other feeding strategies (Johnson et al. 2009). It has been theorized that the feeding strategy of snails, like *Tegula*, have a different feeding strategy than other gastropods, such as abalone. The net result is thus an increased exposure to *Toxoplasma* oocysts in *Tegula* diets, than in abalone (Krusor et al. 2015).

The epidemiology of toxoplasmosis is similar to that described for sarcocystosis. The presence of the putative definitive host (felids) which shed large numbers of oocysts into the terrestrial watershed adjacent to sea otter habitat, a durable infectious stage capable of persistence for extended time periods outside of the host, land-based surface freshwater runoff acting as the source for *Toxoplasma* in the near shore marine environment, and the ability of benthic filter feeders, such as bi-valves, to accumulate infectious stages for eventual consumption by the sea otter (Miller et al. 2002). This pathway has been confirmed for the more virulent genotype, Type X (Shapiro et al. 2019).

While toxoplasmosis is not transmitted horizontally between sea otters, there may be some degree of concern for its potential impact on a recently re-introduced sea otter population. Significant infection, even with the less virulent types, may have impact on reproductive success. Type X infections may be associated with mortality. There may also be some bio-political and public perception issues. While sea otters cannot transmit toxoplasmosis to humans under normal circumstances, it may be difficult for the public to avoid association of sea otters' well described toxoplasma relationship with any publicized human cases.

Acanthocephalid peritonitis.

Acanthocephalid peritonitis (AP) is not an uncommon primary or contributing cause of death in southern sea otters (127/560) but is rarely reported in the northern subspecies (White et al. 2018, Miller et al. 2020). The sea otter is considered an aberrant or dead-end host for the causative agent, *Profilicolis spp*, of AP. The normal life cycle is complex with a free-living stage, an arthropod intermediate host, and a vertebrate definitive host. In the case of *Profilicolis*, the intermediate hosts are the sand crab, *Emerita analoga,* and the spiny mole crab, *Blepharopoda occidentalis*, and the definitive host is a scoter, gull, or sea duck (Mayer et al. 2003).

While the definitive hosts are found throughout the eastern Pacific coast, the intermediate host are somewhat more inconsistently found in that area. *Emerita* is commonly found in sandy and mixed substrate habitats on the California coast. Sand crab populations are much more sporadically found along the Oregon coast. It has been postulated that the species is re-stocked by larvae drifting northward on the currents with highest number identified during El Nino years (Sorte et al. 2001).

The disease is most often diagnosed in recently weaned pups, sub adults, and aged adult animals living near appropriate habitat for the intermediate host. There may also be a relationship between disease incidence and resource (food) availability (Shanebeck and Lagrue 2020, Tinker et al. 2021b). When the population is at or near carrying capacity, energy recovery rates are lower implying that otters need to work harder to find adequate food. During these periods, the more shallowly located, easily extracted sand crabs may be an attractive source of food. When food is plentiful, hunting is less demanding and even the less physically fit otters are able to forage on normal prey species. This theory is obviously speculative and needs to be interpreted as such, although the positive relationship between sea otter density and the incidence of AP mortality in southern sea otters is statistically significant (Tinker et al. 2021b).

It is unclear how significant AP may be to a recently introduced sea otter population. There may be opportunities to mitigate the risk to some degree through thoughtful release site selection and physical conditioning of animals pre-release. Ample food availability (at least in early years after reintroduction) may result in otters avoiding predation upon some of the high-risk food sources, such as *Emerita* and *Blepharopoda*.

Larval migrans.

In this venue, larval migrans will be used as a generic term to describe the aberrant migration of helminth larvae through various tissues in a non-definitive host, the sea otter. Excluded from this definition is the previously described acanthocephalid peritonitis.

Larval migrans is an uncommon primary or contributing COD in the sea otter. The most commonly described parasite species are the raccoon roundworm (*Baylisascaris sp*) and the lung fluke (*Paragonimus sp*) (White et al. 2018, Miller et al. 2020). Peripheral migration through viscera, muscle, etc. tends not to be clinically significant. On occasion, however, the larva may enter the eye, causing blindness or the brain resulting in an encephalitis. Both diseases tend to be fatal in free-ranging animals due to the untoward impacts on foraging and other life-supporting activities.

Despite their uncommon occurrence, they are included within this discussion as examples of the potential health hazards associated with land – sea pathogen transmission. The presence of freshwater runoff and human-dominated land use, such as impervious surfaces, cropland, and human dwellings, seem to provide increased risk of pathogen pollution of the nearshore habitat.

Non-Infectious Disease

Toxic diseases.

Domoic acid intoxication

While domoic acid intoxication was not identified as a cause of death in the recent Washington death assemblage, it was a significant primary or contribution cause of death (probable/possible) in the California study (White et al. 2018, Miller et al. 2020). Domoic acid is a water-soluble neuronal glutamate receptor analog that is produced by certain strains and species of the diatom *Pseudo-nitzschia (*PN). It the cause of amnesic shellfish poisoning which was first recognized in Canada in 1987.

Harmful algal blooms (HAB) are known to occur along vast stretches of the eastern Pacific coastline, including Oregon. There are a number of factors that are known or suspected of enhancing PN blooms including changes in the oceanographic conditions, overfishing, eutrophication of marine waters, and global climate change (Landsberg 2002, Chavez et al. 2003, Lefebvre et al. 2016, McKibben et al. 2017). A great deal of work has been done in an attempt to better understand the relationship between oceanographic conditions and HAB along the coast of Oregon.

PN blooms tend to be seen during spring and summer months which are early to mid-point of oceanic upwelling of nutrient rich water. This upwelling tends to be associated with northerly winds. As winds relax, phytoplankton blooms are moved closer to shore where they may interact with benthic invertebrates, prey for sea otters (McKibben et al. 2015). It should be noted that not all PN blooms are associated with the production of domoic acid.

An important cautionary note is that reliance of off-shore PN and domoic acid monitoring may not reflect the degree to which benthic sea otter prey is exposed to the biotoxin. Exposure is dependent upon movement of the algal bloom into the more shallow surf zone. This is in turn affected by surf zone hydrodynamics and morphology (Shanks et al. 2018). Dissipative surf zones are often associated with rip currents which are efficient in exchanging water and associated algal blooms with off-shore water masses. More reflective surf zones limit the exchange of water, thereby reducing the entry of algal blooms into nearshore areas (Shanks et al. 2016). The net result is that the degree to which sea otter filter-feeding prey is exposed to domoic acid may vary dramatically on small spatial scales. The use of data generated over larger scales is likely to be relatively insensitive in predicting sea otter risk to intoxication.

Because domoic acid intoxication occurs in humans, as well as marine mammals and birds, active monitoring programs are carried out by state and local agencies. Several sentinel species, as well as evaluation of the water column for PN are used. Mussels are a common bio-accumulator that are easily managed; therefore, they are commonly used as sentinel species for the presence of domoic acid. There is some suggestion that they are less sensitive than other benthic invertebrates, such as sand crabs (Ferdin et al. 2002). Razor clams, a significant commercial and recreational fishery in Oregon, are highly effective bio-accumulators of DA. They also have a slow depuration rate relative to mussels (Blanco et al. 2002). As a result, high levels of DA in razor clams may represent an acute, high level exposure, or alternatively a chronic, low level exposure over time (McKibben et al. 2015). Because monitoring efforts vary from region to region, and due to differing mechanisms of bioaccumulation between species, the use of human-centric toxicity thresholds, and the emphasis on human-consumed species, the use of established monitoring systems have limited applicability to predicting sea otter exposure (Figure 10.2).

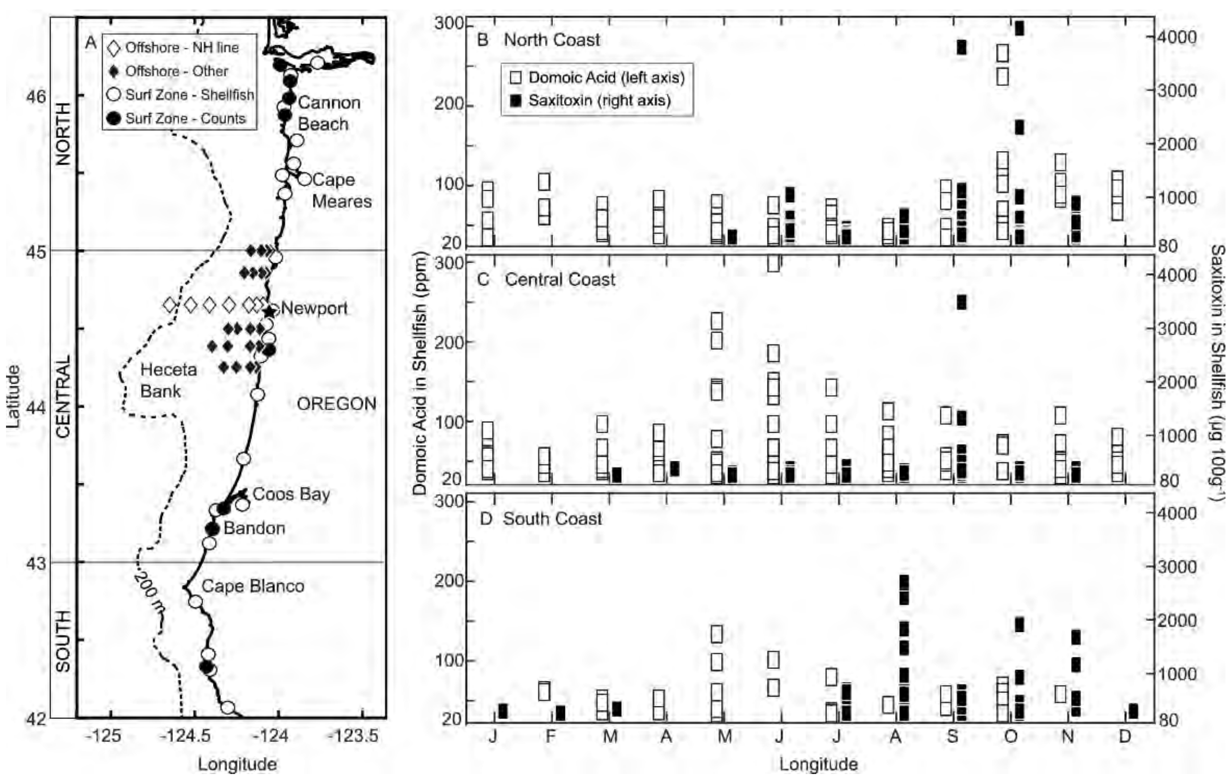

*Figure 10.2. A) Map of coastal Oregon (area to the right of solid black line is land), with dashed line showing the continental shelf break at the 200-m isobath. Diamond symbols show offshore locations sampled aboard research vessels. White diamonds highlight the Newport Hydrographic (NH) line at 44.658N. Wind data were collected at Newport, Oregon (star symbol). Circles on coast represent surf zone sampling locations for shellfish DA and STX (white) or Alexandrium and Pseudo-nitzschia cell counts (black). Surf zone data are binned into north (45–46.58N), central (43–458N), and south (42–438N) regions. B–D) Monthly STX and DA are shown as black squares (right axis) and white squares respectively for (b) north, (c) central, and (d) south coast locations defined in (a). Only values above the 80 mg * 100 g^{-1} and 20 ppm harvesting closure thresholds for STX and DA, respectively, are shown (i.e., y-axes start at closure thresholds). From (McKibben et al. 2015).*

Other potential sea otter prey items have been evaluated as potential depositories for DA. One study looked at eight benthic invertebrate species representing four feeding groups, filter feeders (*Emerita* *analoga, Urechis caupo*), a predator (*Citharicthys sordidus*), scavengers (*Nassarius fossatus, Pagurus samuelis*), and deposit feeders (*Neotrypaea californiensis, Dendraster excentricus, Olivella biplicata*). While DA was identified in all eight species, it was above the human safety threshold of 20 ppm in six (*N. fossatus, E. analoga, U. caupo, C. sordidus, N. californiensis,* and *P. samuelis* (Kvitek et al. 2008).

The potential impact and pathogenesis of domoic acid exposure is likely to be directly related to the manner in which various prey species respond to the toxin, local and regional environmental factors, and the age/size of the prey (Egmond 2004). Mussels, one of the primary sentinel species for domoic acid, accumulate domoic acid in the digestive gland. As a result, it depurates quickly, but it does accumulate to high levels. Domoic acid accumulates in different body tissues, the mantle and foot, of the razor clam. This accumulatory pathway results in a significantly slower depuration rate (Novaczek et al. 1992). As a result of the rapid accumulation and elimination in mussels, sea otters may be exposed to high levels of domoic acid in a short time; an acute intoxication is the result. Prey species with slower depuration rates, such as razor clams (Blanco et al. 2002), may result in the accumulation of high levels of domoic acid from either profound *Pseudo-nitzschia* blooms or exposure to low, persistent levels of the toxin (McKibben et al. 2015). Domoic acid intoxication is difficult to diagnose ante-mortem. The toxin is readily absorbed via the gut and eliminated via the urine. Its serum half-life is short, making serological evaluation insensitive. Urine is a more sensitive test; however, it too is eliminated within a short time period. There are three major post-mortem presentations of domoic acid intoxication based on dose consumed over time. Acute intoxication is primarily a neurological disease with seizures dominating the clinical presentation. A subacute disease with doses being spread out over time has both neurological changes and some degree of effect on the heart. The chronic form is a cardiac disease often associated with cardiomyopathy and other degenerative diseases of the heart (Miller et al., *in press*).

Given the significance of known or suspected domoic acid-related mortality, and recently published information demonstrating the relationship between DA and cardiac disease in sea otters (Moriarty et al. 2021), the potential for DA-related morbidity and mortality is highly probable in an Oregon coast re-introduction effort. Methods for mitigation are uncertain, although likely sea otter prey items (especially razor clams) should be included in the process of identifying release sites. Additionally, local oceanographic conditions and the potential for anthropogenic eutrophication of nearshore waters warrant consideration.

Saxotoxin intoxication

A second marine biotoxin warranting discussion is saxitoxin (STX), the causative agent of paralytic shellfish poisoning (PSP), which is produced by some species of the dinoflagellate, *Alexandrium*. STX is not a single compound, instead a group of neurotoxins produced by species of dinoflagellates, including *Alexandrium* (Horner et al. 1997). Based on regional native American customs and the apparent ability of some marine mammals to proactively reject toxin-bearing prey, it appears that PSP has been present on the west coast for centuries (Fryxell et al. 1997). For this reason, the Oregon Department of Agriculture (ODA) has been monitoring shellfish for the presence of STX since 1979.

The typical pattern does not involve DA and STX events co-occurring (McKibben et al. 2015). Both are more common in warmer water and are initiated by upwelling-causing northerly winds. As winds decline, the blooms are moved towards shore exposing nearshore invertebrates to biotoxins. Dinoflagellate blooms, including *Alexandrium*, are classically seen later than DA-associated blooms, traditionally peaking in the months of June through November (McKibben et al. 2015).

The marine biotoxin sampling program for DA/STX and *Pseudo-nitzschia*/*Alexandrium* is inconsistent along the Oregon coast with the north coast being most heavily monitored, followed by the central coast, and the south coast the lowest level. (Figure 2). Mussels are sampled more commonly than razor clams, and the frequency of sampling decreases from north to south. Significant STX and *Alexandrium* have been reported. In 2010, the ODA closed the entire Oregon coast to all harvesting of mussels, scallops, razor clams, oysters, and bay clams; all are potential sea otter prey (McKibben et al. 2015).

Despite the frequency that shellfish commercial and recreational harvesting is closed along the eastern Pacific coast, the incidence of STX intoxication in sea otters is low. Recent comprehensive analyses of causes of death for sea otters in Washington and California did not report any cases of STX intoxication (White et al. 2018, Miller et al. 2020). Sea otters are susceptible to the effects of the neurotoxin; however, experiments involving wild caught sea otters from Kodiak Island suggested that they seemed to detect and avoid heavily toxic loads (Kvitek et al. 1991).

In the butter clam, *Saxidomus gigantus*, approximately 60-80% of the toxin bioaccumulates in the siphon, gills, kidneys, and pericardial glands. STX depurates slowly, and potentially toxic levels can remain in the butter clam one year following a seasonal bloom (Shumway 1990).

Following consumption of toxic levels of STX, sea otters demonstrate a spectrum of neurological and behavioral anomalies, including vocalization, muscle tremors, and agitation. When toxic prey is removed, recovery appears to be complete (Kvitek et al. 1991). This may explain the absence of STX-related mortality in recent mortality reviews for sea otters (White et al. 2018, Miller et al. 2020).

It is likely that despite the prevalence of STX in Oregon shellfish, there is minimal potential for significant population-level impacts on re-introduced sea otters. Sea otters appear to be able to detect and develop an aversion to STX in levels above a certain threshold (Kvitek and Bretz 2004). It is unclear how this occurs and whether it occurs below the surface. The Kodiak Island study (Kvitek et al. 1991) involved wild caught, independent otters. Therefore, it is not clear from previous work whether the STX avoidance behavior is an innate or learned one. If the latter is true, it is possible that naïve, rehabilitated juvenile and sub-adult otters may be a greater risk of Saxitoxicosis.

<u>Microcystin intoxication.</u>

Microcystin intoxication is not a common cause of sea otter morbidity or mortality; however, its prevalence in freshwater systems is becoming a worldwide problem (De Figueiredo et al. 2004). As with several other causes of sea otter mortality, there is a freshwater link to the disease. Microcystin is an environmentally stable toxin produced by several species of cyanobacteria, formerly known as blue-green algae. It is found in both freshwater and estuarine waters throughout North America and worldwide. In a case study published in 2010 (Miller et al. 2010b), microcystin was transported from freshwater systems into Monterey Bay via nutrient-impaired rivers. Based on experimental evidence, it is believed that the toxin bio-magnified up to 107 times in the tissues of bi-valves (Miller et al. 2010b). Sea otters that consumed toxic levels of microcystin-containing prey died of acute liver failure. The ability of benthic filter feeders to bio-accumulate the toxin above ambient levels and depurate the compound slowly poses a potential health threat to otters foraging adjacent to freshwater streams and rivers.

It is unlikely that microcystin is a significant, population-level health threat to a re-introduced sea otter population. It does, however, warrant some degree of consideration during the evaluation of release sites. The Oregon Health Authority, Public Health Division publishes guideline for cyanobacterial blooms in freshwater bodies, a potential resource for this evaluation. (https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/RECREATION/HARMFULALGAEBLOOMS/Documents/2019%20Advisory%20Guidelines%20for%20Harmful%20Cyanobacterial%20Blooms%20in%20Recreational%20Waters.pdf)

Tributyltin or organotins

Tributyltin (TBT) was employed as an anti-fouling agent in marine paint for boat hulls starting in the 1960s, until its use was regulated in 1988 (Huggett et al. 1992). As TBT ablated from its original site of application, levels increased in the water column, sediments, and local organisms. It became apparent that the effects of TBT extended beyond target organisms, such as barnacles and marine worms, to include oysters, snails, other mollusks, and crustaceans (Kannan et al. 1998). In fish and mammals, TBT tends to bio-accumulate primarily in the liver, however significant levels are also found in the brain and kidney. Likely as a result of the sea otter's diet and high energetic demands, levels found in sea otters are more than twice that seen in cetaceans (Kannan et al. 1998).

It appears that TBT is associated with immunosuppression in birds and mammals (Snoeij et al. 1987, De Vries et al. 1991). A study of butyltin residues and cause of death for southern sea otters recovered from 1992-1996 did not demonstrate a strong association between TBT levels and immunosuppression as evidenced by disease as cause of death (Kannan et al. 1998). This finding was supported in a study of organotins in sea otter carcasses from California, Washington, Alaska, and Kamchatka, Russia from 1992-2002 (Murata et al. 2008). Again, the correlation between tissue levels and infectious disease was not strong, although infectious disease cases tended to have higher TBT levels in general. Immunosuppressive effect may be relatively long term, as the half-life of the compound is estimated to be three years (Murata et al. 2008).

Since the use of organotin compounds as marine anti-biofouling agents was federally regulated in 1988, the levels seen are likely declining. Residues have historically been higher in enclosed marinas, such as Monterey Harbor and Morro Bay, and lower in open areas. There is some evidence that the compound may persist longer in larger harbors, which attract larger vessels and those from foreign fleets.

Other Contaminants.

There has been a significant amount of work done looking at contaminants and (to a lesser degree) their potential impact on sea otters (Kannan et al. 1998, Nakata et al. 1998, Bacon et al. 1999, Kannan et al. 2006, Jessup et al. 2010, Reese et al. 2012). Organic compounds may be found concentrated in the water, such as methylmercury, or in sediments, such as PCBs. The mechanism for introduction into sea otter tissues is not completely understood, but is most likely associated with bio-accumulation and slow depuration in benthic invertebrate prey (Rudebusch et al. 2020). Unfortunately, with the exception of localized concentrations of PCBs associated with military base activity in the Aleutian Islands (Reese et al. 2012, Tinker et al. 2021a), there is little information available for linking environmental concentrations to those found in sea otters. There is also little or no information showing population-level consequences of contaminant exposure for sea otters. Therefore, it is unclear if contaminant levels previously identified in sea otters are biologically significant. Again, site selection for a translocated population will be important in the potential for exposure to anthropogenic contaminants.

Oil Spills

A discussion of anthropogenic contaminants would not be complete without including oil spills. While the incidence of direct oil-associated impacts on sea otters is uncommon, the experiences of the 1989 Exxon Valdez Oil Spill (EVOS) graphically illustrate the potential devastation that oil can have on sea otter populations.

The short term, acute effects of oil exposure are dramatic and well known. Affected otters suffer from life threatening loss of thermoregulatory capacity due to the fouling of the fur with oil. Loss of thermoregulation results in a cascade of metabolic events associated with not only the toxicity of the petroleum compounds, but also the animals inability to meet caloric and fluid needs, either through active loss of heat or inability to hunt. Acute toxic effect observed during EVOS included pulmonary and mediastinal emphysema, gastric erosion and hemorrhage, hepatic necrosis, and hepatic and renal tubular lipidosis (Lipscomb et al. 1993).

Long-term effects of oil contamination can also be significant. This includes animals which may have been exposed to sub-lethal amounts of oil, persistent exposure to low levels of lingering oil, effects of oil on prey populations, and exposure to petroleum compounds bio-accumulated in prey species (Bodkin et al. 2011). In EVOS-affected areas of Prince William Sound, Alaska, lingering oil in intertidal sediments provided both direct and indirect exposure to foraging sea otters (Monson et al. 2000). At the population level, sea otter survival rates decreased in EVOS impacted area and population growth slowed significantly as a result of both continued mortality and movements of new animals into the affected areas (Monson et al. 2011).

The potential for oil related morbidity and mortality in a re-introduced sea otter population in Oregon cannot be ignored. It seems most likely that exposure would most likely affect low numbers of otters at a time, because of small spills from recreational or commercial vessels and runoff from adjacent lands. Catastrophic oil spills may also occur along the Oregon coast. While they historically have not reached the level of EVOS, spills such as the *New Carissa* spill of as much as 70,000 gallons in Coos Bay in Feb/Mar 1999 (http://www.mhhe.com/biosci/pae/es_map/articles/article_29.mhtml) may be devastating to a newly introduced population, were a spill to happen at the wrong time and place.

Fortunately, most of Oregon's power comes from hydro-electric plants, renewable sources, and natural gas. The last oil refinery stopped in 2008. A small portion of the state's energy is fueled by oil refined primarily by Puget Sound refineries. It is then transported to Oregon via the Olympic Pipeline or by barge. The oil shipped from Puget Sound is refined and not the problematic "Bunker C" oil that causes the worst contamination of wildlife and habitats; nonetheless, opportunities for oil spills in Oregon do exist.

The Oregon Department of Environmental Quality's Emergency Response Program has the responsibility of working together with industry and other agencies to prevent and respond to oil spills. While facilities and training for oil spill response in Oregon likely exist, there is probably not much consideration of sea otters and oil spill response. As a re-introduction program becomes more likely, a pro-active sea otter-based response plan and training program should be considered. Fortunately, California, Alaska, and Washington are good resources for such a program.

Trauma Caused Disease

Shark bite.

Shark bite trauma is the most common primary COD described for the southern sea otter from 1998-2012 (Miller et al. 2020) with dramatic increases being recorded since 2003 (Tinker et al. 2016). A recent analysis indicates that shark-bite mortality has a greater impact on overall population recovery in California than any other cause of death (Tinker et al. 2021b). The reported incidence in Washington State otters is not nearly as common, with only 2/93 reported between 2002-2015 (White et al. 2018). Predation, although not specifically attributable to sharks, is also thought to be an important limiting factor on sea otter populations in southwest Alaska (Estes et al. 1998).

Shark-related mortality of southern sea otters have been attributed to white shark (*Carcharadon* carcharias) bites, as a result of recovered tooth fragments and parallel scratches on sea otter bones. Unlike other marine mammal bites, sea otter attacks are non-consumptive, probably exploratory bites. The nature of the resulting wound and tissue trauma occurs later because of blood loss, tissue trauma, or the loss of thermal integrity and subsequent metabolic collapse.

The nature of the shark bite-related mortalities involving northern sea otters was not provided, however, the pathogenesis of the ultimate death was likely similar to that observed in southern sea otters (White et al. 2018).

The potential threat posed by shark predation to a re-introduced sea otter population in Oregon is unclear. It is likely to depend on several factors, including prey availability, kelp canopy cover, numbers and species of predatory sharks, and water temperatures (Tinker et al. 2016, Nicholson et al. 2018, Moxley et al. 2019). Tagging data (T. Chapple, unpublished data) and anecdotal evidence indicate a presence of white sharks in Oregon; however, recent personal communication with shark biologists from California State University Long Beach (C. Lowe) and Oregon State University (T. Chapple) suggest that there is not currently a good sense of the abundance or distribution of white sharks off the Oregon coast. Recent evidence does suggest that white shark distribution in California may be moving northward (Tanaka et al. 2021) with warming conditions. While these size classes do not feed on marine mammals, it is possible that the larger size class of white sharks, which does feed on marine mammals may be experiencing a similar northward distribution shift. This would mirror a hypothesized northward shift in white shark distribution along the US east coast (Bastien et al. 2020).

A second shark species with the potential for sea otter predation is the broadnose sevengill shark (*Notorynchus cepedianus*). Broadnose Sevengill sharks are circumglobally distributed ectothermic predators; on the west coast of North America they range from Baja Mexico to southeast Alaska, typically occupying shelf waters (<200m) including bays and estuaries. With the exception of the White sharks, Broadnose Sevengills are thought to be the dominant shark predator in coastal marine ecosystems where they reside, foraging individually or cooperatively and transitioning from a fish-based feeding structure to a diet focused on other elasmobranchs and marine mammals as they grow (Ebert 2002). While not considered to be a significant threat to sea otters in California, their potential impact in Oregon is less certain given their high trophic level and abundance in estuarine and coastal systems. There is a well described and documented migration pattern between the continental shelf and the shallow nearshore and estuarine habitats in this shark species (Williams et al. 2012).

Sevengill sharks feed on a broad spectrum of animals, including other sharks, batoids, teleost fishes, and marine mammals (Ebert 1991, Lucifora et al. 2005). The sevengill shark employs multiple hunting strategies, including stealth, similar to that of the white shark, but also social facilitation, in which a pack of sharks surround its victim to prevent escape prior to subduing it; a strategy employed at depth (Ebert 1991).

Unfortunately, the risk posed by shark attacks on sea otters in a re-introduction program is unknown, and unlikely to be known prior to embarking on such a program. Similarly, it is purely speculative to predict the potential impact that the broadnose sevengill shark may have on the population. Their known presence in both nearshore and estuaries is of some concern. While the white shark population of Oregon is uncertain, the effects of ocean warming due to climate change on white shark distribution may place Oregon-resident sea otters in harm's way. An example of the northward shift of white shark populations is exemplified by the recent documentation of a nursery area in Monterey Bay (Tanaka et al. 2021).

Anthropogenic trauma.

There are several direct human-caused health risks warranting discussion during an evaluation of a potential re-introduction of sea otters to the Oregon coast. While coastal Oregon has not been closely evaluated to date, a recent evaluation of anthropogenic risks for sea otters in San Francisco Bay was published, and may serve as a roadmap for an Oregon introduction (Rudebusch et al. 2020). In this study, anthropogenic risks were subdivided into four groups: vessel traffic, contaminants, commercial fishing, and major oil spills. These categories cover the majority of direct human-caused primary and contributing COD reported for northern and southern sea otters (White et al. 2018, Miller et al. 2020), the exceptions being blunt trauma to the skull and gunshot.

Vessel traffic.

The incidence of boat strike-related mortality was low in both the California and Washington State studies; 25/560 and 1/93, respectively (White et al. 2018, Miller et al. 2020). The negative effects of vessel traffic are not limited to boat strikes. Any disturbance of resting or grooming otters, normal social structure, and foraging efforts may also have significant impacts both directly and indirectly through stress (the immunosuppression caused by chronic adrenocortical hormone release), as well as the energetic expense of responding to the disturbance (Barrett 2019). Consideration of anthropogenic disturbance should include not only commercial boating and fisheries traffic, but also recreational fishing, watersports, such as kayaks, and boat-based nature watching tours. The risk associated with vessel traffic will likely be site specific, and as human numbers continue to grow, can be expected to increase.

Fishing gear related trauma.

Trauma in sea otters associated with commercial and recreational fisheries is most frequently attributable to net entanglement, fishhook injuries/consumption, or entrapment in fish/invertebrate traps (Figure 10.3). Since fishing regulations in California were changed to move gill net fisheries into deeper water, the incident of net entanglement has decreased significantly (Wendell et al. 1986). However, it still does occur on occasion, either as a result of illicit fishing practices or lost/abandoned/damaged net entanglements. By mandating gill nets be set at depths deeper than sea otters dive (40m), the hazard seems avoidable.

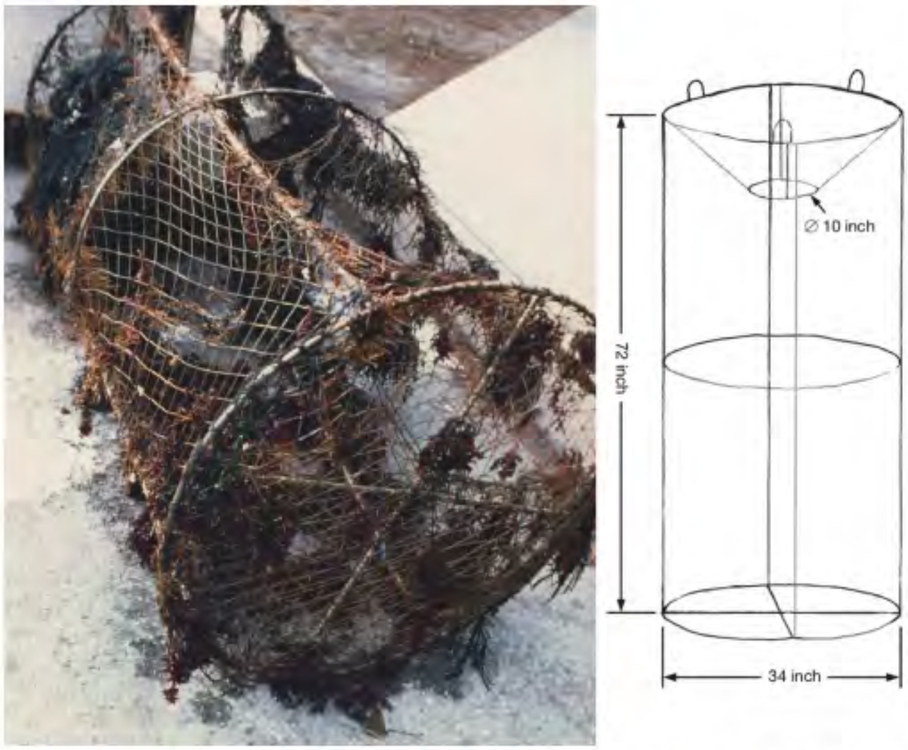

Figure 10.3. A) photograph, and B) line drawing, of a derelict fish trap that drifted into Monterey Harbor I 1987, containing 2 drowned sea otters (1 adult female and 1 large male pup). Note the 10" diameter (25.4 cm) fyke opening. Figure from (Hatfield et al. 2011)

Rigid traps, especially those used for Dungeness crabs, have been recognized as a potential entrapment threat, especially for younger sea otters, who may be capable of entering the trap. Following extensive testing using rehabilitated otters at the Monterey Bay Aquarium, a solution to the mortality in fish and shellfish traps was identified. By reducing the fyke size from a 10" circle to a 3" x 9"rectangle, most independent sea otters were excluded from the traps, and yet crab capture rates were not significantly impacted (Hatfield et al. 2011).

Anthropogenic trauma.

Two forms of direct anthropogenic trauma – gunshot and blunt trauma to the skull – have been reported that are most assuredly malicious in nature (trauma from boat strikes is discussed above under the sub-heading "vessel traffic") (White et al. 2018, Miller et al. 2020). These incidents seem to be uncommon. Published reports do not identify locations, either specifically or generically, nor do they postulate the "justification" for the use of deadly force. Rather than speculating without adequate basis, suffice to say public reaction to a sea otter re-introduction program is unlikely to be universally embraced. It is incumbent upon project managers to recognize the potential for this type of trauma and take steps necessary to mitigate its occurrence, if possible. Public outreach and education may be the most effective mitigation strategies.

Animal Welfare.

Animal welfare and its application to free ranging wildlife is a challenging subject: welfare assessments tend to be focused on individual animals, while conservation goals tend to be focused on populations, and these two underlying goals are not always consistent (Estes and Tinker 2017). While aspects of animal welfare have gained increasing degrees of scientific grounding, they still remain predominantly subjective, and by the nature of welfare, are not static and change frequently.

Original concepts of animal welfare were based on The Five Freedoms written for Britain's Farm Animal Welfare Council in 1965 and released in 1979: (https://webarchive.nationalarchives.gov.uk/20121010012427/http://www.fawc.org.uk/freedoms.htm). These have been subsequently modified and renamed the Five Opportunities for the Association of Zoos & Aquariums' animal welfare and accreditation standards: (https://assets.speakcdn.com/assets/2332/aza-accreditation-standards.pdf). The modification was made to better align the concept of animal welfare with wildlife, particularly wildlife under human care.

Within the context of this chapter, the Five Opportunities will provide the structure upon which welfare considerations will be outlined. By their nature, they will be subjective, and attempts will be made to apply them to a re-introduced population whenever possible. At times, however, it may be necessary to consider the individual animal within the context of the opportunities:

- Nutritionally complete diets
- Comfortable living experiences
- Physical health
- Social groupings
- Avoidance of chronic stress

Animal welfare is a hot-button topic in the public's eyes, especially as it applies to marine mammals. The inclusion of animal welfare as a component of the feasibility study may be of benefit if, and when, the project is formally proposed. Consideration not only of the scientifically and model-based aspects, but also the humane and welfare considerations of the project will undoubtedly be helpful as the Alliance strives to gain public support.

Nutritionally complete diets.

Several aspects of nutrition and diet will need to be included in release site selection. Not only will availability of prey be important, but also the spectrum of species and the otters' recognition of the species as food warrants consideration. The availability of a variety of prey may provide some degree of insulation from naturally occurring recruitment cycles and other forms of variability of species availability. Prey will also need to be present in sufficient quantities at depths attainable by re-introduced otters.

Wholesomeness (or health risks) of food items also warrants consideration. Areas with large aggregations of *Emerita* and *Blepharopoda*, the intermediate hosts of the cause of acanthocephalan peritonitis, may be problematic. Similarly, food-based risk factors associated with toxoplasmosis and those known to bioaccumulate domoic acid effectively are noteworthy.

Comfortable living experiences.

A great deal of effort has been made in identifying appropriate habitat suitable for release of sea otters, particularly animals that will be unfamiliar with the release site(s). It is important to factor into the decision-making process the ability of animals to rest comfortably without undue disturbance from boat traffic and other noxious stimuli. In addition, while the potential for shark attack is unknown, risk factors that have been identified in California warrant consideration in the release site evaluation process (Moxley et al. 2019).

As plans for pre-release holding and conditioning are developed, animal welfare will be an important consideration. The federal Animal Welfare Act and Regulations: https://www.aphis.usda.gov/animal_welfare/downloads/AC_BlueBook_AWA_508_comp_version.pdf has established minimum standards for marine mammal enclosures for exhibition and research animals based on animal size (§ 3.104(f)), but their applicability to animals in a re-introduction program is doubtful. Regardless, however, there must be some consideration for the size of animal enclosures. Tanks used for surrogate reared, pre-release juveniles at the Monterey Bay Aquarium are approximately 20 ft. in diameter and 3 ft. deep. Animal comfort appears to decrease significantly with group sizes exceeding six animals. Population density within holding facilities will be an important consideration.

Physical health.

Much of the discussion about the welfare considerations of animal health are found in the first section of this chapter. There are several additional considerations which are not disease specific. There should be a protocol developed which describes the frequency (i.e., pre-transport, pre-release, and post-release) with which individual animal health assessments are made. It is readily apparent that starting with healthy animals before re-introducing them to a new site is important.

After otters have been released, what will be the response to animals in distress? There will undoubtedly be a public expectation that attempts will be made to capture and rehabilitate sick or injured sea otters associated with the re-introduction program. Development and implementation of a stranding response program may be able to rely on some pre-existing coastal marine mammal rehabilitation centers, but facilities, protocols, and even regulatory agencies will be different for sea otters.

One of the confounding knowledge gaps in review of the previous Oregon re-introduction program has been the lack of information about "why it failed." To better understand the outcome of the project, plans for post release monitoring and carcass recovery and analysis should be made. The development and implementation of these post release efforts warrant further discussion and investigation.

Social groupings.

Successful re-introduction of sea otters into sea otter-free habitats may be difficult; there are no conspecifics to attract and keep the neophytes there. It is not known what the critical mass for re-introduction is, but data from the previous sea otter translocations may be informative. The numbers of otters available for the project will be dependent upon the source populations (see Chapters 3 and 9).

This will be further complicated by the potential need to hold otters at the release site for a time to allow acclimation and recovery of the pelage post transportation. Holding times will be directly proportional to the distance travelled.

The Monterey Bay Aquarium has occasionally released pairs of juvenile animals which spent enough time together to develop a bond while under human care. Despite this pre-release relationship, the otters commonly split up immediately upon release. On occasion, they might re-encounter one another, but there was no evidence of retention of the bond. In some cases, there was a loose re-association at common rafting or feeding areas, or they may remain separated but within the same general location (Staedler, M, Mayer, K, Hazan, S; pers comm). It is important, however, to recognize that these observations were made in release sites already occupied by sea otters, which may have served as anchors to recently released individuals.

While not causally related to social groupings, some consideration should be made to animal age. On one hand, younger animals are less likely to have strong site fidelity and desire to swim back to their original territory. Another perspective, though, is that young animals, particularly rehabilitated sea otters may not be as athletic or physically conditioned as wild otters of similar age. In addition, rehabilitated otters have not experienced the realities of the open sea or estuary. Their lives have been confined to tanks of varying sizes and depths.

The animal welfare aspects of social groupings may be the most problematic of the five opportunities. The questions are relatively straightforward, the answers less so. The options available are not numerous and involve a series of trade-offs.

Avoid chronic stress.

This animal welfare opportunity is a bit oxymoronic. There is no way to avoid stress during a re-introduction, and some of it may be prolonged. Every aspect of the project will be associated with some degree of stress to the otters. A more realistic goal will be to minimize stress whenever possible during the process. Minimizing human contact, both directly and indirectly, management of isolation, and segregation of sexes are examples of actions which will reduce stress. Other stressors are likely to be mitigated through the attention paid to the other four opportunities. The design of a re-introduction program will be such that opportunities for success are maximized. Minimizing sea otter stress and discomfort will be a natural outcome of the plans to succeed.

Summary

A chapter on the animal welfare concerns associated with a re-introduction of sea otters onto the Oregon coast would not be complete without some discussion of the potential for failure. While the success or failure of the project is determined by population level metrics, both outcomes are based on the sum of individual otters, which is where animal welfare is relevant. The concept of failure will need to be evaluated and defined on different levels, which may impact the decision to continue re-introductions, re-evaluate site of release, and modification of methods for animal capture, transportation and release.

The preceding paragraphs represent an attempt to identify, summarize, and extrapolate information regarding sea otter health and welfare from known circumstances to an anticipated re-introduction site. It is impossible to predict all of the potential health threats that may exist in the future, or that occur cryptically along a coastline free from sea otters for several centuries. That being said, a good faith effort has been made to identify those of greatest concern, either known or suspected. A summary table (Table 10.1) ranks the population-level risks and likelihoods of the diseases described within this chapter.

Based on a review of all the risk factors in Table 10.1, it appears that the most substantial threat to sea otters living along the Oregon coast is likely to be domoic acid intoxication. Its presence in shellfish has been recognized as a potential human health threat for well over a decade; a concern most directed towards acute intoxication of shellfish consumers. Monitoring activities and associated toxicity thresholds have been designed to protect the public, therefore it is likely that chronic, low levels which have been shown to be a driver of cardiac disease in sea otters may go undetected (Moriarty et al. 2021).

A second disease of high concern, but one which is one with uncertain potential is shark bite trauma. Shark bites are a significant cause of mortality for southern sea otters, and the white shark has been accepted as the primary source of the injury. White sharks have been found off the Oregon coast, however, their population numbers and locations are unknown. A second potential sea otter predator, the broadnose sevengill shark is present in high numbers in coastal, offshore, and estuarine systems. A known marine mammal predator, its proclivity to interact with sea otters is unclear.

While it is unlikely that infectious disease will have population-level impacts on the re-introduction program, it may have significant impacts in specific areas, and may also increase over time as sea otter numbers increase, in the case of density-dependent diseases (Tinker et al. 2021b). Contagious diseases, such as one of the morbillivirus infections, have been associated with epizootics in a spectrum of marine and terrestrial mammals. They tend to be density-dependent due to the mode of transmission; a population spread out over a relatively lengthy stretch of coastline may be advantageous, especially for a disease like canine distemper. The same consideration may not apply to other morbilliviruses, such as phocine or cetacean morbillivirus, which may be carried by animals with large home ranges or a few animals making longer-distance movements (Jameson 1989, Ralls et al. 1996).

Table 10.1. Summary of health threats for sea otters in the case of a reintroduction to Oregon, including a subjective ranking of the potential population impact and the relative likelihood of the threat occurring, as well as other attribute of the threats.

Health Concern	Category	Contagious	Population Impact	Likelihood	Source	Site Specificity
Domoic acid	Non-infectious, toxic	No	High	High	Prey, HAB	Possible
Shark bite	Trauma	No	Med-High	Med-high	White shark, 7-gill shark	No
Morbillivirus, phocine	Infectious, viral	Yes	Med-High	Med	Phocid seals	No
Morbillivirus, canine distemper	Infectious, viral	Yes	Med-High	Med	Terrestrial carnivores	No
Sarcocystis	Infectious, parasitic	No	Med-High	High	Land-sea, runoff, prey	Freshwater runoff
Toxoplasma	Infectious, parasitic	No	Med-High	High	Land-sea, runoff, prey	Freshwater runoff
Oil spill	Non-infectious, toxic	No	Med-High	Med-low	Vessels, land-based run-off	Site specific increase
Streptococcus phocae	Infectious, bacterial	Possible	Med	Med-high	Bite wounds, prey	No
Acantocephalid peritonitis	Infectious, parasitic	No	Med	Med	Prey, sandy substrate	Sandy seafloor
Microcystin	Non-infectious, toxic	No	Med	Med	Freshwater runoff	Freshwater runoff
Saxitoxin	Non-infectious, toxic	No	Low	Med-high	Prey, HAB	Widespread
Tributyl tin	Non-infectious, toxic	No	Low	Low	Prey, sediment association	Marinas, large harbors
Influenza	Infectious, viral	Yes	Low	Low	Pinnipeds	No

Health Concern	Category	Contagious	Population Impact	Likelihood	Source	Site Specificity
Leptospirosis	Infectious, bacterial	Yes	Low	Low-med	Pinnipeds	Possible pinniped haul outs, rookery
Bordetella bronchiseptica	Infectious, bacterial	Yes	Low	Low	Open	No
Coccidioidomycosis	Infectious, fungal	No	Low	Low	Environment	Possible
Fishing gear	Anthropogenic	No	low	Low	Nets, crab pots	Possible
Larval migrans	Infectious, parasitic	No	Low	Low	Land-sea, runoff, prey	Freshwater runoff
Vessel traffic	Anthropogenic, trauma	No	Low	Low	Commercial, recreational,	Heavily travelled, populated areas
Contaminants	Anthropogenic	No	Low	Low	Sediments, water column	Yes
Strep bovis/equinus	Infectious, bacterial	Possible	Uncertain	Med	Probable prey	No
Bacterial infections, not specified	Infectious, bacterial	Possible	Uncertain	High	Multiple	No

Non-contagious infectious diseases, such as Sarcocytosis and Toxoplasmosis, are not density-dependent in terms of their transmission processes, but in some cases their impacts on population health can be greater at higher population densities because individual animals are in poorer heath and/or selecting sub-optimal prey species (Johnson et al. 2009, Burgess et al. 2018, Tinker et al. 2021b). Such diseases may also have significant impacts on small populations in localized areas, especially those associated with freshwater runoff. A significant first-flush runoff may flush a large pathogen load into the nearshore system, and bio-accumulation by sea otter prey may be the result. This would be unlikely to have a significant impact on an established population, but may be devastating to a recently introduced one.

The animal welfare issues associated with the re-introduction are important for the effect they may have on the population, albeit one otter at a time, and for their role in maintaining public confidence and support. This will be most notable during their time under human care; the capture (if that is needed as an animal source), transportation, acclimation, and release of sea otters in Oregon. During those activities, animals will be best considered individuals. Each of the five opportunities, nutrition, comfort, health, social structure, and stress relief will need to be addressed. Many of the considerations and recommendations are not well defined, as they are dependent upon animal numbers, sources, and release plans. Once these parameters have been set, it will be important to address these.

An additional health and welfare consideration which does not fit well into the previously described categories is post-release activities. Tracking after release may provide important insight into the acclimation and adjustments being made by the otters. It will also be important in identifying otters in distress, retrieval of carcasses, and perhaps following those who emigrate from the release site. Tracking questions are naturally associated with consideration of tagging technologies and the myriad of associated decisions (refer to Chapter 9).

Although not necessarily a population-level health consideration, plans for management of live otters in distress (i.e., sick or injured) must be made. Will they go to a rehabilitation center? If so, which one? A plan for retrieval of beach-cast otter carcasses is important. A component of the carcass program will be the postmortem examination of dead animals. Development of a standardized necropsy protocol is recommended. Again, the questions of who, where, and what, need to be answered before a reintroduction begins.

There are no glaring concerns which suggest that re-introduction of sea otters to the Oregon coast would be likely to face insurmountable health and welfare issues. There are known diseases and conditions which may be somewhat problematic, but this is the case for every extant sea otter population. There are also several unknowns that should be recognized. The effects of climate change through direct impacts on weather patterns, oceanographic parameters, and sea level rise will have an impact at some point in time. Indirect effects, such as changes in prey species, pathogen distribution, and animal movements also exist. Lastly, if 2020’s SARS-Coronavirus19 pandemic has taught us anything, it may be that there are things out there which can have devastating effects on animal (and human animal) populations; things we don’t know about, and have difficulty predicting. While there are no fail-proof insurance policies for such unknowns, the most prudent strategy for reducing potential for failure is likely to consist of frequent, close monitoring of individuals in a newly established population, with the flexibility to respond quickly should un-anticipated risks emerge.

Final Conclusions

The discussion above is not intended as an all-inclusive list of the potential diseases, infectious and non-infectious, which may have impact on sea otters, or of the considerations for animal welfare. It is an attempt to present information on those which have been shown to have the potential for population-level effects on a re-introduced sea otter population. Much of the information provided is interpreted as an extrapolation of data from the southern sea otter and the Washington populations. Alaskan otters also warrant consideration; however, the nature of the Alaskan coast and subsequent access to otters, especially distressed or dead otters, and the incidence of scavenging upon dead and moribund beach-cast otters, makes mortality investigations problematic for that region.

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Chapter 11: Stakeholder Concerns and Perspectives

Shawn Larson and M. Tim Tinker

The potential return of sea otters to the Oregon coast, either through natural range expansion, or through translocation, is viewed favorably by many people. Positive views of sea otter recovery in Oregon are based on several factors, including the potential for restoring connectivity of existing sea otter populations between California and Washington and the functional restoration of coastal ecosystems in nearshore areas of the Oregon coast. Sea otters are considered a keystone species (Estes and Palmisano 1974), whose presence as functioning components in nearshore ecosystems has a number of important ecological effects (Estes et al. 2004) such as increasing stability and productivity of kelp forests and eelgrass beds and enhancing the abundance of nearshore fish species such as rockfish and salmon and various invertebrates, even abalone, that that use these kelp and eelgrass habitats (refer to Chapter 5 for a full discussion of ecological effects of sea otter recovery). This well studied trophic cascade is often considered a conservation success story for those that are supportive of the return of this keystone species to marine ecosystems (Estes 2015).

However, sea otter recovery has not been viewed favorably by everyone in places where it has occurred: their return to regions from which they had been extirpated a century earlier has in some cases led to conflicts with commercial and subsistence fisheries in areas where sea otters compete with humans for commercially valuable invertebrates like crabs, clams, urchins and sea cucumbers (Wendell 1994, Larson et al. 2013, Carswell et al. 2015). Weighing the relative costs and benefits of sea otter recovery is challenging, and in addition to economic considerations there are also non-monetary social values that must be considered (see Chapter 7). A recent economic analysis of the impacts of sea otter recovery in British Columbia, Canada (Gregr et al. 2020), illustrates some of the challenges of this accounting task. Gregr et al. (2020) found that the benefits of sea otter recovery to Vancouver Island included 37% more total ecosystem biomass annually with associated increases in the value of finfish landed (>$9.4 million), carbon sequestration (>$2.2 million) and ecotourism (>$42.0 million), which all combined to offset an associated estimated economic loss to invertebrate fisheries (<$7.3 million). However, these economic considerations fail to address other equally important issues, such as social impacts to the communities that support (and are supported by) those invertebrate fisheries, and challenges to food security and self-governance of First Nations communities in the areas affected (Salomon et al. 2015, Burt et al. 2020). Inevitably there would be those who would gain and those who would lose economically from sea otter recovery in Oregon, but those gains and losses are unlikely to be distributed equally or evenly. And while it is important to consider the loss of income and revenue associated with impacts to nearshore fisheries, it is also important to recognize and address non-monetary costs to people's livelihoods, lifestyles and futures. Given these challenges, it is extremely important that decisions about sea otter reintroduction efforts are made in full consideration of all stakeholder opinions, both positive and negative. Doing so can help to foster consensus and stakeholder engagement indecisions and plans, as well as more effective management after the fact.

Sea otters have been absent from Oregon for over 100 years and current coastal human institutions and practices (e.g., fisheries, recreation, resource management) have developed during that time. It is likely that some of these activities will be affected by the return of sea otters; however, predicting how different members of coastal communities will respond to these impacts is challenging. One approach is to look to and learn from other regions where sea otters have recovered, either through "natural" growth and expansion of remnant populations, or via successful reintroductions, and where the resulting sea otter populations are now interacting both positively and negatively with people. While every region is different, and the return of sea otters to Oregon will likely involve some unique costs and benefits, nonetheless there are some commonalities to the types of concerns and human responses that have been raised in previous examples of sea otter recovery, and a review of some of these perspectives may be informative.

One of the most successful reintroductions of sea otters (from the perspective of sea otter conservation) occurred in the late 1960s in southeast Alaska (Jameson et al. 1982). Over 450 animals were distributed among 7 translocation sites (see Chapter 2 for details), leading to a rapid rate of increase in both abundance and distribution (Esslinger and Bodkin 2009), such that the total abundance at the time of the last comprehensive surveys (2010-12) was >25,000 and is likely now closer to 40,000 given a 5-10% estimated annual rate of increase (Tinker et al. 2019). Based on the wide range of social and economic concerns about the impacts of sea otter recovery on commercial activities and local communities in southeast Alaska, the US FWS convened a workshop in November of 2019 at which a diverse set of stakeholders were invited to share knowledge, express concerns, and begin to develop a proposed set of approaches for addressing key challenges associated with sea otter recovery and its impacts (https://www.seaotterstakeholders.com). A final report from that meeting has also been released ("Southeast Sea Otter Stakeholder Meeting", US FWS Report MMM 2020-01). Below we highlight some key points from the meeting and report that illustrate the range of stakeholder concerns regarding the impacts of the return of sea otters to southeast Alaska.

Stakeholder views in Southeast Alaska

Subsistence Harvest of Sea Otters

Sea otter harvest has been an important component of Native communities' cultural practices for thousands of years. Under the 50 CFR 18.23 exception of the Marine Mammal Protection Act (MMPA), Alaskan Natives are allowed to continue to harvest sea otters for their pelts and creation of handicrafts. This is most clearly enacted in southeast Alaska where the expansion of sea otters across the region has created economic opportunities for individuals involved in harvest, sea otter hide tanning, and modifications of the hides for artistic purposes and sale of handicrafts. However, there is inequity in these opportunities as many Alaska Native community members lack the training, access to a boat, and equipment to harvest sea otters. For those that do have access, there is concern over the blood quantum policy, including whether non-Native individuals can be on harvest vessels and whether Alaska Native individuals from communities outside of southeast Alaska are eligible. Second, some community members lack training in sea otter hide preparation, skin sewing, and artistic modifications of the hides. Third, there are concerns over access to markets for selling handicrafts to tourists. And finally, there are concerns about misperceptions by the public about the legality and ethical/historical underpinnings of the subsistence harvest of sea otters.

While subsistence harvest issues are unlikely to be immediately and directly relevant for an Oregon sea otter reintroduction, they do indirectly raise issues of local governance and different perceptions about how sea otters and humans can and should interact, as well differing cultural practices and traditions associated with sea otters. It is clear from the southeast Alaska example that local communities, including First Nations communities, should have a important voice in decisions about sea otter reintroduction and recovery.

Conflicts with Subsistence and Commercial Shellfish Fisheries

For Alaska Native communities, traditional harvest practices often included localized harvest of sea otters to alleviate predation pressure on shellfish by sea otters, which in turn, could increase availability of shellfish for harvest. Shellfish collection continues to be an important component of Alaska Native community cultural practices, but the situation since sea otter reintroduction and range expansion has been complicated with additional legal considerations and stakeholder interests.

Modern commercial shellfisheries emerged in southeast Alaska during an “abnormal” historical period when sea otters were entirely absent. Without sea otter predation, certain shellfish populations thrived and allowed for productive fisheries on these species to develop. Since the successful reintroduction of sea otters, their abundance has increased and their range has expanded, putting sea otters into direct conflict with these commercial fisheries. As sea otters have increased, productivity of many shellfish fisheries have declined, causing some fisheries to become unprofitable and even close.

To further complicate the problem, sea otters are currently managed at the regional stock level (all of southeast Alaska), but their impacts are apparent at a much smaller, localized scale. For this reason, subsistence and commercial fishery stakeholders expressed interest in exploring ideas for more local spatial management of sea otters in a coordinated manner. This could potentially be accomplished if Alaskan Native subsistence harvests were to be focused locally to protect subsistence harvest of fisheries. However, it was also recognized that such local harvests would likely not be feasible at a larger scale sufficient to protect many commercial fisheries.

Sea Otter Population Ecology and Ecosystem Status

The United States Fish and Wildlife Service (USFWS) is responsible under the MMPA to collect data on sea otter population size, distribution, and trends. These population surveys are to be carried out on a regular basis and use standardized and reliable methods to accurately document population trends. Stakeholders requested further clarification on how values for Optimum Sustainable Population (OSP), carrying capacity (K), and Maximum Net Productivity Level (MNPL) are estimated. These terms are used within the MMPA and are therefore a critical component of how sea otters and their ecosystems are managed. Additional information on the abundance and distribution of shellfish as prey for sea otters and suitable habitat are also important for understanding how the ecosystem affects, and is affected, by sea otters. This ecological information is challenging to collect at appropriate scales and monitoring changes through time is even more challenging. Stakeholders expressed interest in future research and monitoring efforts to provide current estimates of sea otter population size and distribution, and the dynamics among sea otters, shellfish, and nearshore habitats. In addition, Alaska Native community representatives expressed their interest in facilitating collection of Traditional Ecological Knowledge to better understand how sea otters and associated ecosystems have changed through time.

All stakeholder groups present at the meeting recognized the important ecological role sea otters play in the ecosystem. Sea otters have experienced drastic changes over the past few hundred years, in which they went from being locally abundant, to entirely absent in the early 20th century, to their current status of recovery and range expansion into former habitats. There are differing perspectives on how this ecosystem should function in the future, and how “balance” can be achieved between sea otters and people in a way that is acceptable to all stakeholders.

Stakeholder views in Oregon

People in Oregon are now beginning to explore what it may look like to have a viable sea otter population once again. Reintroductions of carnivores are typically controversial in nature, including past reintroductions of wolves and grizzly bears. Sea otter reintroductions have also caused conflict in California, British Columbia and Alaska (Carswell et al. 2015). Experiences in southeast Alaska and British Columbia (Burt et al. 2020) suggest that it is important that all concerned stakeholders be engaged early in the process, prior to any management decisions about reintroduction.

Stakeholder interests specific to Oregon have been explored by three graduate students from Oregon State University in a 2019 student report titled “Assessing the feasibility of a sea otter reintroduction to Oregon through a coupled natural-human lens”, conducted in partial completion of a National Science Foundation fellowship (Curran, Kone and Wickizer 2019; Appendix E). The authors surveyed 78 potential stakeholders to gauge perceptions around a potential future sea otter reintroduction. Sampled stakeholders included the following: Elakha Alliance Board members, environmental advocacy groups, staff from Pacific shellfish advocacy and research organizations, board members of Oregon’s Ocean Policy Advisory Council (marine stakeholder groups that advise the Governor’s office), local governments on marine policy issues, commissioners for Oregon’s Department of Fish and Wildlife Commission, the Oregon Trawl Commission, the Oregon Salmon Commission and the Oregon Dungeness Crab Commission. The survey response rate was 36% (28/78) and participants were asked to invite others that had an interest in marine or fish and wildlife issues to also participate (N=21), increasing the total survey sample size to 49. The authors recognized that this was a limited and informal survey, due to small sample size, and without formal survey methodologies (e.g. random selection of potential respondents) there is no guarantee of unbiased representation of public perceptions and views. Nonetheless, many of the survey respondents were leaders in their coalitions and thus were thought to be representative of their particular stakeholder groups.

A summary of respondent views on key topics associated with sea otter reintroduction is provided in Table 11.1. For the open-ended questions related to potential outcomes, 21 respondents provided one or more negative outcomes that they anticipated, and 46 respondents provided one or more positive outcomes. The majority of Oregon survey respondents (94%) perceived that there would be positive potential outcomes associated with the reintroduction of sea otters to Oregon; however, 43% of respondents also perceived that there could be negative outcomes as well. The authors reported the most common negative outcomes identified were harm to fisheries or reductions to certain sea otter prey species (n = 15), loss of access to marine areas as a result of federal, state and local regulations related to sea otters (n = 4), and community conflicts resulting from different perceptions around the reintroduction (n = 3). Two individuals mentioned the conflicts created by sea otters in southeast Alaska, citing the harm the otters have caused to fisheries there and expressing concerns that similar phenomena could occur in Oregon. For the open-ended items related to positive outcomes of sea otter reintroduction, the most frequently cited outcome was the improvement in nearshore marine ecosystem health and the restoration of a balanced ecosystem (n =27), followed by increased tourism (n =24) and positive impacts on kelp (n = 23). Other positive outcomes listed included the following: reductions in urchins and other benthic species (n=14); benefits to fisheries such as fin fish (n=11); wildlife viewing, recreational, and cultural benefits (n=4); sea otters serving as a flagship species that may increase interest in conservation and provide educational opportunities (n=7); the restoration of a keystone species (n=7); species-wide benefits to sea otters (e.g. increased genetic diversity, viability and species connectivity) (n=4); the ethical obligation and “righting a historic wrong” (n=4); increases in "blue" carbon (n=3); cultural benefits to Native American tribes (n=2); and increases in seagrass/eelgrass abundance (n=2). Overall, a majority of respondents (88%) supported reintroducing sea otters to Oregon to some degree, with only 10% strongly opposing and 2% somewhat opposing.

Table 11.1. Summary of Stakeholder perceptions about the return of sea otters to Oregon, based on survey results. Source: Curran, Kone and Wickizer 2019; Appendix E

Stakeholder affiliation*	**% associated negative outcomes**	**% Associated positive outcomes**	**% Stakeholder Policy support**
Commercial fisher (n=7)	71	86	43
Recreational fisher (n=20)	45	90	75
Native American tribe (n=3)	0	100	100
Scientist (n=12)	50	100	83
Local government (n=8)	75	88	75
State government (n=4)	75	75	50
Federal government (n=2)	50	50	50
Environmental group (n=27)	37	96	93
Charter boat/tour operator (n=2)	0	100	100
Coastal recreationalist (n=28)	36	96	89
Oregon coastal resident (n=26)	31	92	81
Oregon non-coastal resident (n=15)	60	100	100

**Respondents could self-assign to more than one stakeholder group*

Key positive outcomes identified by stakeholder survey respondents

Increased ecosystem health & ecosystem services

When sea otters reclaim historical habitat, they can increase overall species diversity via trophic cascades triggered by top-down forces. Increased species diversity has been linked to improved ecosystem resilience and health. More resilient and healthy ecosystems can provide a suite of ecosystem services. Accessibility of these sites by stakeholders is a potential confounding variable as this could serve as a potential source of disturbance to sea otters; however, access could also facilitate recreational activities (wildlife viewing and fishing) and the benefits derived from those activities.

Species recovery & conservation

Survey responses suggested that respondents could appreciate both the historical context of a sea otter reintroduction such as increasing connectivity of sea otter populations and increasing genetic diversity. Over two-thirds of respondents favored a reintroduction source that reflected the genetic heritage of the extinct Oregon sea otter. In addition, half of respondents found a balance of rescues from stranding programs and wild-caught otters to be appropriate.

Restored cultural connections

The prevalence of sea otter remains in First Nations midden remains speaks to their place in Native American culture for thousands of years (Hall et al. 2012). First nations accounts, both written and oral traditional knowledge, speak of the value placed on their pelts and their importance in trade. A successful sea otter reintroduction to Oregon would restore not only ecosystem function but the cultural connection between native tribes and the sea otter.

Key negative outcomes identified by stakeholder survey respondents

Fisheries conflicts

Competition between sea otters and fisheries is a common concern wherever sea otters and people co-occur (Carswell et al. 2015).- Sea otter recovery can reduce abundance and size of local sea otter prey populations (benthic invertebrates such as crabs, clams and urchins), however the species most impacted would depend on where sea otters are located (see Chapter 7). Oregon has several important commercial and recreational fisheries that could potentially be impacted by the reintroduction of sea otters, but the potential for conflict depends on overlap of sea otters and important commercial fishing areas (e.g. crabbing grounds), which itself would be determined by the location of reintroduction and the rate at which the population spreads out along the coast (see Chapter 3). It would therefore be critical for managers from federal (USFWS), state (Oregon Department of Fish and Wildlife (ODFW) and tribal agencies to carefully monitor the growth of the sea otter population and recreational and commercial benthic fisheries, to maintain a balance and report survey results effectively to assure all stakeholders are engaged and their concerns are addressed.

Quantification of sea otter effects on economically important fisheries can be achieved by a combination of direct observation of sea otter diets combined with fisheries trend data on recreational and commercial harvests (e.g. Hoyt 2015). For example, fisheries managers in Washington have closed razor clam fishing in the Kalaloch area most years since 2012 due to low clam abundance and small size (https://wdfw.wa.gov/sites/default/files/publications/02168/wdfw02168.pdf). Kalaloch is the area where the Washington sea otter population has been seeing the highest growth since 2008 and the sea otters there eat razor clams almost exclusively (Hale et al. 2019). While some benthic invertebrate fisheries may decrease, other fisheries may increase. For example, the indirect food web effects of sea otter recovery include increased abundance and stability of kelp forests, important habitat for some finfish species, and there have been documented increases in commercially fished species in other regions where sea otters have recovered (Markel and Shurin 2015).

Community polarization

Survey respondents identified community polarization as a possible negative consequence of sea otter reintroduction. One respondent questioned the legitimacy of a sea otter reintroduction because they believed it was an interest group effort, as opposed to an effort being undertaken by the government. Others may also share this perception, and this could potentially be made into a political narrative to oppose reintroduction. It is clear that, in each location, there will be people that are for and against sea otter reintroductions. Such concerns are important and should be dealt with through continued dialogue.

Survey Conclusions

The small survey of Oregon stakeholders summarized here indicated that most respondents recognized at least some positive benefits from potential sea otter reintroduction, including those who also identified negative consequences and expressed opposition to reintroduction. One of the negative outcomes of sea otter reintroduction that was identified by respondents was restricted access to the marine environment. Considering what areas are already protected in Oregon when evaluating potential reintroduction locations in Oregon, could help minimize the possibility of new potential restrictions associated with reintroducing a nearshore marine mammal. To ensure a successful reintroduction with the least possible amount of conflict, it will be important for sea otter reintroduction managers to establish an open and ongoing dialog with all stakeholders, to build trust and facilitate understanding.

Summary

Sea otters have been absent from Oregon's coast for over 100 years and human activities such as commercial and recreational fisheries have developed during that time without sea otters as competitors. Thus, the return of sea otters to the nearshore often elicits both positive and negative reactions from coastal communities. Some First Nations community members may welcome the return of the sea otter, to re-establish the relationship that native people have had with sea otters for both cultural and spiritual reasons. Other coastal community members have more mixed opinions, as the expected gains and losses will not affect all people equally. Economic benefits to coastal communities following the return of sea otters are often emergent as an increase in total ecosystem biomass, increased value of finfish, increased carbon sequestration, and increased ecotourism. Economic costs to coastal communities following the return of sea otters are most often associated with a loss to invertebrate fisheries such as crab, clam, cucumber and urchin fisheries. A small survey of Oregon stakeholders found that over 90% of survey respondents perceived that there would be positive potential outcomes associated with the reintroduction of sea otters to Oregon while over 40% also perceived that there could be negative outcomes as well. The return of the sea otter to Oregon's nearshore will almost certainly be associated with disruptive changes to the nearshore ecosystem, some of which will be perceived as positive and some perceived as negative by people, and as has been the case in other regions this will evoke both positive and negative responses from stakeholders. Engaging and continuing a constructive dialogue with all affected stakeholders and community groups should therefore be a fundamental component of the decision-making process.

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Chapter 12: Conclusions

M. Tim Tinker

1. Reintroductions are a successful conservation tool.

Reintroduction of sea otters to their former habitats has been the single most important management action contributing to recovery from near extinction in regions of the eastern north Pacific. Approximately 30% of global sea otter abundance today can be attributed to reintroductions to southeast Alaska, British Columbia, and Washington. Reintroductions have increased species viability, helped recover genetic diversity and improved gene flow throughout populations in the regions north of the geographic break between the Washington and California populations. Previous reintroductions, even those that failed, can provide practical and logistical lessons that will improve the chances of success.

While some previous sea otter reintroductions were not successful including to the Pribilof Islands and to the Oregon coast in the 1960s, the lessons learned from past reintroduction efforts – both successful and unsuccessful – have led to insights into the demographic, behavioral, and ecological factors that are important to success (Chapter 2). A review of these previous efforts, including the most recent reintroductions to San Nicolas Island and Elkhorn Slough in California, reveals some strategies that may improve the chances of success of future reintroduction efforts (Chapter 9).

Potentially important future genetic consequences could result from a reintroduction of sea otters to Oregon. Based on historical records, it appears that sea otters once occurred throughout most of the Oregon coast although there are outstanding questions about the relative densities of sea otters in Oregon. Three published genetic analyses of tissue samples from midden sites suggest that Oregon sea otter populations historically represented a “genetic hybrid zone”, with ancestors that genetically resembled both southern and northern sea otters.

The current distribution of sea otters in the northeast Pacific (Figure 4.1) features a large break between southern sea otters in California and northern sea otters in northern Washington. This break has eliminated gene flow between the two regions and thus limited potential recovery of genetic diversity, especially for southern sea otters. Re-establishing sea otters in Oregon could re-establish such a genetic hybrid zone, aiding in the recovery of genetic diversity by restoring mixing of northern and southern sea otters and restoring the potential for gene flow to the largest remaining gap in sea otter distribution within their current range.

2. Reintroducing sea otters to Oregon is likely to succeed, with appropriate considerations.

A spatially explicit population model developed specifically for evaluating potential sea otter reintroductions to Oregon shows that a reintroduced population (or populations) of sea otters is likely to be viable assuming sufficient numbers of animals are released to appropriate habitats. However, there is a high degree of uncertainty associated with the outcome of any one reintroduction scenario. This model, when combined with an analysis of habitat suitability, suggests several areas mostly along southern coast that are likely to support a successful *reintroduction. The model also suggests that multiple release locations may be more effective than a single release site. The population model used in the Feasibility Study can provide guidance on alternate reintroduction strategies, including determining appropriate numbers, demographic structure, sequencing, and location of reintroduced populations,*

The resource that is most critical for survival of a sea otter population is access to sufficient and suitable prey. The sea otter's diet is determined largely by the type of habitats in which they forage, which include rocky reefs (where kelp forests can occur) and unconsolidated substrate or "soft sediments," with the latter further divided into outer coast areas vs. protected estuaries. Suitable prey species can occur in all these habitats, though their abundance and productivity can differ. In addition to habitat with adequate prey, sea otters also tend to select habitats that offer protection from adverse environmental conditions and/or predators such as kelp forests and estuaries. These two variables – adequate prey species and access to protected habitats – are crucial factors in assessing different areas with respect to their potential suitability for a reintroduced sea otter population.

Of outer coast habitats in Oregon, it appears that areas in the southern half of the state have a higher abundance of preferred habitat features and prey populations (especially urchins): in particular, the reef complexes near Port Orford (Blanco Reef, Orford Reef and Redfish Rocks) and Cape Arago (Simpson reef).

3. Estuaries may be an important reintroduction environment.

In addition to nearshore ocean habitats, several estuaries in Oregon may offer suitable habitat for a founding sea otter population. Use of estuarine release sites could increase the potential for successful establishment of a population center, especially when close to suitable nearshore ocean habitat (e.g., Coos Bay or Yaquina Bay).

Recently, sea otters have been shown to exert strong indirect influences on the abundance of seagrass in estuaries (in one California estuary the recovery of sea otters resulted in a 600x increase in seagrass abundance). This influence has broad implications for the diverse species assemblages that rely on healthy estuaries. An experimental release of re-habilitated juvenile sea otters into Elkhorn Slough in central California demonstrated the potential for successful release of sea otters into an estuary. In particular, it appeared that a small number of juveniles were more likely to remain in place and contribute to an established population within the estuarine environment than when the same number were released to the outer coast. Moreover, it was also easier to monitor them within an enclosed estuary, and re-capture them for further rehabilitation and later rerelease if necessary. Thus, reintroduction of sea otters to an estuary may be a viable alternative or complementary addition to reintroduction to an outer coast habitat.

Three larger estuaries in Oregon appear to have an optimal combination of prey resources (clams, crabs) and resting habitats (eelgrass beds and tidal creeks) which suggest they could potentially support viable sea otter populations: Tillamook Bay, Yaquina Bay, and Coos Bay. Of these, the latter two have the additional advantage of proximity to outer coast reefs and kelp beds that could provide alternative habitats for establishing sea otter populations.

4. Return of sea otters will have many direct and indirect effects.

As a keystone species, sea otters have inordinately strong effects on the nearshore ecosystems they inhabit. Impacts associated with sea otter recovery include both direct effects on prey species some of which, such as Dungeness crab, currently support commercially-important fisheries as well as indirect effects throughout the nearshore or estuarine environment mediated through ecological interactions. Many of the indirect ecosystem effects are beneficial, including increases in kelp forests and eelgrass beds that, in turn increase finfish and invertebrate species that rely on kelp and eelgrass, increase overall biodiversity, and productivity, and increase in carbon capture and fixation. Impacts of sea otters on some shellfish species can have negative social and economic effects.

The "top-down" effects of sea otters discussed in Chapter 5 include the direct influences of sea otters on their macroinvertebrate prey, including some shellfish species of commercial and social importance. Importantly, sea otters also have significant indirect influences on other species and ecological processes. The most well-known sequence of indirect effects occurs through sea otter's ability to limit the abundance of herbivorous sea urchins that, in turn, enhances the abundance and persistence of kelps and other macroalgae that subsequently affects numerous other species and ecological processes. This phenomenon has earned sea otters the characterization as a *keystone species*.

The sea otter's powerful and diverse top-down influences result in both costs and benefits to human societies. The direct effect of sea otter predation can lead to conflicts with existing shellfisheries in areas of sea otter recovery, and thus are generally perceived as negative. These direct effects also tend to be the easiest to quantify and often the first to be documented, in part because sea otter diets have the highest proportion of commercially valuable species during initial stages of recovery.

In contrast, indirect effects of sea otter recovery are more difficult to quantify but often result in changes that are perceived as positive, such as increased productivity and resilience of kelp forest and seagrass ecosystems, enhanced biodiversity overall, increases to some nearshore finfish species, reduced wave energy and protection of shorelines from erosion, and increased carbon sequestration by kelp and seagrass. It is important to consider the full suite of ecological effects and not focus on only those perceived to be positive or negative.

5. Social, economic factors and regulatory issues must be considered.

While the biological and ecological factors summarized above are critical for determining whether to undertake a species reintroduction effort, social and economic considerations and legal and regulatory issues must be considered. Outreach and engagement with a broad array of stakeholders and community groups likely to be impacted is essential to ensuring that decisions about reintroductions have considered all the relevant socioeconomic factors and have a broad base of support.

<u>Social and Economic Considerations:</u>

In Oregon, invertebrate species that are fished commercially or recreationally and that potentially would be affected by sea otter recovery, include Dungeness crab, red rock crab, razor clams, butter clams, Gaper clams, littleneck clams, cockles, mussels, ghost shrimp, and red and purple sea urchins. For some of fisheries (e.g., urchin dive fisheries) there is good reason to project a substantial negative impact of sea otter recovery. However, in the case of others (e.g., crab, shrimp) it is far from clear whether there would be a negative impact, or how substantial such an effect would be. In the case of Dungeness crab, negative impacts were found to be associated with sea otter recovery in some parts of Alaska, while in California there were no measurable impacts associated with sea otter recovery, and in fact there has been a positive correlation between sea otter recovery and crab landings. Further research on the potential for fisheries conflicts is warranted, especially for Dungeness crab because of the economic scale of this fishery.

The socioeconomic costs and benefits associated with the indirect effects of sea otter recovery are often more difficult to measure than for direct effects, as they involve complex suites of interactions with other species. In cases where indirect effects have been measured, they are often associated with increases in primary producers (plants), including kelp and sea grass, and many of the associated knock-on effects (such as increases in finfish populations, and stabilizing and protecting shorelines), most of which are perceived as positive.

A comprehensive tabulation of the monetary costs and benefits associated with sea otter recovery, including both direct and indirect effects, can be challenging. A recent attempt to do so in British Columbia, based on analysis of a broad array of socioeconomic changes attributable to sea otter recovery on the west coast of Vancouver Island, found a net positive economic impact (Gregr et al. 2020).

However, monetary considerations are not the only way of measuring human values. Communities based around fishing activity provide many important non-monetary values to people. In the case of First Nations peoples, subsistence shellfisheries often provide cultural as well as economic value, while the return of sea otters to the ecosystem may also have cultural importance. Any assessment of socioeconomic impacts of sea otter recovery should therefore provide a comprehensive accounting of the social values of the relevant communities, including both monetary and non-monetary variables.

Chapter 11 of this report provides a brief overview of some of the stakeholder concerns and views that have been previously expressed about this subject (in Oregon and in other regions); however, we recognize that this summary barely scratches the surface, and is no substitution for a formal and comprehensive outreach program.

Regulatory Considerations:

Reintroducing a marine mammal that is protected by international, federal, state, and tribal laws requires careful consideration, planning and documentation of legislation including acquisition of multiple permits (see Appendix). Internationally permits are required for trade between countries. In the USA sea otters are managed at the federal level by the U.S. Fish and Wildlife Service and are protected under the Marine Mammal Protection Act. The southern sea otter subspecies and the southwestern Alaskan stock of the northern sea otter subspecies are listed and regulated as threatened under the Endangered Species Act (ESA) thus requiring federal permits. A reintroduction of sea otters from non-ESA listed stocks within the United States, such as sea otters in southeast Alaska or

Washington, would require the least regulatory oversight and legal/permitting. However, even for these non-ESA listed source populations, a reintroduction would still require extensive documentation and permits under federal law, as well as careful adherence to state laws and regulations as well as local ordinances and First Nations tribal laws. Thus, any future reintroduction proposals should factor in the necessary effort and time required for consultation and permit acquisition.

Logistical Considerations:

In addition to the legal documentation and permitting requirements, there are many other logistical considerations that need to be addressed in any future reintroduction proposals. Selection of a suitable source population is the first of these logistical considerations. As discussed above, this decision involves demographic and genetic questions as well as legal/permitting issues.

Alternative reintroduction strategies should be considered such as: 1) a single "hard release" of animals to a suitable habitat location on the outer coast; 2) a "soft release" to an outer coast location, whereby animals are initially held for some time in net pens to accommodate them to the new location; 3) a single "hard release" of animals to a suitable estuarine habitat; 4) a single "soft release" to a suitable estuarine habitat; 5) sequential soft reintroductions of small groups of sea otters over several years into an estuary, with the potential for re-capture, rehabilitation and re-release of animals that do not appear to be thriving initially, an approach successfully used in Elkhorn Slough, California (Mayer et al. 2019); 6) any of the above methods (or a combination) could be used at multiple, geographically distinct locations, to achieve more than one founding "nodes" of population growth, as was the case for the southeast Alaska reintroduction. The ORSO sea otter population model (Chapter 3) can be used to help evaluate and compare these alternative release strategies in terms of their potential for success and future population growth.

In addition to identifying source populations and release strategies, additional logistical considerations include 1) sea otter capture methods; 2) selection of appropriate sex and age composition of captured animals (to maximize reproductive potential of the founding population as well as likelihood of animals remaining in their new habitats); 3) animal holding, care and transport methods; 4) pre-release ecosystem monitoring/surveys, used to help identify suitable release sites as well as for before-after comparison studies to evaluate ecosystem impacts; 5) tagging and post release monitoring of reintroduced sea otters; 6) re-capture and re-habilitation methods for animals failing to adapt to new habitats.

Health and Welfare Considerations:

Perhaps the most substantial health threat to sea otters living along the Oregon coast is domoic acid (DA) intoxication. Its presence in shellfish has been recognized as a potential human health threat for well over a decade, a concern most directed towards acute intoxication of shellfish consumers. Chronic, low levels of DA have been shown to be a driver of cardiac disease in sea otters (Moriarty et al. 2021) which can have population-level consequences.

A second health threat of high concern, but one which is one with uncertain potential in Oregon, is shark bite trauma. Shark bites are a significant cause of mortality for southern sea otters, and although the white shark (which is known to occur off the Oregon coast) has been accepted as the primary source of injury and death in California, the broadnose sevengill shark in Oregon is present in high numbers in coastal, offshore, and estuarine systems, and may also be a potential sea otter predator.

In addition to DA exposure and shark bite mortality, several infectious diseases could have population-level impacts on the reintroduction program, and may also increase over time as sea otter numbers increase in the case of density-dependent diseases (Tinker et al. 2021). These include contagious diseases such as morbillivirus infections, non-contagious infectious diseases such as *Sarcocytosis* and *Toxoplasmosis*; and bacterial infections and toxicosis associated with nutrient-rich or contaminated freshwater inputs to coastal habitats. Such diseases may have significant impacts on small populations in localized areas, especially those associated with river mouths or estuaries in watersheds that are strongly influenced by agricultural or urban activities.

In addition to all the above, the effects of climate change will impact the health and welfare of all sea otter populations through direct impacts of oceanographic parameters and sea level rise, as well as indirect effects that include changes in prey species, pathogen distribution, and animal movements.

Other animal welfare considerations relate to sea otter capture, transportation, acclimation, and release of sea otters in Oregon: during those activities, close attention must be paid to individual animal nutrition, comfort, health, social structure, and stress relief.

Conclusion:

Restoring a population of sea otters on the Oregon coast is feasible if steps are taken to account for ecological, habitat, logistic, economic, and social factors highlighted in this Feasibility Study. There appear to be no insurmountable ecological, habitat, physiological, logistical, or regulatory barriers to restoring a population of sea otters in Oregon.

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Appendix A: Oregon Sea Otter Population Model, User Interface App (“*ORSO*” v 1.0)

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Contents

1 Introduction/Context

The Oregon sea otter population model has been developed as a user-friendly interface for community members and managers to explore possible sea otter recovery patterns after introduction. The model can contribute to responsible stewardship of sea otters and other nearshore marine resources. The overall goal of the Oregon sea otter population model is to anticipate the approximate magnitude of expected population growth and spread of sea otters in coastal Oregon in the foreseeable future, under different scenarios of translocation/re-introduction. This information will help in evaluating management options and anticipating ecological and socio-economic impacts in a spatially and temporally explicit way. However, experience from prior reintroductions demonstrate that it is extremely difficult to predict where translocated animals will settle, how many will remain following release and how soon population growth will commence. This model is therefore not intended to predict specific outcomes, but rather to explore a range of outcomes that may be most likely, given an extensive range of model inputs and assumptions.

2 Methods

2.1 Overview

The model has been developed using information from published reports and previous examples of sea otter introductions, population recovery and range expansion in the northeast Pacific. In particular, data collected from areas of sea otter recovery in California, Washington and SE Alaska can be used to inform our expectations for sea otter colonization and recovery in Oregon. The distinct habitats and differing historical contexts of these neighboring populations preclude a direct translation of expected dynamics; however, the data from studies of these populations can be used as the basis for developing a predictive model that is tailored to the habitat configuration of Oregon.

Spatially structured population models have been constructed for other sea otter populations in North America and have proved effective at predicting patterns of population recovery and range expansion in diverse habitats (Udevitz et al. 1996, Monson et al. 2000a, Tinker et al. 2008, USFWS 2013, Tinker 2015, Tinker et al. 2019a, Tinker et al. 2021). By building on these previously published model designs and incorporating locally relevant data on sea otter vital rates, movements, habitat quality and environmental parameters, it should be possible to define realistic boundaries for the expected patterns of population abundance and distributional changes over time. These patterns can then be used as a basis for designing an appropriate monitoring design for sea otters and the habitats they are expected to affect, as change occurs over time. Such a model can also be used to combine and integrate information on habitat impacts and sea otter monitoring data over time, allowing us to update projections and modify monitoring methods; in essence, a quantitative tool for conducting adaptive management.

Using data from comparable sea otter populations and geographic areas, primarily California (but also augmented by data and models from SE Alaska and Washington), we developed a spatially explicit, simulation-based population model for use in evaluating a range of realistic scenarios of sea otter re-introduction to Oregon. The Oregon Sea Otter Model (ORSO) incorporates demographic structure (age and sex), density-dependent variation in vital rates, habitat-based variation in population growth potential, dispersal and immigration, and uses a spatial diffusion approach to model range expansion over time.

2.2 Demographic processes

As with previous sea otter models (Tinker 2015), the core of ORSO is a stage-structured projection matrix describing demographic transitions and thus population growth over time (Caswell 2001). The projection matrix is used to model transitions among four age/sex classes (*c* = 1:4): 1) juvenile females (weaning-3 y), 2) adult females (3-20 y), 3) juvenile males (weaning-3 y) and 4) adult males (3-20 y). Transition probabilities are described by 3 parameters: 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 the growth transition parameter (*G,* 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). Survival rates are age- and sex-dependent and are assumed to vary stochastically and as a function of population density (Siniff and Ralls 1991, Eberhardt and Schneider 1994, Monson et al. 2000b, Tinker et al. 2006).

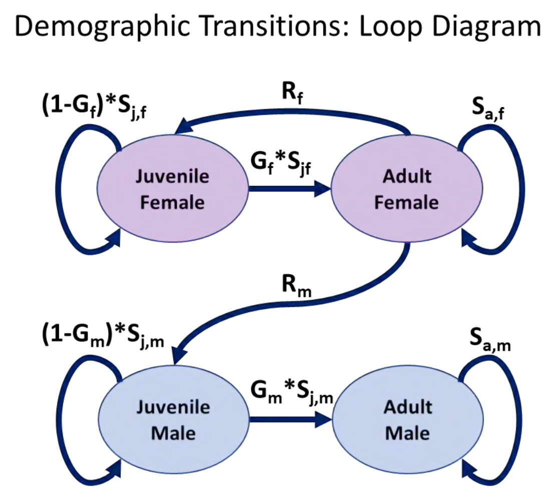


Figure 1 Loop Diagram of demographic transitions for sea otters in population model

Reproductive contributions to juvenile stages by adult females are assumed to reflect a 50:50 sex ratio at birth, and estimated as:

$$R_{f/m} = S_{a,f} \cdot \tfrac{1}{2} b \cdot w \tag{1}$$

where *b* is birth rate (held constant at 0.98; Tinker et al 2006) and *w* is weaning success rate, which is stochastic and density-dependent (Monson et al. 2000b). Note that equation 1 also reflects the fact that pup survival is conditional upon adult female survival. Growth transitions for each sex are calculated using the standard equation for fixed-duration age classes (Caswell 2001):

$$G_{f/m} = \left(\frac{\left(S_{j,f/m}/\lambda \right)^{T} - \left(S_{j,f/m}/\lambda \right)^{T-1}}{\left(S_{j,f/m}/\lambda \right)^{T} - 1} \right) \tag{2}$$

where *T* is the stage duration for juveniles (2.5 years) and λ is the annual rate of population growth associated with a specified matrix parameterization. Combining all parameters into matrix form, we estimate annual population dynamics using matrix multiplication (Caswell 2001):

$$\begin{pmatrix} n_{1,t+1} \\ n_{2,t+1} \\ n_{3,t+1} \\ n_{4,t+1} \end{pmatrix} = \begin{pmatrix} \left(1-G_f\right)S_{j,f} & R_f & 0 & 0 \\ G_f \cdot S_{j,f} & S_{a,f} & 0 & 0 \\ 0 & R_m & \left(1-G_m\right)S_{j,m} & 0 \\ 0 & 0 & G_m \cdot S_{j,m} & S_{a,m} \end{pmatrix} \times \begin{pmatrix} n_{1,t} \\ n_{2,t} \\ n_{3,t} \\ n_{4,t} \end{pmatrix} \tag{3}$$

In equation 3, the population vector $n_{c,t}$ tracks the abundance of otters in each age/sex class in year *t* of a model simulation. At low population abundance (defined as $\Sigma\, n_{c,t}$ <50) we adjust equation 3 to account for demographic stochasticity, as described elsewhere (Morris and Doak 2002).

Parameterization of vital rates was based on published data for sea otter populations in California, Alaska and Washington (Siniff and Ralls 1991, Monson and Degange 1995, Garshelis 1997, Gerber et al. 2004, Tinker et al. 2006, Laidre et al. 2009, Tinker et al. 2017, Tinker et al. 2021). Results from past work suggests that much of the variation in age specific survival and weaning success is explained by density with respect to carrying capacity, although individual variation and random year-to-year variation (i.e. environmental stochasticity) can also be important (Staedler 2011, Miller et al. 2020). Accordingly, following methods used in other simulation models (Gerber et al. 2004, Bodkin and Ballachey 2010), we sampled from the survivorship schedules reported for populations at varying densities (ranging from low-density, rapidly growing populations to high density populations at carrying capacity) to inform our model. We collapsed all age-structured data down to the age/sex classes using geometric averaging of the annual rates for year-classes in each age class, and we accounted for uncertainty by drawing from beta distributions with means and variances corresponding to the published data sets. Re-sampling from these distributions we created a table of 1000 sets of vital rates (survival, birth rates and weaning success rates) reflecting the full range of potential demographic schedules for sea otter populations having biologically feasible growth rates ($0.90<\lambda<1.22$). We calculated the value of λ associated with each set of vital rates (using standard matrix algebraic methods; Caswell 2001) to facilitate the use of these vital rates for parameterizing model simulations, while allowing for both environmental stochasticity and density-dependence. Specifically, in year *t* of a simulation we calculate the expected growth rate using a stochastic theta-logistic model:

$$\lambda_t = e^{r_{\max}\left(1-\left[N_{t-1}/K\right]^{\theta}\right)+\varepsilon_t} \tag{4}$$

where r_{max} is the maximum instantaneous growth rate for sea otters (r_{max} = 0.2; Estes 1990), N_{t-1} represents the total abundance of otters in the previous year of the simulation ($N_{t-1} = \Sigma n_{c,t-1}$), K is the local carrying capacity or abundance at equilibrium (see section 2.2.3, below), θ allows for non-linear effects of density-dependence, and ε represents the effect of environmental stochasticity, where ε_t is drawn randomly from a normal distribution with mean of 0 and standard deviation σ, a user-specified parameter where $0<\sigma<0.2$ (Tinker et al. 2021). Having calculated λ_t, we then randomly draw a set of vital rates after filtering the table to just those sets with associated λ equal to our computed λ_t, and we use these to parameterize equation 3 in year *t* of the simulation. We note that demographic processes are expected to be different during the years immediately following a re-introduction, as a new population becomes established, and thus we allow for modified dynamics during this establishment phase, as described below (section 2.5).

2.3 Spatial Processes

The processes of population dynamics and regulation (as described by equations 3 and 4) occur at relatively small scales in sea otter populations, resulting in potentially divergent population trends and densities at different locations within a regional population (e.g. Laidre et al. 2001, Bodkin et al. 2002, Tinker et al. 2017). To accommodate this demographic structure, previous modeling efforts have divided regional populations into sub-populations and tracked demographic processes within each sub-population, as well as movement of animals between sub-populations (Tinker 2015). The use of spatially-structured models facilitates the incorporation of range expansion, as new sub-sections of habitat can be sequentially added into the model to reflect a population's expansion along a coastline (Tinker et al. 2008). Range expansion has also been modeled effectively as a continuous process using diffusion models (Lubina and Levin 1988, Williams et al. 2017); however, to increase computational efficiency, continuous diffusion dynamics can be approximated within a discretized matrix model by incorporating key features and predictions (e.g. the asymptotic invasion speed of the frontal edge of a population). Discretization can be especially effective if the population is divided into relatively small sub-sections such that demographic processes vary between sub-sections but can be assumed to be approximately homogeneous within sections.

In the case of ORSO, because range expansion was one of the key features we wished to address, we divided the region of interest (all coastal areas of Oregon) into 42 coastal sections, each spanning approximately 15 km of the outer coastline and/or encompassing a single coastal estuary (Figure 2). Annual intrinsic dynamics (changes in abundance due to births and deaths) are modeled for each coastal section using equations 3 and 4; however, each of these sub-populations is embedded within a range-wide meta-population that allows for dispersal of animals between occupied sections. Range expansion of the meta-population along the coast is incorporated into the model by allowing un-occupied sections to be "colonized" by animals from neighboring occupied sections, with the rate of colonization of new sections constrained to maintain a pre-specified rate of advance of the population front along the coast (henceforth ν, the asymptotic frontal wave speed, measured in km/year; Figure 3). We treat ν as a user-specified parameter, noting that a realistic range of values based on previous studies is 1–5 km/year (Lubina and Levin 1988, Tinker et al. 2008).

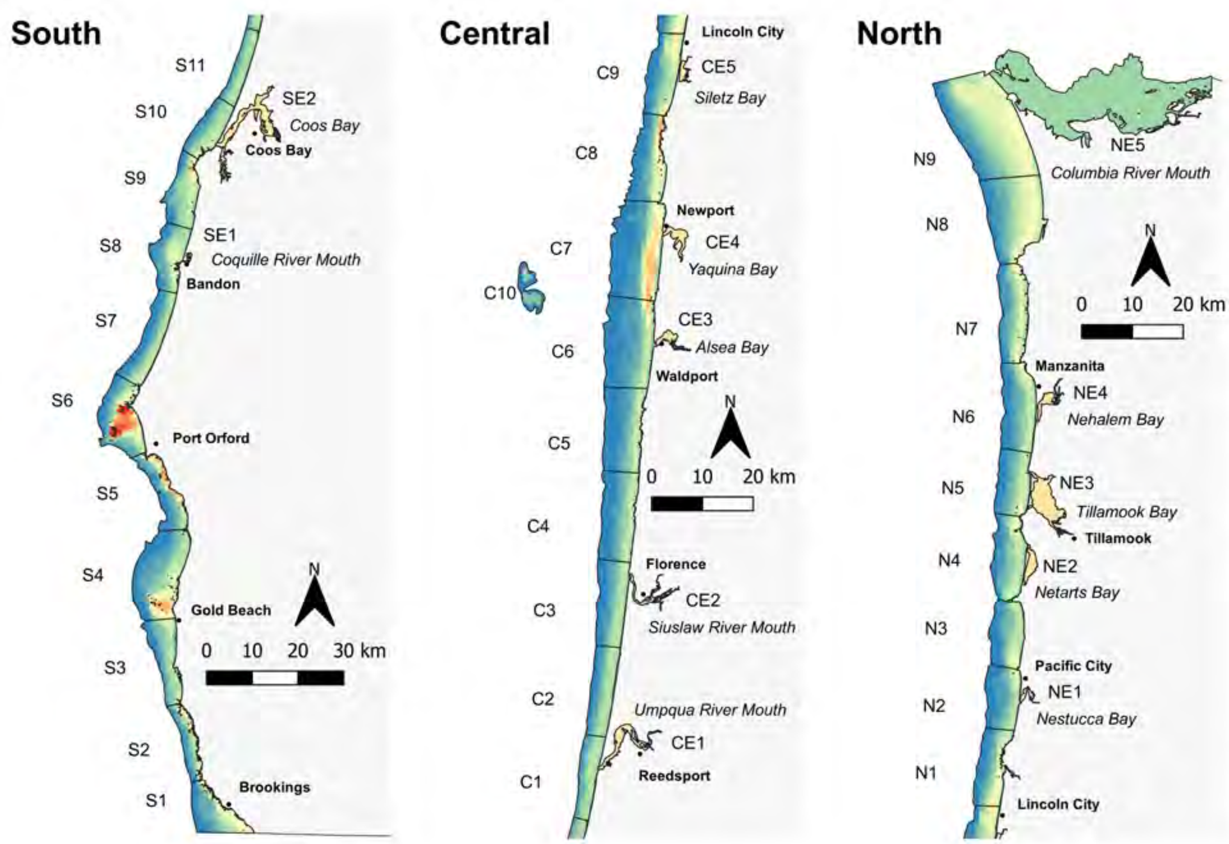


Figure 2. Spatial configuration of coastal habitat in Oregon used for population model. Coastal habitat sections (labeled polygons) show the basic geographic unit for modeling demographic processes, while the colored spatial grid within these olygons show the relative expected density at carryign capcity, based on a previously-developed model of habitat-density relationships (Tinker et al. 2021, Kone et al., in press).

Range Expansion Dynamics

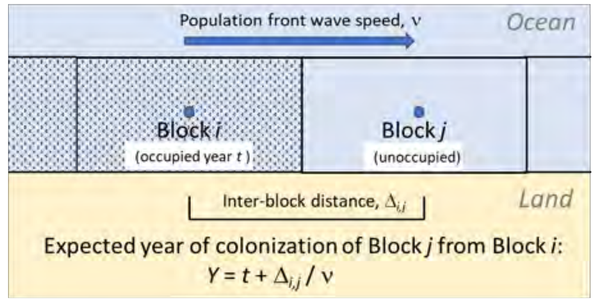


Figure 3. Schematic drawing illustrating how model incorporates range expansion of sea otter population from occupied habitat into un-occupied habitat

Dispersal of sea otters between coastal sections is modeled and tracked separately for each age/sex class in ORSO, reflecting the different mobility and dispersal capability of sea otters of different ages and sex (Jameson 1989, Tarjan and Tinker 2016, Breed et al. 2017). We used previously collected data from radio-tagged sea otters to estimate probabilities that otters of each age/sex class emigrate from coastal section *i* to coastal section *j* in a given year. To account for occasional (but potentially important) long-distance dispersal, we do not restrict dispersal to adjacent cells only: rather, we used the empirical distribution of annual dispersal distances to parameterize this step. For each tagged animal and each year of monitoring we computed "NLD", the net annual linear displacement (Tarjan and Tinker 2016), defined as the number of kilometers between an animal's location at the start of the year and its location at the end of the year in terms of the swimmable distance along the coast[1]. We used maximum likelihood methods to fit exponential distributions to NLD data collected from otters of each age/sex class (implemented using the "fitdistr" library in R). We then used the fitted exponential distributions to calculate the cumulative distribution function (CDF) values at z_i, defined as the average distance from the centroid to the boundary of each coastal section *i*: these computed CDF values correspond to the mean probability of remaining within coastal section *i* for an otter of a specified age/sex class (Tinker et al. 2008), the inverse of which represents $\delta_{c,i}$, the per-capita probability of emigration from section *i* for an otter of class *c*.

The actual number of otters of class *c* emigrating from section *i* in year *t* ($d_{c,i,t}$) was randomly drawn from a Poisson distribution with rate parameter $n_{c,i,t} \cdot \delta_{c,i}$. To determine where emigrating otters dispersed to, we first computed the swimmable distances between all pairwise combinations of section centroids, and for each pairwise distance ($\Delta_{i,j}$) we used the fitted exponential functions to calculate the probability density function (PDF) values at x = $\Delta_{i,j}$. Then during each year of a model simulation we identified the set of all other currently-occupied sections (j = 1,2… J, $j \neq i$), re-scaled the PDF values such that $\Sigma PDF_{i,j} = 1$, and then drew randomly from a multinomial distribution with probability parameters $PDF_{i,j}$ to determine which coastal section *j* would "receive" the emigrating otters. In this way, emigration was treated probabilistically and not deterministically, so that each iteration of the simulation model results in different dispersal outcomes. We note that spatial processes (dispersal and range expansion) are expected to differ during the post-introduction establishment phase, and thus we allow for modified spatial dynamics during this period, as described below (section 2.5).

[1] The distinction of swimmable distance is important: we used swimmable distances as opposed to Euclidean distances because of the complex coastal topography of sea otter habitats and the fact that sea otters cannot travel over land. This for the purpose of calculating NLD, and for all other distance calculations described in the methods, we used a Least Cost Paths function (implemented using the "gdistance" package in R) which estimates the shortest distance between two points while accounting for the "costs" of moving through different habitat classes that might be encountered between the points. By assigning a prohibitively high "cost" to moving over land, we ensure that the Least Coast Path distance is the shortest distance through water only.

2.4 Estimating K and Habitat Effects

Carrying capacity (*K*) is defined as the population size that can be supported in a specified environment over the long term, and this equilibrium abundance is generally dictated by some limiting resource (i.e. prey, nesting sites, refuge habitat). In sea otters, *K* is thought to be primarily determined by prey resource abundance and productivity. Equilibrium abundances of sea otter populations have been found to be highly variable, with local densities ranging from 0.5 sea otters per km^2 of benthic habitat (defined as benthic substrate between the low tide line and the 40 m depth contour) to over 20 sea otters per km^2. Previous studies have found that the density at *K* varies as a function of certain habitat features (presumably because these habitat features are proxies for prey productivity), however the precise nature of these relationships varies across regions (e.g. Laidre et al. 2001, Laidre et al. 2002, Burn et al. 2003, Gregr et al. 2008, Tinker et al. 2021). In California, areas of rocky substrate were found to support higher densities than areas of unconsolidated sediment (Laidre et al. 2001), while in Vancouver Island it was areas of complex coastline that supported higher densities (Gregr et al. 2008), and in SE Alaska some of the highest densities are supported in soft-sediment bays (Esslinger and Bodkin 2009). Given this variation, it is difficult to predict which habitat types in Oregon will eventually support high or low densities of sea otters. However, given the proximity to California and the general similarity of habitat types between these regions, we believed that California habitat-density relationships provide the best starting point for predicting these relationships in Oregon. A recently developed model predicting local carrying capacity as a function of biotic and abiotic habitat variables (Tinker et al. 2021) has therefore been applied to the equivalent spatial layers of habitat variables in Oregon, in order to project potential carrying capacity at fine scales throughout the state (Kone et al. in press). We use this projected carrying capacity data layer to parameterize the ORSO model, interpolating projected equilibrium densities from Kone et al. (in press) at each cell *h* of a hexagonal grid laid over the study area (Figure 2). The absolute number of otters expected within grid cell *h* at carrying capacity is calculated as the product of the expected equilibrium density (K_h^d) and the area of that cell (A_h). Summing this product over all habitat cells contained within coastal section *i* (h = 1, 2,…H_i) gives the expected abundance at *K* for that section (used for equation 4), and dividing by A_i (the total area of habitat in section *i*) gives the mean expected density at *K* for coastal section *i*:

$$K_i^d = \frac{1}{A_i}\sum_{h=1}^{H_i} K_h^d \cdot A_h \tag{5}$$

2.5 Establishment Phase

Previous translocations and re-introductions of sea otters have shown that the years immediately after re-introduction can be a period of great uncertainty (Jameson et al. 1982, Bodkin et al. 1999, Carswell 2008, Bodkin 2015). During this population establishment phase there is limited population growth and often a significant decline in abundance, associated with elevated mortality and dispersal of a substantial proportion of animals away from the release site. Otters that disperse from the introduction site may settle at other areas of suitable habitat within the region (as occurred in SE Alaska), return to their former home ranges if possible (as occurred at San Nicolas Island), or move entirely out of the region (as was suspected to have occurred for some animals in the Oregon translocation, believed to have moved north to join the Washington or BC populations), though in all cases there is likely to be significant mortality for both dispersing and non-dispersing animals. Thus, the "typical" patterns of density-dependent population growth, dispersal, and range expansion, described in the previous sections, only emerge after this establishment phase, which may extend for 5-20 years after the initial translocation (Jameson et al. 1982, Bodkin et al. 1999, Carswell 2008, Bodkin 2015).

To model establishment phase dynamics, we define several additional parameters and associated functions. The first of these is E, the expected duration of the establishment phase itself (in units of years). For all years where $t \leq E$, we adjust the baseline age and sex specific survival rates ($S_{c,t}$, the random survival rates selected based on the solution to equation 4) such that the mean growth rate (λ) is forced to 1 (i.e., no net growth on average) but with default levels of environmental stochasticity. We next define parameter M, the mean excess annual mortality rate during the establishment phase: this parameter, assumed to occur within the range of $0 < M < 0.5$, is used to further adjust stage-specific annual survival rates during the establishment phase, thereby allowing for negative growth rates:

$$S'_{c,t} = S_{c,t} \cdot \left(1 - m_t\right), \quad where\ m_t \sim Beta\left(\alpha, \beta \mid M\right) \tag{6}$$

In equation (6), the annual excess mortality rate (m_t) is drawn from a *Beta* distribution with parameters α and β, which are set so as to create a 0 – 1 bounded distribution with mean of M and coefficient of variance (CV) of 0.25, a level of variation consistent with previously published demographic schedules (Gerber et al. 2004, Tinker et al. 2019b). The modified stochastic survival rates ($S'_{c,t}$) are used to parameterize the population projection matrix **P** (equations 1-3 above) for each year during the establishment phase. Thus, if we define the initial population vector of introduced animals as $n_{c,0}$ (where $N_0 = \Sigma\, n_{c,0}$), then the survivors in year 1 are calculated via matrix multiplication as $n_{c,1} = \mathbf{P_0} * n_{c,0}$.

For those otters that survive the initial re-introduction, we assume that a substantial number will disperse a significant distance away from the re-introduction site. We define φ as the expected probability of dispersal away from the reintroduction site during the establishment phase ($0 < \varphi < 1$), and calculate the actual number of dispersers (D^*) as a random binomial variable:

$$D^* \sim Binomial\left(N_1, \varphi\right) \tag{7}$$

where N_1 is the number of individuals that survived the initial translocation. The stage structure of the disperses is assigned randomly using a multinomial distribution with probabilities corresponding to the stage structure of $n_{c,1}$. Several lines of evidence suggest that the probability of post-introduction dispersal (φ) may be affected by one or more covariates, including the age structure of the introduced population and the release site habitat. Specifically, in the case of the San Nicolas translocation it was observed that younger animals (sub-adults) were more likely to remain at the release sites than adults, with the latter more likely to attempt to return to their original home ranges (Carswell 2008). It has also been suggested that otters introduced into estuarine habitats may be more likely to remain resident (Hughes et al. 2019, Becker et al. 2020), and this may be especially true if enclosures are set up to retain some animals until they become familiar with estuarine prey and substrates. We therefore included two additional parameters to account for these potential covariates: we define ω as the expected ratio of dispersal probability for subadults relative to adults ($0 < \omega < 1$), and ψ as the expected ratio of dispersal probability for otters in estuaries relative to outer coast habitats ($0 < \psi < 1$). If we define φ as the probability of dispersal for a group of adults in an outer-coast environment, then the realized dispersal probability for a given section (φ_i') is calculated as:

$$\varphi_i' = \varphi \cdot \left(R_{Ad,i} + \omega \cdot (1 - R_{Ad,i})\right) \cdot \left((1 - Est_i) + \psi \cdot (Est_i)\right) \tag{8}$$

where $R_{Ad,i}$ is the ratio of adults to sub-adults introduced to section i, and Est_i is a switch variable that indicates whether section i is an estuary (Est_i = 1) or outer coast (Est_i = 0).

To allow for the likelihood that a significant proportion of the animals dispersing from the reintroduction site will either die or else move outside of the study region (i.e., outside of coastal Oregon, possibly joining the Washington or California populations), we define parameter Ω as the loss rate for dispersing animals. The remaining dispersers, calculated as $D^*(1-\Omega)$, are assumed to settle in one of the other coastal sections (Figure 2), which is selected randomly from a multinomial distribution with parameters proportional to the mean K densities of each section (equation 5), thereby assuming that the dispersers are more likely to settle in an area of higher quality habitat.

All of the above-described parameters may be adjusted by the user to explore assumptions about the establishment phase and its implications for success of a proposed re-introduction. We note that the setting parameters to values close to their defaults (E = 10, M = 0.15, φ = 0.9, ω = 0.5, ψ = 0.5, Ω = 0.7) will produce dynamics (on average) that match the observed population dynamics at San Nicolas Island during the 3 decades after that translocation.

2.6 Model Simulations

Having developed and parameterized ORSO as described in the previous sections, we use this model to conduct simulations of sea otter population dynamics in Oregon for a newly established population. Simulations are run to evaluate population growth and range expansion under different re-introduction scenarios and under varying sets of assumptions about population dynamics, as reflected by different combinations of user-specified parameters (see Table 1 for complete list of user-specified parameters, definitions, and suggested values). A stepwise description of model parameterization and dynamics ("pseudo-code") is as follows:

1. Select coastal sections for re-introducing sea otters and specify the numbers of animals ($N_{0,i}$) to be introduced to each section, both during the initial year of translocation, and optionally as "supplemental" additions of more otters in subsequent years ($O_{i,t}$). The age/sex composition of introduced otters is also specified: $R_{Ad,i}$ is the ratio of adults to subadults, and $R_{F,i}$ is the ratio of females to males.
2. User adjusts the expected values of other parameters to investigate their effects: parameters that can be adjusted include maximum population growth rate (r_{max}), environmental stochasticity in growth rates (σ), the functional shape of density-dependence (θ), asymptotic wave speed for population range expansion (ν), the number of years required for the population to become established (E), the excess annual mortality rate during establishment phase (M), the probability of dispersal for adults post-introduction (φ), the dispersal probability adjustment for subadults relative to adults (ω), the dispersal probability adjustment for otters in estuaries (ψ) and the proportion of dispersers lost (Ω).
3. Iterate a large number of simulations ("*reps*"), each one describing "*Nyrs*" years of population dynamics (both *reps* and *Nyrs* are user-adjustable, default = 100 reps of 25 years)
4. Step through the processes of population dynamics for t = 1, 2,…*Nyrs*. For each year of each simulation, the model conducts the following steps:
   a. During establishment phase ($t \le E$), calculate proportion of animals that disperse away from release site (accounting for age and estuary effects), stochastically chose a target coastal

section for these dispersers, and move the dispersers to that location accounting for losses due to death and emigration out of coastal Oregon.

b. If establishment phase complete ($t > E$), determine any new sections that have become occupied since the previous time step: a section is eligible to be colonized depending on its distance to a neighboring occupied section, the number of years the neighboring section has been occupied, and the value of ν, as illustrated in Figure 3.
c. For all sections occupied at time t, calculate intrinsic population growth rates (equation 4). Draw random sets of vital rates corresponding to $\lambda_{i,t}$ and use these to parameterize projection matrix $\mathbf{P}_{i,t}$ following equation 3. If establishment phase ($t \leq E$), adjust rates accordingly based on parameter M (equation 6). To account for spatial autocorrelation in environmental stochasticity, values of $\varepsilon_{i,t}$ are drawn from a multivariate normal distribution with mean of 0 and co-variance matrix adjusted (using standard auto-regressive methods) to produce standard deviation σ and correlation across neighboring sections of 0.8 (Gelfand and Vounatsou 2003).
d. If establishment phase complete ($t > E$), draw randomly from Poisson distribution (with rate parameters $n_{c,i,t} \cdot \delta_{c,i}$) to determine how many (if any) otters of each age/sex class disperse from section i ($d_{c,i,t}$).
e. Draw randomly from multinomial distribution (with probability vector $PDF_{i,j}$) to determine which occupied sections will receive the dispersers from section i.
f. Calculate the stage-specific change in abundance for section i in year t as:

$$n_{c,i,t} = \mathbf{P}_{i,t} \cdot n_{c,i,t-1} - d_{c,i,t} + \sum_{j} a_{c,j,i,t} + o_{c,i,t} \tag{9}$$

where $d_{c,i,t}$ represents dispersal of animals out of section i in year t, $a_{c,j,i,t}$ represents otters dispersing into section i from any other occupied section j in year t, and $o_{c,i,t}$ represents additional supplemental otters introduced to section i (the numbers of these supplemental otters, age/sex, and number of years that otters are added are all adjustable parameters).

5. Tabulate the abundance of otters in each section for each year of each model simulation.
6. Down-scale estimated densities to the scale of 1-km^2 habitat cells by spatial-interpolation between section centroids, weighted by the habitat suitability index of each cell (equation 5).
7. Summarize results graphically and in tables.

The complete R code used to run ORSO is provided in Appendix A, and digital versions of this code as well as the associated data files needed to run it are available upon request.

The user-specified parameters can be varied independently to produce an enormous range of different dynamics, allowing users to create and explore highly customized scenarios. For illustrative purposes we present results for a “typical” scenario, using values provided in Table 1.

Table 1. Default values for user-specified parameters for Haida Gwaii Sea Otter Recovery Habitat Model (HGSORHM).

User Param	Default Value	Explanation
reps	100	Number of replications for population simulations
Nyrs	25	Number of years to project population dynamics
Intro_Sections	NA	Coastal section(s) for re-introduction
$N_{0,i}$	50	Number of otters introduced to each specified coastal section
O_i	3	Number otters (annually) in supplemental introductions to section *i*
Nyrs_add	5	Number of years for supplementary introductions
$R_{F,i}$	.6	Proportion of introduced animals that are female
$R_{Ad,i}$	.25	Proportion of introduced animals that are adult
E	10	Expected years before population becomes fully "established" (i.e. before "normal" population growth and range expansion begins)
M	.15	Mean excess annual mortality rate during the establishment phase
φ	.7	Probability of dispersal (for adults) in establishment phase
ω	.5	Dispersal probability adjustment for subadults relative to adults
ψ	.5	Dispersal probability adjustment for otters in estuaries
Ω	.75	Proportion of post-introduction dispersers lost (die or move out of study area)
ν	2	Asymptotic wave speed of range expansion, km/yr, minimum
r_{max}	0.18	Maximum instantaneous rate of growth: default rmax=0.2 (Note: exp(0.2) = 1.22 or 22% per year)
σ	0.1	Environmental stochasticity (std. deviation in log-lambda)
θ	0.9	theta parameter for theta-logistic model: for standard Ricker model, theta = 1; for delayed onset of D-D effects, use theta > 1

3 Simulation Results: Sample Scenario

The ORSO model simulations can produce a broad range of projected patterns of growth and range expansion, appropriately reflecting the large amount of uncertainty about the future after a re-introduction event. The outcome after 25 years (in terms of the magnitude of growth and extent/pattern of range spread) depends upon the re-introduction scenario and the various assumptions implicit in the user-specified parameters (Table 1). For areas of Oregon that do become occupied, the model predicts fine-scale spatial variation in sea otter densities after 25 years, explained in part by the length of time a particular area is occupied, and in part by the suitability of the local habitat (Figure 2). Running model simulations with "typical" values for user-specified parameters (Table 1) revealed that that an initial translocation of 50 otters to coastal section S6 (assuming 60% female and 25% adult), with supplemental additions of 3 juveniles per year for 5 years, could grow to a population of approximately 78 sea otters after 25 years (Figure 5), although there is considerable uncertainty around this value (CI_{95} = 17 - 190). Range expansion over this period is projected to be limited to the southern portion of Oregon coast (coastal sections S1-S11; Figures 5, 6). This fairly low rate of growth and range spread reflects a population establishment phase of 10 years as well as a relatively low diffusion rate (ν = 2 km/year), which is comparable to the rate of range spread observed for California and Washington state (Tinker et al. 2008, Laidre et al. 2009). We note that changing the user-specified parameters can lead to considerably different projections of both population growth and range expansion.

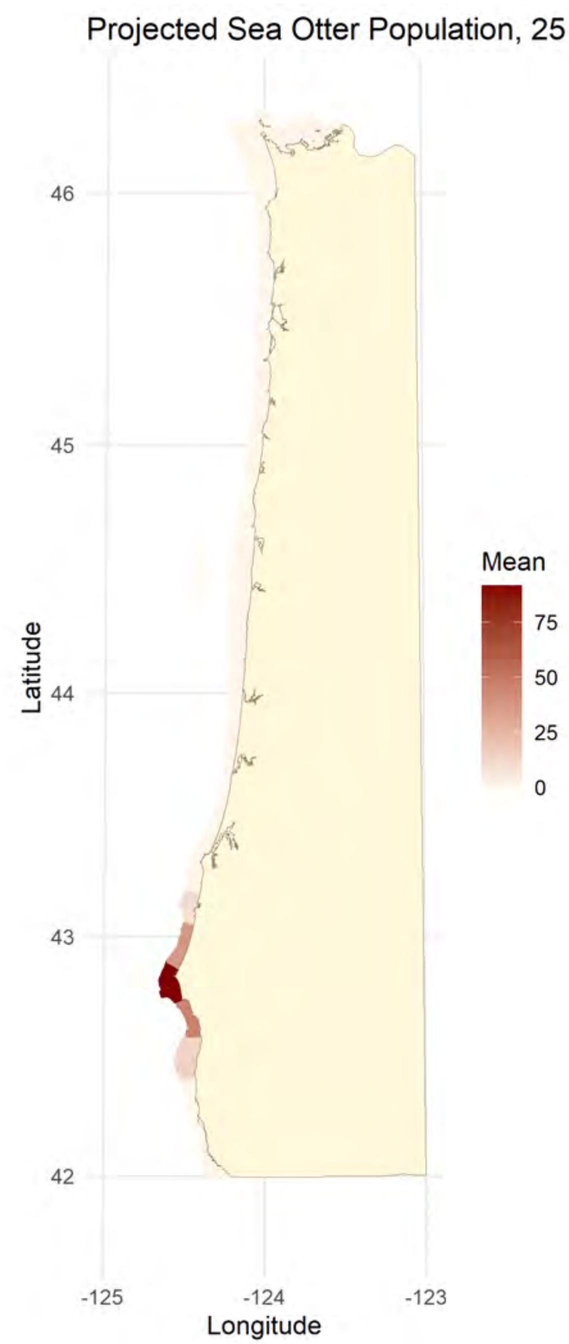


Figure 4. Map of coastal Oregon showing projected sea otter abundance and distribution after 25 years.

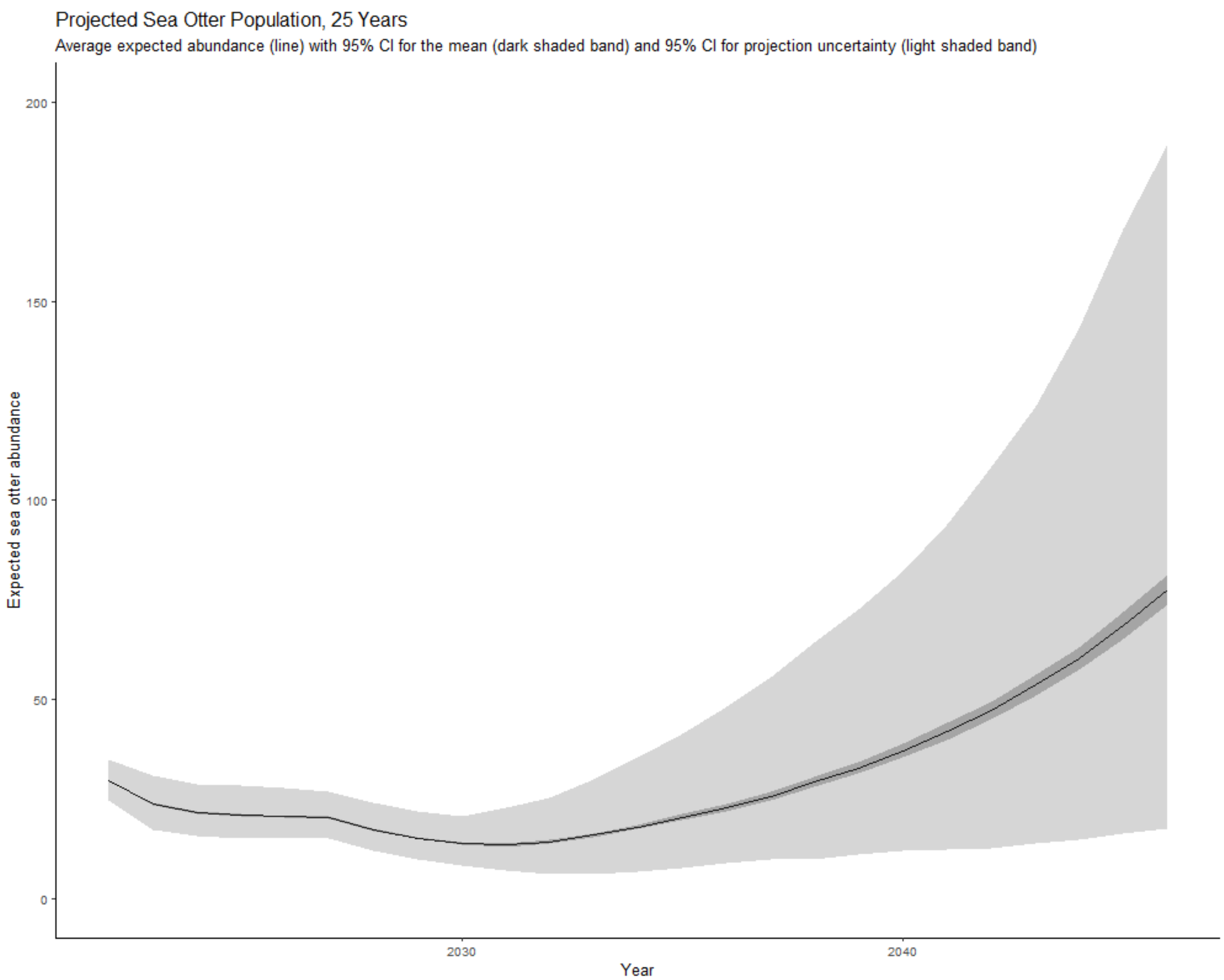


Figure 5. Results from model simulations of sea otter population dynamics over 25 years in coastal Oregon, showing projected population trends. Light gray band shows 95% CI for simulations; dark gray band shows 95% CI for mean.

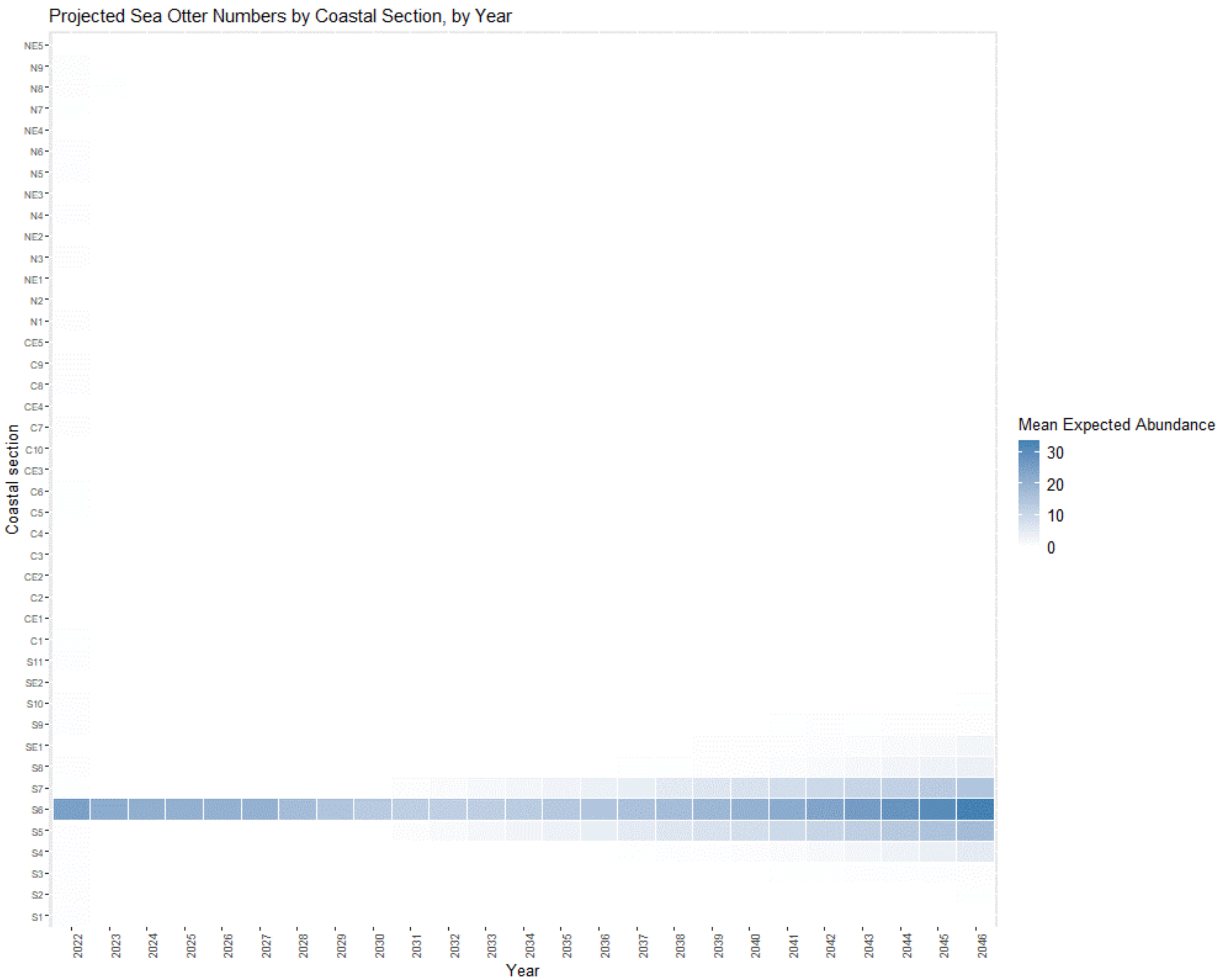


Figure 6. Results from model simulations of sea otter population dynamics in coastal Oregon, showing a heatmap of mean expected abundance by Coastal Section over a 25-year period. Refer to figure 2 for locations and boundaries of each coastal section.

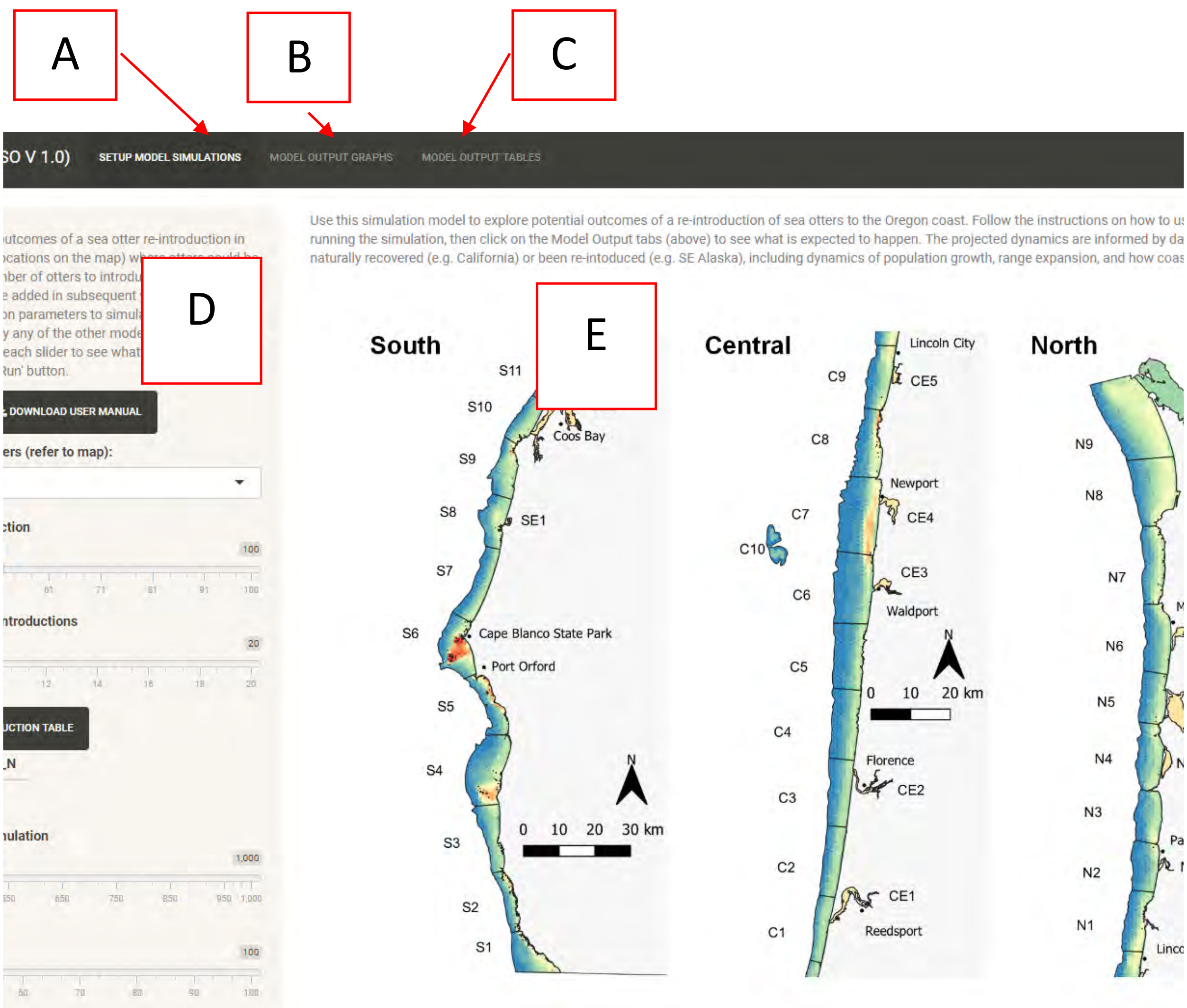
Oregon Sea Otter Population Model (ORSO), User Interface

https://nhydra.shinyapps.io/ORSO_app/

Overview

The web based ORSO app is organized into several panels, which the user can navigate between by clicking on any of the three selection tabs embedded in the title bar at the top of the screen, as shown in the Figure below (items A, B and C). The panel that is active by default when the app is opened is "SETUP MODEL SIMULATIONS", while the other two panels ("MODEL OUTPUT GRAPHS" and "MODEL OUTPUT TABLES") can be navigated to by the user to view model results AFTER having run simulations.

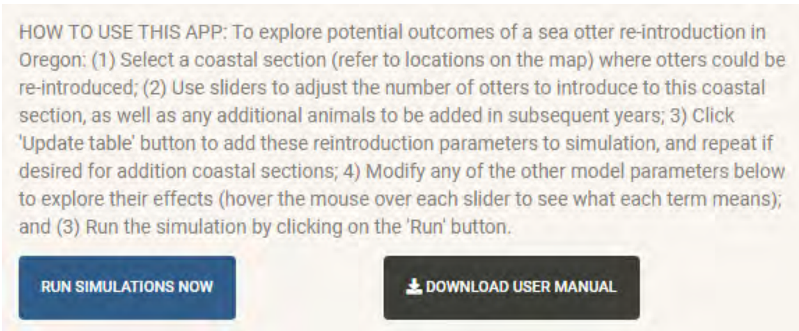
When active, the "SETUP MODEL SIMULATIONS" panel is itself divided into two main sections: a sidebar panel at left (item D) where the user can adjust various parameters and run the simulations; and an information panel at right (item E), which shows a map of Oregon with coastal sea otter habitat (the nearshore zone out to 60 m of depth, plus estuaries) divided into 42 numbered coastal sections. These coastal sections represent the main spatial units for tracking sea otter abundance and distribution over time: the map allows the user to see the location of specific sections, as needed to initiate simulations and interpret model results.



Components of ORSO App

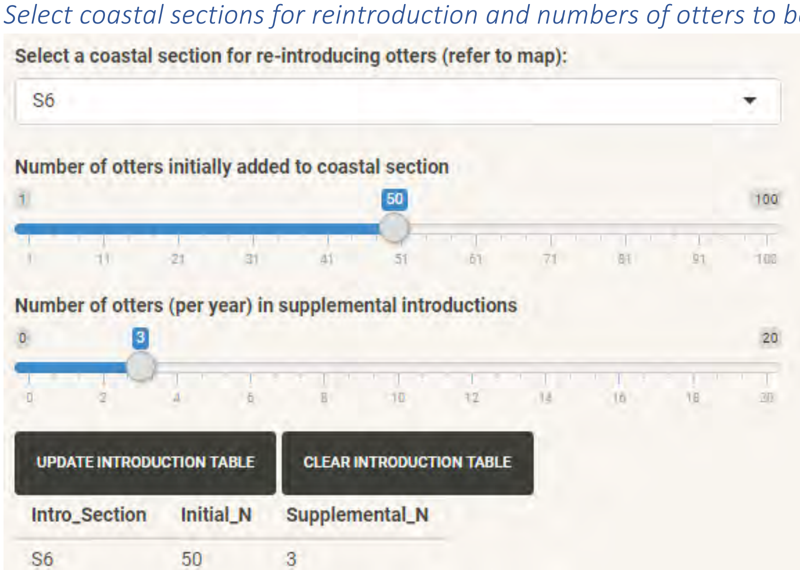
Setup Model Simulations Panel

At the top left of the sidebar panel are some simple instructions to guide the user, and two large buttons: "Run Simulations Now" and "Download User Manual".



The "Download User Manual" button at right allows the user to download this manual at any time. The "Run Simulations Now" button at left is the primary action button of ORSO, used to run a set of simulations. HOWEVER, this button should only be clicked AFTER having first selected one or more coastal sections under consideration for a sea otter re-introduction and setting the user-adjustable parameters in the sidebar panel that describe the details of the reintroduction and control the underlying assumptions about the nature of population growth and range expansion. A description of each of the user-adjustable parameters will appear when the cursor is moved over top of the name of each parameter, and default values for each parameter are set based on data from other sea otter populations. These user-parameter adjustment controls are illustrated and explained below:

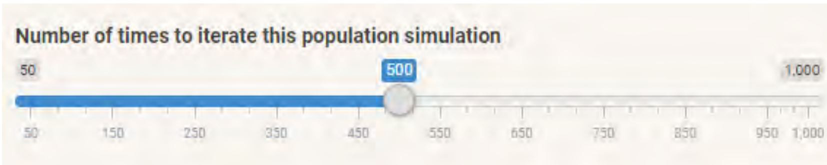
Select coastal sections for reintroduction and numbers of otters to be added



Clicking on the selection box at top reveals a drop-down list of the 42 coastal sections (whose geographic locations can be viewed on the map at right), from which the user can select a coastal section where sea otters are to be introduced. Next, the two sliders below the selection box can be used to adjust the number of otters in the initial translocation event, as well as (optionally) the annual number of animals added to this section as part of supplementary introductions in subsequent years.

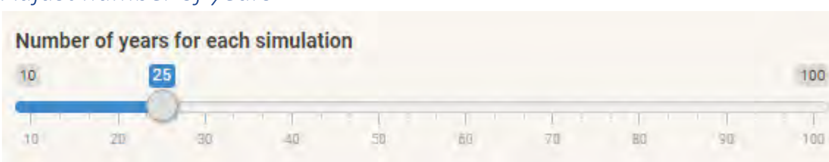
Clicking on the “Update Introduction Table” button will add these user selections to a parameter table below the button. The user can then repeat this process (if desired) to specify additional coastal sections and associated translocation parameters and add those to the parameter table. To clear the table and start again at any time, click on the “Clear Introduction Table” button.

Adjust number of iterations



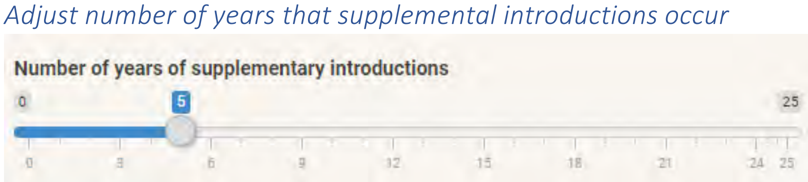
This slider control is used to increase or decrease the number of simulation iterations: that is, the number of times a population simulation is replicated with random draws of all appropriate stochastic parameters. Increasing the number of replications of a simulation improves the precision of model predictions but will take longer to run. At least 100 iterations are suggested.

Adjust number of years



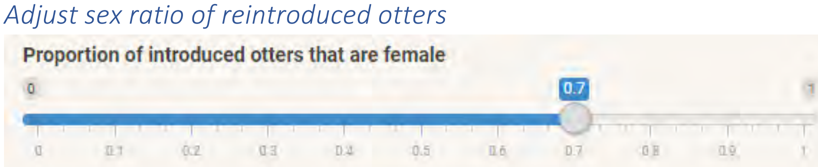
This slider control is used to increase or decrease the number of years into the future the simulation is run. Increasing the number of years ('N') can provide insights into conditions farther in the future, but results become less reliable the farther ahead in time the model is projected.

Adjust number of years that supplemental introductions occur



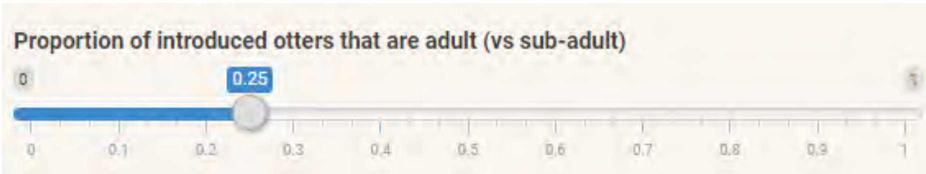
This slider control is used to increase or decrease the number of years after the initial translocation event in which additional otters may be added to the initial reintroduction site (supplemental reintroductions). Adding more otters could potentially improve success of the reintroduction by stabilizing the population during the establishment phase. These additional otters could be wild otters or juvenile re-habilitated otters from captivity.

Adjust sex ratio of reintroduced otters



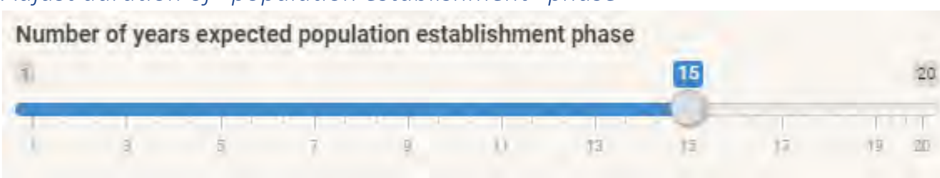
This slider control allows the user to specify the proportion of introduced otters that are female. Including a higher proportion of females can increase the potential for growth, though there must be at least some adult males for reproduction to occur.

Adjust age composition of reintroduced otters



This slider control allows the user to specify the proportion of introduced otters that are adult (vs sub-adult or juvenile). Only adult sea otters produce pups, so introducing adults can hasten reproduction. However, in past translocations it has been found that sub-adults may be more likely to successfully 'take' to their new habitat, so a higher ratio of sub-adults may improve success.

Adjust duration of "population establishment" phase

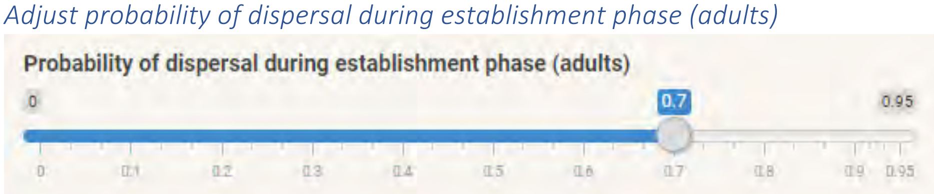


Newly established sea otter populations often experience an initial period of reduced growth and limited range expansion, as the population becomes established. This establishment period has varied from 5-15 years in previous re-introductions and natural return events. This slider control allows the user to set the expected duration of this phase. In addition to reduced survival rates and range expansion during the establishment period, the user can specify the probability of post-introduction dispersal away from the release site.

Adjust excess mortality during establishment

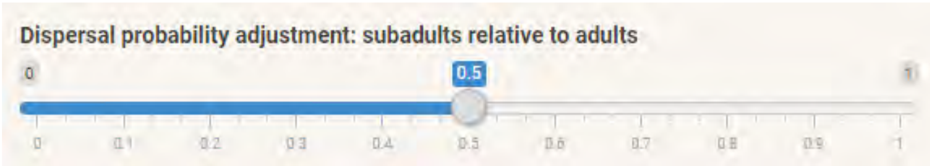
During the establishment phase of an introduced population, there may be higher than average levels of mortality as the introduced animals become accustomed to their new habitat. In past translocations, excess annual mortality rates of 0.1 - 0.25 have caused translocated populations to decline substantially during the establishment phase

Adjust probability of dispersal during establishment phase (adults)



In several previous sea otter translocations, a substantial proportion of the introduced animals moved a significant distance away from the introduction site during the establishment phase. The details and destination of post-release dispersal is impossible to predict, but the user can set the mean expected proportion of otters to disperse.

Adjust probability of dispersal during establishment phase for subadults



In previous sea otter translocations, it has been observed that subadult animals may be less likely to disperse than adults (i.e. more likely to remain near the introduction site). This parameter adjusts the likelihood of dispersal for subadults as compared to adults: a value of 0.25 would mean that subadults are 1/4 as likely to disperse as adults.

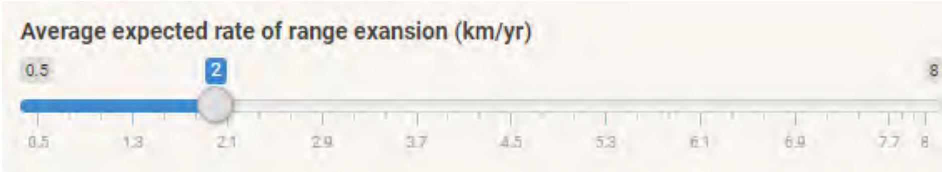
Adjust probability of dispersal during establishment phase for otters in estuaries

Based on several lines of evidence it has been suggested that otters re-introduced to estuaries may be less likely to disperse (i.e. more likely to remain near release sites) than otters added to outer coast habitats. This parameter adjusts the likelihood of dispersal for estuaries as compared to open coast: a value of 0.25 means otters in estuaries are 1/4 as likely to disperse post-introduction.

Adjust mortality rate of otters that disperse during establishment phase

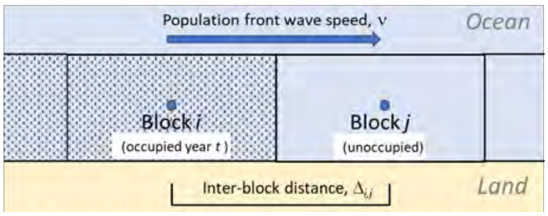
The fates of otters that disperse away from a re-introduction sites is hard to determine in most cases: in some reintroductions there appears to have been high levels of mortality for dispersers, in others there is emigration to a different region altogether. This parameter sets the expected loss-rate for the dispersers: that is, the proportion that die or move entirely out of the study area (and are effectively lost to the Oregon meta-population).

Adjust rate of range expansion



This slider control allows the user to adjust the expected rate at which the growing population spreads into new habitat. Distribution of the initial sea otter population will likely be limited to a relatively small area(s) of the coast where sea otters are introduced. As the population grows it's distribution (range of occupancy) will spread outwards along the coastline, encompassing more habitat. The rate of range expansion is measured as the speed at which the frontal edge of the population moves along the coastline (Figure 3). In other populations, this range expansion speed has varied from 1 to 5 km/year.

Range Expansion Dynamics



Schematic drawing illustrating how the model incorporates range expansion of sea otter population from occupied habitat into adjacent unoccupied habitat

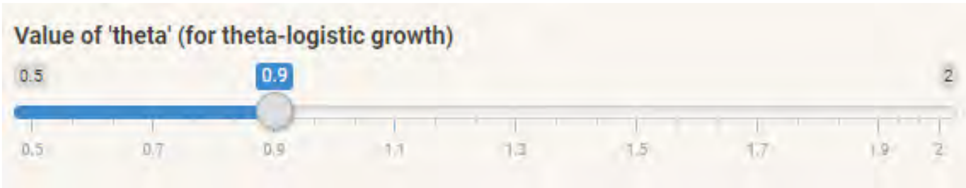
Adjust maximum rate of growth

Sea otter populations tend to show the highest rate of growth at low densities: as local abundance increases, the growth rate slows until it eventually reaches 0 when population abundance reaches carrying capacity, or '*K*'. This slider control allows the user to adjust the maximum rate of growth (at low densities): in most sea otter populations this value is between 0.15 and 0.20.

Adjust environmental stochasticity

The average rate of growth for a re-establishing sea otter population in a given area can be predicted as a function of the local density with respect to carrying capacity, or '*K*'. However, year-to-year variation in environmental conditions and prey population dynamics can lead to unpredictable deviations in growth rate, referred to as 'environmental stochasticity'. This slider control can be used to adjust the degree of annual variation in growth rates: typical values are 0.05 - 0.15.

Adjust 'theta' parameter, for theta-logistic growth

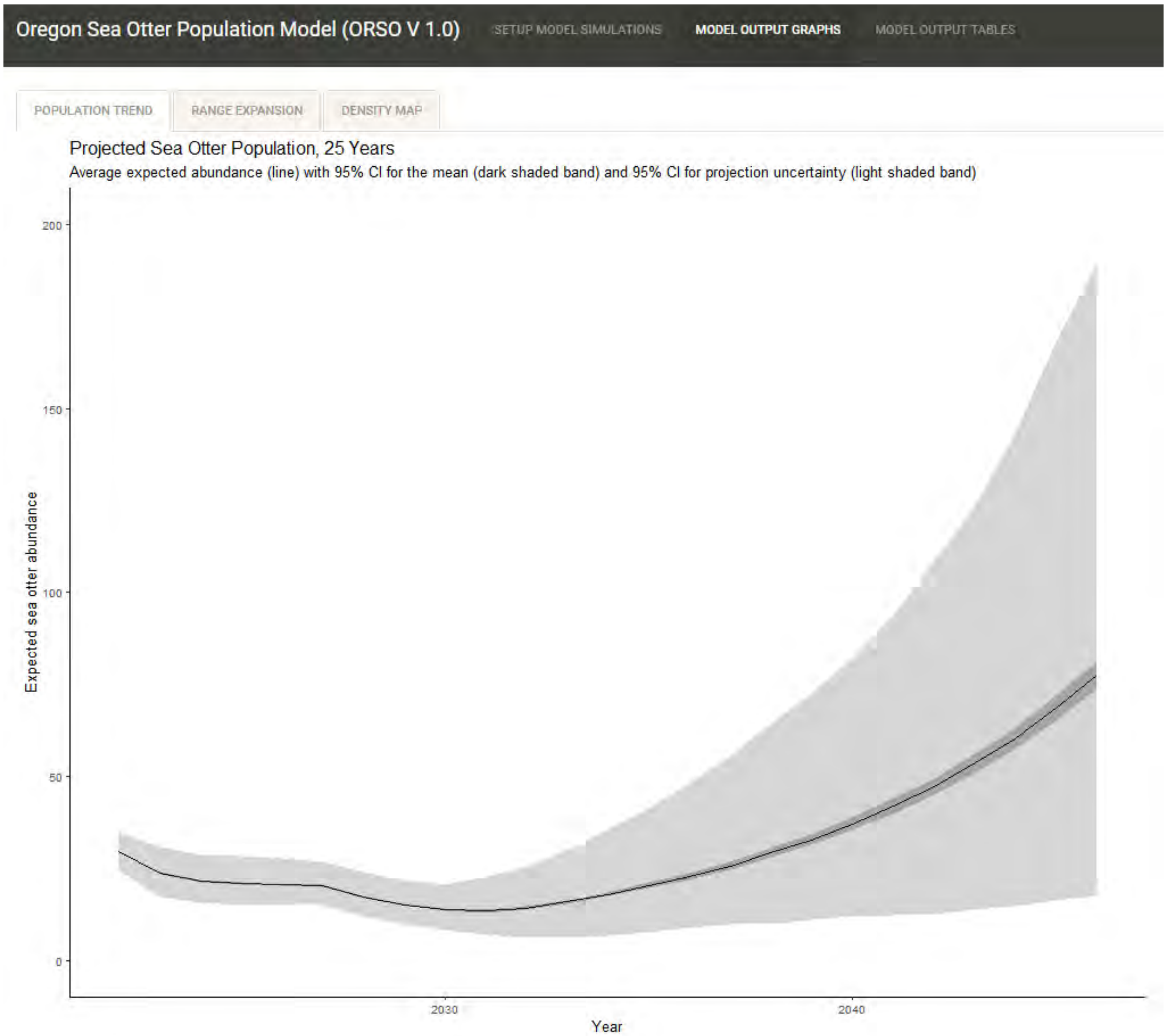


The average rate of growth for a re-establishing sea otter population in a given area can be predicted as a function of the local density with respect to carrying capacity, or '*K*'. One of the parameters of this function is 'theta', which determines the nature of the onset of reduced growth rates at higher densities: 'theta' values <1 lead to onset of reduced growth rates at fairly low densities, while 'theta' values >1 mean that significant reductions in growth occur only at higher densities. This slider control can be used to adjust 'theta': typical values reported for marine mammals are between 0.8 and 2, and a recent study in California reported a value of close to 0.9 for southern sea otters.

MODEL OUTPUT GRAPHS Panel

After setting up and running simulations, the user can navigate to the “MODEL OUTPUT GRAPHS” panel in order to view graphical results from model simulations. There are three separate graphs that can be viewed, and the user can move between these by selecting one of the three graph selection tabs just below the title bar.

Population Trend Graph

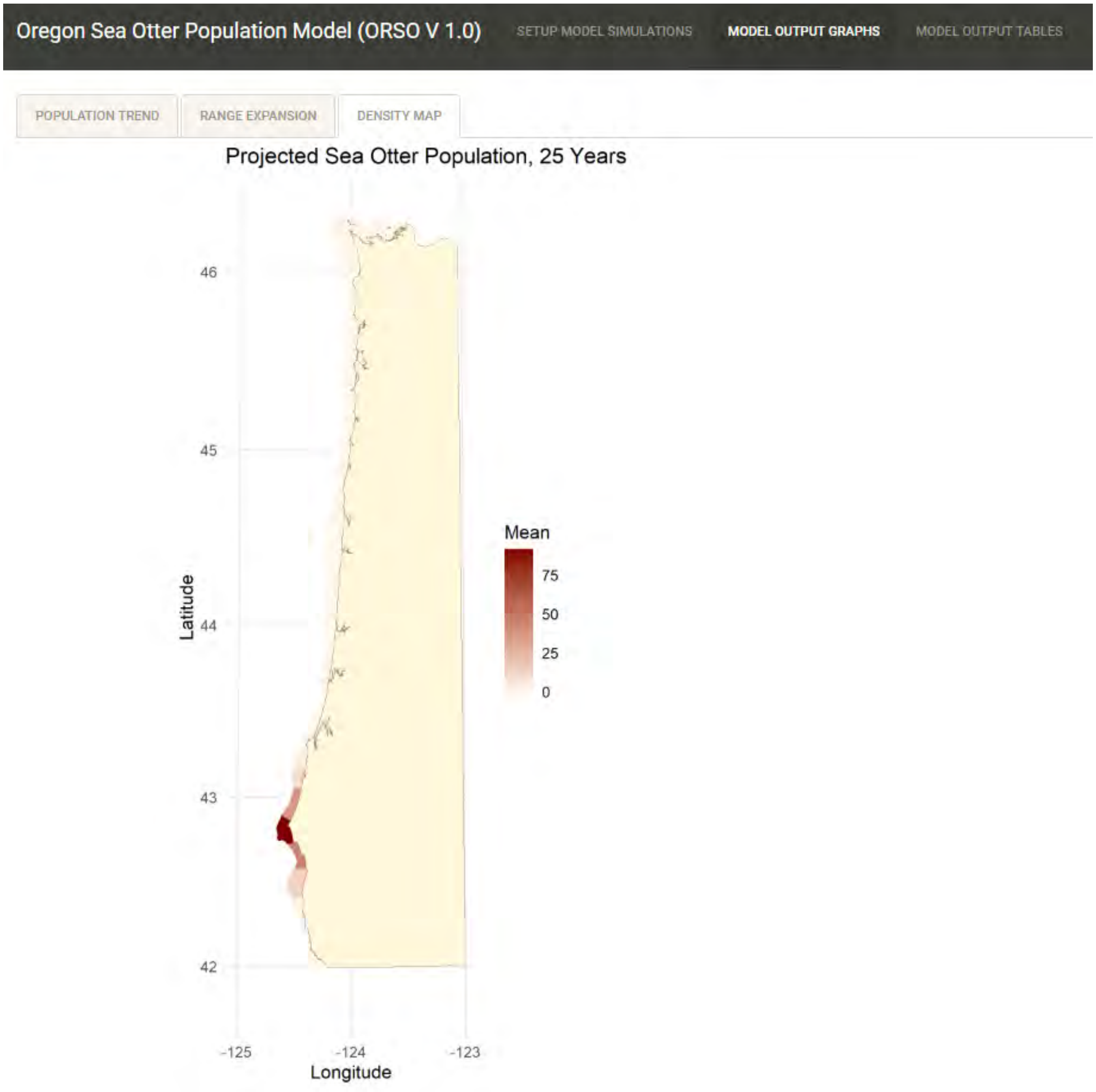


This plot shows the projected abundance over time of sea otters in Oregon, based on results from the simulation model (EXAMPLE SHOWN IS FOR ILLUSTRATIVE PURPOSES ONLY). The horizontal axis represents years into the future, while the vertical axis represents the expected total number of sea otters in a given year. Uncertainty about model results is calculated based on the distribution of results from stochastic iterations of the simulation. The solid black line represents the average abundance trend (i.e. averaged across all iterations), the dark grey band shows the 95% CI for the mean trend (i.e. uncertainty about the true average), and the light grey band shows the 95% CI for the full distribution of results (i.e. uncertainty about the range of possible outcomes).

Range Expansion Graph

This heatmap graph shows the average projected abundance and spatial distribution of sea otters over time (EXAMPLE SHOWN IS FOR ILLUSTRATIVE PURPOSES ONLY). Each grid cell represents a coastal section (vertical axis), as defined by the map on the front page, on a given year (horizontal axis): the shading of the grid cells indicating the relative abundance of sea otters (darker colors = more otters, white cells = no otters). The increase from left-to-right in the number and intensity of shaded cells illustrates the spatiotemporal patterns of range expansion. At the left-hand side of the heatmap (year 1), the spatial distribution is constrained by the starting conditions (density = 0 at all but the section(s) where sea otters are introduced). As one moves from left to right across the heatmap (i.e. moving forward through time), the changes in density and distribution reflect the rates of population growth and range expansion.

Density Map



This map figure of coastal Oregon shows the average projected abundance and distribution of sea otters at the end of the simulation period (EXAMPLE SHOWN IS FOR ILLUSTRATIVE PURPOSES ONLY). The mean expected number of sea otters in each coastal section (for the specified reintroduction scenario) is illustrated by the shading of the nearshore habitat zone, with darker shades of red-brown indicating higher abundances of sea otters.

MODEL OUTPUT TABLES Panel

The results of the simulation model can also be viewed in tabular form. After setting up and running simulations, the user can navigate to "MODEL OUTPUT TABLES" panel, where two standardized tables can be viewed and/or downloaded as *.csv files:

"Table 1: Projected Sea Otter Abundance by Year"

"Table 2: Projected Abundance by Coastal Section in Final Year".

Oregon Sea Otter Population Model (ORSO V 1.0) SETUP MODEL SIMULATIONS MODEL OUTPUT GRAPHS MODEL OUTPUT TABLES

TABLE 1: PROJECTED SEA OTTER ABUNDANCE BY YEAR | TABLE 2: PROJECTED ABUNDANCE BY COASTAL SECTION IN FINAL YEAR

DOWNLOAD TABLE 1

Year	Average Number	Lower Estimate (CI)	Upper Estimate (CI)	Estimation Uncertainty (SE)	Lower 95% CI for the Mean	Upper 95% CI for the Mean
2021.00	21.81	4.16	42.90	0.00	21.81	21.81
2022.00	21.62	5.81	40.04	0.39	20.86	22.38
2023.00	22.81	7.66	41.17	0.39	22.05	23.57
2024.00	24.61	9.30	42.80	0.44	23.75	25.47
2025.00	26.35	11.36	46.31	0.44	25.49	27.20
2026.00	28.59	13.02	49.71	0.44	27.74	29.45

Table 1 summarizes total projected abundance across all of coastal Oregon for each year of the simulation, and includes six metrics: average projected abundance, lower estimate 95% CI of the projected abundance distribution, upper estimate 95% CI of the projected abundance distribution, estimation uncertainty expressed by the standard error (SE) of the mean projected abundance, lower 95% CI for the average expected abundance, and upper 95% CI for the average expected abundance.

Oregon Sea Otter Population Model (ORSO V 1.0) SETUP MODEL SIMULATIONS MODEL OUTPUT GRAPHS MODEL OUTPUT TABLES

TABLE 1: PROJECTED SEA OTTER ABUNDANCE BY YEAR | TABLE 2: PROJECTED ABUNDANCE BY COASTAL SECTION IN FINAL YEAR

DOWNLOAD TABLE 2

Coastal Section	Area (km2)	Year	Average Number	Lower Estimate (CI)	Upper Estimate (CI)	Density (#/km2)	Lower Density Est.(#/km2)	Upper Density Est.(#/km2)
S1	86.97	2045.00	0.09	0.00	0.00	0.00	0.00	0.00
S2	55.32	2045.00	0.10	0.00	0.00	0.00	0.00	0.00
S3	90.69	2045.00	0.09	0.00	0.00	0.00	0.00	0.00
S4	181.74	2045.00	13.11	0.00	30.00	0.07	0.00	0.17
S5	82.00	2045.00	44.95	13.00	94.00	0.54	0.16	1.15
S6	123.91	2045.00	91.54	29.00	191.00	0.73	0.23	1.54
S7	100.98	2045.00	35.90	10.00	72.00	0.35	0.10	0.71
S8	87.37	2045.00	9.51	0.00	23.00	0.11	0.00	0.26
S9	88.00	2045.00	0.54	0.00	4.00	0.00	0.00	0.05
S10	71.63	2045.00	0.23	0.00	0.00	0.00	0.00	0.00

Table 2 summarizes the projected abundance and density in each coastal section on the final year of the simulation: columns include area of benthic habitat in each section (km2), average projected number of sea otters, lower estimate 95% CI of the projected abundance distribution, upper estimate 95% CI of the projected abundance distribution, average density (number of sea otters/km2), lower 95% CI of the projected density distribution, upper 95% CI of the projected density distribution.

In addition to viewing the tables, they can also be downloaded as csv files by clicking on the download buttons above each table.

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Appendix B: Habitat Maps of Oregon State Waters from the Active Tectonics and Seafloor Mapping Lab at Oregon State University (https://activetectonics.coas.oregonstate.edu).

Figure S1. Seaside

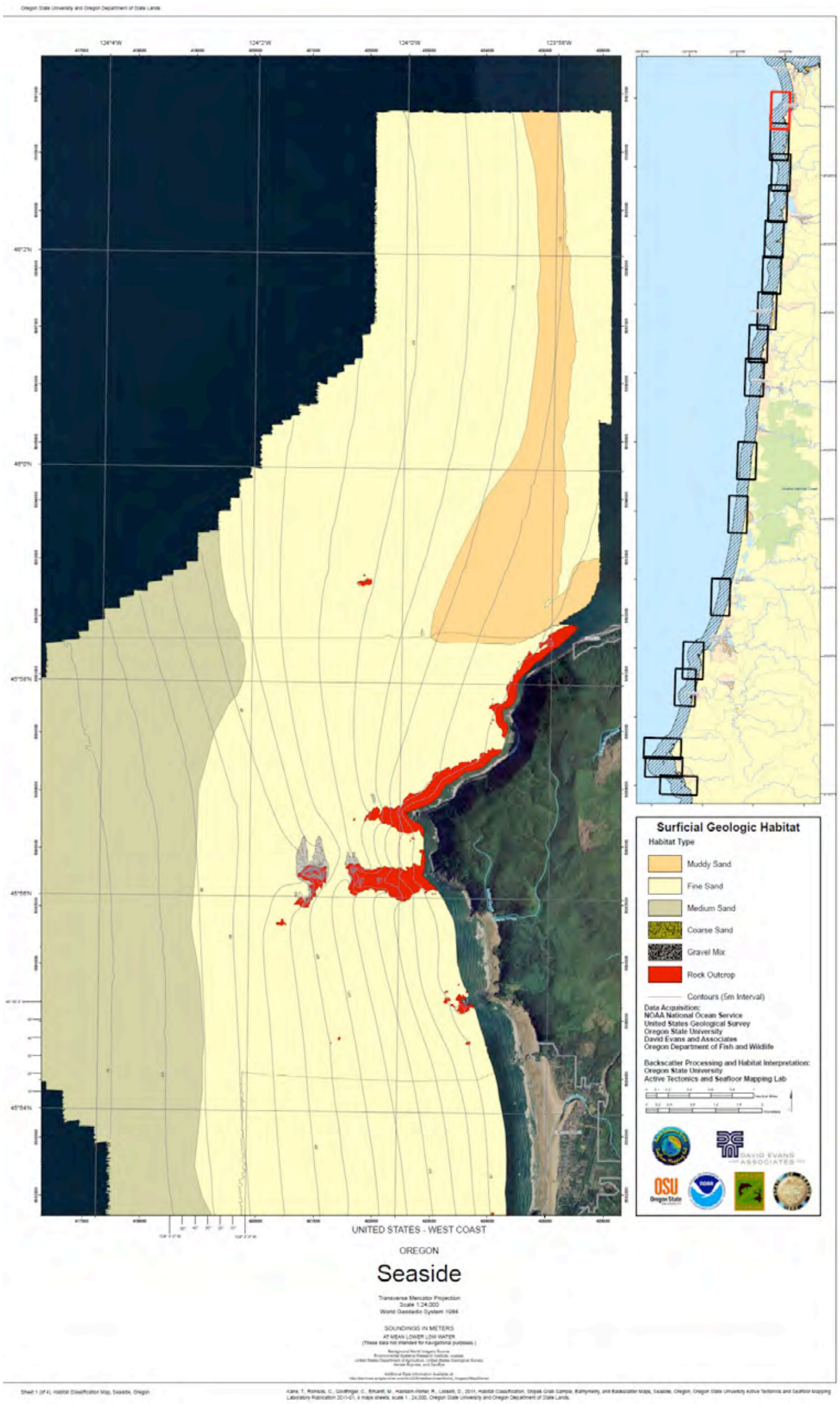


Figure S2. Hug Point

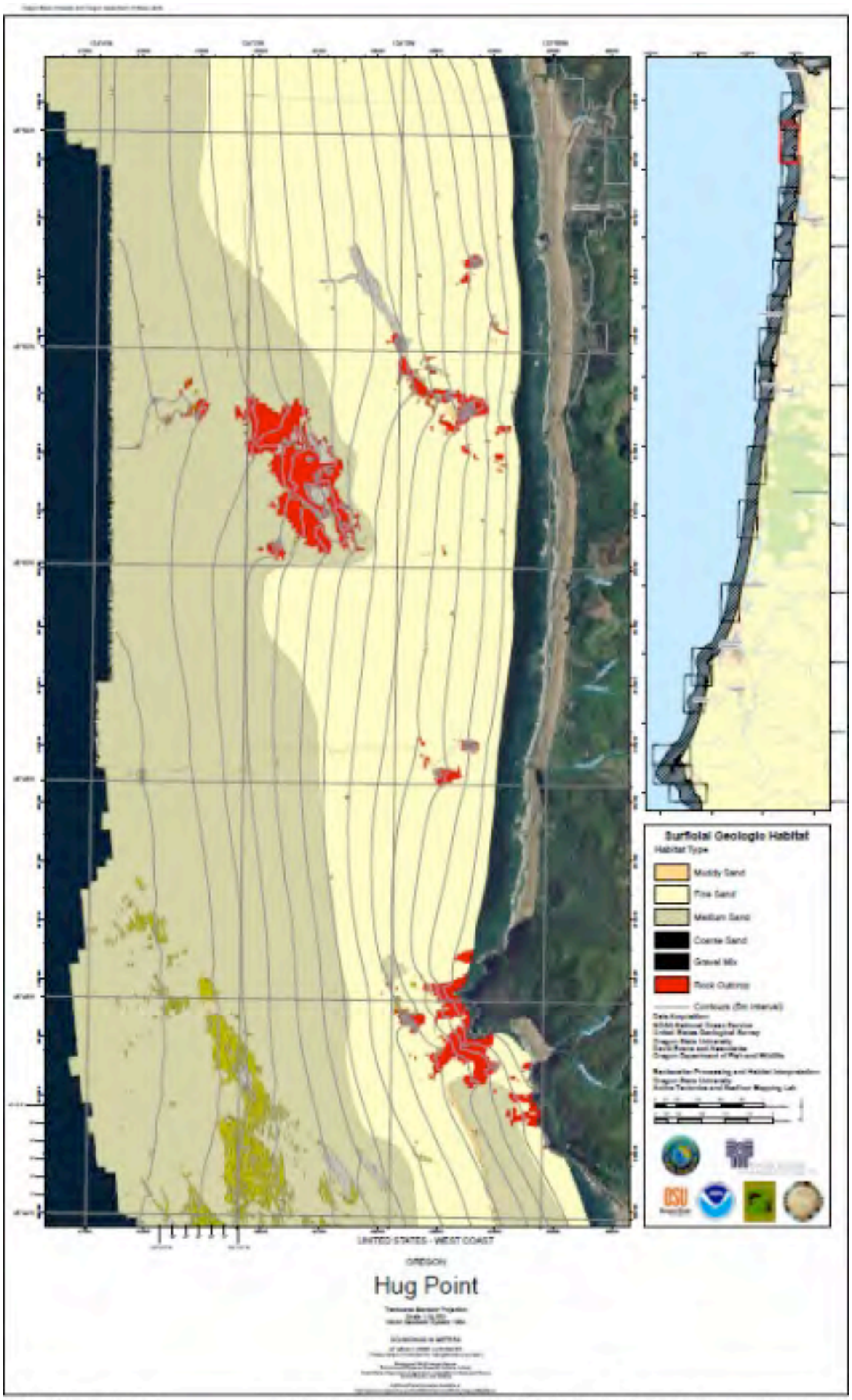


Figure S3. Nehalem

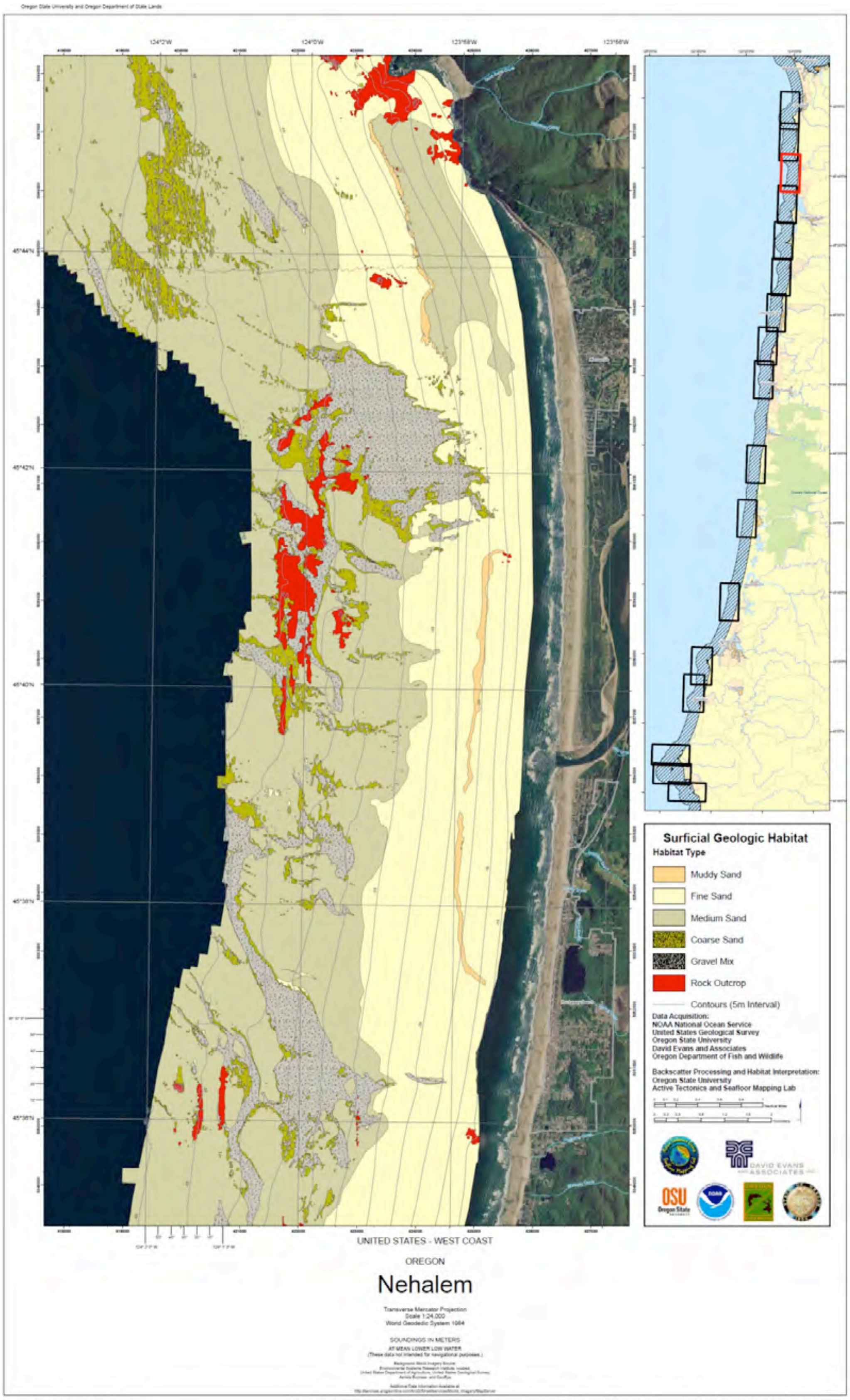


Figure S4. Cape Mears

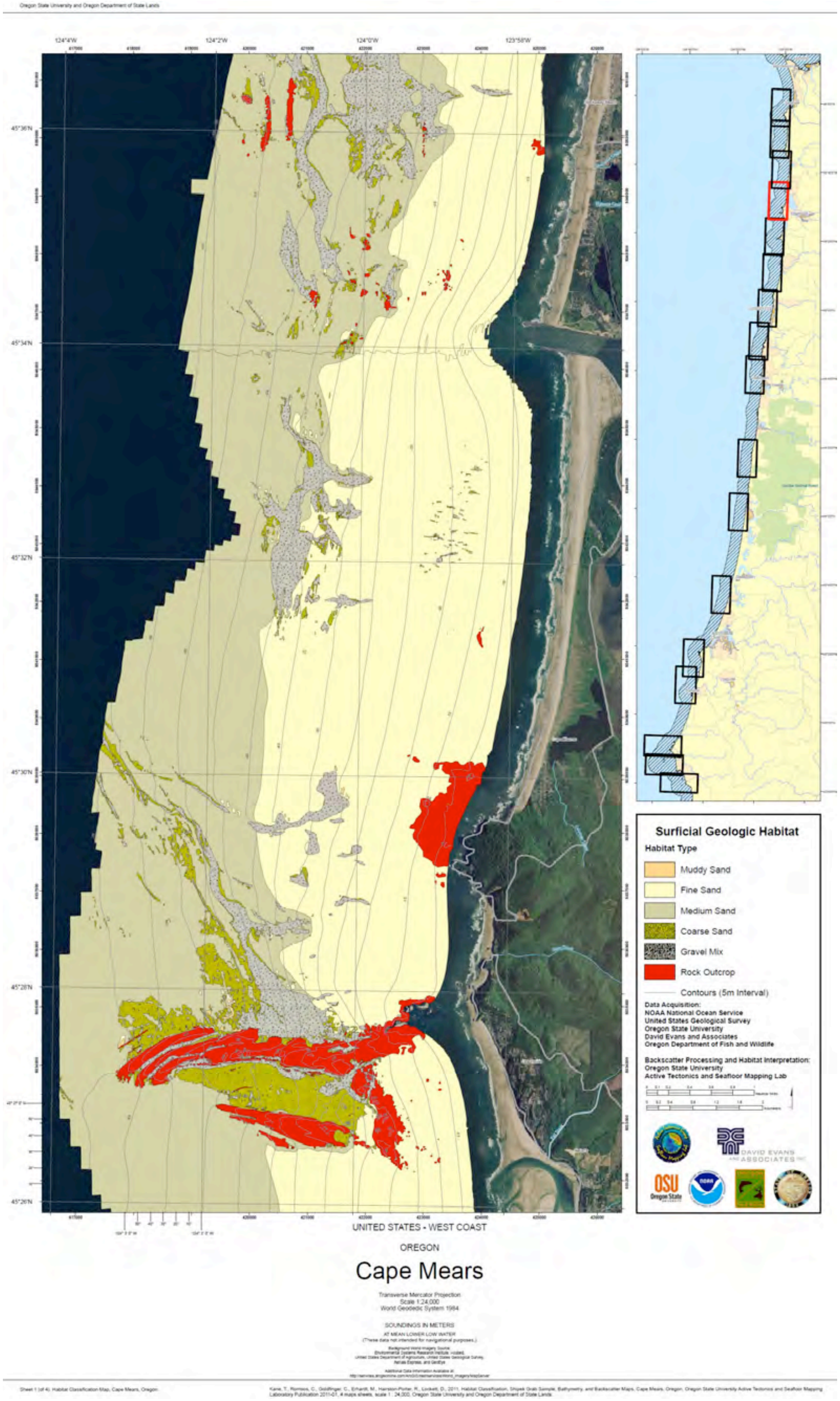


Figure S5. Cape Lookout

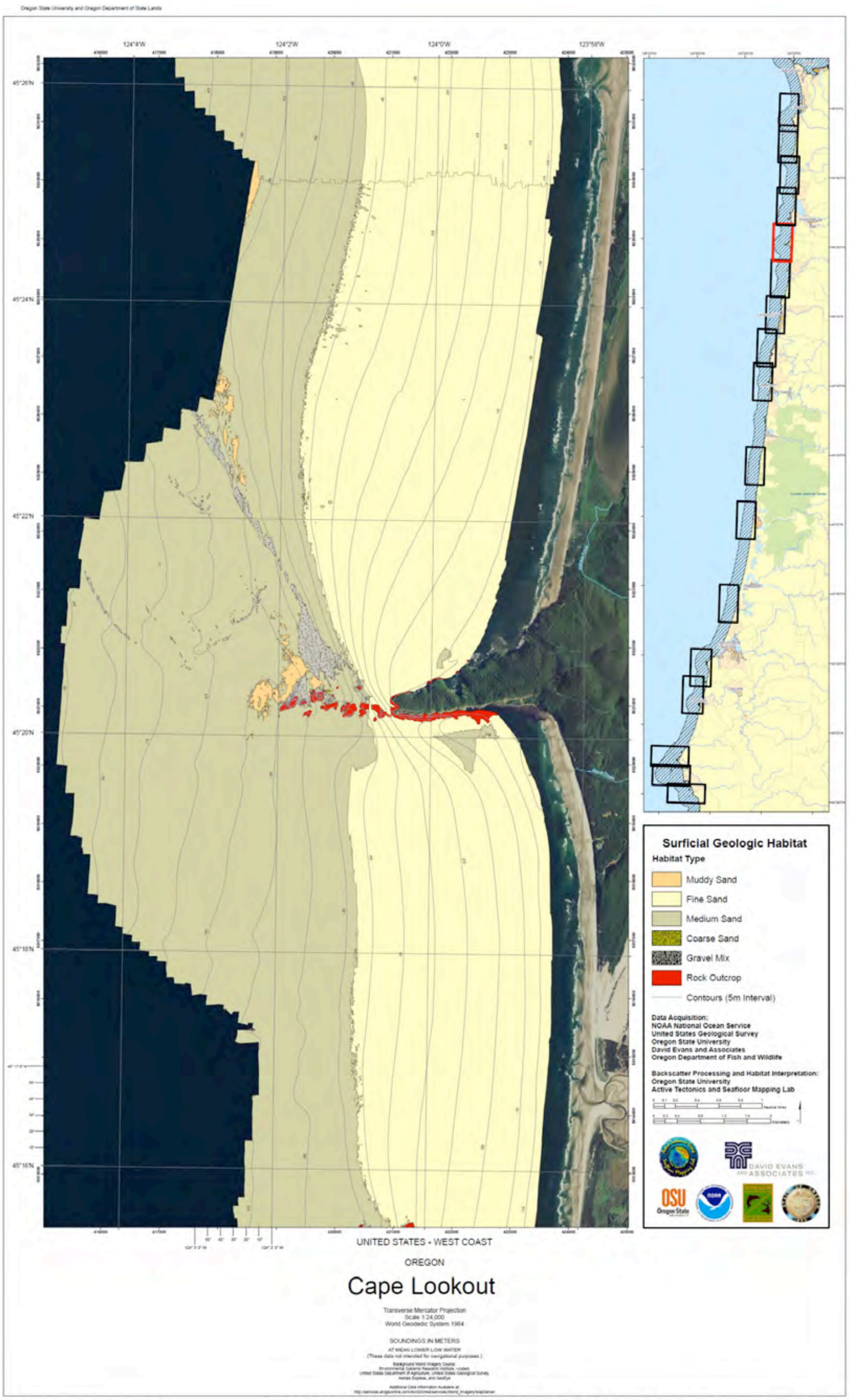


Figure S6. Cape Kiwanda

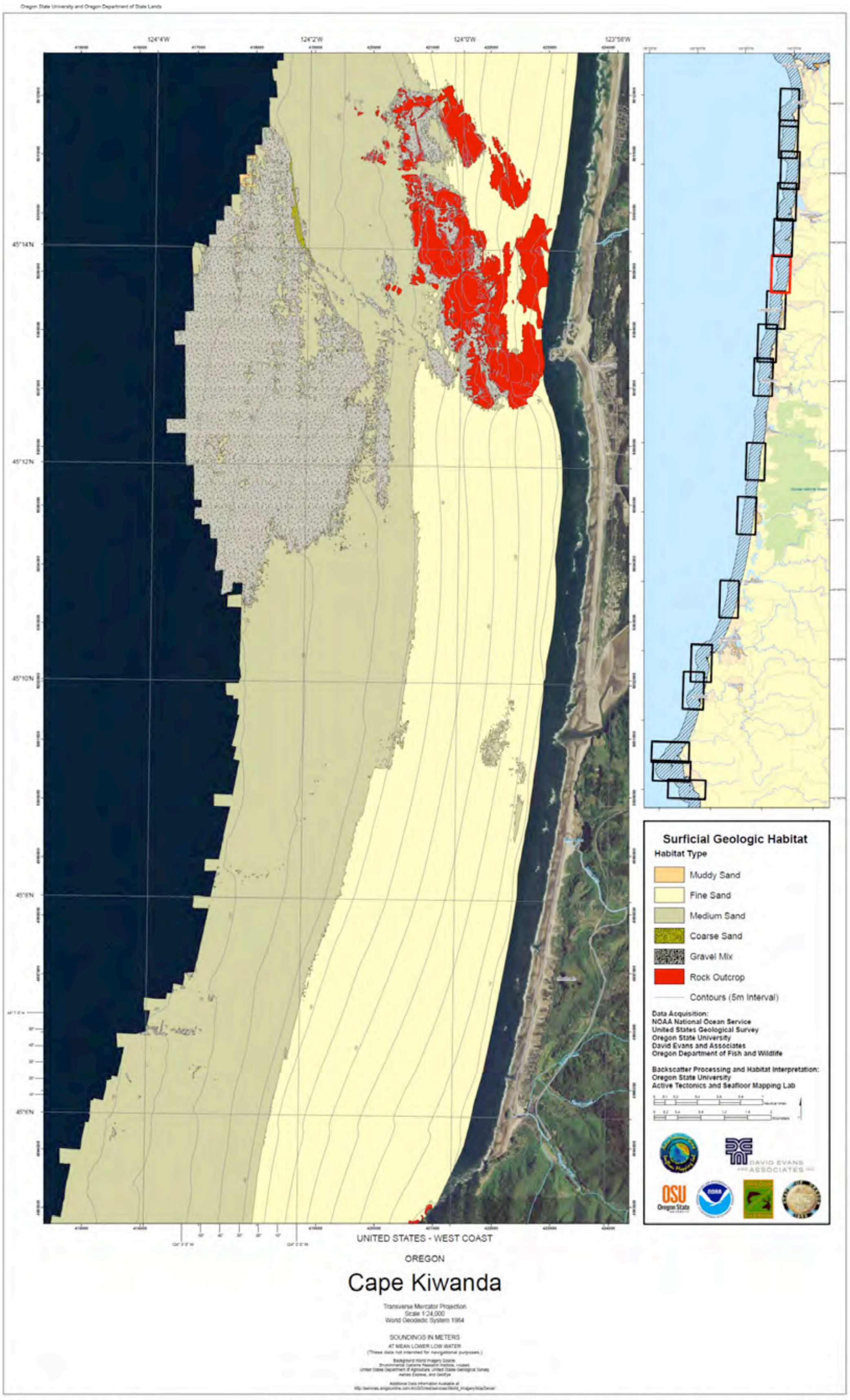


Figure S7. Lincoln City

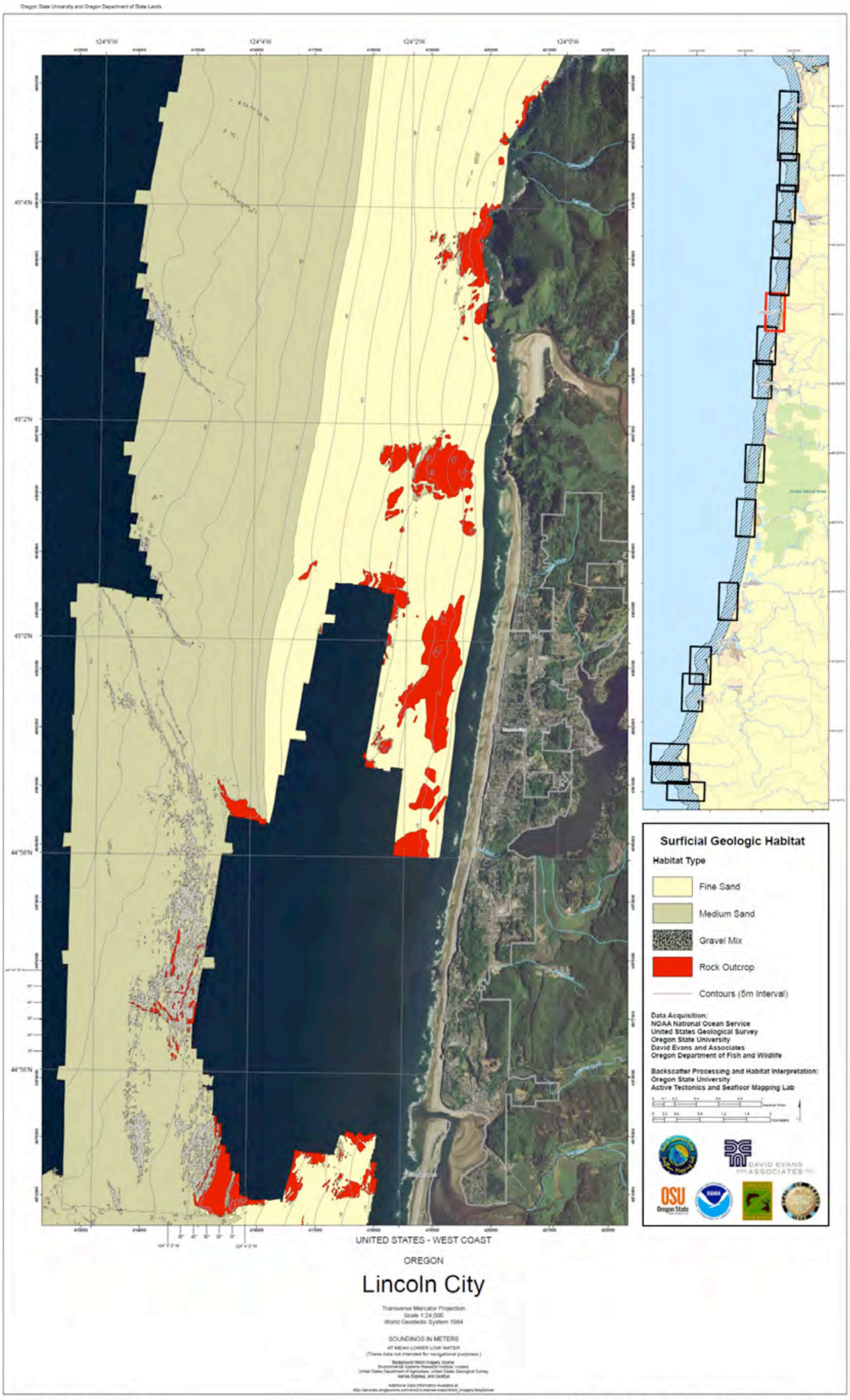


Figure S8. Depoe Bay

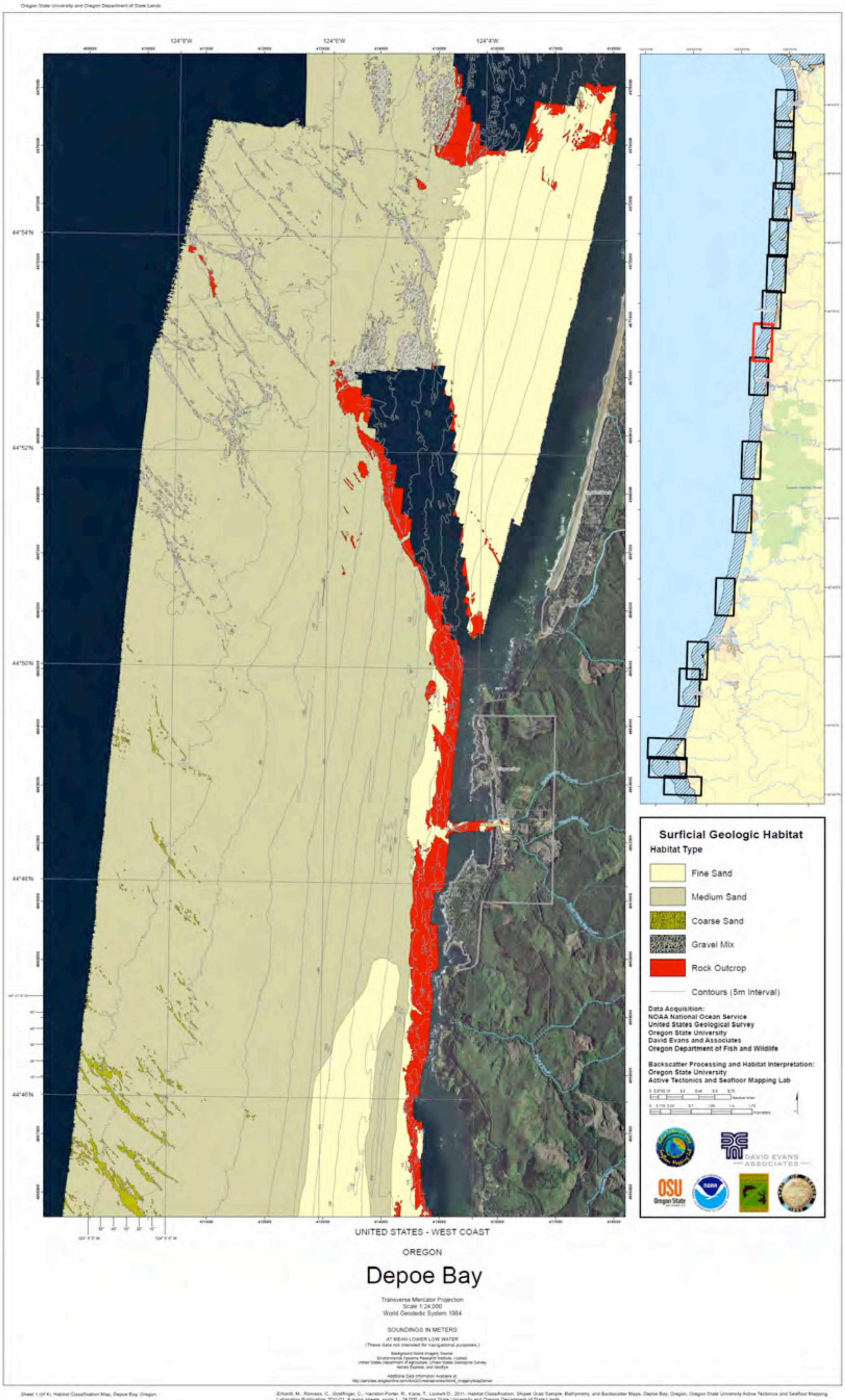


Figure S9. Newport

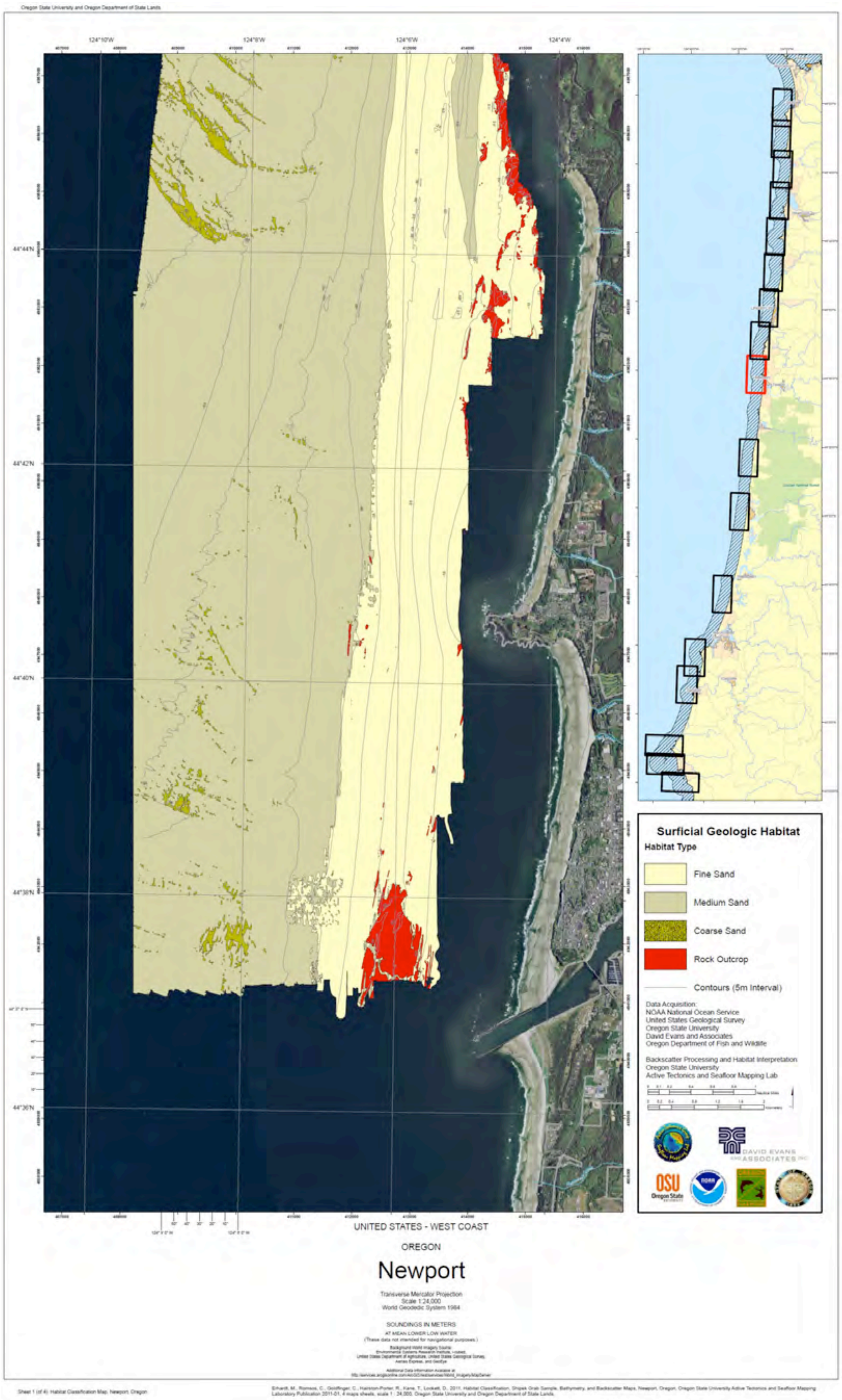


Figure S10. Cape Perpetua

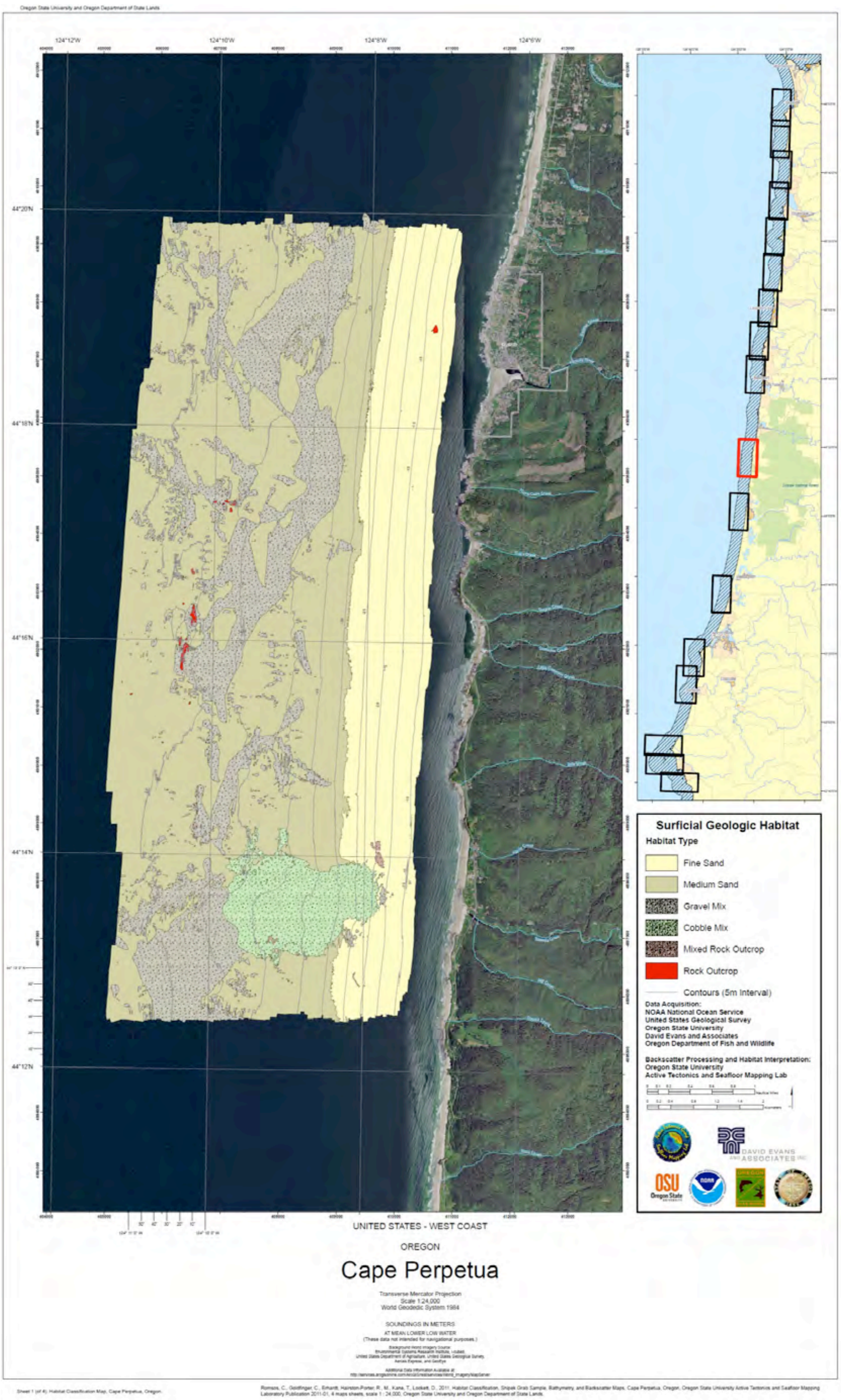


Figure S11. Florence

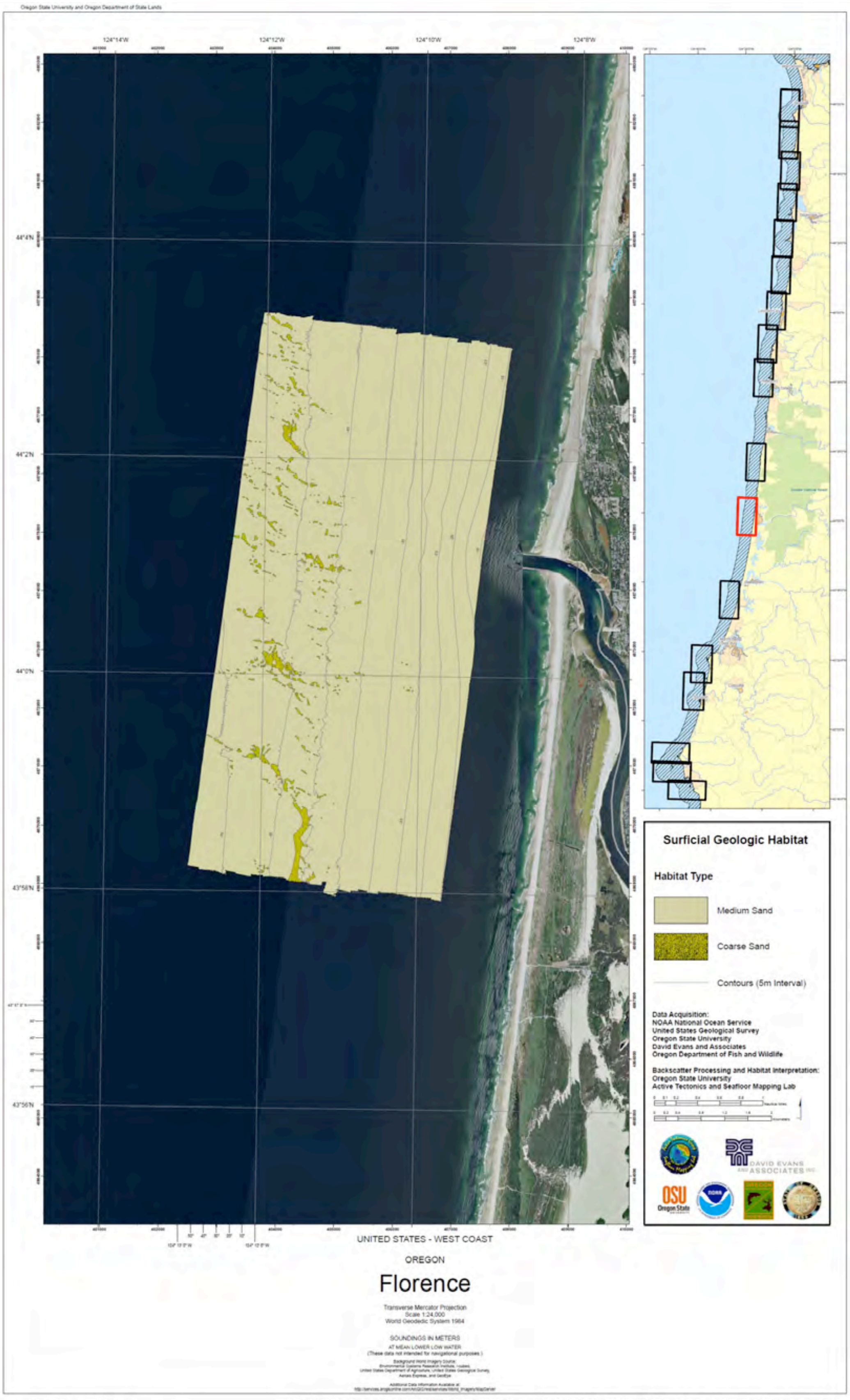


Figure S12. Lakeside

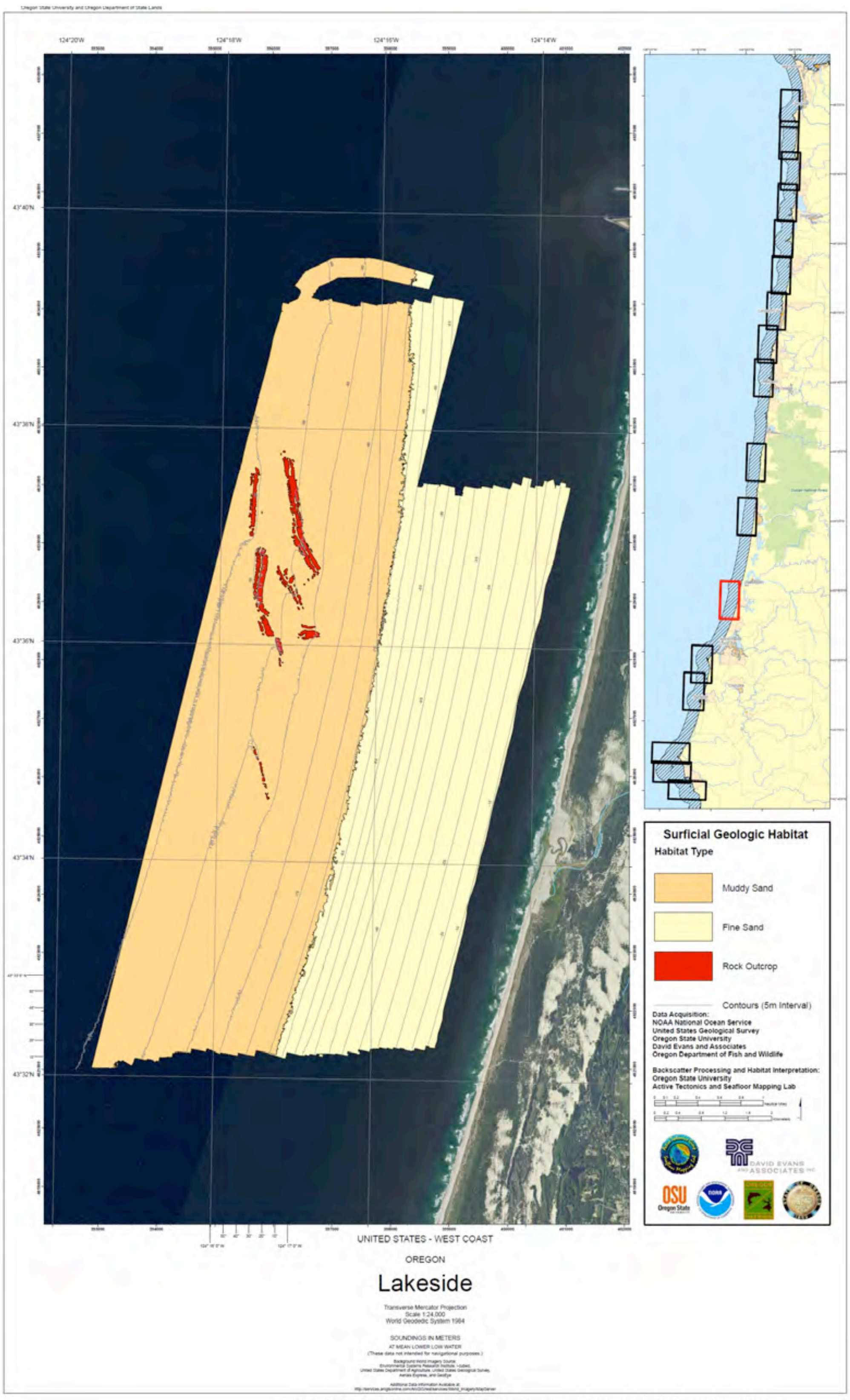


Figure S13. Cape Arago

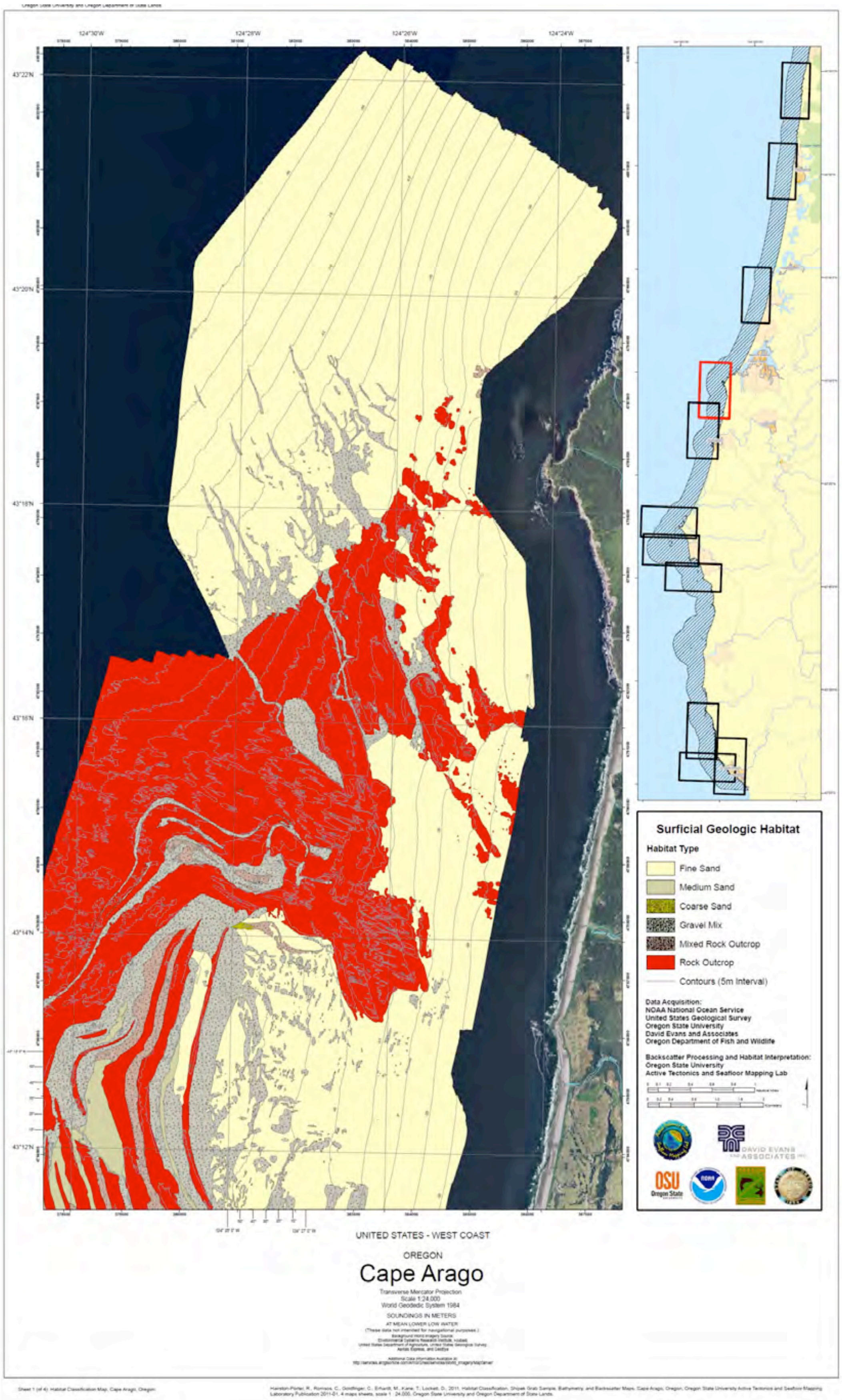


Figure S14. Bandon

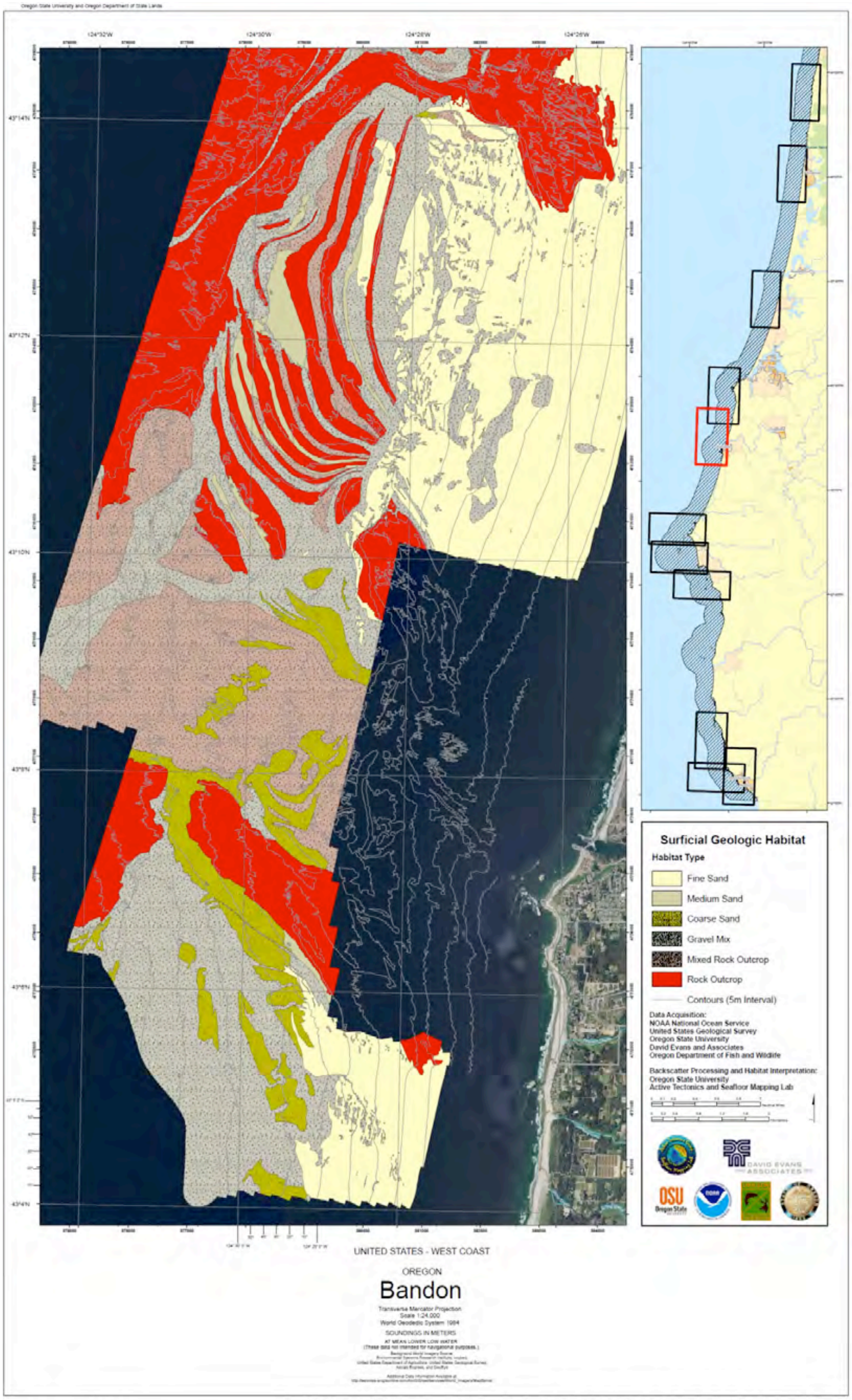


Figure S15. Blacklock Point

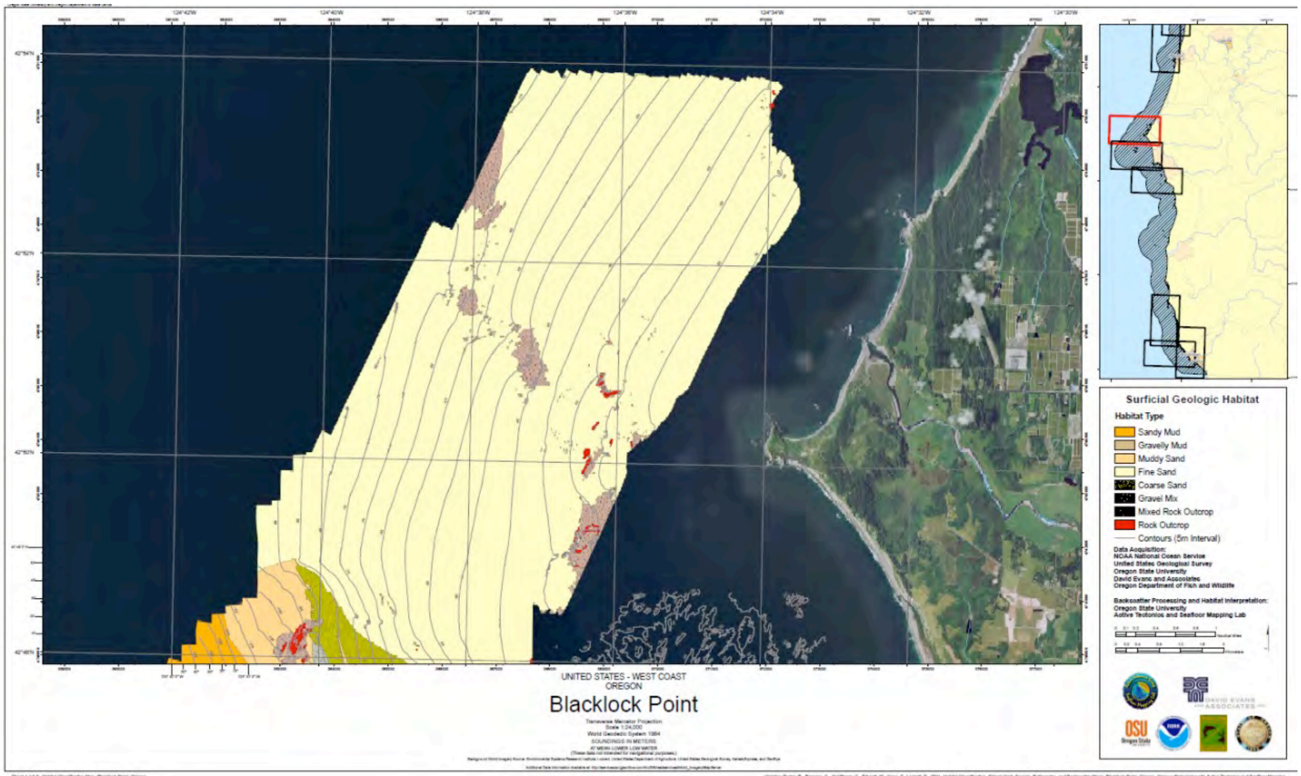


Figure S16a. Cape Blanco

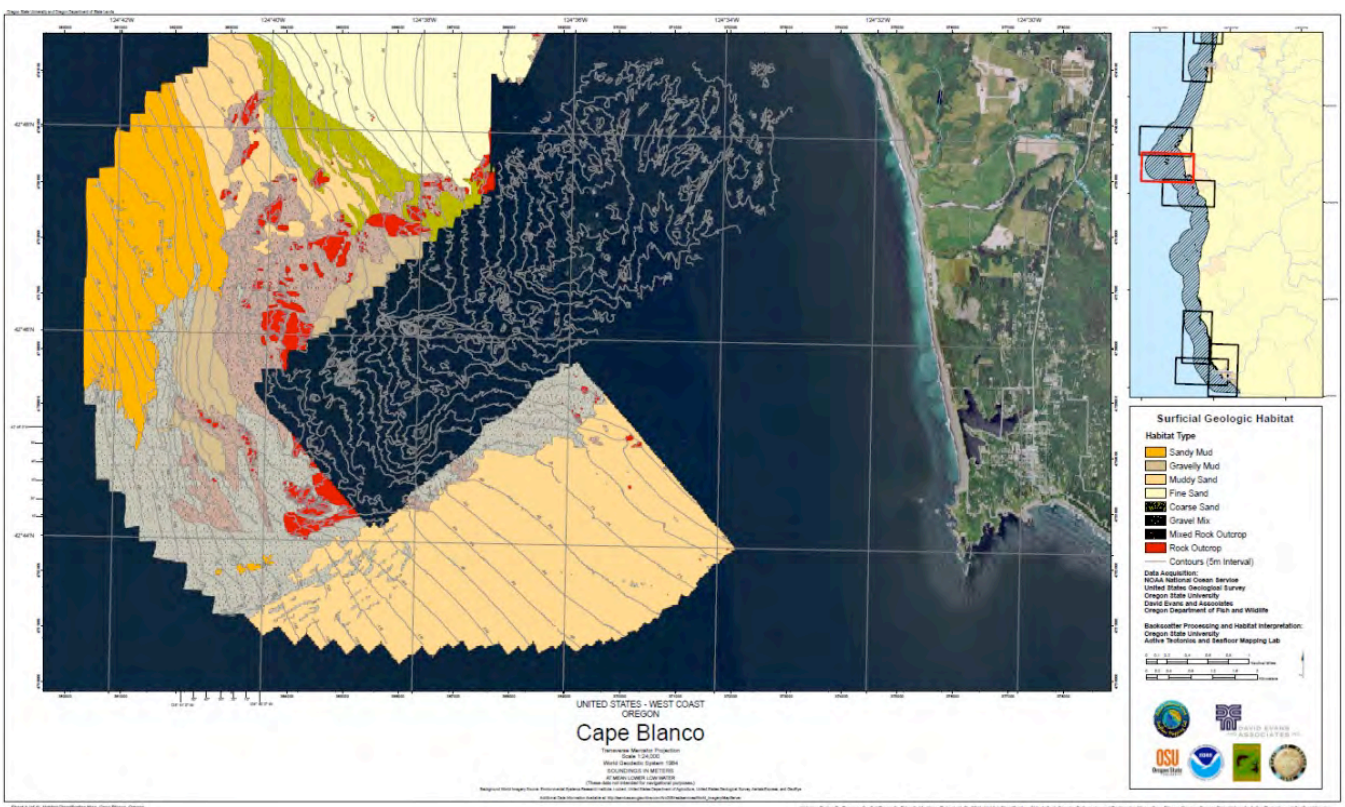
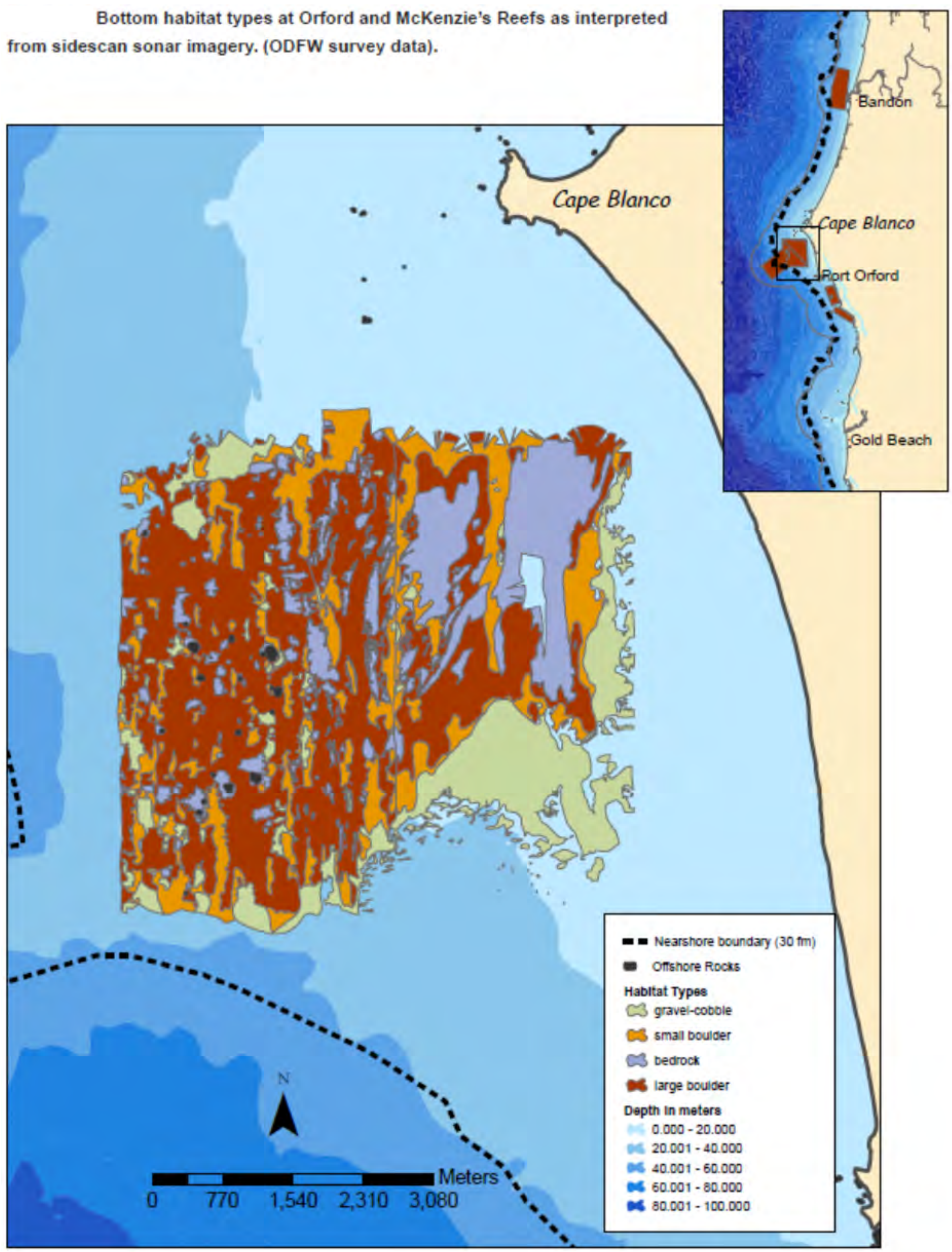
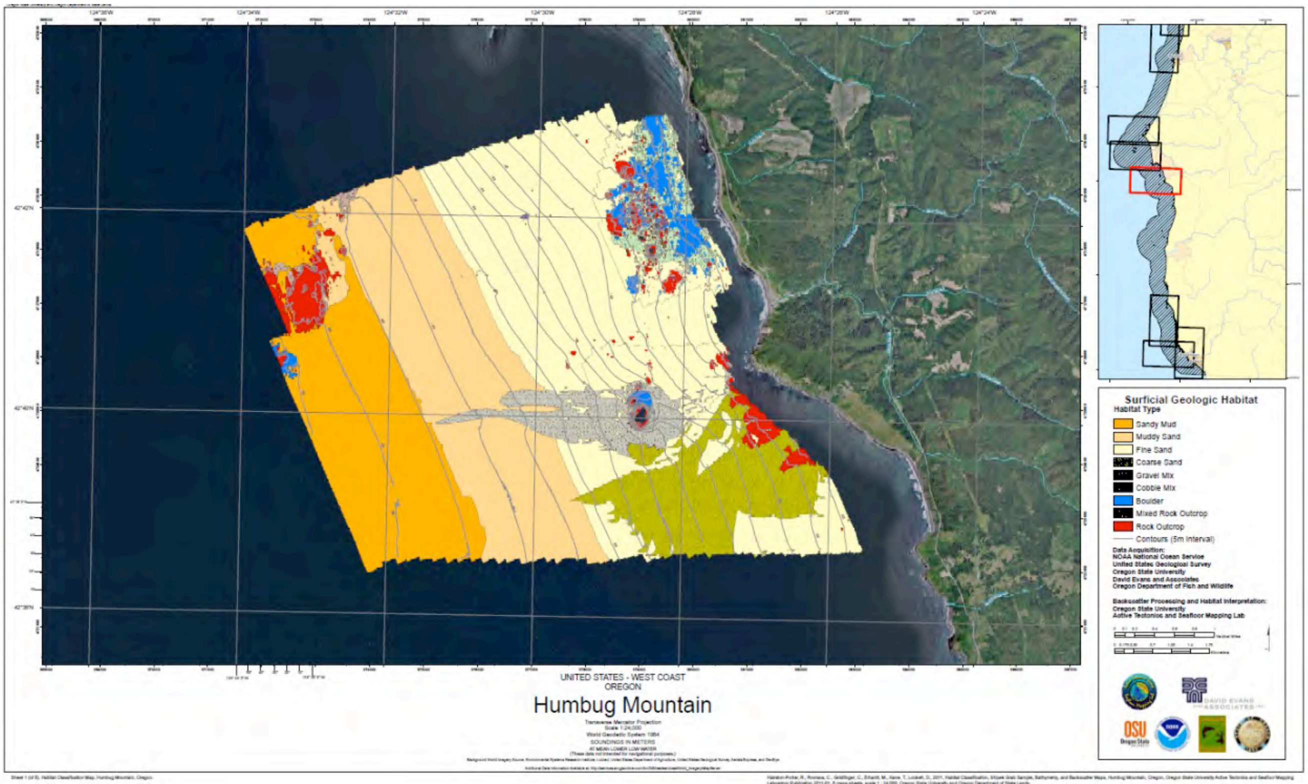


Figure S16b.



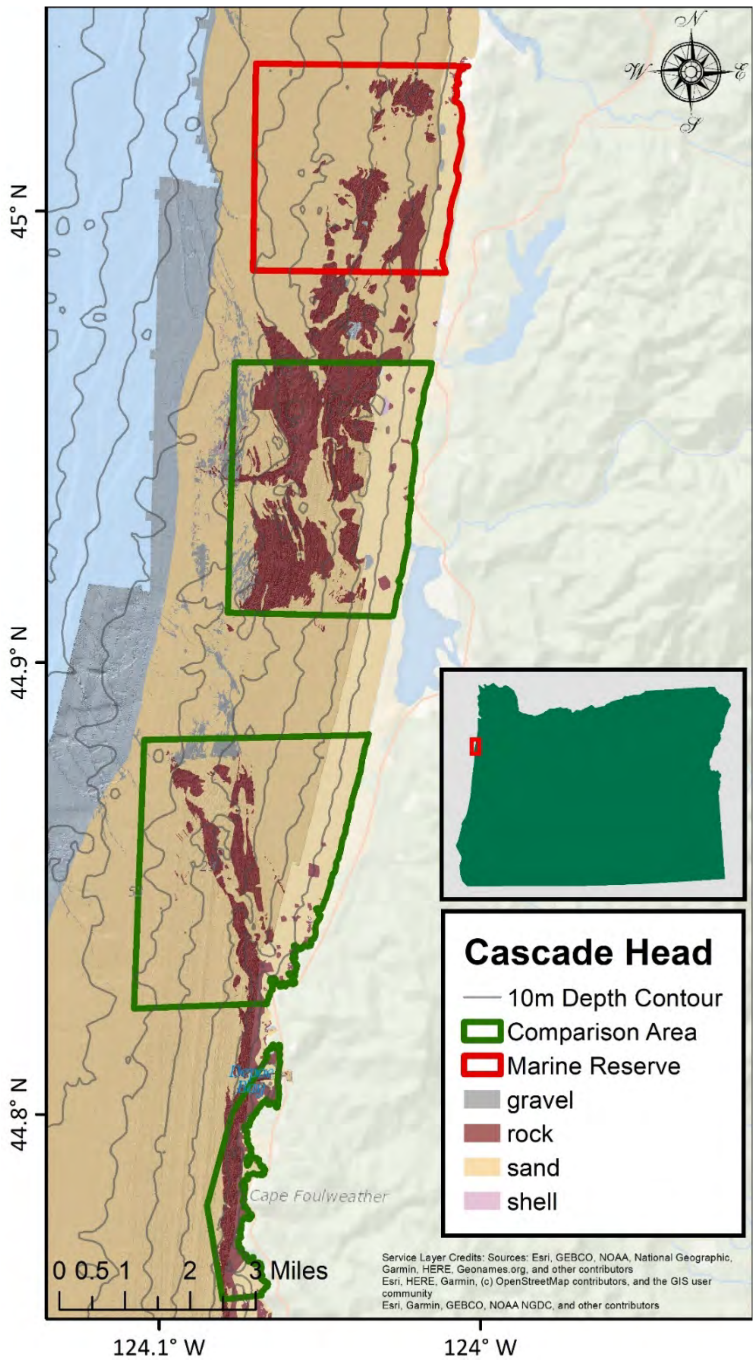
(Source: Oregon Department of Fish and Wildlife. 2006. Chapter 5 Oregon's Nearshore Environment in Oregon's Nearshore Strategy. pg 64.)

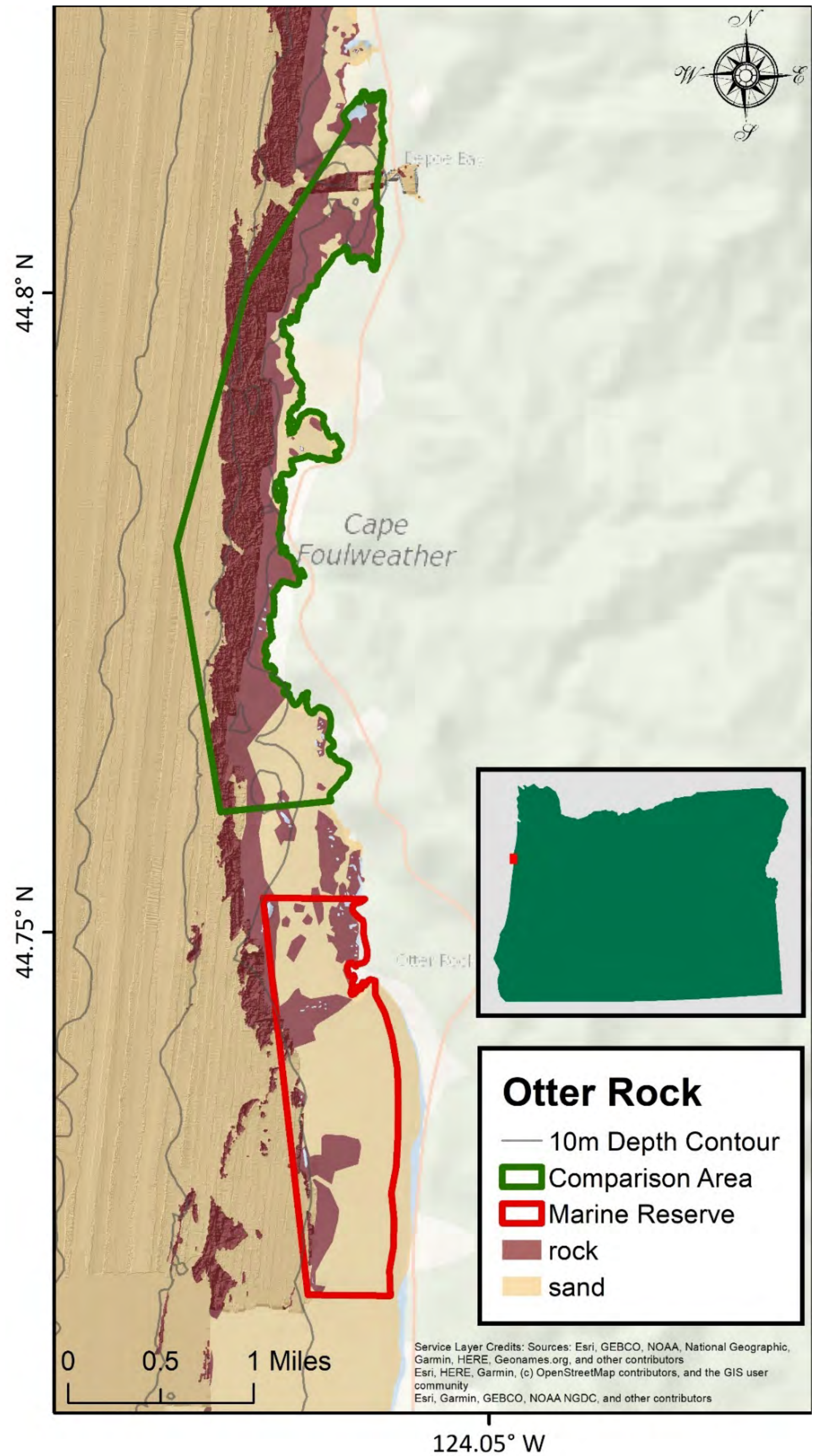
Figure S17. Humbug Mountain



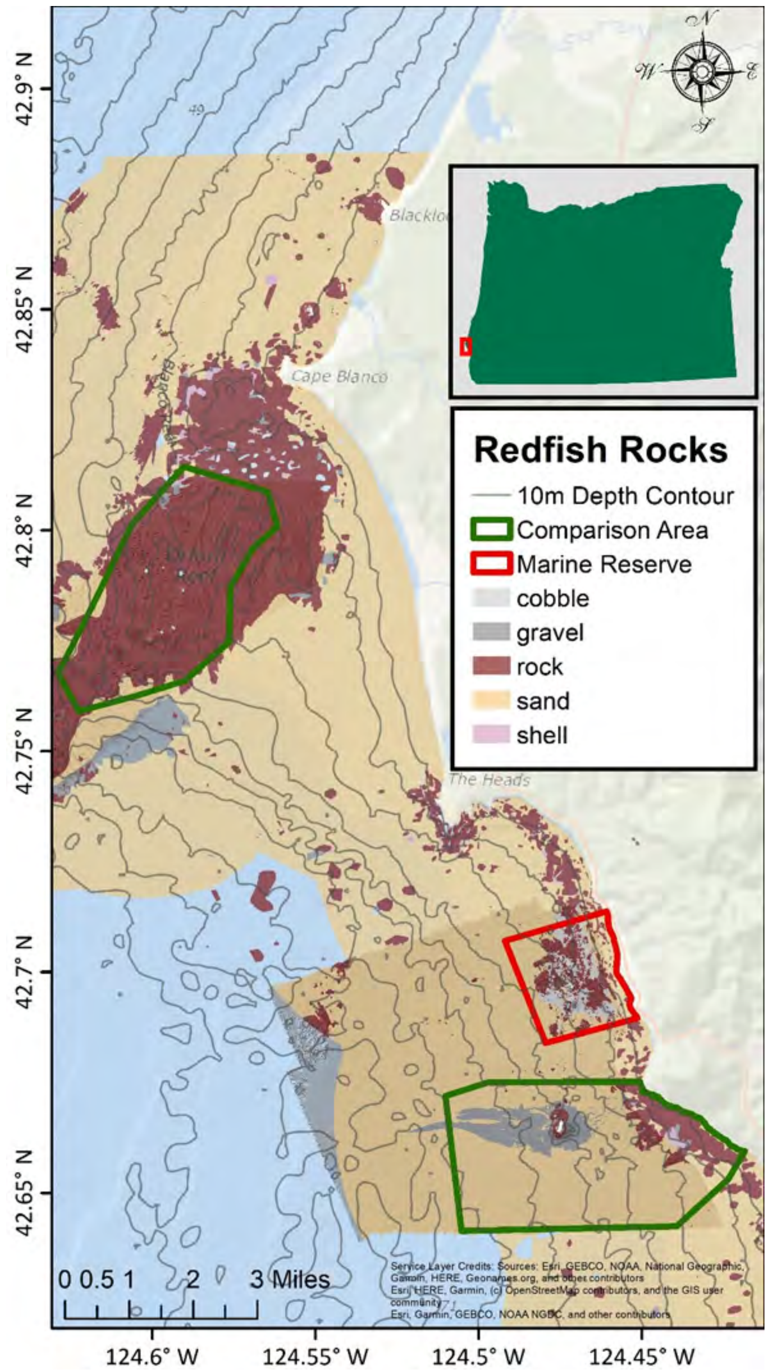
Appendix C: Substrate Characteristics for Oregon’s Marine Reserves

https://odfwmarinereserves.shinyapps.io/Marine_Reserves_Shiny_App_v7/



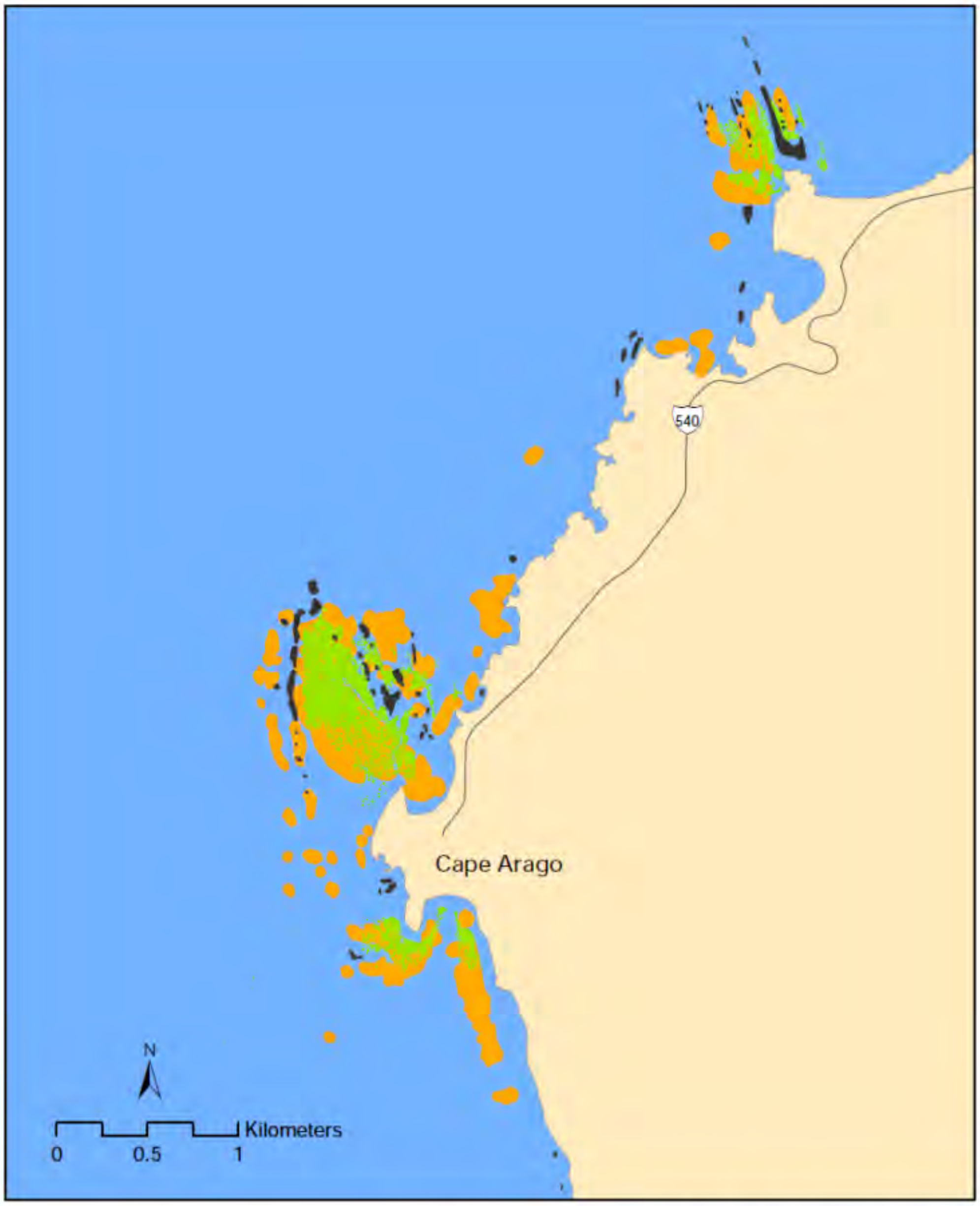


44.8° N
44.75° N
124.05° W
Cape Foulweather
Otter Rock
10m Depth Contour
Comparison Area
Marine Reserve
rock
sand
0
0.5
1 Miles
Service Layer Credits: Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Esri, Garmin, GEBCO, NOAA NGDC, and other contributors


Redfish Rocks
10m Depth Contour
Comparison Area
Marine Reserve
cobble
gravel
rock
sand
shell
Blacklo
Cape Blanco
The Heads
42.9° N
42.85° N
42.8° N
42.75° N
42.7° N
42.65° N
124.6° W
124.55° W
124.5° W
124.45° W
0 0.5 1 2 3 Miles
Service Layer Credits: Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

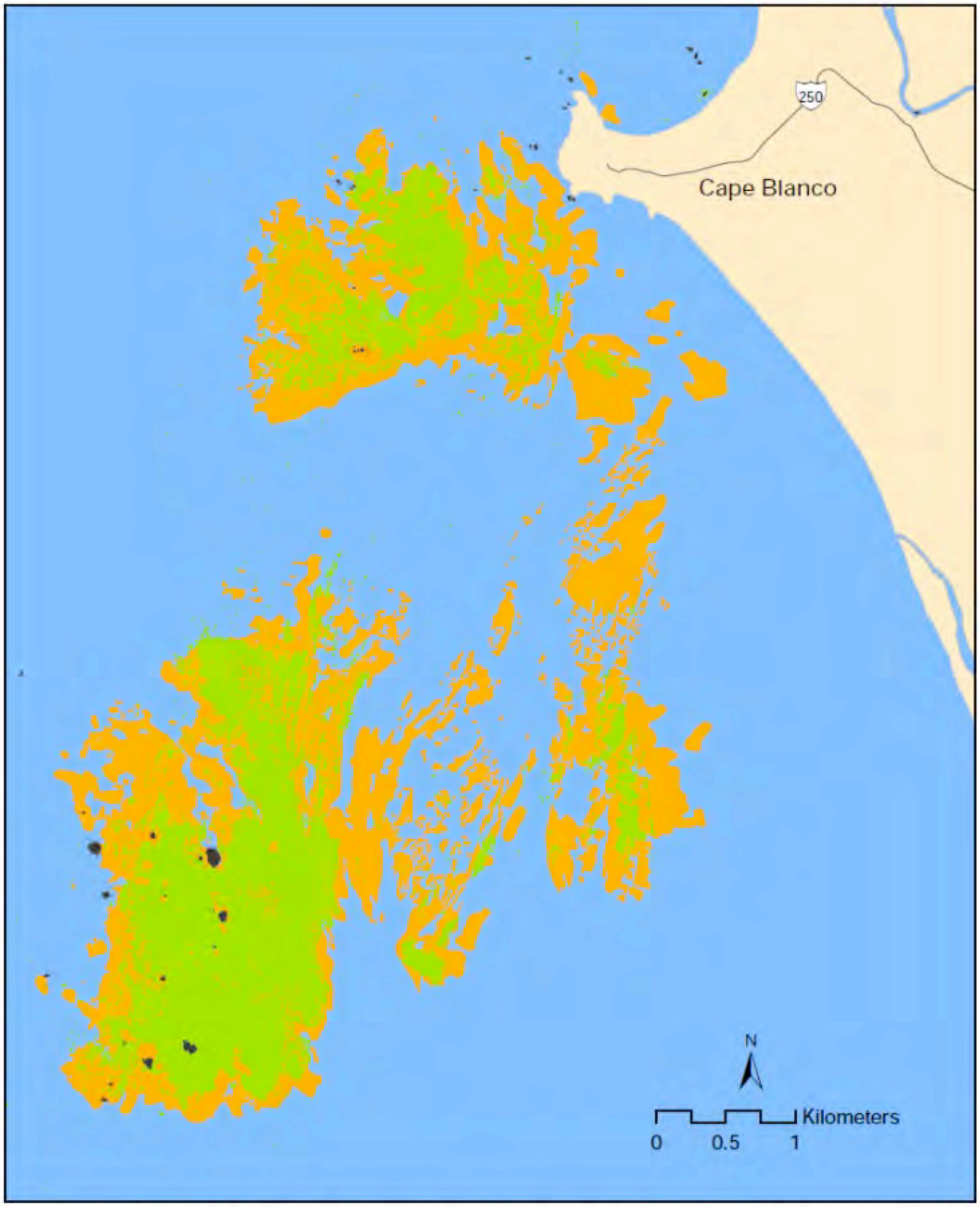
Appendix D: Kelp canopy extent from ODFW's Kelp Canopy and Biomass Survey Report (2011)

Figure S1. Cape Arago
This region was not included in the 1996 - 1999 surveys.



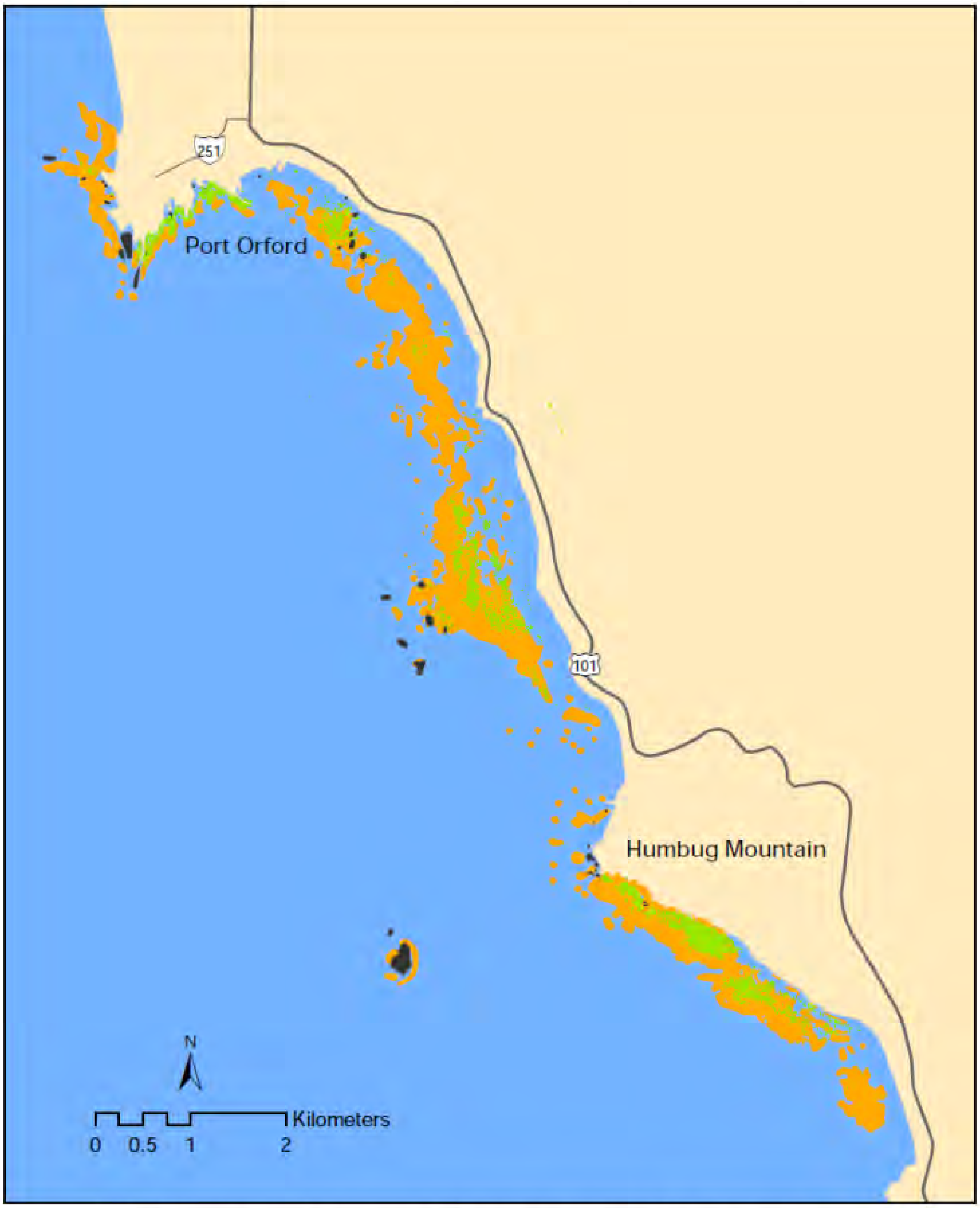
Comparison of maximum kelp canopy extent at Cape Arago from all kelp surveys in Oregon. A single coastwide survey in 1990 (orange polygons) is overlaid with the kelp canopy of this current survey (green polygons). The1990 kelp beds were delineated from near-infrared photography using methods that do not differentiate beds at the resolution of DMSI methods, so bed density is not comparable between survey types in this image.

Figure S2. Blanco and Orford Reefs



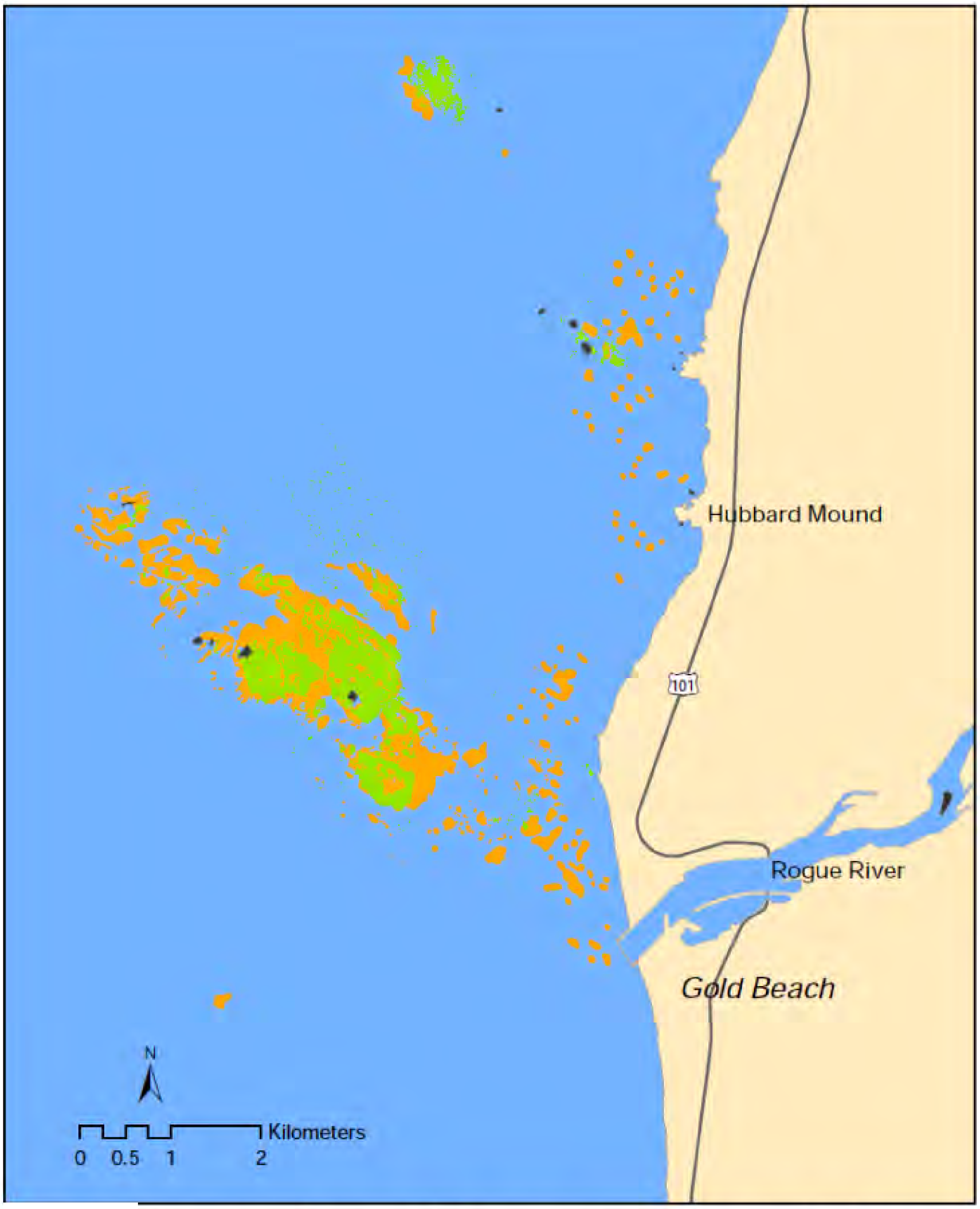
Comparison of maximum kelp canopy extent at Blanco and Orford reefs from all kelp surveys in Oregon. A single coastwide survey in 1990 is merged with 5 annual south-coast regional surveys from 1996-99 (orange polygons) and is overlaid with the kelp canopy of this current survey (green polygons). The1990-99 kelp beds were delineated from near-infrared photography using methods that do not differentiate beds at the resolution of DMSI methods, so bed density is not comparable between survey types in this image.

Figure S3. Port Orford, Redfish Rocks and Humbug Mountain



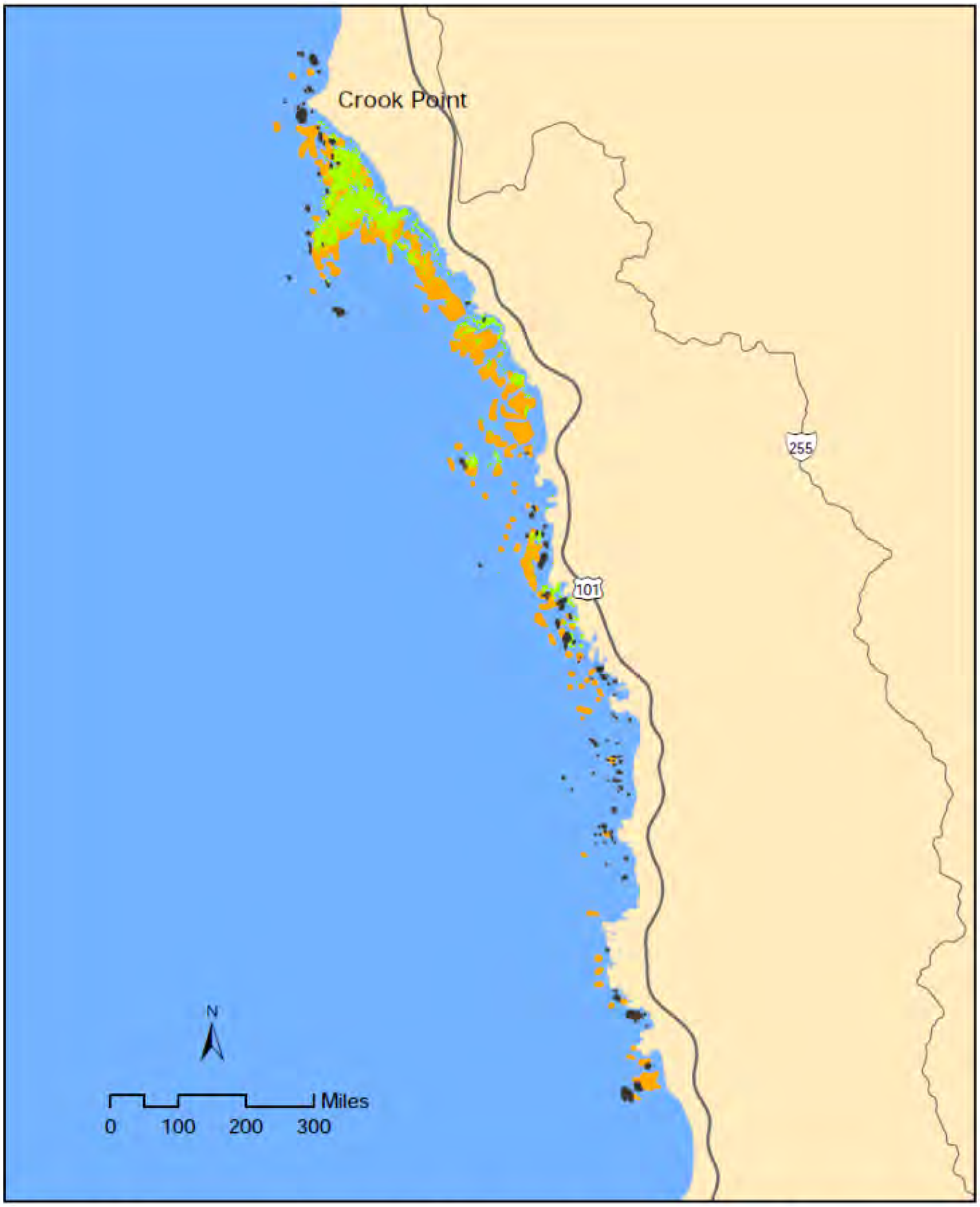
. Comparison of maximum kelp canopy extent at Redfish Rocks and Humbug Mountain reefs from all kelp surveys in Oregon. A single coastwide survey in 1990 is merged with 5 annual south-coast regional surveys from 1996-99 (orange polygons) and is overlaid with the kelp canopy of this current survey (green polygons). The1990-99 kelp beds were delineated from near-infrared photography using methods that do not differentiate beds at the resolution of DMSI methods, so bed density is not comparable between survey types in this image.

Figure S4. Rogue River Reef



Comparison of maximum kelp canopy extent at Rogue Reef and a nearby shallow reef from all kelp surveys in Oregon. A single coastwide survey in 1990 is merged with 5 annual south-coast regional surveys from 1996-99 (orange polygons) and is overlaid with the kelp canopy of this current survey (green polygons). The1990-99 kelp beds were delineated from near-infrared photography using methods that do not differentiate beds at the resolution of DMSI methods, so bed density is not comparable between survey types in this image.

Figure S5. Crook Point and the Mack Arch Complex
This region was not included in the 1996 - 1999 surveys.



Comparison of maximum kelp canopy extent at Mack Arch from all kelp surveys in Oregon. A single coastwide survey in 1990 (orange polygons) is overlaid with the kelp canopy of this current survey (green polygons). The1990 kelp beds were delineated from near-infrared photography using methods that do not differentiate beds at the resolution of DMSI methods, so bed density is not comparable between survey types in this image.

Figure S6. Cape Ferrelo
This region was not included in the 1996 - 1999 surveys.

. Comparison of maximum kelp canopy extent at Cape Ferrelo from all kelp surveys in Oregon. A single coastwide survey in 1990 (orange polygons) is overlaid with the kelp canopy of this current survey (green polygons). The1990 kelp beds were delineated from near-infrared photography using methods that do not differentiate beds at the resolution of DMSI methods, so bed density is not comparable between survey types in this image.

Appendix E
Assessing the feasibility of a sea otter reintroduction to Oregon through a coupled natural-human lens

Lorne Curran, Dom Kone, Ben Wickizer. 2019.

NOTE: This report is the product of National Science Foundation fellowships awarded to graduate students at Oregon State University (1545188 NRT-DESE). It has not been formally peer reviewed, and some components may already be outdated: it is provided as-is as a supporting document

INTRODUCTION

The issue

Top predators dictate food web dynamics at lower trophic levels via top-down forcing. Across the world, many of these predators have declined or been extirpated due to human exploitation and/or habitat loss (Ripple et al. 2014). The sea otter is perhaps the most recognized example of this phenomenon in the eastern Pacific's nearshore marine environment. In rocky kelp ecosystems, sea otters fulfill a keystone role by heavily predating on sea urchins. This intense predation alleviates urchin grazing pressure on kelp, allowing the macroalgae to grow relatively uninhibited. Due to this relationship, high kelp biomass is generally associated with sea otter presence (Ripple et al. 2016, Estes & Palmisano, 1974; Estes & Duggins, 1995). Sea otters can play similar roles in seagrass communities. In Elkhorn Slough, California, their predation on crabs promote seagrass growth (Hughes et al. 2013). Thus, sea otters can greatly influence ecosystem function and structure.

The sea otter's historic range included much of the west coast of North America. The maritime fur trade, however, brought them to the brink of extinction in the early twentieth century, and the last Oregon sea otter was taken in 1907. An effort was made to translocate sea otters to Oregon in the early 1970s. Unlike in Southeast Alaska and Washington, where translocations were successful, this early effort failed (Jameson et al. 1982). Although the occasional sea otter finds its way to Oregon, it is unlikely that a sea otter population will re-establish itself in the near future. Interest is growing, although still nascent, in reintroducing sea otters to Oregon. No official process has been initiated by environmental managers. Many unanswered questions remain before a productive discussion can take place on the advisability of a contemporary sea otter reintroduction in Oregon.

It is important to recognize that reintroductions are a conservation and management strategy to augment the recovery of endangered and threatened species (IUCN 1998). In the U.S., two out of the 5 federally recognized sea otter stocks (i.e. distinct populations) are listed as threatened under the Endangered Species Act (ESA). The IUCN Red List rates the global population of sea otters as endangered and declining (Doroff & Burdin 2015). Conservation and recovery continue to be a priority for the species. Yet, species reintroductions are inherently risky and involve several sources of uncertainty.

From an ecological perspective, the potential for species reestablishment – based on available habitat, or human interactions – is one source of uncertainty that must be addressed before any reintroduction plans are initiated (Seddon et al. 2007). Sea otters exist across a range of habitats (e.g. kelp forests, seagrass beds, outer coast, estuaries, etc.) (Laidre et al. 2009, Lafferty et al. 2014). They feed on more than 40 different prey species (Ostenfeld 1982), and require anywhere from 25% to 30% of their own body weight in food, on a daily basis (Costa 1978, Reidman & Estes 1990). With such high energy demands, identifying suitable habitat, which may provide adequate prey resources, is crucial to this reintroduction effort. Lack of habitat could result in an inability to effectively forage, and ultimately reduce the likelihood of reestablishment or even lead to extirpation of the reintroduced population.

Sea otters have been absent from Oregon for over 100 years (Jameson et al. 1982). Coastal human institutions and practices (e.g. fisheries, recreation, resource management) have developed~~,~~ and expanded during that time. On one hand, if sea otters are reintroduced, some of these activities could reduce reestablishment potential by reducing or making otter habitat inaccessible or unavailable. On the other hand, sea otters also have the potential to affect or influence human practices by changing the ecosystem or reducing prey (e.g. Dungeness crab and red sea urchins) populations, some of which are commercially and/or recreationally important to nearshore fisheries. Changes or impacts to any of these institutions could have implications for management.

Sentiment has been growing for a public discussion over the absence of sea otters in Oregon. The earlier attempts were made prior to the landmark environmental legislation of the 1970s: the Endangered Species Act (ESA), the Marine Mammals Protection Act (MMPA), and the National Environmental Policy Act (NEPA). Species translocations now go through a NEPA-mandated and publicly transparent process to evaluate for a spectrum of factors in the affected coupled natural-human system (CNH). Oregon has since developed land-use planning goals, including Goal 19: Ocean Resources. Much as Oregon's marine reserves were sited with local involvement, the locations and magnitude of any potential sea otter relocation will generate intense public input.

How we choose a source population reveals our true goal. Do we simply restore the species to its former range as a coarse fulfillment of the MMPA? Then the relatively abundant southeastern Alaskan stock of the northern subspecies is the source of convenience. People may advocate instead for the southern subspecies. Populations of this Californian sea otter currently have limited resilience in the face of pollution and other persistent threats. Establishing an "outgroup" in Oregon would provide redundancy in a system that must not fail. We argue instead that the focus on the populations that carry the alleles most adaptive to the Oregon nearshore environment and fulfills the MMPA's more nuanced concern for the marine mammal stock once extant in the area. Surprisingly, despite the regional extirpation of the sea otter, we may be able to answer the question of what subspecies or combination thereof once populated the Oregon nearshore by studying the ancient DNA in sea otter remains left to us by First Nations people.

Members of introduced species have been deliberately targeted and killed in a number of instances, suggesting that as species' welfare depends on community tolerance and prevailing values and attitudes (Reading et al. 1991). Many species translocations fail (Griffith et al. 1989), and because of the complexity inherent to reintroductions, greater integration of different disciplines and types of knowledge will likely improve reintroduction outcomes (Reading et al. 1991). It is important that policymakers and wildlife managers understand stakeholder attitudes and dynamics, as it allows them to tailor appropriate communication strategies and informs participatory approaches, increasing the likelihood of a successful reintroduction. Additionally, stakeholder attitudes and dynamics could indicate a reintroduction might be inappropriate or politically dubious.

The inclusivity of reintroduction decision-making processes can also affect outcomes. For example, the US Fish and Wildlife Service attempted to reintroduce grizzly bears to the Bitteroot Ecosystem on the Idaho/Montana border in the mid-1990s, and despite enjoying widespread public support, the reintroduction was not realized (Smith 2003). This failure may have been partly attributable to the omission of key stakeholders from reintroduction decision-making processes. Fostering dialogue that potentially builds trust and understanding between potentially adversarial stakeholders may mitigate conflict and nurture compromise (Opotow & Brook 2003), as well as create more social sustainability if and when a translocation occurs. Having insight into stakeholder attitudes and points of commonality and divergence between relevant groups is important in reintroduction decision making. Elucidating select preferences and perceptions among stakeholders, could provide insight to policymakers navigating sea otter reintroduction decisions in Oregon.

Sea otter reintroduction to Oregon is an apt issue to address through a coupled human and natural systems lens due to the many interactions between natural and social factors that are best analyzed and addressed collectively. The dynamic nature of these social-ecological interactions introduces a high degree of uncertainty around how either system may respond to a sea otter reintroduction, as well as the associated risks (e.g., species extinction, effects to fisheries, unfavorable habitat alterations). Numerous factors, across disciplines, must be addressed before managers can decide whether to proceed with a reintroduction.

Study objectives

The objective of this study is to assess various ecological, genetic, demographic, and social factors to investigate the feasibility and suitability of a sea otter reintroduction to Oregon. To accomplish this goal, we will complete the following tasks:

1. Synthesize relevant literature to examine the rationale and motivations of translocations. Demonstrate the relevance and importance of incorporating genetic considerations into the reintroduction process. Examine the state of genetic research into the pre-fur trade Oregon sea otter.
2. Assess the potential for sea otters to reestablish in Oregon by identifying suitable habitat, and relating to a range of human activities that may influence reestablishment potential;
3. Conduct a preliminary population viability analysis to assess the likelihood of reintroduction success based on population demographic indices; and
4. Collect information on key stakeholder groups' level of support or opposition for sea otter reintroduction in Oregon, their perceptions of positive and negative outcomes of a potential reintroduction, and their support or opposition for specific Oregon coastal locations containing sea otters.

Lastly, to adequately address this issue through a coupled natural-human lens, we integrate and compare our disciplinary findings across localized geographic areas, and qualitatively assess and discuss the potential feasibility and suitability of a sea otter reintroduction at these finer spatial scales. These results could better inform a sea otter reintroduction by investigating how these various factors, across disciplines, could be used together in determining whether to proceed with a reintroduction effort.

STUDY AREA

The state of Oregon is located on the U.S. West Coast, on the North Pacific Ocean. Its coastline stretches north to south from the Columbia River to the Oregon-California state border (~ 584 km). It is characterized by temperate climates with seasonal fluctuations in wind direction, wave intensity, and upwelling regimes (Huyer & Smith 1978). The shoreline is comprised of alternating stretches of sandy beaches and rocky, complex geologic features (e.g. coves, inlets, cliffs), as well as bays and estuaries. The relatively narrow continental shelf extends offshore 75-135 km and is comprised of hard-to-soft substrates (Kulm & Fowler 1974). Many coastal communities exist along the Oregon coast, supporting approximately 65,311 people. Most people live along the central and northern coast, with only 13% along the southern coast of Coos and Curry counties (State of Oregon 2012).

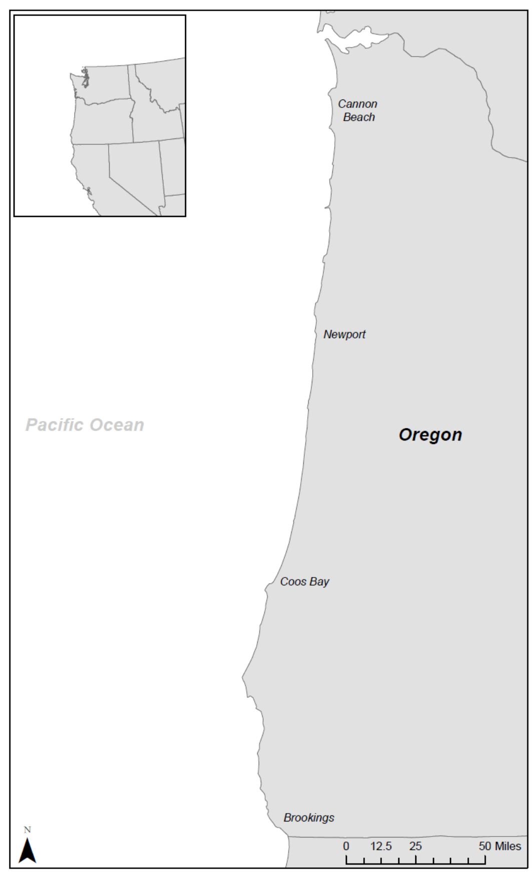


Figure 1: Our study area - The Oregon coast.

These communities rely on a range of coastal activities and economies, including fishing, recreation, tourism, and shipping. These areas are also used for scientific research and conservation, and feature several protected areas. We define our study area as the entire Oregon nearshore from the 0 m to the 60 m isobaths; corresponding to the common maximum diving capacity of sea otters (Bodkin et al. 2004).

THE COLLABORATIVE PROCESS

In-person meetings

Our team met on a weekly basis to develop project ideas, share data, and discuss research progress. These meetings initially focused on getting to know each other and our respective expertise, as well as proposing and discussing research ideas, questions, and how best to integrate our interdisciplinary chapters. As the year progressed, these meetings evolved into more-targeted dialogues on methods, data collection and synthesis, and end products – all with a focus on integration. With only three members in our team, meetings were highly collaborative and each member had adequate opportunities to provide input and feedback. Our team held meetings with the entire cluster each, where the team provided updates and advisors provided guidance and support on experimental design and execution. Importantly, we engaged with federal resources managers and environmental non-profits to gain a better understanding of the overall reintroduction process and stakeholder interests. This input was vital to understanding how our research informs the broader reintroduction discussion.

Expertise identification

Our team is comprised of one social scientist, with experience in public policy, and two ecologists, one focusing on fisheries and genetics and the other in community ecology and natural resource management. Before identifying our individual skills, we discussed why we were involved in the NRT program, our interests in this issue, and the questions we were most interested in investigating. We each presented our individual theses to one another. This initiated several discussions on what skills we currently had or planned to acquire through our research, and how we could put those skills to use in the NRT project. These discussions allowed us to become familiar with one another and what we wanted to contribute to this project. Once we had this understanding, we assessed how our skills and disciplines could be integrated into one project to effectively address this issue through a coupled natural-human lens.

Question identification

To determine our transdisciplinary question, we each presented ~~a list of~~ the questions we wanted to answer in our interdisciplinary chapters. We discussed the relevance – both societal and academic – of our proposed questions, how we might address those questions (i.e., methods), what data was available to conduct those analyses, and expected results. We repeatedly mixed and matched different combinations of questions – from each of our disciplines – to find commonalities and potential areas of integration. This was the most challenging step in our process. We were allowing our interdisciplinary questions to determine our overall transdisciplinary question. While this step took some time to complete, we feel it allowed us to better understand how our various analyses and data sources complemented one another. We took a broader look at the overall reintroduction process, and recognized - given the nascence of this effort - that managers were still looking for scientific input on the potential feasibility of this effort. Therefore, we focused our transdisciplinary question on synthesizing information to assess reintroduction feasibility and suitability.

Analyses

Each of our interdisciplinary analyses required some degree of individual research and work. Yet, our team made efforts to leverage each other's expertise in other disciplines to fine-tune and better-target our analyses, when possible. These types of collaborations included, but were not limited to, testing and discussing methodological or model assumptions, further developing research questions, collecting and sharing data, constructing surveys, and reaching out to external experts for additional input and feedback.

Our team updated and included each other in most step of our analyses so we could learn from one another and gain each other's perspectives. At the end of this process, each of our interdisciplinary chapters incorporate some amount of analysis, input, or feedback from one another.

METHODS

The rationale for reintroduction

We broadly survey the conservation literature on translocations to present the rationale for reintroduction. Population genetics also informs translocations. Accounts of past reintroduction efforts, especially that of predators, are surprisingly common.

The precontact Oregon sea otter

To demonstrate the importance and need of incorporating genetic considerations into the reintroduction process, we search the literature to obtain information on the genetic makeup of pre-fur trade sea otter populations, as well as incorporate archaeological findings as further evidence to prove their nativity.

Genetics

Literature searches in sea otter genetics do well to start with the book Sea Otter Conservation (Larson et al., eds. 2015). Information on sea otter genomics was obtained at Genbank, the National Institute of Health's genetic sequence database. We collected background materials from two recent workshops: 2018 Elahka Alliance Symposium at Newport Oregon USA, with videos available, and 2019 Sea Otter Conservation Workshop at the Seattle Aquarium (Washington USA). We obtained taxonomic information from the Integrated Taxonomic Information System (itis.gov). Statistical analyses were conducted in R 3.6.1 (R core Team 2019). Least cost distance analyses were made in marmap (Pante & Simon-Bouhet 2013) for the purposes of modelling sea otter movement. Bathymetries for the above were built from the ETOPO1 Global Relief Model (NOAA National Centers for Environmental Information) in a 4 arc-minute grid. Data exploration involved the packages ggplot2 (Wickham 2016) and GGally (Schloerke et al. 2018).

Archaeology

We focus on coastal Native American archaeological sites with confirmed faunal contents, but maintain a more comprehensive set in the event that some prove useful to zooarchaeology. Prehistoric site surveys are inevitably a convenience sample, with the research here intentionally restricted to sources such that are readily accessible to researchers outside of the archaeological discipline's channels. Much of the primary sources would otherwise have to come from the "gray literature" that Hall (2009) and Lyman (2011) describe as unpublished or poorly archived. With the exception of Minor 1985, sources are summaries, surveys of sites, not primary accounts. All cited publications can be downloaded or accessed in university libraries. In the literature, sites are identified by a three-part designation: "35" for the state of Oregon, a two- or three-letter abbreviation for the county, and a final set of digits reflecting the order in which the site, prehistoric or historic, was assigned a number by the Oregon State Historic Preservation Office. The Cape Creek Shell Midden is, then, 35LNC27 and located in Lincoln County. Sites are compiled and sources given in Appendix 8. We follow best practices in only vaguely specifying site locations in order to preserve them despite problematic artifact-hunting. The Native American Archeological Sites of the Oregon Coast Multiple Property Submission to the National Register of Historic Places (NPS 2017) has extensive coverage if scant detail. Hall (2009) inventories many faunal sites and in various unpublished products (e.g. 2018) has made sea otter-specific compilations. Substantive coverage of coastal First Nations sites with sources referenced can be found in Aikens et al. (2011).

Reestablishment potential

To understand the potential for sea otters to reestablish in Oregon, we first predicted and related potential sea otter habitat to a range of human activities that may influence reestablishment potential.

Carrying capacity predictions

We adapted and applied a recently-developed Bayesian state-space habitat model (CA model) (Tinker et al. 2019, in prep) to predict sea otter densities and total abundance at carrying capacity in Oregon. The CA model estimates the functional relationship (parameters) between equilibrium otter densities and a suite of habitat features and environmental variables (habitat variables) between the 0m and 60m isobaths. Habitat variables include benthic sediment (hard or soft), depth, distance-to-shore, seafloor slope, kelp, estuaries, and net primary production (NPP). We followed the methods developed in Tinker et al. 2019 (in prep), where further details can be found. Details on the parameters and how they were estimated are in Appendix 2. Information on where and how each of the Oregon habitat variables were collected and/or calculated are in Appendices 3 & 4. To calculate predicted otter densities (otters/km^2) at carrying capacity along the outer coast, we applied each parameter from the CA model to the Oregon habitat variables, within a 100m grid, using the following equation:

$$\log(K_g') = \kappa_s + \alpha_j H_{j,g} + f(D_g \mid \beta_i, D^*) + \zeta_{g|p}$$

Each 100m grid cell (g) within the study area was assigned a predicted sea otter density at carrying capacity (K_g), which is a function of the mean log density of sea otters in soft sediment habitat (intercept K_S), the suite of habitat variables ($H_{j,g}$), a non-linear depth function (third term), and environmental stochasticity (4th term). Further details on each of these terms and how they were calculated are in Appendix 5. For estuaries, we calculated total abundance by applying a uniform ~3.7 otters/km^2 density parameter (i.e. average otter densities in Elkhorn Slough, CA) to all estuaries. We summed the predicted abundances for all estuaries, and combined with the outer coast to determine total predicted abundance of sea otters at carrying capacity in all of Oregon.

Suitable habitat identification

We identified suitable habitat based on predicted otter densities and distance. The non-linear relationship between otter densities and depth means cells beyond the 40m isobath will be assigned relatively lower densities, producing right-skewed data. To correct this, we log-transformed the predicted densities to obtain a normal distribution. We extracted any density within the top two standard deviations, and applied a distance threshold where remaining pixels within 2 km (daily dispersal of sea otters) were combined to represent a single suitable habitat area.

Zonal Approach

To assess the interaction between suitable habitat and human activities at a finer spatial scale, we defined geographically distinct potential reintroduction sites (zones), spanning the entire outer coast. Zone boundaries were created around distinct suitable habitat areas - some zones did not have suitable habitat – and further adjusted around marine reserves. We created zones around estuaries with total predicted abundances > 60 otters (Coos Bay, Yaquina Bay, Umpqua river, and Tillamook Bay). To incorporate habitat quality considerations, we calculated the average predicted otter density for each zone, as higher densities signal higher quality habitat, which could increase reestablishment potential. For estuaries, we originally applied a uniform ~3.7 otters/km^2 density parameter. This creates relatively high densities within estuaries, de-emphasizing the importance of outer coast areas, which researchers suspect are preferential otter habitat. We halved the estuary densities to make the coast and estuaries comparable.

Human activities

For human activities, we estimated (1) the level of human accessibility, (2) potential for interactions between sea otters and fisheries, and (3) protection for sea otters within protected areas, for each zone.

We used two factors to determine accessibility: coastal viewing and vessel travel distance. We assessed accessibility as this could facilitate effective research and monitoring by scientists and managers, potentially increasing reestablishment potential. We acknowledge it also indicates a level of potential disturbance from recreationalists, decreasing reestablishment potential. Viewpoint accessibility was estimated as the average number of viewing points per kilometer of coastline, while vessel accessibility was defined as the travel distance between large ports and suitable habitat. We assessed potential interactions with fisheries as fishing activity could also be a potential source of disturbance, but also create competition with fishermen that harvest otter prey species. We spatially-related important commercial Dungeness crab fishing grounds to suitable habitat to identify areas that present potential for interaction. We chose the commercial crab fishery as it is the most lucrative commercial fishery along the Oregon coast (Davis et al. 2017), and therefore, may be disproportionately important to coastal community economies. Important commercial crabbing grounds were identified through interviews with fishermen where they were asked to identify where their crabbing grounds were located and the value attributed to them (Hesselgrave et al. 2011). Responses were spatially joined and the top 75%, 50%, 25%, and 10% most important grounds identified. We quantified the total abundance of sea otters within suitable habitat predicted to overlap with each of these important percent bands. Lastly, we assessed the level of protection of sea otters within protected areas, as these areas could prevent or limit disturbance, and increase reestablishment potential. We included all 5 marine reserves (Redfish Rocks, Cape Perpetua, Cape Falcon, Cascade Head, and Otter Rock) and the Oregon National Wildlife Refuge on the outer coast, and the South Slough National Estuarine Research Reserve in Coos Bay. We estimated protection as (1) total otter abundance within protected areas and (2) total otter abundance in suitable habitat within protected areas. Details on the data layers and analyses for each factor are in Appendix 6.

Modelling sea otter population growth

Input into the model comes from Kevin Shoemaker (UN Reno). We employ a density-dependent growth model of annual time-steps with allowances of stochasticity appropriate for small populations. This model projects sea otter population growth as a result of a reintroduction to Oregon. In the simplest form of the Ricker (1954) model of $N_{t+1} = \lambda \cdot N_t \, \square \, (1 - N_t / K)$, next year's population N_{t+1} is the present N_t multiplied by the annual per capita growth rate λ. The density effect increases as N_t approaches K. For mean λ, we use the 1.145 for a rapidly-growing population from Bodkin & Ballachey (2010). Environmental stochasticity is incorporated by drawing variances of λ in iterative calculations of N_{t+1} from a normal distribution of mean λ and standard deviation 0.1. Further, we anticipate the potential for catastrophic setbacks for a sea otter population: severe El Nino, toxic algal blooms, etc. A probability of 0.07 is drawn from a uniform distribution with a consequent 20% setback to the population for each occurrence. While Bodkin & Ballachey applied their rates to populations as a whole, we use it with the carrying capacity K within each zone, exclusive of juveniles and pups.

Population projections for zones are compared irrespective of zonal area. There is co-variation of K and area ($F_{1,23} = 4.67$, $p = 0.0417$) but an R^2 of 0.168 suggests that it is not the predominant factor. We take the point of view that the zones each have a centroid of high quality habitat surrounded by sharply decreasing foraging potential and minimal sea otter occupancy. We end the projection at 7 years as eventual otter dispersal means that the utility of the simple model must give way to a meta-population model. A starting population of 20 sea otters might require some 35 to be introduced, allowing for initial emigration and mortality. Augmentation of the reintroduction with 4 individuals each year might come in part from immigrants from the Washington population. The model was replicated 1000 times for each zone.

Preferences and Perceptions

In light of social dimensions' importance in species reintroduction success (Serfass et al. 2014; Worthington et al. 2010; Reading & Kellert 1993), we elucidated attitudes, risk perceptions, and policy preferences on this issue among select stakeholders. Furthermore, we assessed subjective preferences for sea otter reintroduction at specific sites and geographic locations within our study area. To assess these social factors, we distributed an online survey using Qualtrics to select stakeholder groups with an interest in a potential sea otter reintroduction in Oregon. Stakeholder perceptions and preferences are important factors in species reintroduction and wildlife management generally, particularly with the growth of ecosystem-based management and collaborative governance approaches.

A purposive sampling approach was used in drawing the sample, the goal being to include a diversity of likely Oregon sea otter reintroduction policy actors who are issue stakeholders. The sample included board members of the Elakha Alliance (Alliance) – an Oregon-based sea otter reintroduction advocacy organization – as well as a selection of attendees at a sea otter reintroduction symposium that the Alliance hosted in October 2018. Attendees were principally associated with Oregon environmental interest groups and conservation organizations (e.g. the Oregon Zoo). Although a number of state and federal resource managers, researchers, and Oregon state politicians were in attendance, we did not include them in the sample. Select staff from other environmental advocacy groups that have prioritized this issue were also included in the sample, as were staff from Pacific Northwest shellfish advocacy and research organizations. The sample included voting board members of Oregon's Ocean Policy Advisory Council, which is comprised of various members of marine stakeholder groups and advises the Oregon Governor's office, state agencies, and local governments on marine policy issues, as well as commissioners for Oregon's Department of Fish and Wildlife Commission, the Oregon Trawl Commission, the Oregon Salmon Commission, and the Oregon Dungeness Crab Commission.

The survey response rate was 36% (28/78). We employed a snowball sampling approach and provided respondents the opportunity to invite others, via email, they believed had an interest in marine or fish and wildlife issues to participate (n = 21). It should be noted that the survey sample was comprised of a limited number of groups and thus is not comprehensive with respect to all stakeholders with potential vested interests in a sea otter reintroduction. However, survey respondents are in positions of leadership within their respective stakeholder groups and coalitions and potentially poised to influence the opinions of not only members of their own groups, but also the media and the general public, both of which are important forces for potentially shaping reintroduction policy decisions (McBeth & Shanahan 2004; Shanahan et al. 2008). Another limitation of the survey sampling approach is its non-representativeness, as we did not employ probability sampling. Though we strategically identified leaders who may play a role in sea otter reintroduction dialogues and policy activities, the opinions of these individuals cannot necessarily be generalized to represent those of their entire stakeholder group. Hence our focus on descriptive statistics.

Respondents were asked to self-identify as members of a list of sea otter reintroduction stakeholder groups (Table 1). Respondents were able to select more than one stakeholder group, if applicable. It should be noted that although data collection is continuing, at the time of writing, certain stakeholder groups were more heavily represented within the dataset than others. Thus, we recommend being mindful of the sample's stakeholder group affiliations and potential values and biases when interpreting results.

Table 1: Stakeholder Affiliations of Respondents

Stakeholder affiliation	% of sample
Commercial fisher	14%
Recreational fisher	41%
Native American tribe	6%
Scientist	25%
Local government	16%
State government	8%
Federal government	4%
Environmental group	55%
Charter boat or tour operator	4%
Coastal recreationalist	57%
Oregon coastal resident	53%
Oregon non-coastal resident	31%

Despite the survey's limitations, the respondents' perceptions and preferences are still insightful considering the positions of influence that they occupy. Furthermore, it should be recognized that this is an initial effort at capturing the perceptions and preferences of sea otter policy actors. This data can inform future research related to Oregon sea otter reintroduction that involves larger sample sizes and may substantiate or counter these preliminary findings.

Measures

Respondents were queried about the potential positive and negative outcomes they associated with a successful Oregon sea otter reintroduction, which are factors in determining wildlife policy support (Slagle et al., 2012; Stankey & Shindler, 2006). They were asked to indicate if they associated any negative outcomes as well as any positive outcomes with successful sea otter reintroduction in Oregon, and if they did, they were given the opportunity to describe open-endedly up to 6 negative and positive outcomes, respectively. The importance and certainty of these outcomes were assessed using unipolar response items (*not important at all* [1] to *extremely important* [5]) and (*not certain at all* [1] to *extremely certain* [5]), respectively. Policy support for sea otter reintroduction to Oregon was evaluated using a bipolar response item (*strongly oppose* [1] to *strongly support* [5]), and respondents also had an opportunity to indicate if they were unsure.

Preferences towards potential sea otter reintroduction locations were measured using a series of bipolar response items (*strongly oppose* [1] to *strongly support* [6]) in relation to zones comprising the Oregon coast; respondents also had an opportunity to indicate if they had no preference. The following is an excerpt of the language used to explain the exercise, "We would like you to rate each segment based on your opposition or support for that location containing a potential sea otter reintroduction site. Please consider the ways in which you and stakeholders similar to you use and value different areas along the coast to inform your ratings. It should be noted that actual reintroduction sites are likely to be substantially smaller in area than the coastal segments presented here. Therefore, these segments represent general locations where sea otters may occur if a reintroduction is pursued." Potential reintroduction site choices within the survey were derived from the carrying capacity and habitat suitability model, with the goal of comparing these subjective preferences to the rest of our ecological and demographic factors within each zone.

Integration
We investigated reintroduction feasibility and suitability by comparing all factors (i.e., otter densities, fisheries overlap, protected areas, accessibility, population growth, and levels of support or opposition) for each zone. Ecological and demographic factors are regularly used in reintroduction feasibility studies (Seddon et al. 2007). To better incorporate social considerations and address this issue through a coupled natural-human lens, we ranked zones based on their mean level of support among respondents, and compared factors across the 5 highest (i.e. relatively more support) and lowest (relatively less support) zones. We also selected a few zones based on disagreements in factors. Lastly, we selected several potential outcomes reported by survey respondents on this issue, and use these responses to drive our discussion on the perceived risks and benefits our analyses can address, and if not, we note the remaining sources of uncertainty.

RESULTS

Reintroduction rationale and historical justification

Why translocate
The International Union of Concerned Scientists defines translocations as "the movement of living organisms from one area with free release into another" (IUCN 1998). *Augmentation* supplements an existing population, *introduction* places organisms outside of its historic range, and *reintroduction* returns a species or stock to that part of its historic range from which it has been extirpated. Weeks et al. (2011) delve into the motivations for a translocation. Conservation translocations are species-specific in their focus, creating or maintaining populations with persistence and abundance in numbers. Ecological restorations intend to promote an increased biodiversity of indigenous species. Suggested benefits of sea otter reintroduction have touched on both rationales. Thus far, sea otter conservation has been the dominant theme in reintroduction discussions, and ecological restoration has been a supporting argument.

<u>Conservation translocations</u>
Conservation translocations are inevitably motivated by the desire to augment species recovery. But the genetic motivations behind translocation efforts and their genetic risk implications are less well-defined. *Genetic capture*, a term introduced by Weeks et al. (2011), can capture the majority of a source population's genetic variation and take advantage of a reintroduction site's abundant resources to grow the population's effective size, its breeding population, to over 1000. At this point in population growth, most genetic variation is preserved and continue to be maintained. The rationale is applicable when source populations are highly constrained and suffering from genetic load. These are deleterious mutations owing to cases of too small effective population sizes, likely when the source is a small captive colony. This was the case with California Condors in 1991 (Roach and Patel 2019). Both *genetic rescue* and *genetic restoration* (Hedrick 2005) assume there is a recipient population suffering from inbreeding depression, but with locally adaptive alleles (genic varieties) to be preserved. Excess augmentation, on the other hand, would dilute locally-adaptive alleles. These conservation measures have short to medium timeframes and are applicable when saving an existing population is paramount.

<u>Ecological restorations</u>
Ecological restorations, by contrast, have an underlying motivation of *genetic adaptation* (Broadhurst et al. 2008). Even when a small recipient population persists in an environment, its genetic variability may be limited, and the attempt to recruit from it exclusively may further depress its viability. Rather, the focus is on bringing in high-quality stock that will generate genetic diversity, some of which will prove adaptive to the local environment. This approach is well-suited for keystone species that have the potential to dramatically enhance local ecosystems. Timeframes are necessarily greater in scope with this

strategy, with long-term persistence the goal. The 25-year window that Alaskan sea otter recovery plans (USFWS 2013) employ in determining listing status are appropriate.

The Oregon sea otter

To what subspecies (ssp.) did the Oregon sea otter belong? The southern ssp. continues to recover in California, and the northern ssp. is reestablished as far south as Washington. Oregon may have been a hybrid zone between the two, or one ssp. may have dominated. The constellation of recognized ssp. is expanded to the west by the Asian sea otter (*Enhydra lutris lutris*), ranging from the Kuril Islands north of Japan to the Commander Islands in the northwestern Pacific Ocean. Public policy considerations factor into both the taking of sea otters from the source population and the status of the reintroduced population. Choosing the appropriate source population may supply the founding population with genetics more adapted to the Oregon marine environment. In the face of criticism from stakeholders inclined to oppose reintroduction efforts, aligning the genetics of the source population(s) to that once native to Oregon is more scientifically defensible. We examine three studies that have variously proposed an affiliation of the Oregon sea otter with the ssp. to the south and the ssp. to the north.

<u>Taxonomy by morphometrics</u>

Taxonomists have employed traditional techniques, especially skull measurements, to distinguish sea otter ssp. since Linnaeus first described the nominate Asian sea otter (*Enhydra lutris lutris*) in 1758 (itis.gov). Merriam described the southern sea otter (*Enhydra lutris nereis*) in 1902. Only in 1991 was the northern sea otter (*Enhydra lutris kenyoni*) given ssp. status by Wilson et al. (1991), again on the basis of morphometrics. He ascribed to the northern sea otter the contemporary range of the Aleutian Islands southward to the state of Washington.

The position of the Oregon sea otter along a gradation of sea otter morphological features along the eastern Pacific coast has invited investigation. But with no extant sea otters in Oregon, researchers can only turn to archaeological artifacts for inference. Lyman (1988) measured teeth from prehistoric Oregon (n = ~13) samples with those of historic Californian (n = ~10) and Alaskan (n = ~20) samples and analyzed results with student's t-tests.

He found the lower M1 (molar) width comparison significantly different for California:Alaska (t_{30} = 2.486, $P < 0.01$) and Oregon:Alaska (t_{33} = 1.791, $P < 0.05$) but not California:Oregon. Lyman judged differences for the upper M1 significant for California:Alaska (t_{28} = 3.391, $P < 0.005$) and Oregon:Alaska (t_{32} = 2.478, $P < 0.02$). Again, California:Washington are not significantly different. For the upper P4 (premolar), the same pattern holds: California:Alaska (t_{25} = 1.955, $P < 0.05$) and Oregon:Alaska (t_{24} = 1.897, $P < 0.05$) are significantly different, but not California:Oregon. The lower P4 measurements were commensurate throughout the region. The inference is that the Oregon sea otter largely aligned with the southern ssp., but shared some characteristics in common with the northern ssp.

Unfortunately, these statistical analyses are problematic. The heteroscedacity (unequal variance) among groups precludes the student's t-test for at least one of the comparisons. We set this issue aside and used tables (Zar 2010), as Lyman would have, to check p-values. Though an unusual approach, it appears that Lyman employed one-tailed tests in all cases but for the one case that was unequivocally significant (C:A, upper M1). There is some suggestion in the text that one-tailed tests were the intention. Roest (1973) had found Alaskan sea otter teeth to be larger than Californian teeth, and so an eastward, then southward, gradation in size could be argued. For just the change in analysis of going to two tails, all upper P4 and the Oregon:Alaskan lower M1 significance would be lost. More importantly, given the multiple comparisons made between groups, a Bonferroni or other adjustment is appropriate. Reducing alpha to 0.0167 would lose half of the 6 significant findings. Applying both conditions, exclusive of heteroscedacity concerns, would leave just the one comparison intact. We find that no real inference as to the relation of the Oregon sea otter to the southern ssp. can be made from the Lyman analysis of these data.

The beginning of genetic phylogeny: allozymes and the challenge of statistical power

Phylogenetic questions, here the taxonomic status of putative ssp., can also be addressed using genetics. With both systematic zoology and genetics, the power of inference is limited by sample size. The number of specimens to be included should be part of an *a priori* assessment of statistical power. For genetics, the number of loci, or markers, along the genome is key to power as well. In systematic zoology, power can similarly be increased. Building on Lyman's morphometrics, Wellman (2018) is increasing both sample size and incorporating humeri and femora measurements. Molecular work in sea otters has been a story of the limitations of successive generations of genetic markers as much as it has been the story of our understanding of population structure in sea otters. In 1966, Lewontin and Hubby revolutionized population genetics by showing variation across dozens of loci in enzymes for the fruit fly *Drosophila pseudoobscura*. Numerous phylogenetic studies in the 1990s employed allozymes in testing for population structure in contemporary sea otter populations. Findings trended toward concluding a lack of genetic diversity, let alone structuring, in the meta-population across the sea otter's range. Lidicker and McCollum (1997) showed no geographic clustering in the variation of the 5 loci with polymorphisms of the thirty that they studied. Given the pervasive lack of variance, though, the findings of no genetic basis for ssp. distinctions could as well be a false negative as they could be a true negative.

RFLP: first use of DNA

Genetic investigations using DNA began with the use of restriction enzymes, "cutters" of DNA strands, in the early technique of random fragment length polymorphism (RFLP). Sea otter work was done on mitochondrial DNA, a different set of DNA instructions from that contained in (nuclear) genomic DNA. The sea otter mitochondrial genome is 16,431 bp (base pairs) long versus the 2.4 giga-bp (Gbp) of (nuclear) genomic sea otter DNA (ncbi.nlm.nih.gov). During the same period as allozyme studies were underway, these RLPF studies, such as in Cronin et al. (1996), began what will become a familiar pattern of contradicting prior work: their findings supported the ssp. designations of Wilson et al. in contraposition to the allozyme studies.

Taxonomy matters

Sea otter phylogenetic studies matter for conservation biology and wildlife management. For vertebrates, the ESA's definition of species for potential listings can extend to the subspecies level. or Distinct Population Segments. The Marine Mammal Commission and, at times, the Fish and Wildlife Service (USFWS) characterize marine mammals as *stocks*, an MMPA term. Gorbics and Bodkin (2001), among others, developed the case for defining three Alaskan sea otter stocks, based on geographical distributions, phenotypes, and genetic data (primarily mitochondrial). They espoused a definition of stocks to include a degree of divergent allelic frequencies, reflecting some level of genetic isolation. Of these now-designated stocks, the southwestern Alaskan stock is listed under the ESA as Threatened.

Microsatellites as genetic markers

Variation at genetic markers is most frequently assumed to be neutral in effect. They indicate, by proxy, adaptive variation within genic regions. In small, isolated populations, allelic dropout is more likely to occur due to the stochastic effects of genetic drift and fewer recombinations. Deleterious mutations are more likely to become fixed. The affected populations will likely lose or lack sufficient adaptive variation with which to respond to changes in the environment. Thus, monitoring genetic diversity is a prime concern for conservation biologists. Microsatellites are short DNA repeats distributed broadly among genomic DNA, largely within selectively neutral regions. They become an important marker in measuring diversity. Larson et al. (2002) utilized primers developed for mustelids to collect genotypes at 6 microsatellite loci and developed a novel 7th microsatellite locus. Additionally, they found 4 genotypes within the control region of mitochondrial DNA. Given the primary goal of comparing genetic variability in translocated sea otter populations versus remnant populations, they found no evidence of reduced genetic diversity, but significant heterogeneity among populations.

Genetics and the Oregon sea otter

Much of the conservation genetics work on sea otters focuses on the status of genetic diversity among contemporary populations and comparisons to pre-fur trade populations. Only limited research has addressed the taxonomic status of the Oregon sea otter. Valentine et al. (2008) began with the 4 mitochondrial genotypes developed by Larson et al. (2002). Valentine et al. extended the range of genotypes to pre-fur trade Oregon sea otters. First Nations peoples hunted along the margins of the eastern Pacific, discarding bones in shell middens. The alkalinity of the shells offsets the acidity of soils, even preserving DNA. Valentine et al. extracted ancient DNA (aDNA) from specimens taken from two archaeological sites for a sample size of 16 pre-harvest sea otters, (Figures 4B, C, below).

Combining the 135 samples of sea otter mitochondrial DNA (mtDNA) from Larson et al. (2002) with their 16 samples gave Valentine et al. 6 genotypes with which to postulate the ssp. status of the Oregon sea otter. Samples from Oregon sea otters (n = 11) matched the C genotype of southern sea otters. The A genotype (n = 2) occurs in lesser proportion in the southern sea otter but in greater proportion in northern sea otters. Two genotypes, W and X, were unique to Oregon. The genotypes distribute geographically in an intriguing manner (Figure 2). Valentine et al. report two G-tests for significance. They found no significant difference between Oregon and Californian populations (P = 0.6). The frequency of the C genotype for these two populations in comparison to the rest was found to be highly significant. They infer that the prehistoric Oregon sea otter shared characteristics with the northern ssp., but largely matched the southern ssp.

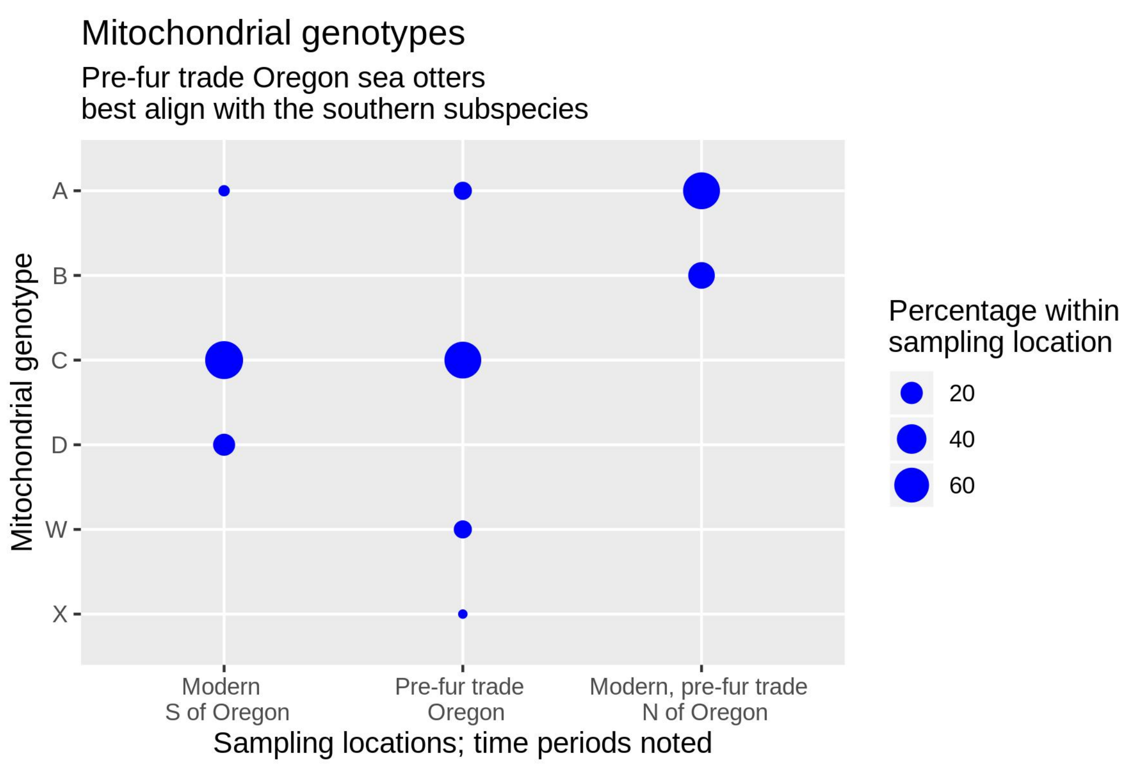


Figure 2: Genotypes from mitochondrial DNA were compared across three groups of sea otters. Modern Californian samples represent the southern ssp. Washington and Alaskan samples ancient and modern are pooled to compare to ancient Oregon.

Given the small sample sizes, Fisher's Exact Test is more conservative than the G-test applied in Valentine et al. In a test for differences between the contemporary southern ssp., precontact Oregon, and northern populations (Washington precontact and contemporary northern ssp. populations pooled), there is a highly significant difference ($P < 0.0005$, Markov simulation with 2000 replicates). We adjust alpha to 0.0167 for the multiple comparisons between groups. In pairwise tests, differences in modern southern ssp. versus old Oregon lacked significance ($P = 0.0279$), but old Oregon versus Washington and north is highly significant ($P < 5.5E-15$), even with the Bonferroni adjustment. Modern California versus Washington and north is also highly significant ($P = 3.01E-26$). We find the Valentine et al. statistical analysis to be reasonable. Still, these mtDNA findings have sampling shortcomings that limit support to the inference that the Oregon sea otter aligned to the southern ssp.

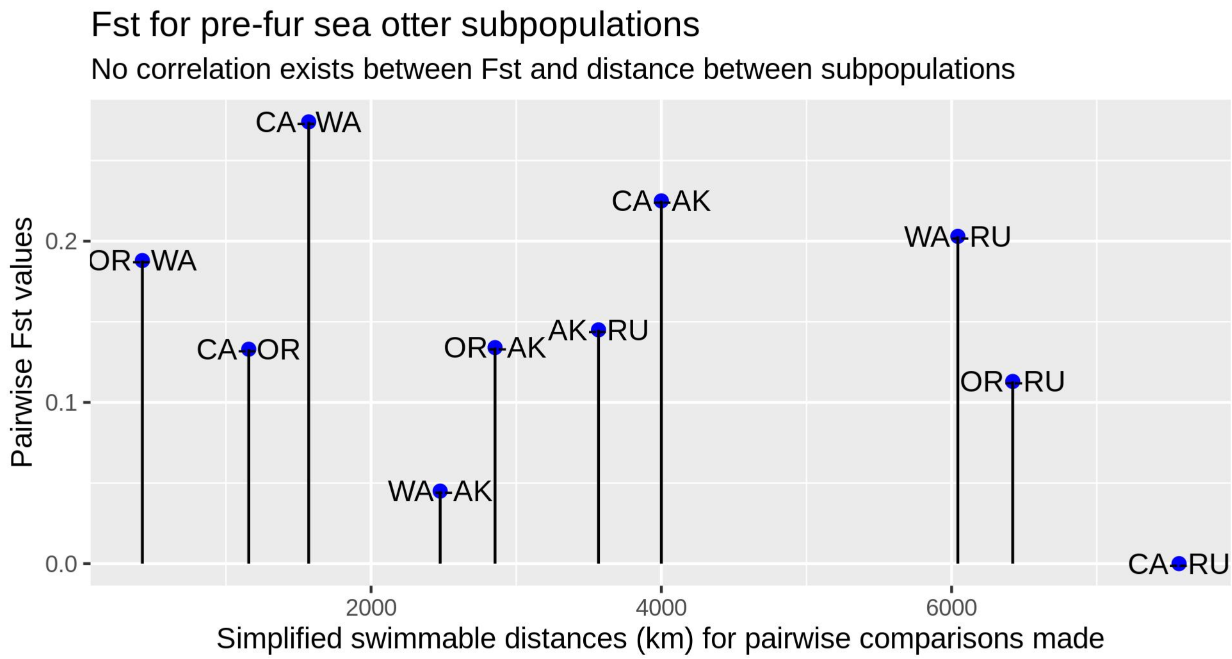
In a study more generally concerned with genetic diversity and population parameters for the species as a whole before the fur trade, Larson et al. (2012) employed 5 microsatellite loci in a study that drew on samples of 5 pre-fur trade populations and 5 contemporary populations. From Oregon, 40 samples in total came from 5 archaeological sites (Figures 5-6, below). In contrast to Valentine et al., Larson et al. concluded that the microsatellite loci of Oregon sea otters are most similar to those of pre-fur trade Washington samples. Finding the inferences from the genomic DNA at odds with Valentine's findings from (maternally inherited) mtDNA suggested to Larson et al. that pre-fur trade Oregon sea otter population genetics may reflect male northern sea otter input and a female southern sea otter component.

As above, the status of the Oregon sea otter among precontact sea otter populations was only one of the questions Larson et al. addressed in the 2012 paper and perhaps a minor objective at that. Two of the three metrics given for comparison are Fst and Nei's genetic distance. Most often given as differences in fixation among populations, Fst here is used as a pairwise comparison between subpopulations. Nei's genetic distance here reflects the degree of divergence between populations or the length of time since they shared a common ancestor.

While not a formal analysis, we can investigate what correlations can be made for the distances between populations and the metrics above. It would make intuitive sense that the further apart subpopulations are from each other, the greater the Fst and genetic distance might appear if those findings were to be useful. Sea otters would not travel in great circle fashion between populations. The requirement for frequent foraging keeps them in comparatively shallow depths. ATOS, or As-The-Otter-Swims, is a frequent metric used in sea otter literature (Tinker et al. 2008), referring to the non-linear path an otter might take along the coastline while still remaining within foraging depths. For our informal comparison, we greatly simplify this path and refer to it as “swimmable distance”. East and south of southwest Alaska, we only limit the traveling otter to the continental shelf (-500 m) more than -10 m offshore. Such passage would nonetheless be multi-generational. Going east to Russia, we give a still more simplified equivalent that allows for direct passage between the islands of the Aleutian chain.

While all pairwise Fst comparisons but CA:RU (California:Russia) were significant, in Figure 3A, we see no correlation between swimmable distances and Fst for the pairwise comparisons. Similarly, among Nei's genetic distance pairwise comparisons (Figure 3B), any correlation between pairwise distance and the values for genetic distance breaks down after OR:WA, CA:OR, and CA:WA. An additional Larson et al. (2012) analysis using the program STRUCTURE (Pritchard et al. 2000) grouped individuals into clusters, but the assigned groupings lack 16 of the 40 Oregon samples. In conclusion, we do not find the study’s conclusions regarding the Oregon sea otter as well-founded as one would wish for. At this point in time, there is not sufficient justification to assign the Oregon sea otter to the northern ssp.

A)



B)

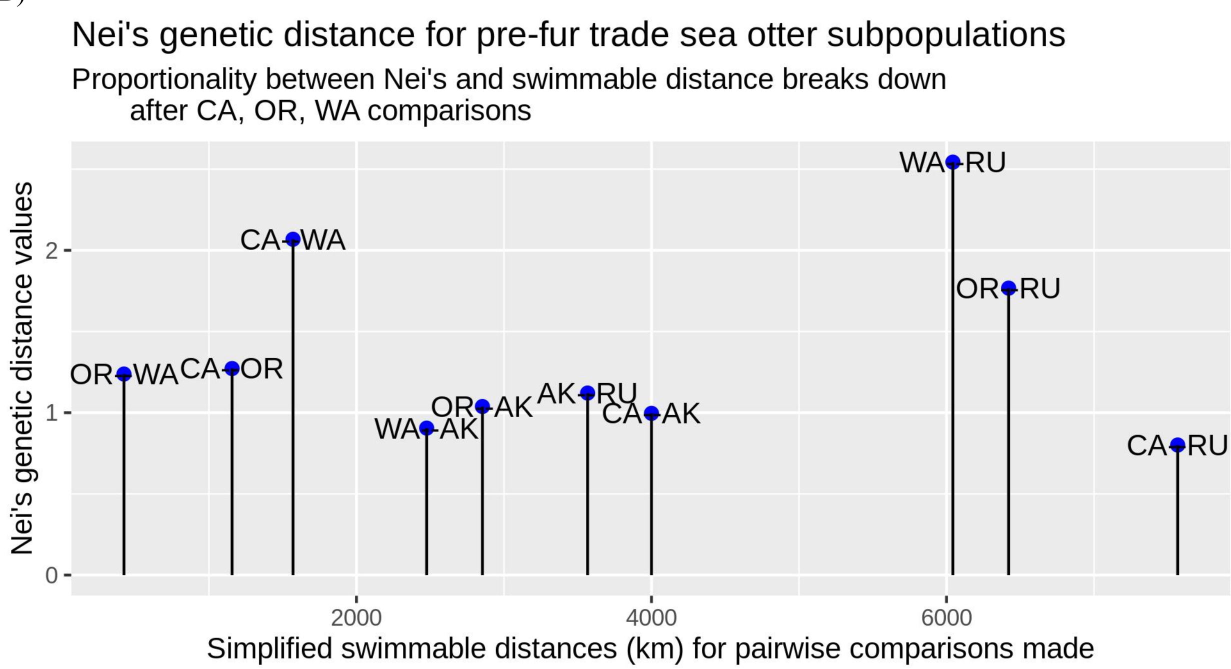


Figure 3: A) the values of pairwise Fst comparisons made among pre-fur trade sea otter populations are plotted against the swimmable distances between each population's geographic location. Swimmable distance refers to the less direct path that sea otters, largely limited to nearshore waters, might take between locations, albeit in a highly simplified manner. B) repeats the comparison to swimmable distance but with Nei's genetic distance.

Sea otter genomics

In hindsight, it is unfortunate that the greater sample size of Larson et al. 2012 was not leveraged to follow the mitochondrial approach of Valentine et al. Statistical power, again, is multifaceted. The microsatellites of Larson et al. are multi-allelic, yet only a few loci were employed. Valentine et al. worked with few samples and slight differences in a short mitochondrial sequence.

The genetics employed to date for sea otter phylogeny lack the statistical power that contemporary genetics have to offer. Loosely called "next-generation sequencing", the current trend in diverse fields of genetic study utilizes variation across the entire nuclear genome. With sea otters, we can gain access to the 2.4-Gbp genome versus the 320-bp mitochondrial segment of Valentine et al. Full genome sequencing is possible but overly ambitious for substantive population sampling, especially for aDNA samples. Many techniques (e.g., RADseq, Miller et al. 2007) instead employ reduced representation sequencing to make short reads across many sequence fragments, many of which are likely available among aDNA samples.

An annotated genome for the northern sea otter was published in 2017 (Jones et al.). "Elfin", the Vancouver Aquarium sea otter individual who contributed his genome, was born in 2002 near Juneau, Alaska. UCLA recently published the southern sea otter genome (Beichmann et al. 2019). "Gidget" was a foster mother and resident sea otter at the Monterey Bay aquarium. Both resources would be invaluable for aligning sequences generated by reduced representation sequencing.

Future paths in Oregon sea otter genetics

In researching the genetic position of precontact Oregon sea otters within the continuum of sea otter ssp., two approaches are possible. Genetic markers can be compared amongst pre-fur trade populations using aDNA. This approach requires the informed participation of West Coast tribes in several states. The Makah Tribe of the Olympic Peninsula, by way of example, curates the faunal remains from their ancestral village of Ozette. The approach would lead to a better understanding of pre-contact population genetics. If we wish for a genetic capture of the source population(s) that best represents the Oregon sea otter, we work instead with Oregon aDNA and tissue samples from potential source populations. Samples from contemporary southern and northern ssp. need to be compared to the Oregon samples taken from late Holocene strata of First Nations middens. The use of these Oregon artifacts highlights the potential for collaboration with tribes, pending their approval.

Reintroduction issues

Public concerns and perceptions factor into policy decisions. Public deliberations must accommodate the voices of diverse stakeholders.The National Environmental Policy Act (NEPA) requires federal agencies planning or funding actions to consider the possible environmental effects and posit alternatives to the proposed action (42 USC Chapter 55). Further, agencies must disclose these effects to the public and solicit the public's opinions on its assessments. To plan for a balanced, fair discussion on the issues surrounding a potential sea otter reintroduction, the lessons from prior reintroductions might be revisited.

Gray wolves: a reintroduction story

Eradicated from the western U.S. by 1930, *Canis lupus* was listed as Endangered in 1978 across the contiguous U.S. We focus here on its National Rocky Mountains (NRM) Distinct Population Segment (DPS). After the drafting of the 1980 NRM Wolf Recovery Plan, the NEPA-required Environmental Impact Statement was completed in 1994 for the reintroduction of wolves into Yellowstone National Park and central Idaho (USFWS 1994). Some 30 wolves from Alberta, Canada, were introduced into each location in 1995 and 1996. ESA protections were removed in 2017 for the Wyoming's ~25 breeding pairs (USFWS 2017), and Montana's 15 breeding pairs in 2011 (MFWP 2016). Wolves were not reintroduced into Oregon, but migrated here as the Idaho stock expanded. The NRM DPS, which includes the eastern third of Oregon and Washington, was delisted in 2011 (except Wyoming) as the result of a congressional budget rider. The listing under the ESA still applies to the western two-thirds of Oregon (USFWS 2019).

The viewpoint of Oregon ranchers in opposition to the gray wolf's protected status deserves special attention. Per the Integrated Taxonomic Information System as curated by the U.S. government, there are 38 recognized ssp. of *Canis lupus* worldwide (itis.gov). Going back to the 1994 EIS, USFWS acknowledges that early taxonomists working with limited samples called out 24 ssp. in North America. National Park policy states that they will strive to restore native species using that which most closely approximates the extirpated species. The 1978 ESA designation was for the species as a whole, and FWS set out that any past or present ssp. designation is irrelevant to wolf recovery efforts. Still, FWS had to address public comments that (1) reintroduced wolves would interfere with the natural recovery of remnant, native wolves (USFWS 1994: there are none), and (2) the genetic mixing of non-native stock with native stock is illegal and lacks scientific integrity (USFWS: there is currently no molecular basis for asserting more than one ssp. in northern North America).

The Oregon Cattlemen's Association has made attempts to undermine wolf recovery. A key argument they employ is that these "Canadian wolves" are non-native, and the public should be able to kill them without restriction. This line of reasoning surfaces in public comments on proposed policies and even in court briefs, as in the challenge to the state's delisting of wolves in its list of threatened and endangered species (Intervenor-Respondents Answer 2017). Willamette Weekly explored how deeply this line of reasoning runs. Are these wolves secretly Canadian? Are these wolves bigger, more predatory than the native wolves that were extirpated in Oregon? Some claim that Oregon wolves were merely the size of cocker spaniels (Green 2017).

The authors encountered this argument as NSF National Research Trainees when our cohort was on the Yaquina Bay (Oregon USA) commercial docks learning the perspective of artisanal fishermen. One such fisherman alleged that sea lions were "non-native", presumably since sea lions numbers have rebounded under the protection of the MMPA.

Should a stakeholder feel threatened—in their economic sense of security, in their sense of community, or in their life values—but lack reasoned arguments with which to counter the perceived threat, they may resort to employing logical fallacies in opposition to a change in the status quo. Much of the objection to gray wolf reintroduction in Idaho and Montana, and their protected status as they moved into Oregon, falls under this category. To counter in advance claims of non-native status for sea otters in Oregon, participants in the reintroduction discussion might be (a) advocating for research into the ssp. status of the Oregon sea otter using current genetic and archaeometric techniques and (b) broadening our collective knowledge of the history of sea otters in Oregon. Archaeological remains provide tangible evidence of the sea otter's part in the human-natural system prior to Russo-European exploitation. Aikens et al. (2011) and Hall (2018) are excellent beginning points for this line of research.

Zooarchaeological arguments, resources for sea otter reintroduction strategies

Shell middens

Native peoples have for millenia created distinctive and enduring landforms with accumulations of snail and bivalve (mussel, clam, oyster) shell in coastal, lacustrine, and riverine environments (Alvarez et al. 2010). These shell middens contain other artifacts of human activity, including faunal remains, tools, and debitage (byproducts of tool manufacture), often with remains of dwellings in close association. The 19th century Danish scientist Worsaae initiated the use of shell middens in interdisciplinary research investigating human-environment interaction. Zooarchaeologists exploit the long-term biological record available in middens to conjecture paleoecological trends. The presence/absence and Number of Identified Specimens (NISP) of remains in different strata can suggest changes in abundance and range. Prior to the 1980s, aquatic resource utilization was considered marginal as compared to terrestrial activities until the assumption was questioned by, among others, Quilter and Stocker (1983). Rick et al. (2009) showed that the Guadalupe fur seal, now largely limited to Baja California, was abundant in southern California well into the late Holocene. Sex and age differences between strata can indicate prehistoric rookeries no longer occupied. Investigation of faunal remains is not limited to aDNA and morphometrics. Sclerochronology, the analysis of periodic bone structure, has been applied to marine mammal teeth to determine the seasonality of human site occupation and resource utilization (Quitmyer 1997).

Oregon coastal archaeology

First Nations peoples flourished along the ribbon of land bordering the eastern Pacific coast. wherein the biotic richness of the nearshore environment could be accessed. Shell middens are distributed in Oregon. both temporally and spatially. Much of the earliest migration and habitation occurred along a shoreline now miles out to sea (Aikens et al. 2011). Terminal Pleistocene/early Holocene (13,000-7,500 YA) sites still extant on headlands have yielded few faunal remains. Middle Holocene (7,500-3,000 YA) faunal remains has been collected from at least 16 sites. For phylogenetic work into the relationships among West Coast sea otters in near-historic times, our primary interest lies in the settlements of the late Holocene (after 3,000 YA) marked by shell middens. Still, we include earlier sites as a future resource.

Sites include prehistoric lithic sites (quarries), petroglyphs, and fishing weirs. Most sites are nonetheless characterized by shell middens. Middens are associated with both permanent villages and seasonal camps, while the permanent settlements are indicated by the presence of housepits. Though vertebrate faunal remains co-occur with shells in middens, we only record documented sites. Of the 191 coastal archaeological sites which we record, 75 are known to have contained faunal remains. At least 21 have sea otter remains. Further investigation at known faunal sites may well increase the number of sites with sea otter artifacts.

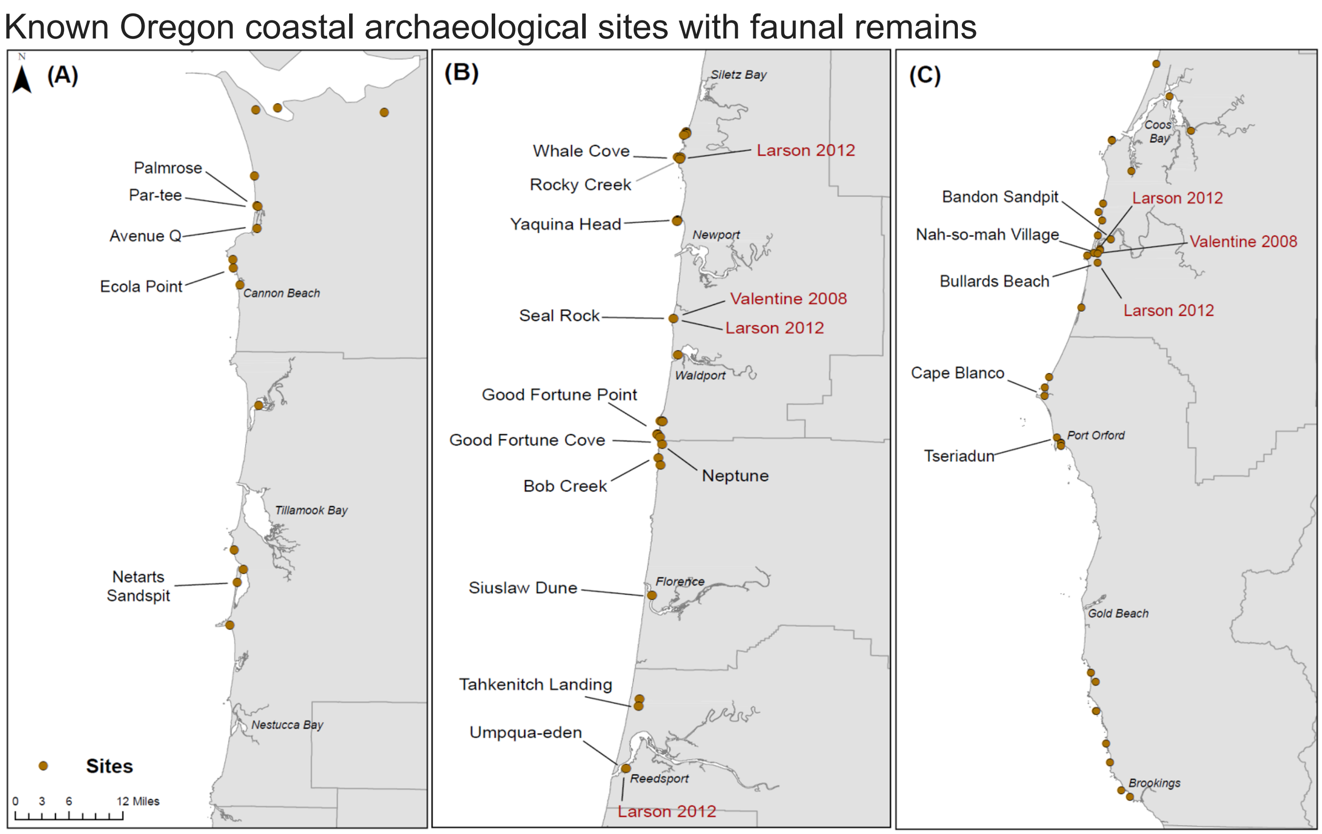


Figure 4: Coastal Oregon archaeological sites with known vertebrate faunal remains plotted across the North (A), Central (B), and South (C) regions. Labelled sites are known to have held sea otter remains. Sites that past genetic studies have sampled are labelled in red.

North Oregon coastal sites

Of the 42 sites noted above the 45th parallel, 15 are noted to have held faunal material, including 5 with sea otter (Figure 4A). Immediately north of Oregon on the far side of Cape Disappointment, Fishing Rocks (45PC35) also held sea otter remains (Minor 1983). Notably, excavations at Columbia River estuarine sites Eddy Point (35CLT33) and Ivy Station (35CLT34) found harbor seal (*Phoca vitulina*) remains, but not those of sea otters. Near the Necanicum River, people frequented the site of Palmrose (35CLC47), at least 3,700 YA. But as one of the oldest known Oregon permanent settlements, Palmrose was dated to 2,700 YA by the large plank house excavated there (Aikens et al. 2011). Habitation shifted to Par-tee (35CLT20) and Avenue Q (35CLT13), likely forced by subsidence events. Middens of all three sites held a large and diverse faunal assemblage, including 14 species of mammals. Ecola Point (35CLT21) excavations produced 38 sea otter NISP (Lyman 1995). The Netarts Sandspit (36TI1) was also a large community, with house remains dated to 1400-1800 CE. Losey (2002) noted the decrease in the hunting of sea otters and an increase in the taking of terrestrial game following the 1700 CE earthquake.

Central Oregon coastal sites

Between the 45th parallel and 43.5° North, 27 of 60 sites tallied held faunal remains (Figure 4B). Sea otter remains have been recovered at 11. Lyman (1988) extensively reviewed the faunal collections of three of the Central Coast sites in documenting the dramatic changes in distribution and abundance of marine mammals following the 18th and 19th century commercial exploitation. He used NISP and not the minimum number of individuals, a more problematic quantitation. Umpqua-Eden (35DO83) on the Umpqua River has shell midden strata dating to 3,100 YA, but is best represented with artifacts from the last 800 years. Lyman records 302 sea otter NISP, 27% of which can be assigned to discrete timespans. The remaining specimen can only be ascribed to the full range of 3,000 YA to 50 years before excavation due to disturbances at the site. Sea otter NISP comprises 17% of the combined sea otter and pinniped NISP. A remarkably full picture of sea otter population dynamics and human utilization can be inferred from this archaeological record. Both sexes and all ages including newborns, are represented (Lyman 1991). Bonnot (1951) records the habit of commercial sea otter hunters to kill pups first, as the mother would remain nearby for a second harvest opportunity. The patterns of the striations found on 17% of the specimen bones offer insights into butchery methods (Lyman 1991).

Whale Cove (35LNC50) yielded 19 sea otter NISP spanning the entire Late Holocene (Lyman 1988). Lyman assigned the 140 sea otter NISP of Seal Rock (35LNC14) to between 400 and 100 YA. Several kilometers inland and across the river from present-day Florence, Siuslaw Dune (35LA25) investigations produced only 4 sea otter NISP and 14 harbor seal NISP for its marine mammal inventory. Tahkenitch Landing (35DO130), near what is now Tahkenitch Lake, was the scene of intensive marine resource use during the middle Holocene. What was once an estuary was blocked by sand 3,000 YA, leading to the site's abandonment.

South Oregon coastal sites

Of the some 89 archaeological sites on the Oregon coast, south of 43.5°, 33 have been shown to have held faunal remains. 4 of those have identified sea otter remains (Figure 4C). The people of the Coquille represented the northward extension of the Athapaskans that radiated out of northern California (Hall 1995, Aikens et al. 2011). Architecture and customs contrasted with those of the Columbia River and north. Several complexes in the Coquille River Valley have been studied in detail, as at Na-so-mah Village (35CS43). Some sites, as in the Bandon Sandspit (35CS35), have since been lost to erosion by the Coquille River. Tseriadun (35CU7), above Port Orford on Garrison Lake, also lost its utility to native marine resource users as the estuary turned to lake.

The abundance of sea otter remains by NISP relative to combined otters and pinnipeds varies. Sea otter remains are the most common marine mammal on the North Coast at Palmrose and Par-tee in the north.

At Bandon Sandspit, NIMS for sea otters has dropped to two (Tveskov 1999). Relative abundance sharply increases in central and southern California (Lyman 2011). Estimates of total NISP for sea otter remains in Oregon currently available for research run higher (e.g., Lyman 2011), but fall below 700.

Carrying capacity & suitable habitat

We predict a total of 4,668 sea otters (1549 – 11372; 95% CI) at carrying capacity along the Oregon coast (Appendix 7). Predicted densities range from 0.02 to 86.7 otters/km^2. We identified a total of 14 potential suitable habitat areas (Figure 7). Suitable habitats varied in total predicted abundance, from 0.1 to 534.87 otters, with an average of 72.16 otters per suitable habitat area (sd = 144.82, n = 14). In total, we estimated 938.12 otters could occur within suitable habitat. We created 21 zones along the outer coast and 4 zones around estuaries (Coos Bay, Tillamook Bay, Yaquina Bay, and Umpqua River).

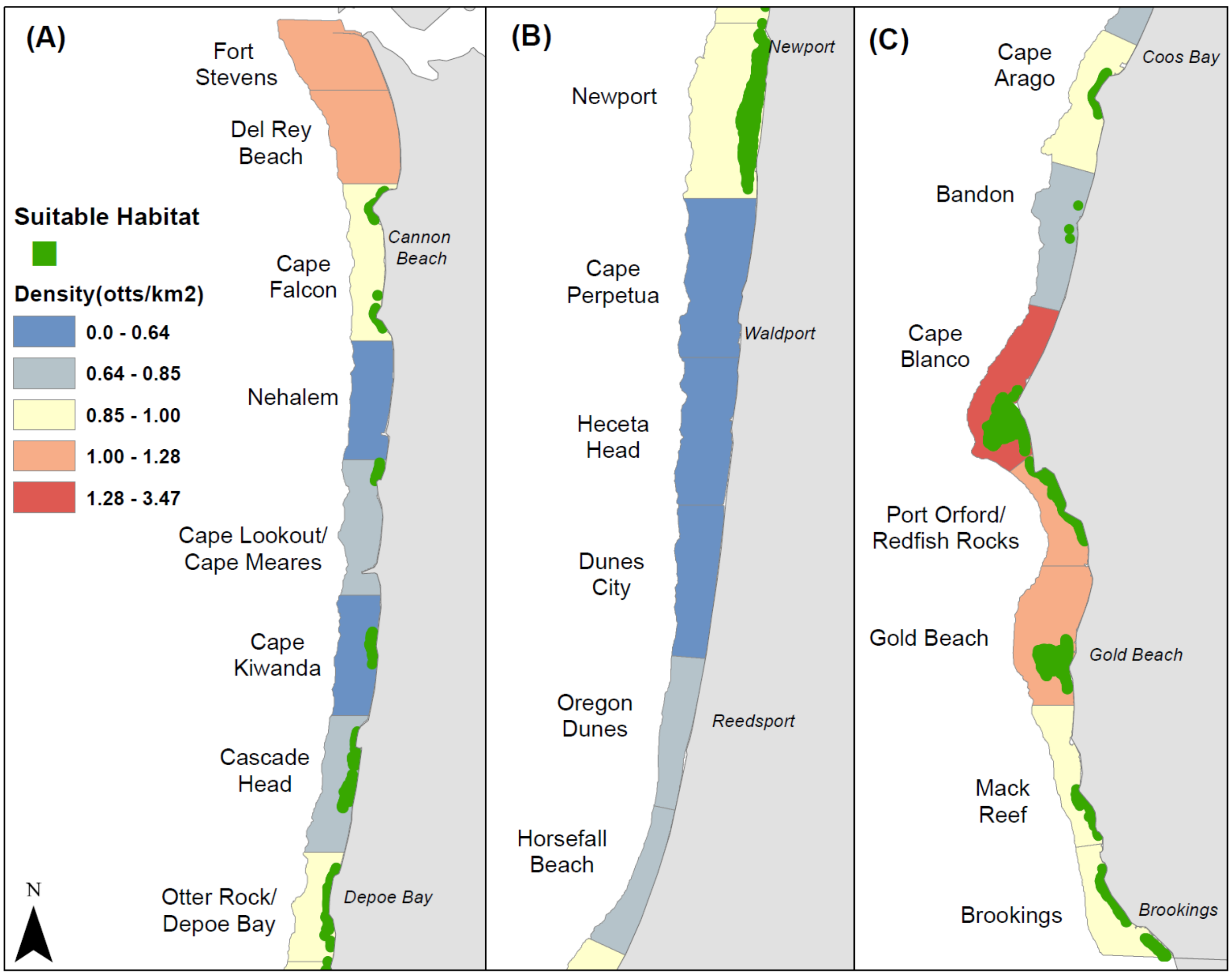


Figure 7. Identified suitable sea otter habitat areas, and outer coastal zones created around suitable habitat with predicted otter densities. Areas are presented by region for visualization (A = north, B = central, C = south).

Predicted otter densities

Predicted otter densities, by zone, ranged from 0.45 to 3.47 otters/km^2 (mean = 1.17 otters/km^2, sd = 0.65), in Cape Perpetua and Cape Blanco, respectively (Figure 7). The next 4 highest predicted densities occur within estuaries at 1.77 otters/km^2. However, these are not directly comparable to outer coast zones. If we exclude estuaries, the next 4 highest zones are Fort Stevens (1.28 otters/km^2), Port Orford/Redfish Rocks (1.24 otters/km^2) Del Rey Beach (1.08 otters/km^2), and Gold Beach (1.07 otters/km^2). Surprisingly, Fort Stevens and Del Rey Beach ranked relatively high, despite lack of suitable habitat. This may be due to shallow depths offshore, providing additional foraging habitat, and elevated NPP that may sustain filter-feeding prey species.

Human Activities

Protected Areas

Total otter abundances within protected areas ranged from 0 to 102.42 otters per zone (sd = 22.35). Cape Blanco ranked first, which can be explained by high predicted densities. One hundred percent of this protection is within the Oregon Islands National Wildlife Refuge. The second protection occurs within Cape Falcon (38.94 otters). Dunes City, Oregon Dunes, and Horsfall Beach afforded the least protection, which can be explained by poor habitat quality and no protected areas. If we only consider suitable habitat within protected areas, zonal ranks change. Cape Blanco (97.72 otters) remains first overall, but Port Orford/Redfish Rocks, Gold Beach, and Mack Reef, move up in rank to 2nd, 3rd, and 4th, respectively. These rankings may provide a more reliable indication of potential sea otter protection.

Accessibility

Overall, viewpoint accessibility ranged from 0.02 to 0.71 viewpoints/km, with an average of 0.39 viewpoints/km (sd = 0.21). While vessel travel distance ranged from 0.1 to 49.15 km, with an average of 23.88 km (sd = 35.53), not including zones without ports. Of outercoast zones, Cape Perpetua contained the greatest viewpoint accessibility, with 0.71 viewpoints/km. Cape Blanco was the least accessible with 0.14 viewpoints/km. All 4 estuary zones were the least accessible for viewers (less than 0.06 viewpoints/km), which may be attributed to their extreme sinuosity. Newport was the most accessible for vessels with the shortest travel distance of 0.10 km. Several other zones were also under 1 kilometer, including Port Orford/Redfish Rocks (0.34 km), Otter Rock (0.41 km), and Gold Beach (0.78 km). We did not estimate travel distance for Cape Blanco, Horsfall Beach, Dunes City, or Mack Reef, as no ports exist within these zones, making them relatively inaccessible to vessels.

Fisheries Overlap

Crabbing grounds within the top 75% stated importance band was identified within every zone, while 86%, 29%, and 19% of zones had some degree of overlap with the top 50%, 25%, and 10% importance bands. Crabbing grounds cover large areas and, for some zones, covered more than 90% of the zone's area. Instead of calculating total otter abundance within crabbing grounds, we only considered suitable habitat within crabbing grounds as this would indicate which suitable habitats are most likely to interact with the fishery. We found no overlap between suitable habitat and the top 50%, 25%, and 10% most important crabbing grounds. We found a small degree (3.26 otters) of overlap with the top 75% crabbing grounds at Cape Falcon.

Sea otter population growth

Given an initial population size of 20 and an annual augmentation of 4 individuals for 7 years, all zones maintain vital rates sufficient to offset attrition and stochasticity, as well as increase the population (Figure 8). Yaquina Bay will be within 9 otters of reaching carrying capacity, Horsfall Beach within 13. Newport numbers will increase to 28% of K, Cape Blanco just 12%. As a group, Central Coast zones will reach 54% of K, estuaries 52%, North Coast 45%, and South Coast 32%.

Yaquina Bay is projected to add 6 otters to the initial population size and augmentation, Cape Blanco 30. As a group, Central Coast zones would see the smallest net increase (26%), estuaries 30%. North Coast zones perform well (37%) and South Coast only incrementally better (37%). By comparison, a reintroduction simulation without density dependence projects 82 otters by the end of the time span, a 71% increase.

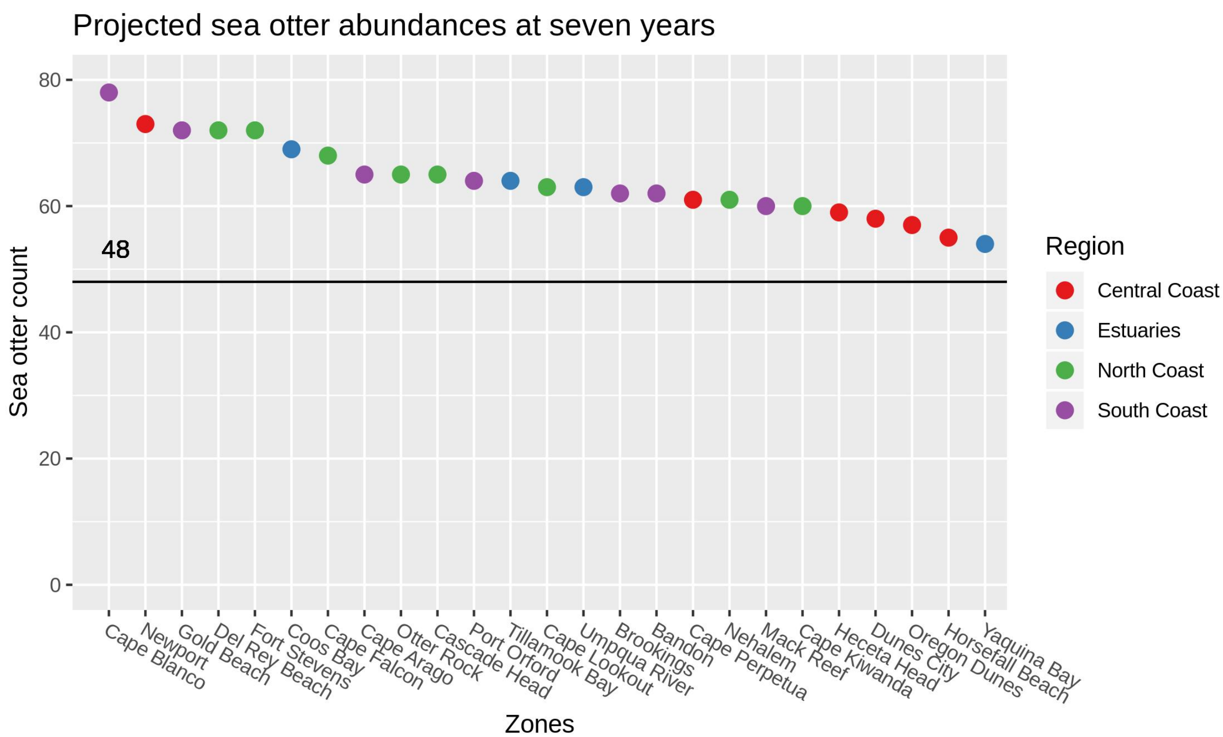


Figure 8: For each zone, population growth over 7 years was projected using a density-dependent model with stochasticity. The horizontal line reflects the 20 of the initial reintroduction and the 7 years x 4 individuals with which the initial population was augmented.

Preferences towards potential sea otter reintroduction locations

Respondents indicated the least support, on average, for Horsfall Beach as a sea otter reintroduction location (M = 3.59, SD = 1.97), and they indicated the most support, on average, for Cape Arago (M = 5.53, SD = 1.32) (*strongly oppose* [1] to *strongly support* [6]) (Table 2). No zone had a mean rating of < 3, meaning among the sample, no zone was opposed as a sea otter reintroduction location. However, the sample's previously mentioned limitations should be recognized in interpreting these results, particularly with respect to the sample's percentage of commercial fishers (14%) and its lack of external validity, which is why confidence intervals and inferential statistics were not employed. A small selection of respondents indicated strong opposition to all zones (n = 1) or strong support for all zones (n = 2). Eight respondents expressed no preference for all zones.

Table 2: Mean Preferences for Sea Otter Reintroduction Locations [a]

Zone	*M*	*SD*	Region	No preference
Cape Arago	5.53	1.32	South	12
Mack Reef	5.52	1.09	South	19
Port Oroford/Redfish Rocks	5.51	1.12	South	13
Cape Blanco	5.43	1.27	South	12
Otter Rock/Depoe Bay	5.24	1.28	North	13
Heceta Head	5.22	1.45	Central	16
Cascade Head	5.21	1.32	North	14
Cape Perpetua	5.21	1.47	Central	14
Cape Lookout/Cape Mears	5.13	1.39	North	16
Cape Falcon	5.07	1.63	North	18
Gold Beach	5.03	1.52	South	18
Bandon	4.93	1.64	South	18
Nehalem	4.88	1.48	North	23
Brookings	4.87	1.69	South	17
Cape Kiwanda	4.7	1.63	North	15
Yaquina Bay	4.6	1.81	Central	17
Coos Bay	4.55	1.70	South	19
Tillamook Bay	4.52	1.72	North	21
Newport	4.42	1.89	Central	15
Umpqua River	4.08	1.96	Central	22
Fort Stevens	3.91	1.88	North	24
Del Rey Beach	3.85	1.87	North	27
Dunes City	3.75	1.87	Central	23
Oregon Dunes	3.72	1.90	Central	23
Horsfall Beach	3.59	1.97	Central	26

[a] Cells are ordered from highest to lowest mean rating

For comparison, we calculated the means for the zones with each region (North, Central, and South) (Table 3). If a respondent failed to provide ratings for at least half of the zones in a region, their response was omitted from the mean calculation. Respondents expressed the greatest support, on average, for the South region zones (M = 5.21, SD = 1.63), followed by North regions zones (M = 4.83, SD = 1.88), and then Central region zones (M = 4.51, SD = 1.87).

Table 3: Mean Preferences for Sea Otter Reintroduction Locations by Region

Region	*M*	*SD*	*n*
North	4.83	1.88	30
Central	4.51	1.87	31
South	5.21	1.63	34

Anticipated outcomes of sea otter reintroduction

The vast majority of respondents (94%) associated potential positive outcomes with reintroducing sea otters to Oregon, while a plurality of respondents associated negative outcomes (43%). Perceptions of positive and negative outcomes varied across stakeholder groups (Table 4).

Table 4: Stakeholder Affiliations and Anticipated Reintroduction Outcomes [a]

Stakeholder affiliation	Associated negative outcomes %	Associated positive outcomes %
Commercial fisher (n = 7)	71%	86%
Recreational fisher (n = 20)	45%	90%
Native American tribe (n = 3)	0%	100%
Scientist (n = 12)	50%	100%
Local government (n = 8)	75%	88%
State government (n = 4)	75%	75%
Federal government (n = 2)	50%	50%
Environmental group (n = 27)	37%	96%
Charter boat or tour operator (n = 2)	0%	100%
Coastal recreationalist (n = 28)	36%	96%
Oregon coastal resident (n = 26)	31%	92%
Oregon non-coastal resident (n = 15)	60%	100%

[a] Cell entries represent percentages of respondents that associated negative and positive outcomes with sea otter reintroduction to Oregon

For the open-ended items related to negative outcomes, 21 respondents provided one or more negative outcomes that they anticipated, and 46 respondents provided one or more positive outcomes. We coded these based on common themes in the data. The most common themes were harm to fisheries or depredation to certain sea otter prey species as an anticipated negative outcome (n = 15), loss of access to marine areas as a result of reintroduction regulations (n = 4), and conflict that reintroduction could engender in communities (n = 3). Two individuals mentioned sea otters in Alaska, asserting that they have harmed fisheries there and that similar phenomena could occur in Oregon if they are reintroduced.

For the open-ended items related to positive outcomes, 46 respondents provided one or more positive outcomes that they anticipated. The greatest number of respondents mentioned the improvement in health of the marine environment and restoration of balance that reintroducing sea otters would engender (n = 27), followed by increased tourism (n =24), and impacts on kelp (n = 23). Reductions in urchins and other species was mentioned by 14 respondents, and benefits to fisheries as a result of sea otters was mentioned by 11 respondents. Wildlife viewing, recreational, and cultural benefits were mentioned by four respondents. Sea otters serving as a flagship species that could increase interest in conservation and provide educational opportunities and the like was mentioned by seven respondents. The restoration of a keystone species in sea otters was mentioned by seven respondents. The benefits to sea otters as a species overall (e.g. increased genetic diversity and increased species connectivity) was mentioned by four individuals. The ethical obligation and "righting a historic wrong" was mentioned by four individuals. Carbon sequestration from increases in "blue" carbon was mentioned by three individuals. Cultural benefits to Native American tribes was mentioned by two individuals. And increases in seagrass/eelgrass abundance was mentioned by two individuals.

Respondents evaluated the importance of their listed negative and positive outcomes using a unipolar response item (*not at all important* [1] to *extremely important* [5]). Respondents' mean score for importance across positive outcomes (M = 4.09, SD = 0.73) exceeded their mean score across negative outcomes (M = 3.78, SD =1.07). Respondents were asked to evaluate their certainty that the negative and positive outcomes they associated with a successful Oregon sea otter reintroduction using a unipolar response item (*uncertain* [1] to *extremely certain* [5]). Overall, respondents reported higher mean scores for positive outcomes (M = 3.66, SD = 0.85) versus negative outcomes (M = 2.85, SD = 1.47) with respect to certainty.

Sea otter reintroduction policy support

Overall, a majority of respondents (88%) supported reintroducing sea otters to Oregon to some degree (Table 5).

Table 5: Sea Otter Reintroduction Policy Opposition or Support

Policy opposition or support (n = 49)	%
Strongly oppose	10%
Somewhat oppose	2%
Neutral	0%
Somewhat support	9%
Strongly support	79%
Unsure	4%

Levels of support differed across stakeholder groups; commercial fishers (43%) were the only group with less than a majority expressing some degree of policy support (Table 6).

Table 6: Sea Otter Reintroduction Policy Support by Stakeholder Group

Stakeholder affiliation	Policy support %
Commercial fisher (n = 7)	43%
Recreational fisher (n = 20)	75%
Native American tribe (n = 3)	100%
Scientist (n = 12)	83%
Local government (n = 8)	75%
State government (n = 4)	50%
Federal government (n = 2)	50%
Environmental group (n = 27)	93%
Charter boat or tour operator (n = 2)	100%
Coastal recreationalist (n = 28)	89%
Oregon coastal resident (n = 26)	81%
Oregon non-coastal resident (n = 15)	100%

[a] Cell entries represent percentages of respondents that expressed some degree of policy support (*somewhat support* [4] or *strongly support*[5]) for sea otter reintroduction in Oregon.

Sea otter reintroduction stock considerations

We asked respondents about preferences towards source populations with which to initiate a sea otter reintroduction would be chosen. Asked how important it would be to prefer sea otters genetically similar to that which existed prior to their extirpation in Oregon, 68% of respondents indicated moderately to extremely important (*n* = 47). When asked whether they preferred sourcing otters for a reintroduction from rescued juvenile sea otters from a stranding program, wild-caught animals, or a combination thereof, 4% of respondents were opposed to reintroduction, 7% favored the stranding program, 21% preferred wild-caught otters, 46% preferred a combination of sourcing juvenile orphans and adult wild-caught otters, and 9% had no preference. Considering the conservation needs of other sea otter populations was favored by 89% of respondents. Concerns over loss of individuals in the initial founding population was expressed by 52% of respondents (7% extremely concerning).

INTEGRATION: The coupled natural-human system's socio-ecological factors

A region-level comparison

We present a broad overview of the socio-ecological factors among the regions, then discuss zones with relatively high and low levels of support. Selected zones are examined in detail, not as recommendations, but to illustrate the comparisons and contrasts possible.

As a whole, Central Coast zones (*n* = 6) were relatively less accessible and less supported by survey respondents. (Further data exploration is in Appendix 8.) Estuaries (*n* = 4) support relatively high predicted otter densities but do reflect the assumptions described in Methods. Monitoring in estuaries ranks low per our methodology. Potential fisheries interaction is present on the North Coast (*n* = 8) but only at Cape Falcon. Predicted otter density and protection on the South Coast (*n* = 7) is above average. The high scores of Cape Blanco skews the distribution of these scores. Survey and Population are favorable for South Coast as well.

High Levels of Support

Survey respondents were most in support of, in descending order: Cape Arago, Mack Reef, Port Orford/Redfish Rocks, Cape Blanco, and Otter Rock (Figure 12) as potential reintroduction sites. Not all of these zones have suitable habitat, nor do we predict relatively high otter densities. Cape Arago and Mack Reef, which respondents were most supportive of, have moderate predicted densities at 0.90 otters/km^2 (ranked 10th and 11th, overall). These zones have suitable habitat, but the densities for the entire zones are reduced by other relatively low predicted densities in deeper, offshore waters. Across all factors, Cape Arago is moderately ranked relative to other zones. Mack Reef is also moderately ranked across all factors, except for being one of the most inaccessible for vessels. If we only consider suitable habitat within protected areas, Mack Reef offers the 4th greatest protection, but only at 9 otters. Mack Reef also had one of the lowest population growth potentials, with an increase of 12 otters over 7 years. Despite having the highest levels of support from survey respondents, these two sites appear to be less suitable by ecological and demographic factors.

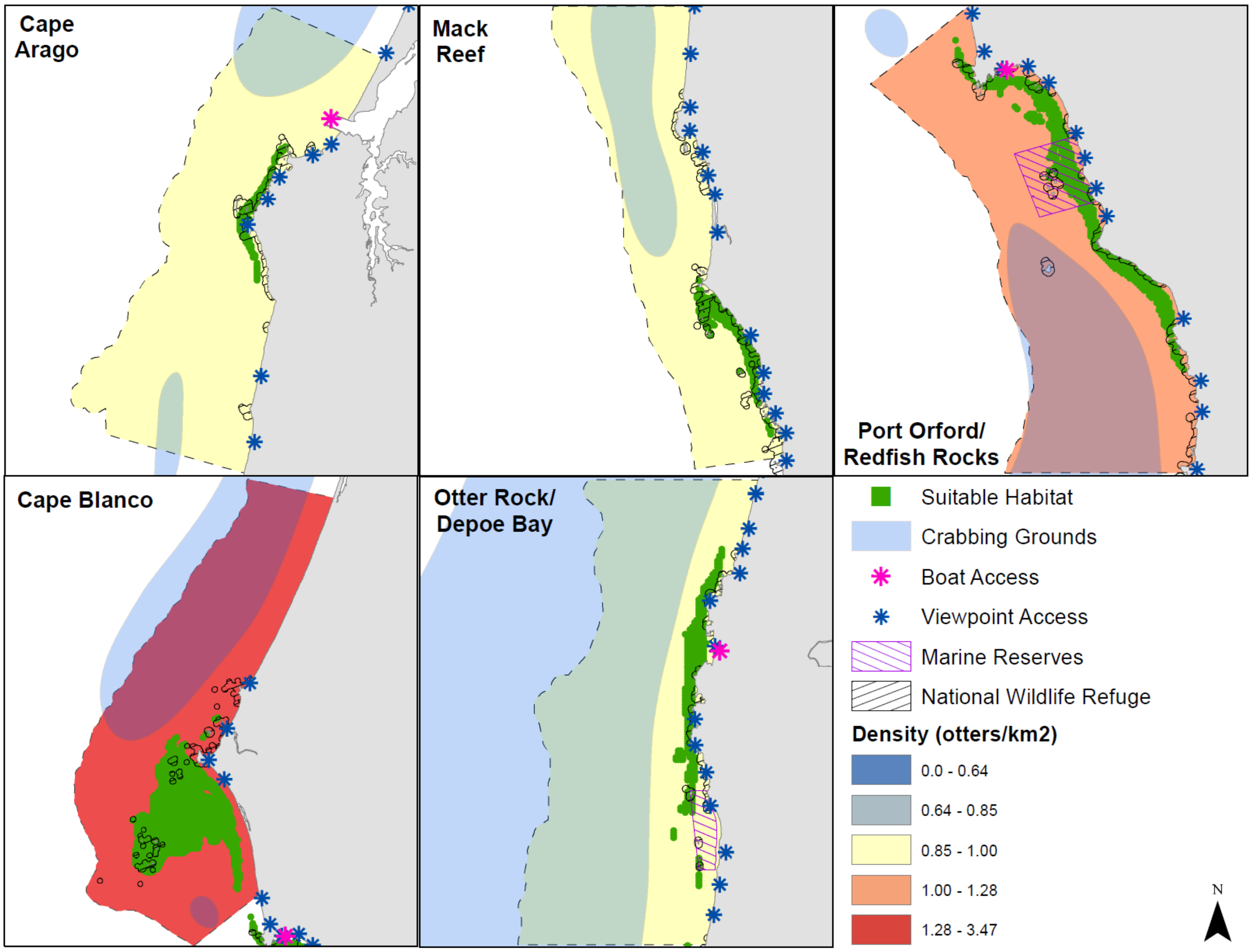


Figure 12: 5 sites across all three regions given high levels of support in survey results with additional ecological and management metrics.

In contrast, Cape Blanco and Port Orford/Redfish Rocks were among the most supported zones and appear to be relatively suitable, ecologically and demographically. Cape Blanco has the highest predicted densities (3.47 otters/km^2) and greatest protection, at 102.42 otters. If we only consider suitable habitat, we find 97.72 otters still occur within protected areas within Cape Blanco. Therefore, 95% of otters within protected areas are located within suitable habitat, potentially elevating the importance of these protected areas. Of outer coast zones, Cape Blanco also is the least accessible for both viewing (0.14 viewpoints/km) and vessels (0 available ports). This could minimize recreational disturbance, but reduce research and management effectiveness. With such high predicted abundances, Cape Blanco also has the greatest population growth potential (30 otters over 7 years). Port Orford/Redfish Rocks had trends very similar to Cape Blanco, with high predicted densities (1.24 otters/km^2) and protection (38.94 otters), with much of this protection attributed to the Redfish Rocks Marine Reserve. Unlike Cape Blanco, Port Orford/Redfish Rocks is more accessible to both vessels (0.34 km; 2nd overall) and viewers (0.51 viewpoints/km; 11th overall). This could facilitate management and research, though also disturbance. Given the presence of suitable habitat, Port Orford/Redfish Rocks also has moderate population growth potential (16 otters). This zone does appear to be suitable for a reintroduction but likely not as suitable as Cape Blanco.

Lastly, Otter Rock/Depoe Bay presents conflicting findings among our factors. Despite having relatively high levels of support (5th overall), this zone has moderate levels of predicted otter densities, and is one of the most accessible zones. But protection is low to moderate despite encompassing both the Oregon Islands National Wildlife Refuge and Otter Rock Marine Reserve. We suspect survey respondents were, in general, in more support of Otter Rock/Depoe Bay because its name enlists some positive response. The presence of the Otter Rock marine reserve in the zone suggests less disturbance and reduced fisheries activity, and the name "Otter Rock" may imply to respondents that this area used to support sea otters. Whatever the reason for slightly elevated levels of support, Otter Rock/Depoe Bay appears to not be as suitable or feasible for reintroduction, according to our ecological and demographic factors

Low levels of support

Survey respondents were relatively less supportive of, in ranked order: Horsfall Beach, Oregon Dunes, Dunes City, Del Rey Beach, and Fort Stevens as potential reintroduction sites (Figure 13). For Horsfall Beach, Oregon Dunes, and Dunes City, these low levels of support generally agree with our ecological and demographic factors. In that, all three had moderate to low predicted otter densities (Horsfall Beach = 0.80 otters/km^2, Oregon Dunes = 0.78 otters/km^2, and Dunes City = 0.62 otters/km^2)—relatively poor habitat quality. These zones also had very low population growth potential at 7, 9, and 10 otters over 7 years, respectively. All three zones afforded zero protection, which can be attributed to lack of protected areas and suitable habitat. These zones were also among the least accessible in terms of both viewpoints and vessel travel distance. Interestingly, these zones (Horsfall Beach = 0.17 viewpoints/km, Oregon Dunes =0.21 viewpoints/km, and Dunes City = 0.33 viewpoints/km) were similar in accessibility to Cape Blanco (0.14 viewpoints/km) and Cape Arago (0.26 viewpoints/km). Any otters located within these zones could experience relatively lower levels of recreational disturbance but may be more difficult to monitor and manage. However, without any suitable habitat, this point becomes moot. It appears that Horsfall Beach, Oregon Dunes, and Dunes City are not very suitable for a reintroduction in the views of respondents, and the other factors agree with this determination.

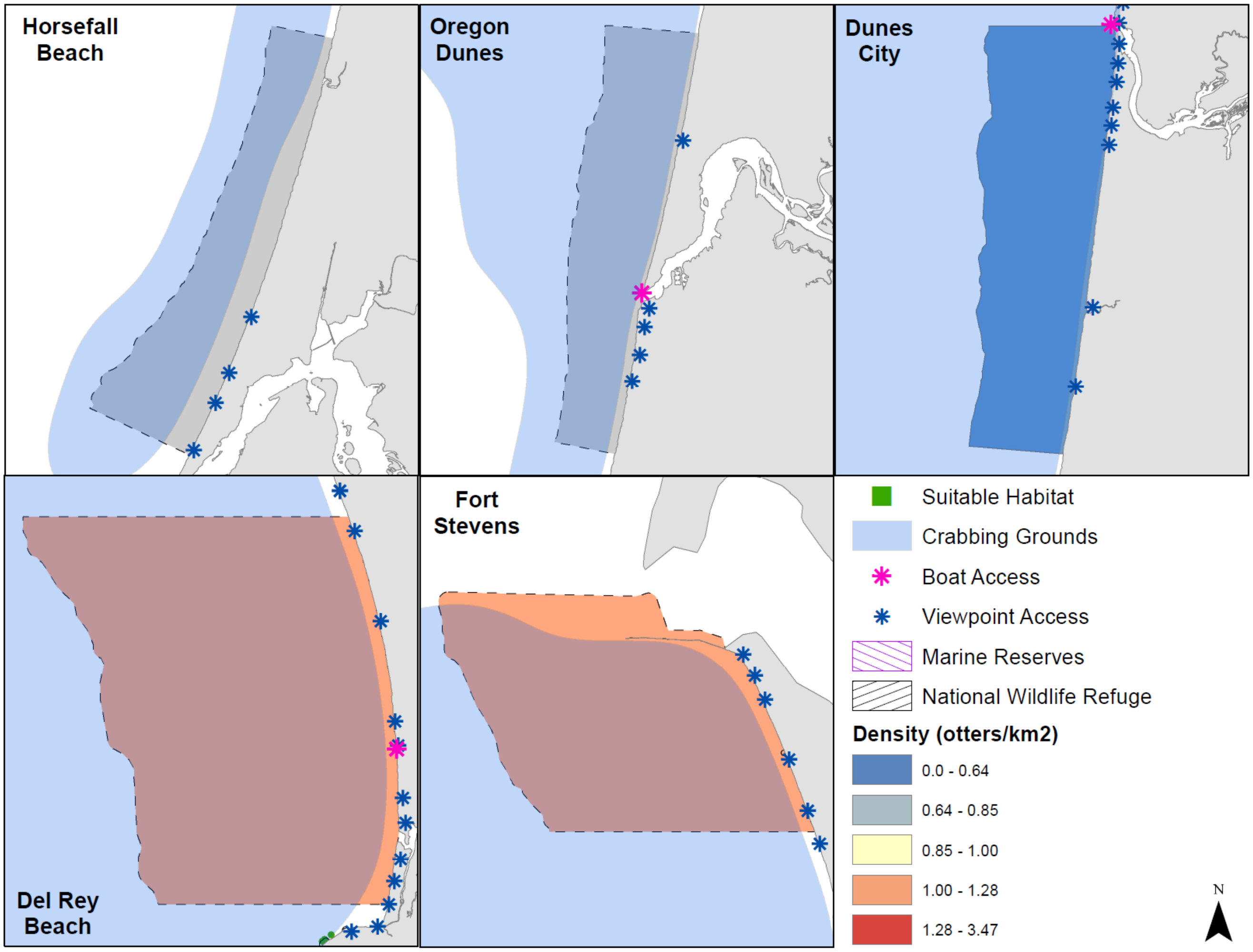


Figure 13: 5 sites that received low levels of support in survey responses with additional ecological and management metrics

Survey respondents were in less support of Del Rey Beach and Fort Stevens as potential reintroduction sites, but—in contrast to Horsfall Beach, Oregon Dunes, and Del Rey Beach—this finding does not fully agree with our ecological and demographic factors. In fact, Fort Stevens and Del Rey Beach had among the highest predicted densities at 1.28 and 1.08 otters/km^2, suggesting relatively high habitat quality. These zones also had moderately high levels of population growth potential, at 24 otters over 7 years per zone. Both sites were relatively inaccessible to vessels. With the exception of zones without available ports, Fort Stevens has the longest travel distance of 36 km and Del Rey Beach the distance of 8.78 km. Despite being inaccessible to vessels, both zones were moderately accessible to viewers with just under 0.50 viewpoints/km. Neither of these zones afford much protection. Del Rey Beach has zero protection due to a lack of protected areas, and Fort Stevens has a negligible protection of 0.10 otters. These two zones have some characteristics that might make them suitable for a reintroduction. However, without suitable habitat or much protection, such interpretations should be made sparingly. Both zones have moderate to low levels of accessibility. On a regional level, the northern coastline has higher human populations. If sea otters were reintroduced, there seems to be some potential for disturbance based on viewpoint accessibility. In contrast, low levels of vessel accessibility could deter vessel disturbance on the water, but it would also make it more difficult for researchers to monitor the population. Altogether, we find some disagreement between our factors and caution should be taken when considering Fort Stevens and Del Rey Beach as potential reintroduction sites.

Zones of particular interest
We extracted a few zones (Figure 14) that we feel warrant some discussion on their suitability as potential reintroduction sites. Zones were selected based on disagreements in suitability factors, which could complicate resource management in the event of a sea otter reintroduction.

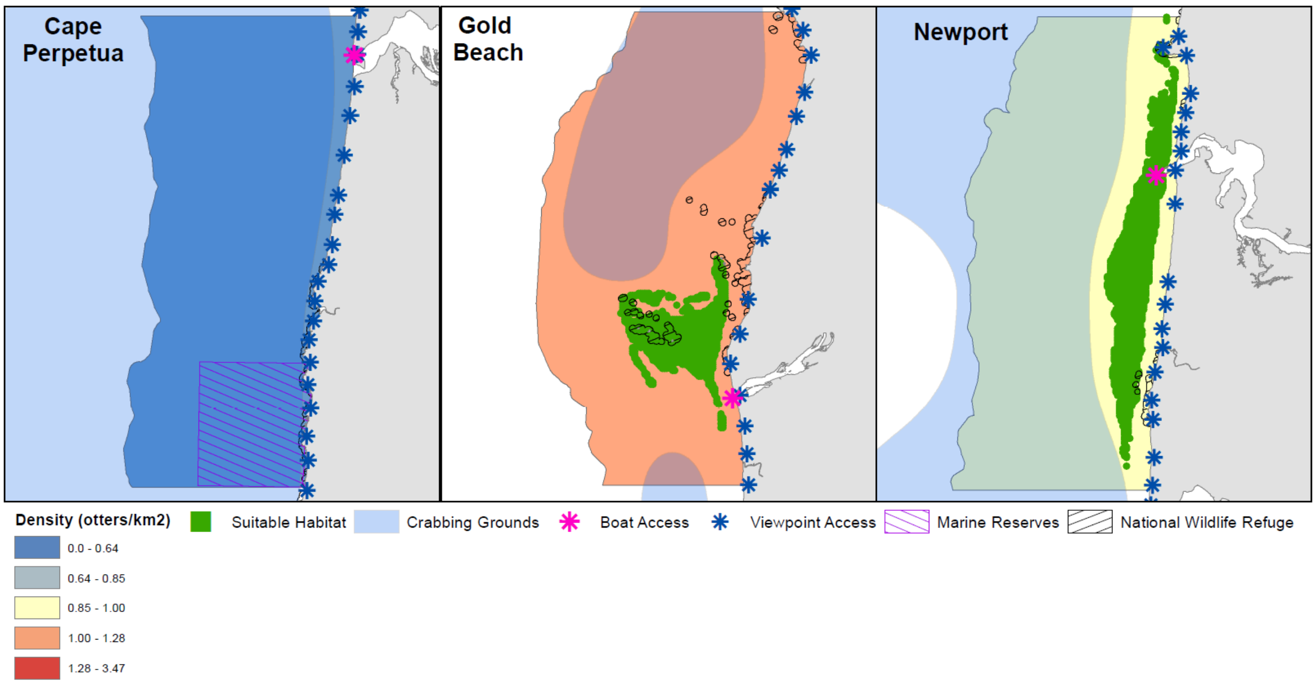


Figure 14: Selected sites that warrant additional discussion.

<u>Cape Perpetua</u>
Cape Perpetua was not among the top 5 zones in support, but survey respondents were still somewhat supportive of this zone (mean = 5.21, not significantly different than the top score). Cape Perpetua may be somewhat suitable as based on the presence of protected areas (24.91 otters, 5th among zones) and moderate vessel accessibility (distance = 3.64 km). There are several other factors that make Cape Perpetua less suitable, including (1) no suitable habitat, (2) lowest predicted densities (0.45 otters/km^2), (3) most vulnerable to disturbance (0.71 viewpoints/km), (4) moderate to low population growth (13 otters), and (5) lack of suitable habitat within protected areas. Ecological and demographic factors suggest Cape Perpetua is relatively less suitable, yet, survey respondents still had some support for this zone as a potential reintroduction site. Like Otter Rock/Depoe Bay, survey respondents may have supported this zone due to the perceived protection opportunity.

<u>Gold Beach</u>
Similarly, Gold Beach was not among the top 5 zones in support, but survey respondents were still somewhat supportive (mean = 5.03, not significantly different than top score) of this zone. Ecologically and demographically, Gold Beach appears to be relatively suitable for a sea otter reintroduction, with high predicted densities of 1.07 otters/km^2 (5th overall), much suitable habitat, high population growth potential of 24 otters (tied 3rd overall), high vessel accessibility of 0.78 km (3rd overall), and moderately high protection of 18.94 otters within protected areas (7th overall). Protection is even higher when we only consider suitable habitat with 12.85 otters within protected areas (3rd overall). The only unfavorable factor may be viewer accessibility, with 0.78 viewpoints/km (4th overall). These findings present some interesting and consistent hypotheses across zones. Respondents may be rating

zones based on emotional or intrinsic values. However, Gold Beach does not contain any landmarks that make it distinguishable or unique, such as Otter Rock/Depoe Bay or Cape Perpetua. It is otherwise unclear why respondents did not support Gold Beach as much as other zones when in fact it contains several ecological and demographic factors that may facilitate a successful reintroduction.

Newport

Newport had some of the greatest disagreements between factors. Survey respondents were not as supportive of this zone as a potential reintroduction site. They rated Newport a 4.42 in support, not significantly different from the top score, but a difference of 1.11 could still suggest slightly less support. In terms of ecological factors, Newport has a large suitable habitat area. Still, we estimate a modest predicted density of 0.94 otters/km^2 (8th overall). Newport had the 2nd highest population growth potential, at 25 otters over 7 years. In terms of protection, Newport ranked very much in the middle of all zones. Yet, these estimates were quite small with only 3.23 otters occurring within protected areas, and only 0.71 otters within suitable habitat. For accessibility, Newport presents some potentially positive and negative results, with the highest level of vessel accessibility (distance = 0.10 km) and 5th highest level of viewer accessibility (0.59 points/km), which could facilitate effective research and management, but also disturbance. Given the disparate rankings of these factors, it's difficult to determine how Newport's suitability compares with other zones. We suggest that Newport does have some potential as a reintroduction site, based on ecological and demographic factors. Yet, there appears to be some unknown reasons as to why survey respondents were not as supportive of Newport, relative to other zones.

DISCUSSION

We asked survey respondents to list any potential positive or negative outcomes of a sea otter reintroduction to Oregon. These responses allow us to better understand the respondents' mental models, as well as what they value and are most concerned with in this effort. We hand select a few of these responses as key points to drive the discussion of our study, and identify which of these responses (i.e., perceptions of risk and benefits) our analyses are able to address - even if partially - and the sources of uncertainty that remain. These responses also help to potentially explain or provide hypotheses behind some of the identified disagreements among our ecological, demographic, and social factors.

Positive outcomes

Increased ecosystem health & ecosystem services

When sea otters reclaim historical habitat, they can increase overall species diversity via trophic cascades triggered by top-down forcing (Estes and Duggins 1995). Increased species diversity has been linked to improved ecosystem resilience and health. More resilient and healthy ecosystems can provide a suite of ecosystem services. While our analyses did not investigate these potential ecosystem changes, by identifying where sea otters are likely to reside (i.e., suitable habitat) we can make some speculations as to where these ecosystem changes and associated benefits may occur. Yet, we must recognize there are several human activities along the Oregon coast that could influence where a sea otter reintroduction should take place occur. Our analyses attempted to investigate some of those factors (i.e. protected areas, accessibility, and fisheries) that could influence sea otter distribution. Some of these factors could increase sea otter reestablishment, facilitate ecosystem service provisioning, or impede sea otter reestablishment. Factors such as accessibility are more complex. While they could serve as a potential source of disturbance to sea otters, they can also facilitate recreational activities (i.e., wildlife viewing, fishing) and the benefits derived from those activities. Ultimately, our analysis did not determine what these ecosystem changes will be, their magnitude, and if and whom they will serve. Regardless, several survey respondents noted these ecosystem benefits as positive outcomes of a reintroduction. It is possible that respondents supported specific zones based on these perceived benefits, which would make some zones appear more suitable as potential reintroduction sites. This raises the question as to whether stakeholders' general knowledge and awareness of these potential benefits influence their level of support for such an effort. As stakeholders become better informed, their attitudes toward reintroduction sites and the prospect of sea otter translocation as a whole may well shift.

Species recovery & conservation

Survey responses suggested that respondents could appreciate both the historical context of a sea otter reintroduction and how the founding would impact on source populations. Over two-thirds of respondents favored a reintroduction source that reflected the genetic heritage of the now-absent Oregon sea otter. Conservation biology concerns were strongly expressed in their support for considering species-level viability concerns. Intriguingly, half of respondents found a balance of rescues from stranding programs and wild-caught otters to be appropriate. This may reflect a sense that no single strategy is best. While half of respondents were not unduly concerned at the prospect of mortality in the founding population, the 7% extremely concerned should be respected. Those fully engaged in sea otter conservation know that excessive mortality is a concern in even established populations. But the charismatic appeal of otters can be expected to elicit deep concerns over animal suffering. If responses among a larger sample size followed the same trend, Oregonians could be said to both deeply value the uniqueness of the Oregon sea otter and also share concern for their global well-being.

We see two favorable outcomes from the preliminary population viability analysis. Despite the clearly optimistic parameters set for the model, prospects for the success of a sea otter reintroduction appear to be promising. All zone outcomes were at least nominally positive. While an actual reintroduction effort will not be afforded a chance to have 1000 replicates, adaptive management strategies can institute precautionary measures and help offset the cost of adverse events to the translocated population for a positive outcome. Secondly, the modest increase in the number of individuals in the medium-term future gives the human side of the coupled human-natural system time in which to adapt. We would hope that the ecological restoration evident in other translocations will take effect in Oregon's nearshore environment as well. However, managers may want to prioritize the uncertainties associated with species reintroductions and trophic cascades to facilitate accurate understanding among stakeholders. Oregon residents may well be able to take advantage of the return to a more balanced nearshore ecosystem dynamic that sea otters may initiate. The projected gradual expansion of an Oregon sea otter population should give managers the ability to monitor and manage sea otter impacts and benefits.

Restored cultural connections

Beyond definitively establishing the sea otter presence in Oregon, the prevalence of sea otter remains in shell middens speaks to their place in Native American culture for thousands of years. Accounts speak of the value placed on their pelts and their importance in trade (Ruby and Brown 1993). In both research (e.g., Hall et al. 2012) and conversations with tribal representatives, we can attest to the importance that Oregon tribes place on the return of the sea otter. Were the decision made to proceed with a sea otter reintroduction, not only would a missing ecological component be remade but the cultural connection between native tribes and the sea otter would be restored as well. Sea otters as a cultural resource, both for tribes and for Oregonians generally, was a positive outcome mentioned by multiple survey respondents. Whether Oregon's general public views sea otters as a cultural resource is unclear from our results, though, and sea otters' absence during the past century may constrain their status as a cultural resource for the public. However, a number of respondents also mentioned as a positive outcome, sea otters serving as a flagship species to promote conservation and education. If reintroduction does occur and sea otters assume a flagship species role, then that could foster cultural connections over the medium to long term.

Negative outcomes

Fisheries conflict

Competition between sea otters and fisheries is a common concern wherever sea otters and people co-occur. Sea otters can sufficiently reduce local prey populations (Estes and Duggins 1995), but reductions will depend on where sea otters are located. Understanding where sea otters are likely to distribute can help us assess whether interactions with fisheries is possible. We found little overlap between suitable habitat and important crabbing grounds. Based on these results, alone, it's possible sea otters will have limited interaction with this fishery. This finding does not mean sea otters will never interact with this fishery, or even other fisheries (i.e. sea urchins, bay clams, mussels) at that. Sea otters can travel dozens of kilometers in search of food and may travel beyond suitable habitat, if necessary. If crabbing grounds are within their dispersal capability, there could be an interaction. However, our study did not assess proximity to fishing grounds. It is also important to note that these important crabbing grounds are (1) stated, and therefore, may not reflect where relatively high catches occur (i.e. grounds may be important for other reasons beyond catch), and (2) were identified approximately 6+ years ago. In that time, crab populations could have shifted, spatially, or the fishery may have experienced some changes that may warrant these grounds no longer important. Ultimately, these assessments of fishery overlap may not hold today.

In terms of reintroduction suitability, it is possible survey respondents are less supportive of certain zones if they perceive or anticipate conflicts between sea otters and fisheries. Respondents could perceive these types of interactions as a risk for sea otters (i.e. disturbance from fishing activity) or fishermen (i.e. competition for resources), which could reduce their overall support for a reintroduction within any zone, thereby reducing the zone's reintroduction suitability. Interestingly, some respondents were already aware of these perceptions, and noted that potential misconceptions of these interactions with fisheries would be a negative outcome. Further research could focus on gaining a better understanding of the likelihood of otter-fishery interactions, while communication and outreach efforts could focus on aligning these perceptions with relatively accurate predictions or case studies from other regions. Here, we attempted to align some of these perceived risks, but the methods used and date of important crabbing grounds introduces uncertainty in our assessments.

Community polarization

Predator reintroductions are typically controversial in nature (Serfass et al 2014). Because our survey sample underrepresents commercial fishing interests and is not random in nature, the overall support exhibited could belie reality to a degree. However, even if a majority of stakeholders' support sea otter reintroduction, there is still the possibility that it could be politically scuttled. One respondent questioned the legitimacy of a sea otter reintroduction because they believed it was an interest group effort, as opposed to an effort being undertaken by the government. Others may also share this perception and it could potentially wrought into a political narrative to oppose reintroduction, which occurred in the case of Bitteroot Ecosystem grizzly reintroduction (Smith 2003).

Most of the sample indicated positive benefits from potential sea otter reintroduction, including some of the select respondents who expressed opposition to reintroduction, and only one respondent expressed strong opposition to reintroduction in any of the zones. Thus, there may be opportunities to identify compromises with potentially opposed stakeholders. One of the negative outcomes respondents expressed was restricted access to the marine environment. Considering what areas are already protected in evaluating potential reintroduction locations could help minimize new potential restrictions. In considering compromises, it is notable that the MMPA does not have as much flexibility as the ESA to temper its restrictions, and thus the MMPA may be a limiting factor in what compromises may be struck. Additionally, opposition may not be entirely based on perceived costs or negative outcomes, but could also relate to social identity and ideology, potentially making compromise less likely. Attempting to engender trust between stakeholder groups and facilitate empathic understanding may be necessary to reach compromise if this is the case (Opotow & Brook 2003). It is notable that less than half of respondents associated potential negative outcomes with sea otter reintroduction, as negative outcomes are certainly possible, and recognition of the effects of reintroduction on affected stakeholder groups could be important for achieving compromise.

Unanticipated outcomes or consequences
Species reintroductions are inherently risky and typically involve some uncertainty. Despite our vast knowledge on the natural science underpinning reintroductions, they don't always go as planned and can lead to unanticipated consequences (e.g. reintroduction failure, con-specific competition, etc.). Outcomes are even more difficult to anticipate when we consider the human system, and all of the complexities of human behavior and psychology. We attempted to address some of these uncertainties so managers can better understand the potential for a successful sea otter reintroduction and anticipate potential outcomes. Our analyses do not and cannot address all uncertainties, but by identifying the limitations and caveats in our analyses, we've provided some key information on what unanticipated outcomes could occur. We must also recognize that our factor assessments and interpretations are temporally-static and only capture contemporary characteristics and trends. If managers decide to proceed with a reintroduction, these factors may change overtime. For example, human populations could continue to increase, increasing disturbance potential; species and habitats could shift under a changing climate, potentially reducing or moving suitable habitat and fishing grounds; or changes in management and research practices, while adapting to rapid environmental change or sustainability needs, could make people change their opinions on their support for a reintroduction. Future analyses may want to consider how these factors may change, as well as other factors and processes outside the scope of this study. Such assessments could help further identify potential outcomes and consequences.

Identified research needs
Phylogenetic investigations into the pre-fur trade sea otter are due for renewed research effort. A more conclusive answer than past mtDNA and microsatellites tools gave us can come from what Toews et al. (2016) discuss and we will call the "problem of riches" with contemporary high throughput sequencing. Thousands of loci along the genome can provide more statistical power to discern population structure. More information comes at a cost--the expense per sample increases. Still, these methods afford more power for the analysis to detect fainter signs of introgression between genotypes. Sequencing is problematic with the degree of degradation found in aDNA, but markers associated with ultra-conserved regions can be more reproducible across samples (Faircloth, 2012). Answering this intrinsically interesting scientific question will also indicate what contemporary ssp. would be the most appropriate source population a given reintroduction effort might utilize.

Experimental methods of selective removal of sea otter prey now can model the effects of sea otter predation. Replicates in the different zones we identified may show that sea otter impacts are spatially variable and guide reintroduction site selection. Work to establish ecological baselines now will prove valuable to managers when they gauge sea otter effects on the nearshore. Social research into stakeholder attitudes toward sea otter reintroduction can indirectly lead to a better-informed community and guide managers in their deliberations on the issue.

CONCLUSIONS & COLLABORATIVE PROCESS REFLECTIONS

This report is the product of National Science Foundation fellowships awarded to graduate students at Oregon State University (1545188 NRT-DESE). Our team within the 2018-19 cohort employed our respective disciplinary expertise in molecular ecology, community ecology, and public policy to develop this narrative by which we hope to have communicated the issues surrounding a potential sea otter reintroduction in Oregon and their potential resolutions.

Teaching us how to integrate our disciplines was a prime goal of the program. Transdisciplinary projects require developing a common scientific understanding among participants and creating the tools of analysis and communication suited to addressing a complex societal issue. Much like our first steps were in developing a transdisciplinary approach, the discussion of a possible sea otter introduction is in its preliminary stages. The difficulty we faced in quantifying concerns and benefits of reintroduction will extend as well to the public deliberation process. Weighting the individual factors requires knowledge of each. Still, the importance of factors will change from person to person. In addressing the perceptions of risks and the levels of uncertainty regarding the effects of a sea otter reintroduction, we hope that this report and future dialogue will contribute to a comprehensive assessment of how the reintroduction of sea otters to Oregon would change the state of our coupled human-natural system.

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APPENDICES

Appendix 1: Coastal Oregon archaeological sites (provisional as of August 31, 2019)
We submit a reference list of coastal archaeological sites known to have held vertebrate faunal remains for the use of science educators, sea otter and pinniped researchers, as well as terrestrial vertebrate researchers. Holocene ages given at this time are not inclusive of all site dates. Sources are given in full in the above References.

Index	Site	Holocene	Sources
35CU37	Lone Ranch Creek Mound	-	Hall-2009 Minor-1986 NPS 2017
35CU160	NA	-	Hall-2009
35CU68	NA	-	Minor-1986
35CU67	Indian Sands	early	Aikens-2011 Hall-2009
35CU35	Whale Head	-	Hall-2009 NPS 2017
35CU157	Khustenete-Hustenete-Xusteneten	-	Minor-1986 NPS 2017
35CU61	Pistol River Site-Chetlessentan-Chetleshin	-	Hall-2009
35CU62	Raymond Dune	mid	Hall-2009
35CU59	Tlegetlinten	-	Hall-2009
35CU12	NA	-	Minor-1986
35CU9	Port Orford	-	Hall-2009 Minor-1986
35CU7	Tseriadun	mid	Hall-2009
35CU2	Cape Blanco	-	Hall-2009

35CU106	Blundon	-	Hall-2009
35CU75	Blacklock Point	early	Hall-2009
35CU47	Strain Site (newman)	-	Hall-2009
35CS3	Bullards Beach	late	Aikens-2011 Hall-2009 Minor-1986 NPS 2017
35CS136	NA	-	Hall-2009
35CS69	NA	-	Minor-1986
35CS43	Nah-so-mah Village	late	Hall-2009 Hall-1995
35CS158	Busman	mid	
35CS61	Blue Barn	mid	
35CS5	Bandon Sandspit	late	Aikens-2011 Hall-2009 Tveskov-1999
35CS1	Philpott	-	Hall-2009
35CS120	Twin Dunes	mid	
35CS2	NA	-	Hall-2009
35CS62	NA	-	Hall-2009
35CS30	NA	-	Hall-2009
35CS17	NA	-	Hall-2009
35CS173	NA	-	Hall-2009
35CS142	NA	-	Hall-2009

35CS24	NA	-	Hall-2009 Minor-1986 NPS 2017
35CS114	Hauser	mid	Aikens-2011
35DO83	Umpqua-eden	mid	Aikens-2011 Hall-2009
35DO130	Tahkenitch Landing	early	Aikens-2011 Hall-2009 NPS 2017
35DO175	NA	-	Hall-2009
35LA25	Siuslaw Dune	late	Hall-2009 Minor-1999
35LA3	Devils Elbow	-	Hall-2009 NPS 2017
35LA16	NA	-	Hall-2009 NPS 2017
35LA10	Bob Creek	late	Aikens-2011 Hall-2009 NPS 2017
35LNC56	Good Fortune Cove	late	Aikens-2011 Hall-2009
35LNC57	Cape Creek Shell Midden	late	Aikens-2011 Hall-2009
35LNC54	Cape Perpetua	late	Aikens-2011 Hall-2009
35LNC55	Good Fortune Point	late	Aikens-2011 Hall-2009 Minor-1995
35LNC63	NA	-	Hall-2009 NPS 2017
35LNC48	NA	-	Hall-2009 NPS 2017
35LNC29	NA	-	Minor-1986
35LNC15	NA	-	Minor-1986
35LNC14	Seal Rock	late	Aikens-2011 Hall-2009 Lyman-1988

35LNC50	NA	-	Hall-2009
35LNC49	NA	-	Hall-2009
35LNC62	Yaquina Head	mid	Aikens-2011 Hall-2009
35LNC43	Rocky Creek	-	Hall-2009 NPS 2017
35LNC68	Rocky Creek Wayside	late	Aikens-2011 Hall-2009 NPS 2017
35LNC92	NA	-	Hall-2009
35LNC60	Whale Cove	late	Aikens-2011 Hall-2009 Lyman-1988
35LNC44	Government Point	mid	NPS 2017
35LNC101	NA	-	Hall-2009
35LNC100	NA	-	Hall-2009
35LNC45	Boiler Bay	mid	Hall-2009 NPS 2017
35TI35	Cove Creek Midden	-	Minor-1986 NPS 2017
35TI1	Netarts Sandspit	late	Aikens-2011 Hall-2009 Minor-1986 NPS 2017
35TI36	NA	-	Minor-1986 NPS 2017
35TI47	Oceanside	-	Hall-2009 Minor-1986 NPS 2017
35TI4	NA	-	Minor-1986
35CLT12	Indian Creek Village	-	Hall-2009 NPS 2017

35CLT21	Ecola Point	late	Aikens-2011 Hall-2009 Minor-1986 Minor-1991 NPS 2017
35CLT34	Indian Point?/Ivy Station	late	Aikens-2011
35CLT13	Avenue Q	late	Aikens-2011 Hall-2009
35CLT20	Par-tee	late	Aikens-2011 Hall-2009
35CLT47	Palmrose	mid	Hall-2009
35CLT66	Earl Dune	late	Aikens-2011 Hall-2009
35CLT33	Eddy Point	late	Aikens-2011 Hall-2009
35CLT22	Young's Bay 2	-	Hall-2009
35CLT16	Young's Bay	-	Hall-2009

Appendix 2. Carrying capacity model & parameters.

Parameters – for which there may be multiple for a single habitat variable – were estimated and confirmed by fitting the model to time-series survey data of sea otters along the central California coast. Annual counts (from 1983 – 2017, except 2011) and geographic location of sea otters were collected using shore-based and aerial surveys. Using a 100m spatial grid, total otter counts across all surveys were summed and key habitat variables recorded for each grid cell. Using Bayesian methods, a process model was fit to the observed survey data, and individual parameters were estimated to represent the functional relationship between otter densities at equilibrium and each of the habitat variables (Table 1).

Table 1. Parameters estimates from the CA model. A description of parameter is provided in text, as well as the mean, standard deviation (SD), and 95% confidence interval (CI) of the fitted posterior distribution. All parameters are associated with habitat features and environmental variables on the outer coast, except where indicated for estuaries. Table was adapted from Tinker et al. 2019 (in prep).

Parameter	Description	Mean	SD	Lower CI (95%)	Upper CI (95%)
k_s	Intercept; mean log-density in soft sediment habitats	0.5613	0.3025	-0.0297	1.1749
k_e	Alternative intercept; mean log-density in estuaries	1.2238	0.7384	-0.2421	2.6498
D^*	modal depth (at which mean densities are highest)	5.7711	0.6978	4.4123	7.1518
b_1	effect of decreasing depth from D^* on log-K	3.4262	1.2871	1.3157	5.9135
b_2	effect of increasing depth from D^* on log-K	0.1266	0.0072	0.1124	0.1409
a_{PR}	effect of increasing proportion of rocky substrate on log-K	1.7268	0.1346	1.4499	1.9786

a_{PK}	effect of increasing proportion of kelp cover on log-K	2.6727	0.1497	2.3820	2.9681
a_{DSR}	effect of deviations from mean slope on log-K, linear response	0.1816	0.0917	0.0006	0.3592
a_{DSR2}	effect of deviations from mean slope on log-K, quadratic response	0.2051	0.0637	0.0787	0.3283
a_{OFSH}	effect of increasing distance from shore beyond 1km (i.e. "far offshore effect") on log-K	-0.6058	0.1713	-0.9334	-0.2618
a_{NPP}	effect of increasing net primary production on log-K	0.5537	0.1305	0.3002	0.8117

Appendix 3. Oregon habitat variable datasets.

Bathymetry data – originally obtained from hydrographic surveys, multibeam surveys, and marine trackline data – were collected from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information U.S. Coastal Relief Model (CRM). We convert this layer into a 100m grid using bi-linear interpolation, and clip from 0m to 60m depths, and from the Columbia River in the north to the Oregon-California border in the south. Kelp canopy cover was collected from the Marine Resources Program at the Oregon Department of Fish & Wildlife. Kelp canopy was derived from multiple aerial kelp biomass surveys conducted in 1990, 1969-1999, and 2010. This data layer is a composite of all survey years. Using maximum area, we converted this kelp layer to our 100m grid, with each grid cell assigned a value for presence or absence of kelp canopy. We obtained benthic substrate data from the Active Tectonics & Seafloor Mapping Laboratory at Oregon State University. Substrate data was collected using several seafloor mapping surveys (e.g. multibeam sonar, side scan sonar, sediment grad samples, etc.). Substrate was classified as hard, soft, or mixed, following the classification scheme used to describe seafloor induration in Greene et al. 1999 (Greene et al. 1999). After comparing with our kelp layer, we reclassified any mixed substrate to hard as these areas could also provide important habitat for other rock-dependent species, such as sea urchins or abalone. Benthic substrate was converted to the 100m grid, with each grid cell assigned a value corresponding to the proportion of rock substrate within each grid. Net primary productivity (NPP) data was previously estimated for the California and Oregon continental shelves by Dr. Tom Bell from the University of Santa Barbara. Data was converted to our 100m grid using bi-linear interpolation, and we filled in the missing nearshore areas using k-d tree to assign cells with missing NPP values with an average of the 5 nearest cells. We incorporate an estuary layer, from Oregon State University, that represents Oregon's coastal tidal wetlands, based on interpreted historic and present remote sensing data. Sea otters regularly use estuarine environments – as evidenced by Elkhorn Slough – as these features provide access to additional prey resources and protection from outer coastal conditions (Hughes et al. 2013). Given the sea otter's high prey requirements, we only include estuaries with seagrass beds, identified from an Oregon shoreline study (Oregon Shorezone 2013), as seagrass could provide habitat for otter prey, such as crabs. Additionally, we only include estuaries with permanently open access to the outer coast. Access was assessed using Google Maps and online sources, such as The Oregon Conservation Strategy and the Oregon Coastal Atlas. While searching for an Oregon land polygon, we found many publicly-available data layers disagreed on the shoreline structure and position. After comparing several datasets, we merged a rocky and sandy shorelines layer from ODFW – used in Oregon's Territorial Sea Plan – and created our own Oregon land polygon. We visually compared this new land polygon with satellite imagery included in several ESRI base maps, provided in the ArcGIS 10.6 program package, to ensure this accurately represented the shoreline.

Appendix 4. Effect of depth, distance-to-shore, and slope

Seafloor slope dictates how dense or spread out a sea otter population is in space. Several areas along the California coast have shallow slopes, where relatively low depths exist further offshore, creating accessible habitat for sea otters. Other locations have steeper slopes, where the bathymetry increases – beyond sea otter diving capacity – relatively closer to shore. This difference in seafloor slope could produce more spread out and denser, respectively, sea otter populations. We incorporate this effect by calculating seafloor slope, using the Euclidean distance-to-shore and depth at each grid cell. In California, researchers observed a strong, non-linear relationship between the log of distance-to-shore and depth (D_g). To detrend distance-to-shore (DS_g) from depth and gain a better understanding of how slope effects otter densities, we apply the following equation:

$$\log(DS_g + 1) \sim 1.669 \cdot D_g^{\;0.289} + 3.123$$

The numeric values in the least-squares equations were estimated using maximum likelihood methods and fit to grid cells along the California coast (Tinker et al. 2019, in prep). The residuals (DSR_g) of this equation are independent of depth and provide a straightforward index of slope, where positive values represent areas that are shallower than expected (i.e. average slope) and negative values represent areas that are steeper than expected.

Appendix 5. Carrying capacity terms

Adult female sea otters can disperse up to, on average, 4 - 5km in one day (Ralls et al 1995, Tinker et al. 2017). This presents potential measurement uncertainty and sampling error during population surveys. Before calculating our expected sea otter densities, we account for this dispersal capability by applying a 4km smoothing window to select habitat variables (kelp, benthic substrate, and the residuals of the distance-to-shore) along predetermined depth bins. We first divide our habitat into 3 large classes of depth: 0m to 20m, 20m to 30m, and 30m to 60m. We then further subdivide these depth classes into individual bands by dividing our 0m to 20m depth class into equal-size bands every 1m in depth, our 20m to 30m depth classes every 10m in depth, and out 30m to 60m depth classes every 5m in depth. A 4km smoothing window was then applied to each of these contiguous depth bands, individually, to average our habitat variables.

There is a non-linear and asymmetrical functional relationship between otter density and depth (Tinker et al. 2017). To account for this depth effect within the carrying capacity equation, we include the following function:

$$f(D_g \mid \beta_i, D^*) = -0.01 \cdot \left[\beta_1 \cdot \max\left(0, D^* - D_g\right)^2 + \beta_2 \cdot \max\left(0, D_g - D^*\right)^2 \right]$$

D* is the model depth at which otter densities peak, while B_1 and B_2 are the rates of otter density decrease as one moves away from the model, either inshore or offshore, respectively.

Appendix 6. Human activity data layer sources & analyses

Accessibility

We assess access to the shoreline and suitable habitats as accessibility could facilitate (1) effective management and research, which could increase reestablishment potential, and/or (2) increase recreation and coastal visitation, which could serve as a source of human disturbance and potentially decrease reestablishment potential. Coastal viewing points were collected from two sources - an Oregon beach access and state parks layer created by the Oregon Parks & Recreation Department, Department of Land Conservation and Development, and the Oregon State Marine Board, and a public access site metric data layer for the Oregon Coastal Zone from NOAA. We found a high degree of overlap between viewing points identified in both layers. However, they did not fully agree. To account for all potential viewing points, we combine these two layers and excluded any duplicate points occurring in the same geographic location. The beach access data layer included access points for a variety of activities and uses, including boating, pedestrian, vehicles, view points, and not developed. For viewing points, we were only interested in locations where sea otters could be observed from the shoreline by foot. Therefore, we exclude any activity, except for pedestrian and view point, before combining with the NOAA data layer. We defined boat access points as any large port collected from a 2011 Ecotrust study that identified large ports that supported shoreline infrastructure and businesses, as well as dock large vessels.

We use two metrics to determine accessibility: (1) mean number of viewing points per kilometer of coastline and (2) distance (km) (for vessel travel) to suitable habitats. We define viewing points as any point within 1km of either the shoreline or an estuary. Boat access points were defined as any coastal port that provides facilities for large ships and commercial fishing vessels (Hesselgrave et al. 2011). We also included smaller ports and ramps where small research vessels could be deployed (e.g. Salmon River, Cannon Beach, Depoe Bay). For the outer coast, we measured the distance from ports to the nearest suitable habitat. For estuaries, no suitable habitat was identified. Therefore, we took the centroid of each estuary and measured the distance from the closest port or ramp. Viewing and boat access points were extremely clustered. To remove unnecessary clustering and avoid overestimating accessibility, we omitted any point within 1km of another.

Fisheries

Sea otters can sufficiently reduce local prey densities (Estes et al. 1995). Oregon has several commercial and recreational fisheries that target typical sea otter prey, including Dungeness crab, Oregon's most lucrative fishery (Davis et al. 2017). Fishermen responses were only collected for the outer coast. To attempt to compare with estuaries, we obtained publicly available commercial landings data (ODFW Landing Statistics) and averaged the annual pounds landed across all ports for bay and outer coast Dungeness crabs, from 2004-2010. We estimated that approximately 99% of all commercial Dungeness crab catch was landed from the outer coast, during that period. Based on this finding, we assume that if stated importance was collected for estuaries, estuaries would not be identified in the top 75% most important crabbing grounds. Therefore, we did not assess the overlap between estuaries and crabbing grounds.

Protected areas

We assessed protected areas because, while various human activities and fisheries activity could disturb sea otters, protected areas could prevent these types of interactions by providing a “safe haven” for otters where they are spatially separated from people. We define protected areas as any marine reserve or national wildlife refuge with no-take restrictions. Oregon has 5 no-take marine reserves (Redfish Rocks, Cape Perpetua, Cape Falcon, Cascade Head, and Otter Rock) within our study area. The Oregon Coast National Wildlife Refuge Complex is composed of 6 individual national wildlife refuges (Oregon Islands, Three Arch Rocks, Cape Meares, Bandon Marsh, Nestucca Bay, and Siletz Bay) spanning both the coastal and nearshore environments. Of these refuges, we only include the Oregon Islands National Wildlife Refuge as it is the only refuge that affords protection to the water (500 feet around any rocks, islands, or cliffs) (Fish and Wildlife Service 2009). We create a 500ft buffer around each island and cliff to serve as protected areas. We quantify both the total predicted abundance of sea otters occurring within and outside suitable habitats, within protected areas. We include the South Slough National Estuarine Research Reserve in Coos Bay. Data on important commercial crabbing grounds were also collected from the 2011 Ecotrust study that spatially-identified crabbing grounds using interviews (Ecotrust 2011). Marine reserve spatial data was collected from ODFW’s Marine Reserve Program and the national wildlife refuge data was obtained from the U.S. Fish & Wildlife Service’s National Cadastral Data. South Slough National Estuarine Research Reserve was also obtained from the National Estuarine Research Reserve System.

Appendix 7. Predicted sea otter densities (otters/km^2) from carrying capacity model.

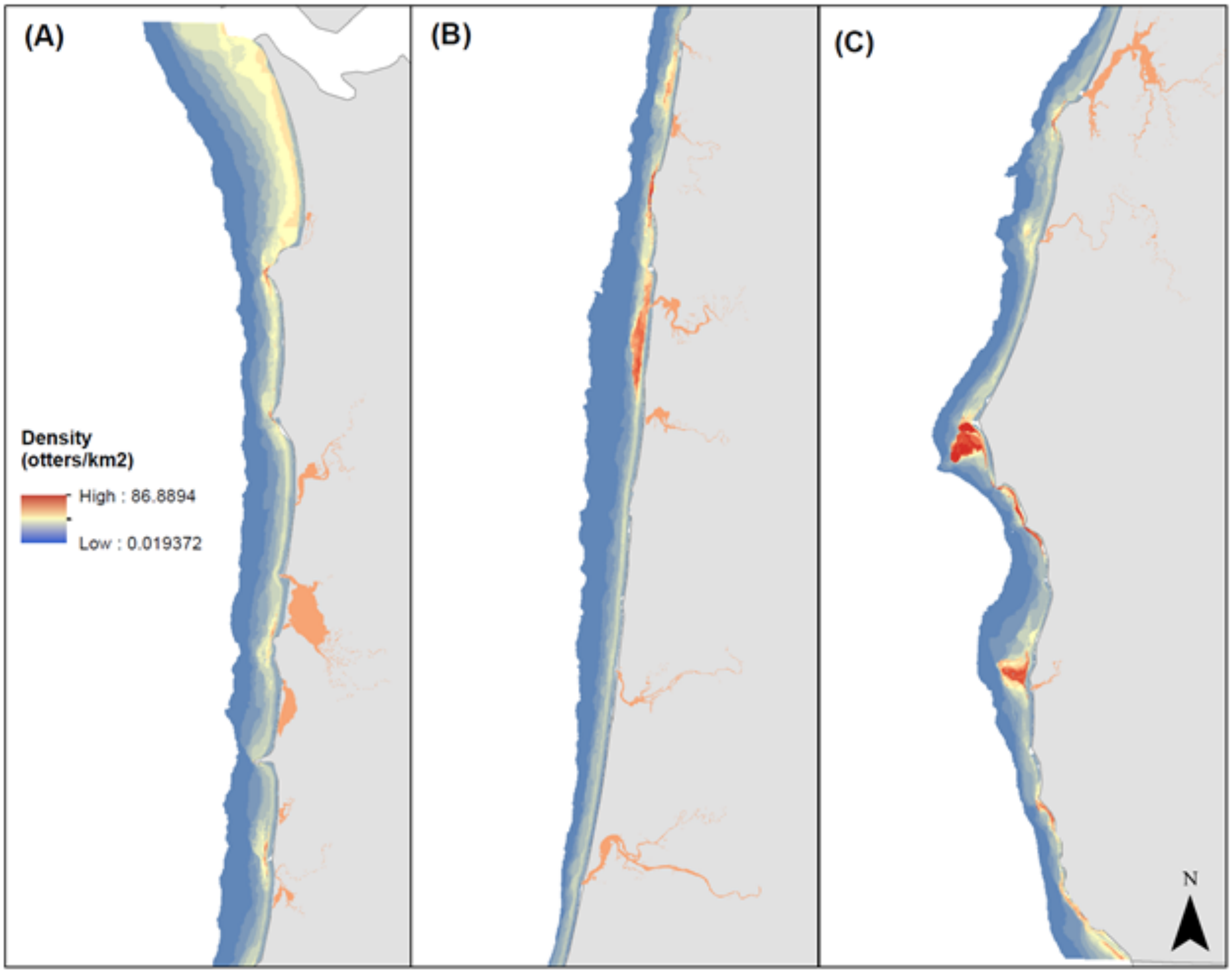
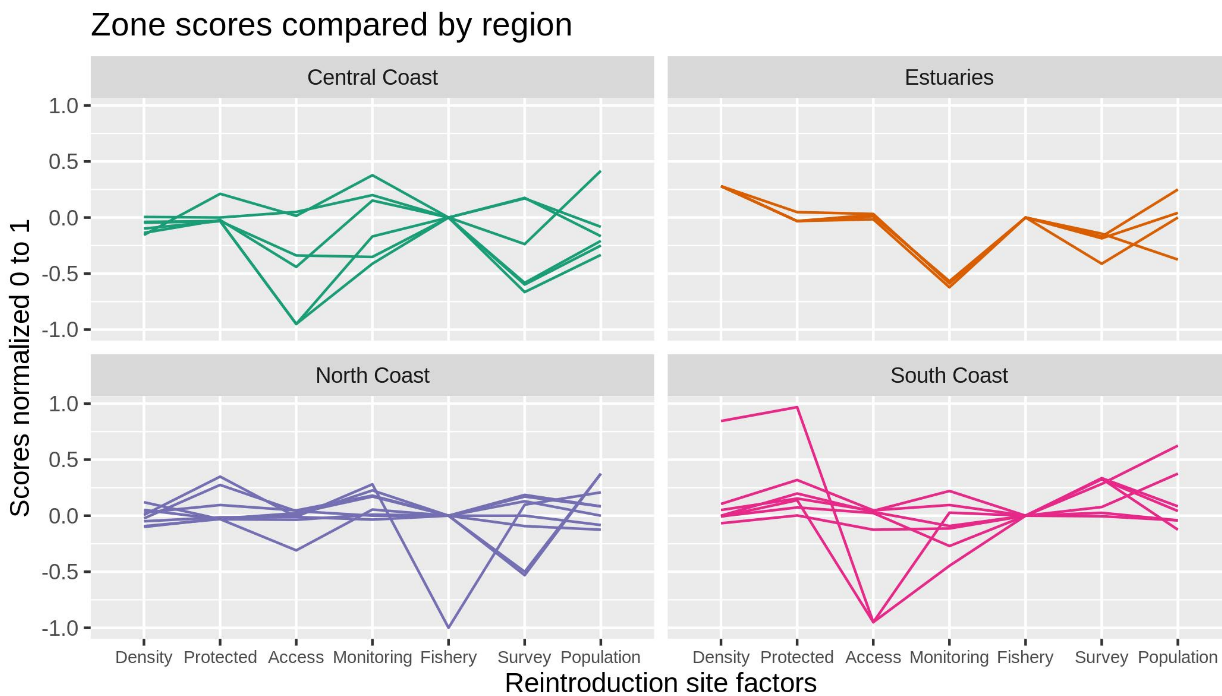
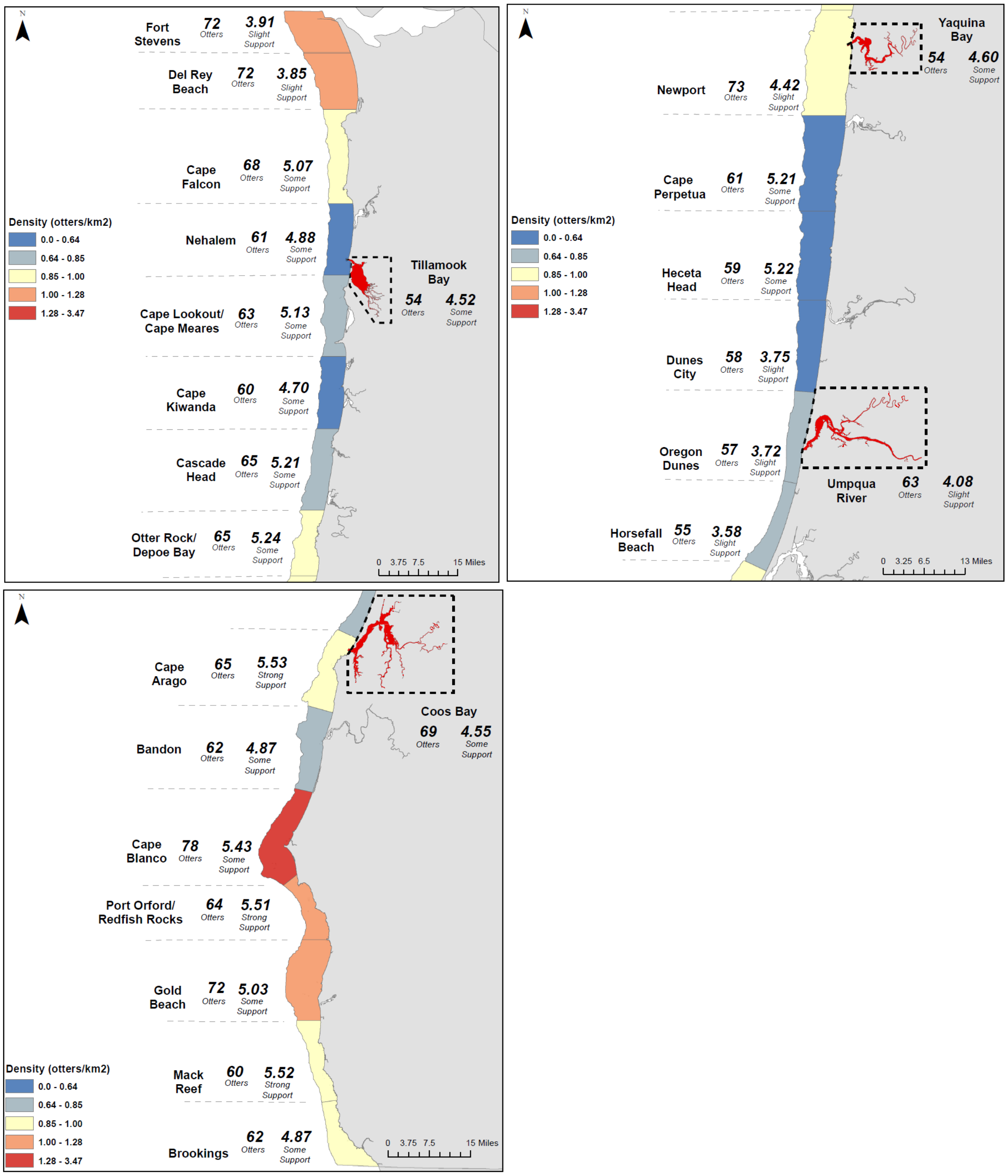


Figure 2. Predicted sea otter densities from the carrying capacity model. Results are presented in regions for visualization (A = north, B = central, C = south).

Appendix 8: Regional comparisons



Diverse metrics were used to rate potential sea otter reintroduction zones. Here, scores are univariately set to a min:mix scale with the center at the median. Density is carrying capacity/km^2, Protected is projected abundance within marine protected areas, Access is boat travel time (negative factor), Monitoring is viewpoints/km coastline, Fishery is known conflict with crabbing, Survey is the level of support by survey respondents, and Population is projected abundance after 7 years of reintroduction effort.



North Coast, Central Coast, and South Coast zones are presented with several key metrics of social/ecological support for their potential as sea otter reintroduction sites. Potential density of sea otters is based on habitat evaluation. Numbers of otters are those projected after 7 years of population growth following an initial introduction of (net) 20 individuals, followed by 7 years x 4 individuals of augmentation. Support are mean levels of favorable support in the survey (1: strongly oppose - 6: strongly support).