RESTORING SEA OTTERS TO THE OREGON COAST

A FEASIBILITY STUDY

M. TIM TINKER, JAMES A. ESTES, JAMES L. BODKIN,
SHAWN LARSON, MICHAEL J. MURRAY, AND JAN HODDER

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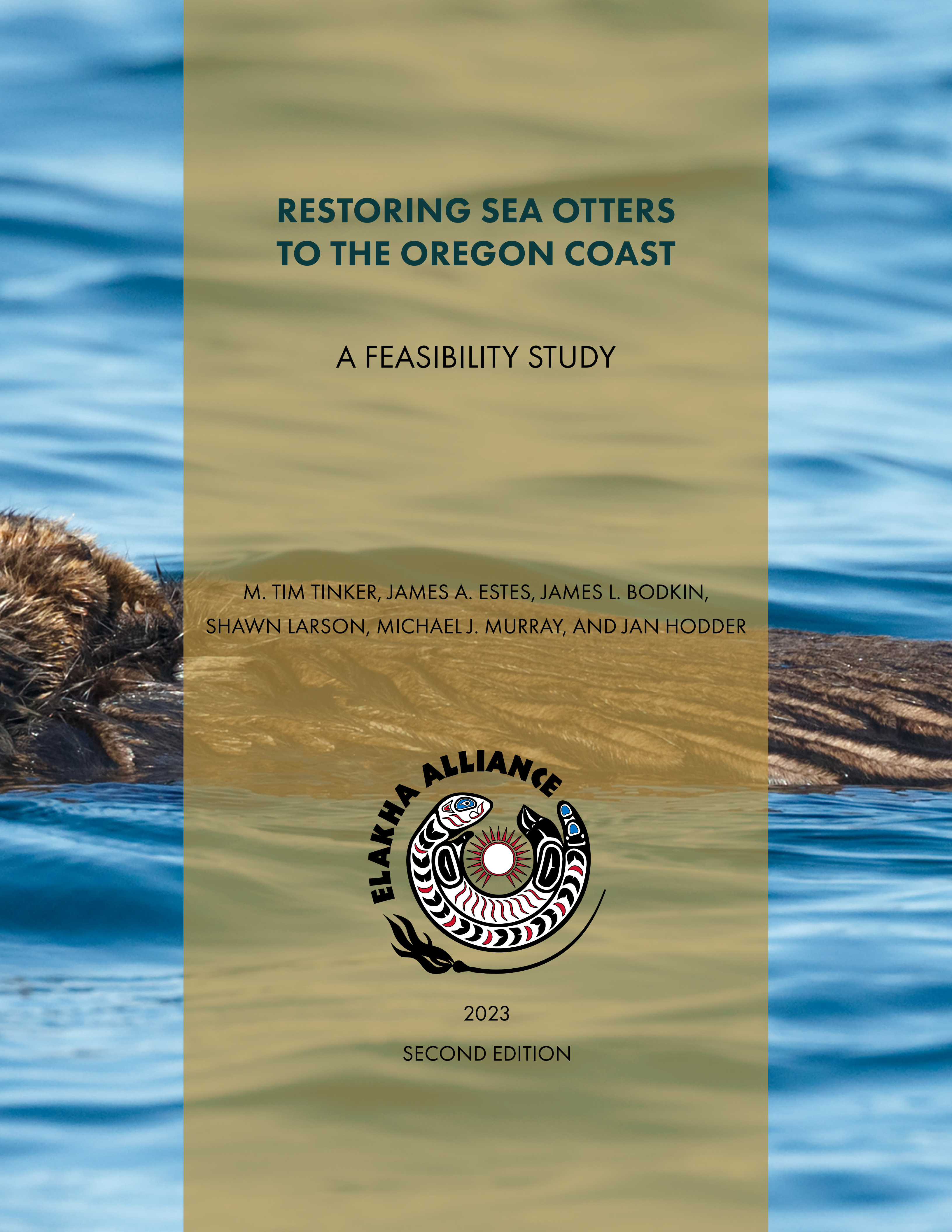

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FOREWORD

The guiding spirit behind this study is David Hatch, a member of the Confederated Tribes of Siletz Indians. He first promoted the idea that sea otters were once part of the lives of coastal Indian people, a central element of the rich, productive marine ecosystem along the Oregon coast, and that sea otters belonged back in Oregon. He came to this idea when, in search of the name for a small boat he had built, he happened on the word "Elakha," the word of the Indigenous Clatsop and Chinook People for sea otter that had entered the so-called Chinook Trade Jargon in the early 1800s. This jargon enabled coastal and inland Indians, sea captains, American and French fur trappers, and others to communicate in this still-wild corner of the world. As Dave began to recruit others to his idea, he dubbed this informal group of individuals and institutions the Elakha Alliance.

After his untimely passing in 2016, many of those touched by his idea came together and determined that the time was right to formalize the Elakha Alliance and actively pursue Dave's dream of restoring sea otters to the Oregon coast. The Elakha Alliance was formally incorporated in 2018. Its board consists of individuals from tribal, nonprofit, scientific, government, and conservation backgrounds with a shared vision of an Oregon coast 50 years from now where our children and grandchildren coexist alongside a thriving sea otter population and a robust marine ecosystem. Thus, the mission of the Elakha Alliance is to restore a healthy population of sea otters to the Oregon coast and, in the process, help make Oregon's marine ecosystem more robust and resilient.

This feasibility study was commissioned by the Elakha Alliance to ensure that the best available scientific information and conservation experience could be brought to bear on discussions with the public and decision-makers about restoring a population of sea otters to the Oregon coast. The study's topics are the result of extensive discussions among leading scientists, agency staff, and conservationists that culminated in a workshop in Seattle in March 2020. This study publishes no new research findings; rather, it is a review and synthesis of existing published information. However, one element that perhaps is "new" is the computerized population model, ORSO, referenced in Chapter 3 and Appendix A. It allows a user to go online and develop different scenarios of translocation and reintroduction for consideration.

Several people played a key role in completing this feasibility study. From the beginning, Paul Henson, former Oregon State Supervisor for the U. S. Fish and Wildlife Service, encouraged our efforts to be the public face of this important work and provided the funds necessary to complete the feasibility study. Lilian Carswell, Southern Sea Otter Coordinator for the U. S. Fish and Wildlife Service, was steadfastly supportive, offering critical advice and information based on years of work on sea otters in California. James Estes, world-renowned "granddaddy of sea otter science," was so very generous in his counsel, quite apart from his long list of scientific accomplishments. He helped us realize that this was not only a good idea but a necessary one that could be accomplished. Michele Zwartjes, U.S. Fish and Wildlife Service, cheerfully and expertly navigated the stream of paperwork needed to direct the funds to this project. These and a long list of other scientists, agency staff, and conservationists contributed to bringing this feasibility study to life.

We especially owe a big thanks to the enthusiastic leadership of principal author Tim Tinker, who has spent a career studying sea otters and their ecology all around the Pacific Rim and has seemingly collaborated with everyone who ever uttered the words "sea otter." When approached about leading this study for our young, unknown organization, Tim hesitated only a moment before agreeing with a twinkle in his eye. He subsequently recruited a world-class team of contributing authors: James Estes, James Bodkin, Shawn Larson, Mike Murray, and Jan Hodder, each of whom brought a lifetime of scientific inquiry and professional experience and enthusiastically aligned their reputations with our upstart effort. Their professional biographies are contained later in this document.

Last, we acknowledge that this study is possible only because of the untold number of scientists, graduate students, technicians, and others across a staggering array of scientific disciplines whose work over the past 50 years has generated a high level of scientific understanding of sea otters and their ecology. Their work has enabled us to assess, with some confidence, the feasibility of returning a population of sea otters to the Oregon coast. These and many others are part of the Elakha Alliance.

Robert Bailey
President of the Elakha Alliance

It is yet to be shown that transplanted otters will form colonies and repopulate vacant habitat. Southeastern Alaska offers hundreds of miles of coastline suitable for sea otters. Will the transplanted otters behave like certain other mammals and scatter after release and therefore fail to form breeding aggregations? Might they also behave like other mammals and seek to return to the home territory where they were captured? These questions can be answered only by continued experimentation.

~ Karl Kenyon, 1969, p. 322 [1]

Note: Today over 30,000 sea otters exist in Southeast Alaska as a result of the experimental translocations begun by Kenyon.

1 Kenyon, K. W. 1969. The sea otter in the eastern Pacific Ocean. *North American Fauna* **68**:1-352. https://doi.org/10.3996/nafa.68.0001.

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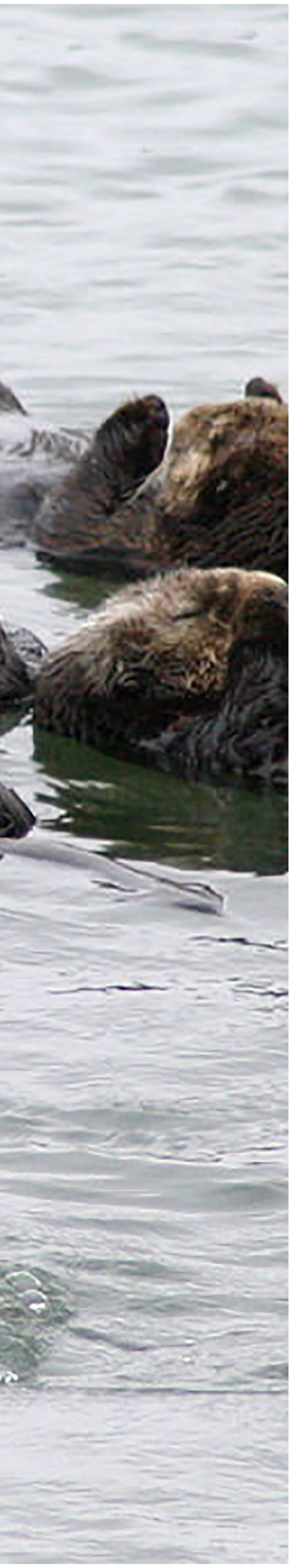
LIST OF ABBREVIATIONS



AP	acanthocephalan peritonitis
APHIS	Animal and Plant Health Inspection Service
AZA	Association of Zoos and Aquariums
CDF	cumulative distribution function*
CFR	Code of Federal Regulations
CI	confidence interval
CITES	Convention on International Trade of Endangered Species of Wild Fauna and Flora
COD	cause of death
CTCLUSI	Confederated Tribes of Coos, Lower Umpqua, and Siuslaw Indians
CZMA	U.S. Coastal Zone Management Act of 1972
DA	domoic acid
DMSI	digital multispectral imaging
DPS	Distinct Population Segment
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPB	Oregon Estuary Plan Book
ESA	U.S. Endangered Species Act of 1973
EVOS	Exxon Valdez Oil Spill
FAWC	U.K. Farm Animal Welfare Council
FR	Federal Register
G	growth transition parameter*
GIS	geographic information system
HAB	harmful algal blooms
IPM	integrated population model
IUCN	International Union for Conservation of Nature

K	carrying capacity
MMPA	U.S. Marine Mammal Protection Act of 1972
MPN	most probable number
mtDNA	mitochondrial DNA
NA	not available / not applicable
NE	northeast
NEPA	U.S. National Environmental Policy Act of 1969
NLD	net annual linear displacement*
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPP	net primary productivity
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
ORSO	Oregon Sea Otter Population Model
OSU	Oregon State University
PDF	probability density function*
PMEP	Pacific Marine and Estuarine Fish Habitat Partnership
PN	*Pseudo-nitzschia*
PVC	polyvinyl chloride
R	reproductive output*
RUVD	Recreation Use Values Database
S	stage-specific annual survival*
SC	south-central
SCORP	Statewide Comprehensive Outdoor Recreation Plan
SE	southeast
SEACOR	Shellfish and Estuarine Assessment of Coastal Oregon
SSNERR	South Slough National Estuarine Research Reserve
STX	saxitoxin
SW	southwest
TBT	tributyltin

U.S.	United States
U.S.C.	U.S. Code
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
VHF	very high frequency

* In ORSO; see Appendix A.

GLOSSARY

This feasibility study does not include a glossary. However, key terms are defined throughout, and you may access an online glossary of these terms at https://www.elakhaalliance.org/feasibility-study/glossary.

Photo by Ingrid V. Taylar on Flickr.

Chapter 1

INTRODUCTION

M. Tim Tinker

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 as playing 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 18th and 19th centuries, 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, no sea otter population exists 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:

- restoring the various ecological functions of a keystone species formerly present in Oregon's marine environment;
- restoring the cultural relations between sea otters and human residents along Oregon's coast;
- 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
- 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 nonprofit 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 [International Union for Conservation of Nature] 2013). For this study, we use the term *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 Midwest United States and Canada (Tordoff and

Redig 2001), and fisher populations in the Pacific Northwest 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 recovering this species from near extinction (Jameson et al. 1982, Bodkin 2015; see Chapter 2 for more about 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/sex classes or selecting inappropriate habitats (Kleiman 1989, Wolf et al. 1998). 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) identified 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) socioeconomic 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 initial feasibility assessments for any reintroduction efforts under consideration.

THE GOAL OF THE FEASIBILITY STUDY

The feasibility study's overall goal 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 regard to

1. implications for the viability of source populations and newly established populations
2. suitability of habitat and the potential for positive and negative effects on ecosystems
3. social and economic impacts, both positive and negative
4. administrative and legal requirements
5. logistical constraints and steps for implementation

It is also important to emphasize what this study is not intended to be: Specifically, it is not intended as a definitive statement about whether reintroducing 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 study is to provide a comprehensive source of pertinent information, history, and the 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), argue for feasibility in the broadest definition of the word.

This study 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, we intend to amass and synthesize the relevant information we believe 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. Secondarily, we seek to provide guidance about what elements such a proposal should include.

CONTENTS OF THIS STUDY

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

Chapter 2, "History of Prior Sea Otter 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 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 a reintroduction effort's success. A principal tool in this assessment is the Oregon Sea Otter Population Model (ORSO), a computerized population model built upon the foundation of previously published population models for sea otters. This model provides a quantitative modeling framework for evaluating probable outcomes and associated uncertainties of various reintroduction scenarios. The model methods are explained in detail in Appendix A, 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.

ORSO uses a stage-structured matrix model of sea otter demography to project future trends in abundance and changes in the 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. It incorporates density dependence, Allee effects,[1] environmental and demographic stochasticity, and realistic dispersal and range expansion behaviors. 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 and Historical Considerations of Oregon Sea Otters," explores the implications of reintroducing sea otters to Oregon from genetic and historical perspectives. 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 the relatedness of 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 of Sea Otters," broadens the assessment from biological and demographic considerations to the ecosystem-level implications of a sea otter reintroduction. Sea otters are often considered 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 to or naturally recovered in other coastal

1 The Allee effect is a phenomenon in biology whereby population size or density is correlated with mean individual fitness (often measured as per capita population growth rate). A positive association may (but does not necessarily) give rise to a critical population size below which the population cannot persist. More at https://www.nature.com/scitable/knowledge/library/allee-effects-19699394/.

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 discusses 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 Oregon's nearshore habitats 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 the availability of critical habitat features. Such an analysis represents an important step in selecting prospective sites for future reintroduction efforts. Also, it 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 begins with a broad overview of the existing literature and previous examples of sea otter socioeconomic impacts. It then focuses on Oregon more specifically. This discussion of socioeconomic impacts is primarily conducted qualitatively. A separate document offering an economic impact assessment has been completed for the Elakha Alliance (2022) and provides a more quantitative examination.

Chapter 8, "Administrative and Legal Considerations," further examines the social dimensions of sea otter reintroduction, reviewing the legal and policy considerations. As with any reintroduction effort, many legal issues are involved. The reintroduction of a marine mammal 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 concerning different applications depending on the reintroduction scenario, especially the selection of a source population.

Chapter 9, "Implementation and Logistical Considerations," discusses practical and logistical considerations of alternative reintroduction scenarios. The logistics considered include some of the topics addressed elsewhere in the study, such as the 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 sea otter reintroduction, it does provide a useful overview of the topics that would need to be addressed in a detailed proposal.

Chapter 10, "Animal Health and Welfare Considerations," addresses a specific set of risks inherent in sea otter reintroductions, centered on sea otter health and welfare considerations. There is rich and extensive literature addressing 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 relevant to 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. Still, it is intended to help foster an open and candid discussion about some societal challenges associated with sea otter recovery. Also, it is meant 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 previous chapters and provides some final thoughts about how these findings might be explored further or developed in any next steps that might occur.

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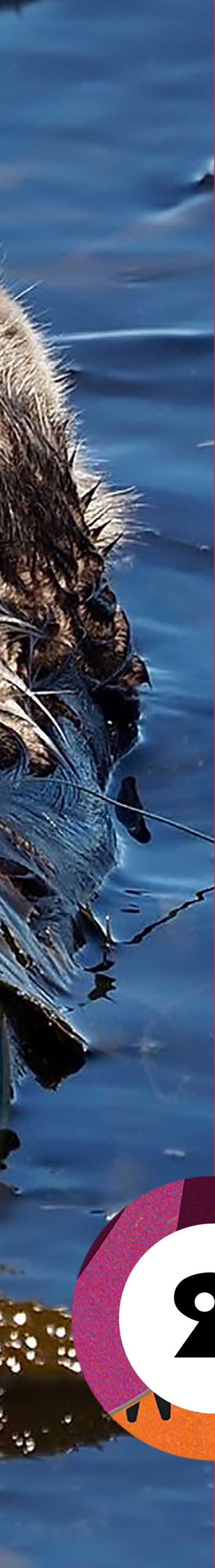

Chapter 2

HISTORY OF PRIOR SEA OTTER TRANSLOCATIONS

James L. Bodkin, James A. Estes, and M. Tim Tinker

Translocations or reintroductions of wildlife are often employed as a tool to mitigate human activities' direct or indirect effects 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 of translocations and reintroductions have also come to include ecosystem restoration (Moritz 1999, Hale and Koprowski 2018). Most recently, establishing genetic connectivity and the recovery of genetic diversity within species and across habitats have become desired attributes and explicit objectives 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 (*Enhydra lutris*) recovery following the North Pacific maritime fur trade and translocations since the mid-19th century (Table 2.1 and Figure 2.1) provides a 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 the 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 behaviors, 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 recovery process illustrate many biological, ecological, 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 the evaluation of achieving specific translocation goals.

HISTORY OF SEA OTTER TRANSLOCATIONS

The first documented sea otter translocation was 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 1947/1962). The intent of the translocation was to establish an additional colony to supplement Russian fur production through captive and wild rearing. It included developing techniques to hold sea otters in captivity before 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 recognizing the need for and documenting suitable environmental conditions and habitats with adequate and appropriate prey resources at the release site before translocation (Barabash-Nikiforov 1947/1962). The second is that animal husbandry practices appropriate to the species are criti-

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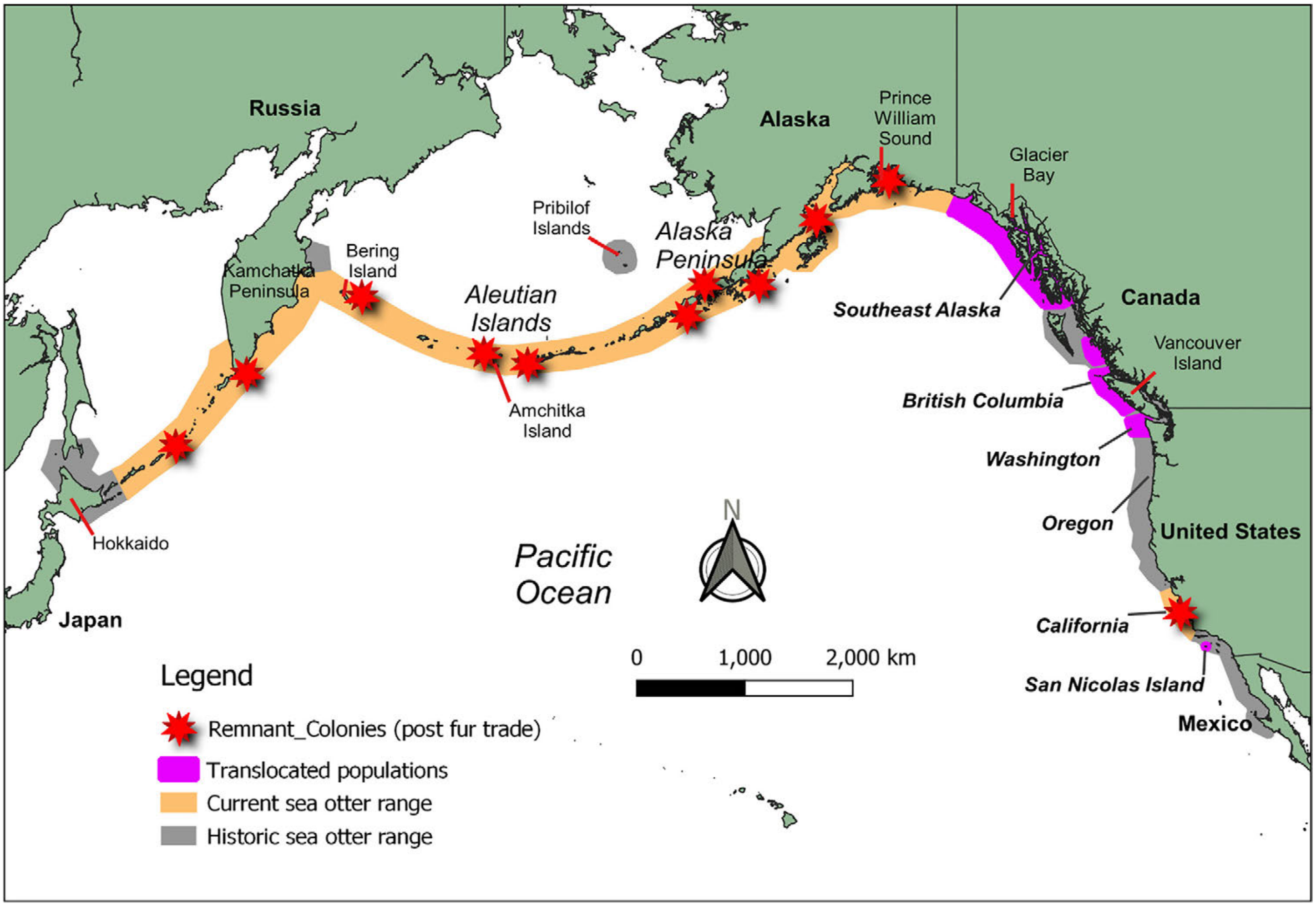
Figure 2.1. Map of the North Pacific showing historical and current sea otter ranges.



Note. The current sea otter range includes translocated populations. The locations of the remnant colonies left at the end of the fur trade (from which present-day populations are descended) are also shown.

cal to translocation success, particularly while in transport. The third is that holding animals in captivity is feasible, and acclimating 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 1947/1962).

Initial efforts to restore sea otter populations within their historical 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 failed. They were translocated in groups of five to 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 five) in the western Aleutians. Fifty-three of the animals captured in these early translocations died in captivity before 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 before 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 (five to Attu in 1956 and six 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

Table 2.1. Summary statistics for 10 previous sea otter translocation and reintroduction efforts.

Release location	Year(s)	Source	Intended for release	Number released	Success	Approx. founding number	Recent estimate
Murman Peninsula	1937	Bering Island, Russia	9	2	no	1	0
Pribilof Islands	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	7000
Washington	1969–1970	Amchitka, Alaska	59	59	yes	10	> 2000
Oregon	1970–1971	Amchitka, Alaska	93	93	no	0	0
San Nicolas Island, CA	1987–1990	California	142	139	yes	12	121
Elkhorn Slough, CA	2002–2016	California	37	37	yes	37 + ~25 wild	120

Note. NA means "not available," and SE means "southeast."

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 a less-than-optimal habitat.

Concurrent with both the Russian and U.S. early translocation attempts, work was undertaken to develop animal husbandry methods that might increase the survival of sea otters in captivity (Barabash-Nikiforov 1947/1962, Kenyon and Spencer 1960, Kenyon 1969). High mortality during holding and transport in both the Russian and American initial attempts identified the critical need for sea otters to maintain their fur's integrity 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 before introduction and improving future translocation success. While early translocations resulted in high mortality and largely failed efforts, insights gained eventually led to what became 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 (SE) Alaska. Twenty-three of these animals survived to be released to Chichagof Island in SE Alaska (Kenyon 1969). Although pre-release mortality was high (44% of the 41 otters) due to overheating in flight, possibly related to tranquilizing, at least some individuals were resighted in 1966.

This event 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 SE 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 and 1971 (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 10 years, with sporadic observations of independent animals until at least 1976 (Schneider 1981). There was some suggestion that their continued presence may have reflected immigration from otters reoccupying historical 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 failures 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 manifest. (2) Frequent and systematic monitoring of post-release populations during the first decade could help inform management actions to influence successful establishment, perhaps through enhancing survival, reducing mortality, or augmenting abundance via supplementary introductions of additional animals.

The reintroductions to SE Alaska, British Columbia, and Washington clearly established the feasibility of reintroductions as a tool to enhance the recovery of sea otters across their range. In SE 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 7000 individuals resided along British Columbia (Nichol et al. 2015), and more than 2000 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 U.S. Fish and Wildlife Service (USFWS) 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 effort was the first translocation to explicitly aid in the recovery of the southern subspecies of sea otter listed under the Endangered Species Act. It was also the first translocation to rigorously evaluate the health of individuals, define the 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 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 San Nicolas Island began to increase in the late 1990s (10 years after the translocation), and a recent census reported a population of 121 animals in 2019, with a five-year average annual rate of increase of 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 unclear whether 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 translocations dedicated significant efforts to ensuring suitable and abundant prey was available at release sites (Barabash-Nikiforov 1947/1962, USFWS 1987). While abundant prey resources do not ensure the rapid and successful establishment of any introduced population, they are nonetheless essential to ensure 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 historical 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 the typical weaning age (six to eight 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 socializing and bonding among the animals eventually released. Third, in contrast to all prior translocation release sites, which 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 already occupied by otters for at least two decades, although in limited numbers and primarily by males. (No reproduction had occurred in the slough before 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 the recapture of juveniles and further rehabilitation in captivity before 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 individuals' capture, holding, transport, and release, 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 the water near where animals reside and long-handled *dip nets* on haul outs or in open water when they are at rest. Most recently, specially designed diver-operated traps, called *Wilson traps*, have been used to capture otters from under the water (Ames et al. 1986, Monson et al. 2001). Federal and state/provincial governments highly regulate the capture of sea otters and require adherence to stringent permitting conditions. In the United States, sea otter permits fall under the purview of the USFWS Division of Management Authority. Permit acquisition 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 species conservation and management. Obtaining the necessary permits for translocation depends on the source population(s) status 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 low rate of morbidity should be expected when handling large numbers of sea otters. Additional details on current capture, holding, transport, and release procedures can be found in Chapter 9 and in Ames et al. (1986).

LESSONS LEARNED FROM PAST TRANSLOCATIONS

Over the past 80 years, nearly 1000 sea otters have been captured, held, transported, and released into unoccupied habitats to restore populations. It is evident that the earliest translocations gave inadequate attention to the physiological needs required 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 1947/1962, Kirkpatrick et al. 1955, Kenyon 1969). Since these 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 their release and, in most cases, appeared to stabilize at 10%-50% of the original number released. Researchers have a 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 the marking of individuals moved to San Nicolas Island provided new insights 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 habitat suitability and prey abundance (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 finding 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 (U.S. Geological Survey, unpublished data). Sea otters translocated into vacant habitats appear unlikely to remain where released, despite the general habitat suitability and prey abundance, 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 only occurring after populations became established, and this dearth 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 at or near the maximum rates feasible for sea otters (Estes 1990), averaging approximately 20% per annum, and significantly greater than growth rates observed in remnant populations (≈ 10%; Bodkin et al. 1999). One recent exception to these results was the 1987 translocation to San Nicolas Island (Rathbun et al. 2000, Carswell 2008), where, following three 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 SE 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 to 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 subadults 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 approximately 12%.

The history of the San Nicolas translocation provided new and vital 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 the 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 by capturing and removing 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 nonlethal 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 must be accounted 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 on 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 translocations to SE Alaska, British Columbia, and Washington (Bodkin 2015).

Third, even successful reintroductions often undergo an establishment phase during which their ultimate success can be questionable (see Chapter 3). During this phase, a variety of factors 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 rates at release sites. Careful consideration of the behavior and social structure within parent populations that may affect the probability of retaining 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, translocations can play roles in restoring coastal marine ecosystem structure and function, from coastal rocky reefs to estuaries (Estes and Palmisano 1974, Hughes et al. 2019; see Chapter 5), and in recovering genetic diversity and facilitating genetic connectivity among sea otter populations (Larson et al. 2015; see Chapter 4). The roles provide ample justification for considering future efforts to continue restoring sea otters and coastal ecosystems.

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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, by the population's performance after the reintroduction. The key metrics of performance are thus evaluated at the population level rather than the individual level. According to the guidelines of the International Union for Conservation of Nature (IUCN) Species Survival Commission:

> 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 a reintroduction program's feasibility is a realistic population and demographic assessment. If a proposed reintroduction is unlikely to result in a viable population within the recipient habitat, 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. These population and demographic considerations represent just one component of a broader suite of issues to be considered before initiating a reintroduction, including socioeconomic, political, and organizational considerations (Reading et al. 2002). Nonetheless, it is a necessary step to carefully examine the likely population-level consequences of reintroduction. We consider these consequences with respect to the source populations (i.e., the population from which individuals will be taken for the reintroduction), 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 removing 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), and the impacts are likely to vary among these potential sources. We consider three potential source populations here: Southeast (SE) Alaska, California, and aquarium-rehabilitated stranded juvenile sea otters (*Enhydra lutris*) 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 Washington as a fourth possible source population 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 the potential use of the Washington population as a source. We note that a population model for Washington was published in the past year (Hale et al. 2022) and is available for use in a similar assessment.

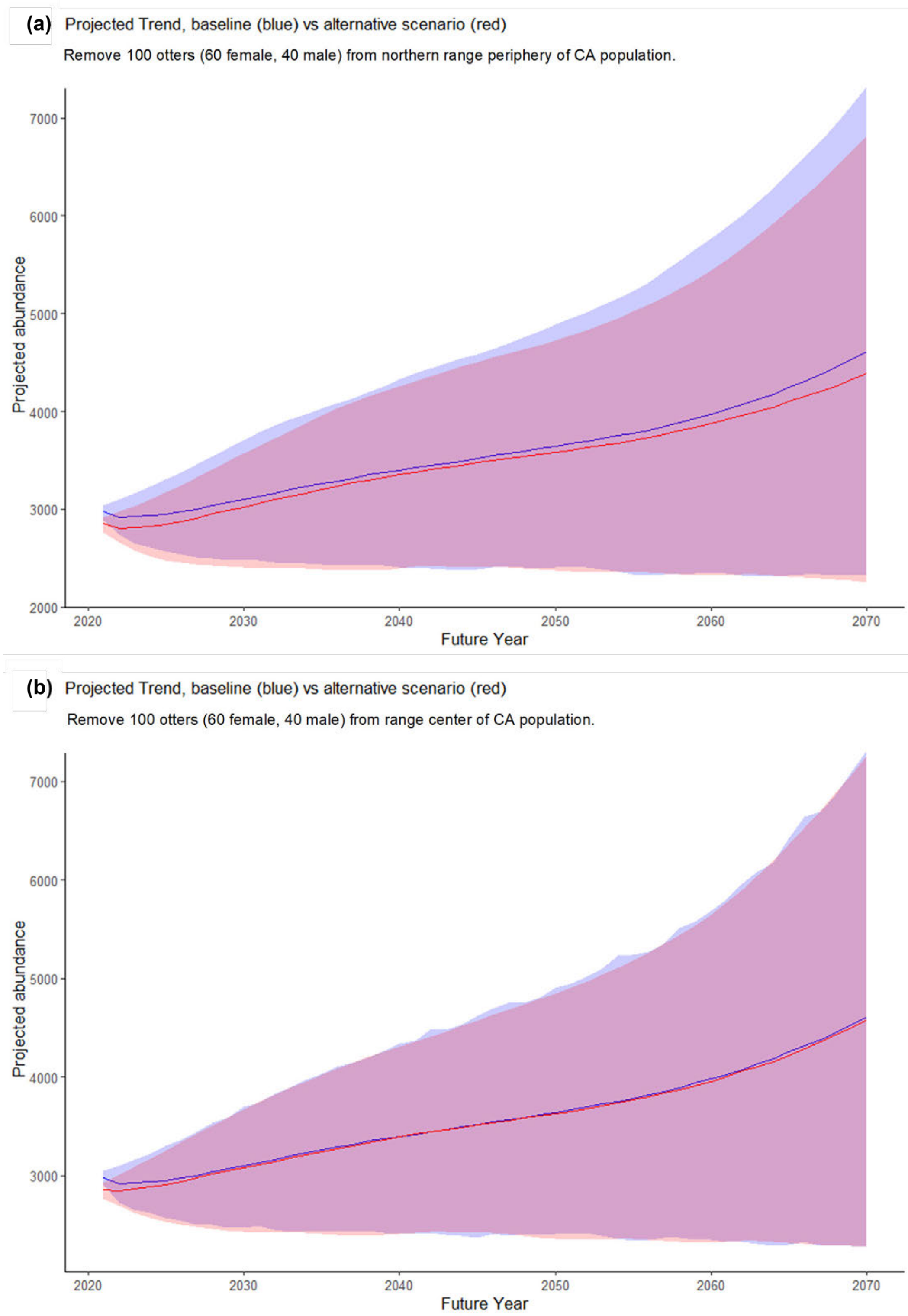
In SE Alaska, translocations of sea otters to multiple locations in the 1960s and 70s successfully established a growing meta-population that has now increased to over 25,000 animals (Esslinger and Bodkin 2009, Tinker et al. 2019). A spatially structured population model was recently developed for sea otters in this region (Tinker et al. 2019), and this model was then adapted to evaluate the population impacts of the Native Alaska subsistence harvest on sea otters (Raymond et al. 2019). Demographically speaking, removing sea otters to translocate them to a different region (Oregon) is identical to the lethal removal of animals during a harvest. Therefore, 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 harvest impact study's key results were that the demographic consequences of harvest were negligible when annual removals were less than 10% of the 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 the effects on population trends were negligible. In Sitka Sound, harvest levels before 2005 were less than 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 decline in abundance greater than 50%. These results highlight two important points: (1) The consequences to a source population of removing animals for translocation should be assessed at a local scale (i.e., within 20-60 km of the capture site) rather than at a regional scale. (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 subregional 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 (*K*; Tinker et al. 2021b), 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. 2021a). The IPM 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. Therefore, we 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 removing 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 then 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 Point) 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 *K*, resulted in only a 0.8% reduction in projected abundance after 50 years (Figure 3.1b). The first scenario resulted in greater impacts on 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 removals from an area already near *K*. (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 evaluated with and without the removal of animals for translocation to Oregon.



Note. 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 from (a) the northern range periphery and (b) the range center.

Thus, if California were used to obtain a source population of sea otters, it is important to consider local population status—areas near *K* will be more resilient to removals than areas well below *K*. Also, the potential implications for future range expansion must be factored in. 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). Researchers have already demonstrated that these rehabilitated juvenile animals could enhance population recovery in areas of low abundance (Estes and Tinker 2017, Mayer et al. 2019). It has also 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 ideal for avoiding negative impacts on a wild population. However, it is also true that the rehabilitated captive juvenile population is a highly limited resource: Currently, only a small number of animals are successfully rescued, rehabilitated, and made available for release to a new area each year. Using these animals as a source population for Oregon reintroduction would prohibit their use to establish new population centers within unoccupied habitats in California (or at least would reduce the number of animals available for reintroductions within California).

Population simulations using the IPM have shown that the reestablishment of new population centers in unoccupied areas of California using rehabilitated animals could substantially impact future population growth. Projected increases are estimated to be up to 50% (compared to simulations without reintroductions) for a population established in the Channel Islands. Projected increases reach up to 100% for a population successfully established in San Francisco Bay (Tinker et al. 2021a). These projections are based on a great many assumptions—most importantly, that the establishment of new populations using rehabilitated animals would be successful. Thus, they should be interpreted cautiously. Nonetheless, these results demonstrate that using 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. Therefore, this strategy's potential benefits (and costs) 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 failed (Jameson et al. 1982), and other translocated populations (such as the one introduced to San Nicolas Island in California) have dropped to very low population sizes before eventually beginning to increase (see Chapter 2 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 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 A. ORSO 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, considering different scenarios of translocation and reintroduction. This information can help evaluate management options and anticipate ecological and socioeconomic 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 the release, and how soon population growth will commence. ORSO is thus not intended to predict specific outcomes but rather to explore a range of outcomes that may be most likely, given an extensive scope of model inputs and assumptions.

ORSO 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 informed 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 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 a spatial diffusion approach to model range expansion over time. The model structure and parameterization are 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 [U.S. Fish and Wildlife Service] 2013, Tinker 2015, Tinker et al. 2019, Tinker et al. 2021b). 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 sea otter translocations and reintroductions 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 might be less for younger sea otters that have not yet formed strong attachments to a specific home range (Carswell 2008). Also, 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 of occurring for some animals in the Oregon translocation, where the otters were believed to have moved north to join the Washington or British Columbia populations). Elevated mortality is also likely for both dispersing and non-dispersing animals during the establishment phase. Thus, the "typical" patterns of density-dependent population growth, dispersal, and range expansion only emerge after this establishment phase, which may extend for five to 20 years after the initial translocation (Jameson et al. 1982, Bodkin et al. 1999, Carswell 2008, Bodkin 2015). ORSO 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 both the 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 ORSO to simulate population dynamics after a reintroduction provides several key insights into the factors affecting the reintroduced population's viability. First and foremost, model simulations reveal a great deal of uncertainty associated with model projections, as indicated by the width of the 95% confidence interval (CI) band around plotted trends over time (e.g., Figure 3.2). Projection uncertainty associated with ORSO 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 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, we suggest the following guidelines based on ORSO results:

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 success (see Chapter 9).

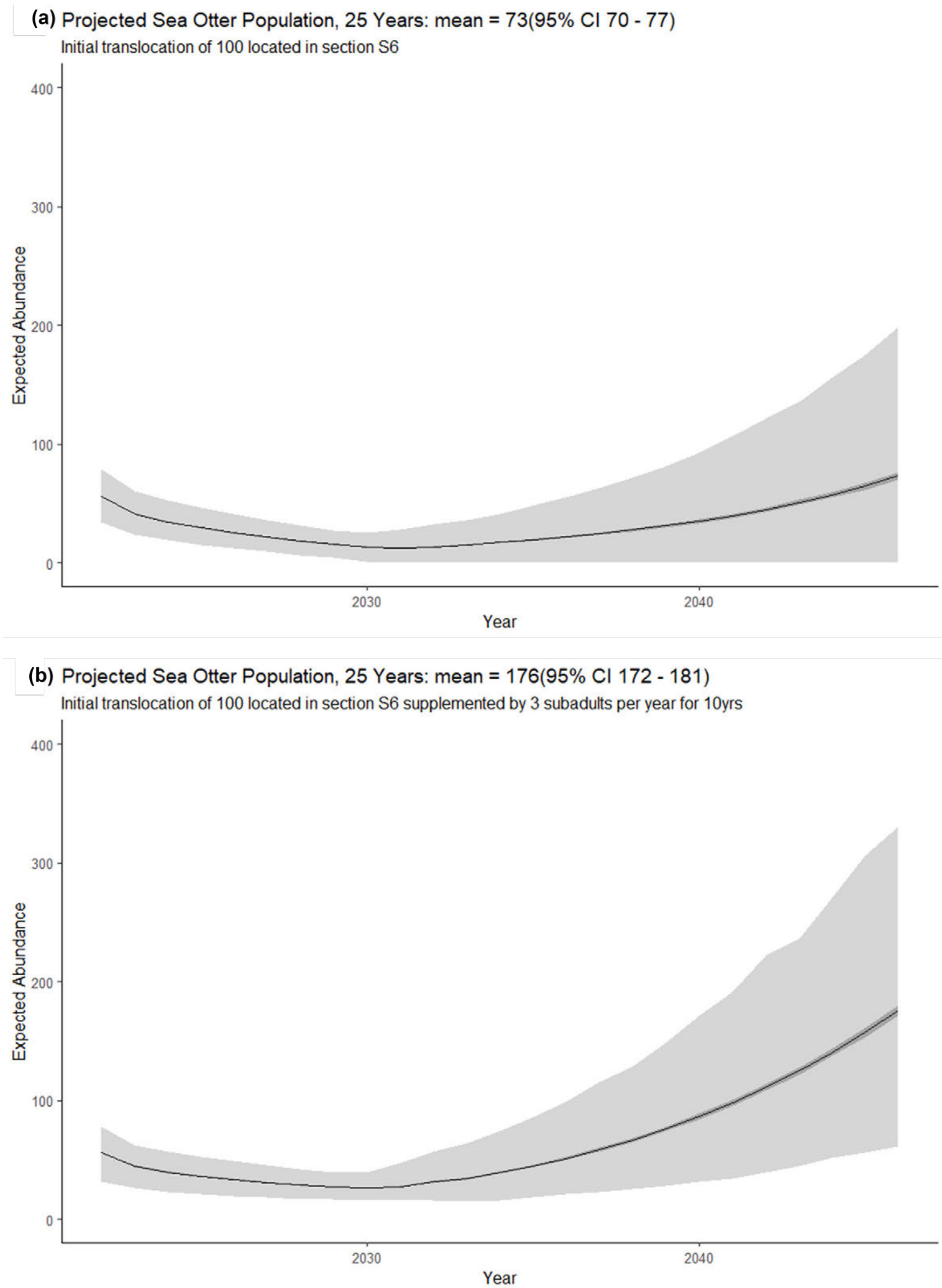
Supplementary introductions could consist of small numbers of rehabilitated juvenile animals added annually to the initial establishing population: This approach has been tested in Elkhorn Slough, California (Mayer et al. 2019), and appears to be an effective means of improving population viability during the establishment phase (Figure 3.2b). In the absence of supplementary additions to enhance viability, ORSO results suggest that at least 100 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).

A third important insight gained from ORSO simulations is that spatial considerations and the 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 the release site's suitability 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 *K*, which can vary at local scales based on the recruitment dynamics and productivity of invertebrate prey (Tinker et al. 2021b). Furthermore, the small home ranges and limited movements of adult sea otters mean that the spatial extent of the population distribution tends to change slowly (compared to the 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 ORSO results are consistent with this prediction.

A previous application of a habitat-based model of sea otter *K* to the Oregon coast (Kone et al. 2021) indicated substantial variation in habitat quality along the coastline (Figure 3.4), as measured by the expected density of sea otters at *K*. 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 that encompass areas of high-quality habitat, such as S6, SE2, or NE3 (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 more than 150 otters after 25 years, as compared to less than 50 otters for low-quality areas.

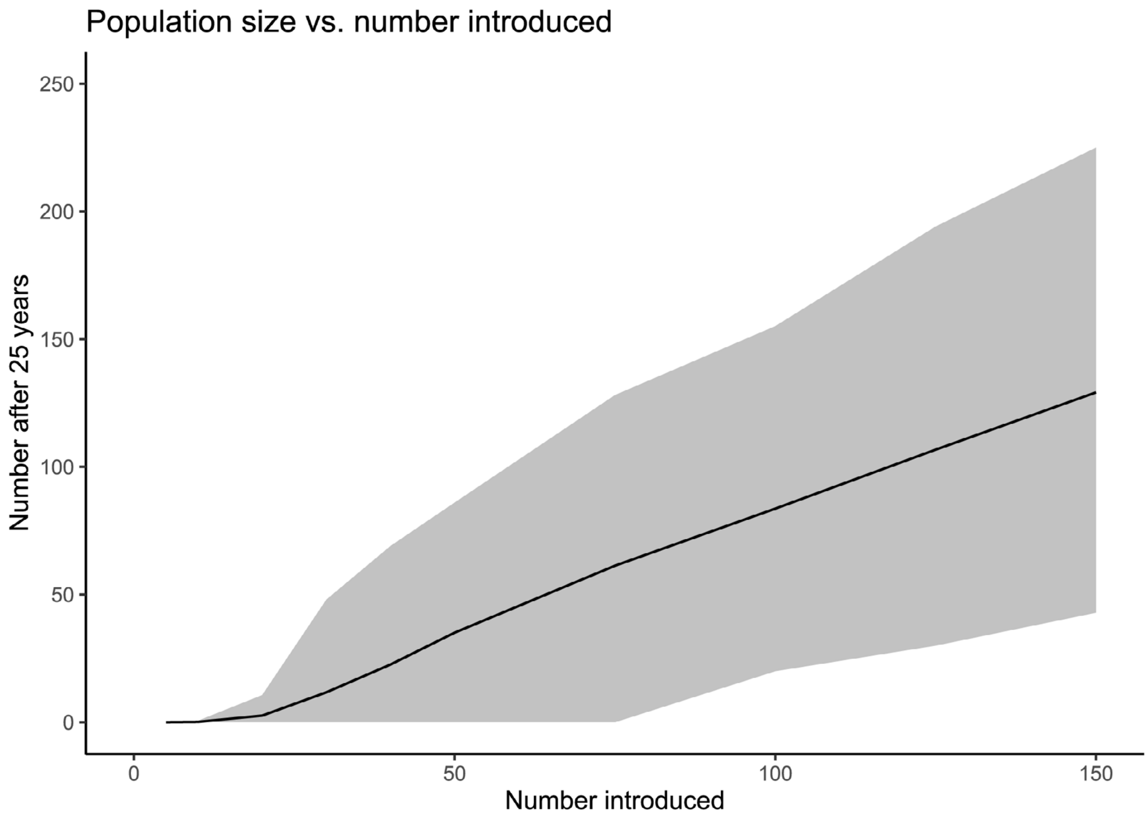
A final key insight from ORSO simulations is that multiple release locations (resulting in multiple "seeds" of population growth) may be more effective than a single center, if logistically possible. There are two primary reasons why this is the case: First, from the risk management perspective, two sites can add a degree of insurance against stochastic and unpredictable failure of a population to establish (if one reintroduced 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

Figure 3.2. Expected trends in sea otter abundance after a reintroduction to coastal Oregon based on ORSO projections.



Note. The ORSO modeling assumes (a) 100 otters introduced to Section S6 or (b) 100 otters plus supplementary additions of three subadults per year for 10 years. In both plots, the solid line shows the mean expected trends, and gray bands indicate 95% CIs. Section S6 is the relevant coastal area shown in Figure 3.4.

Figure 3.3. The relationship between the number of otters introduced to a release site in Oregon and the reintroduction's success.



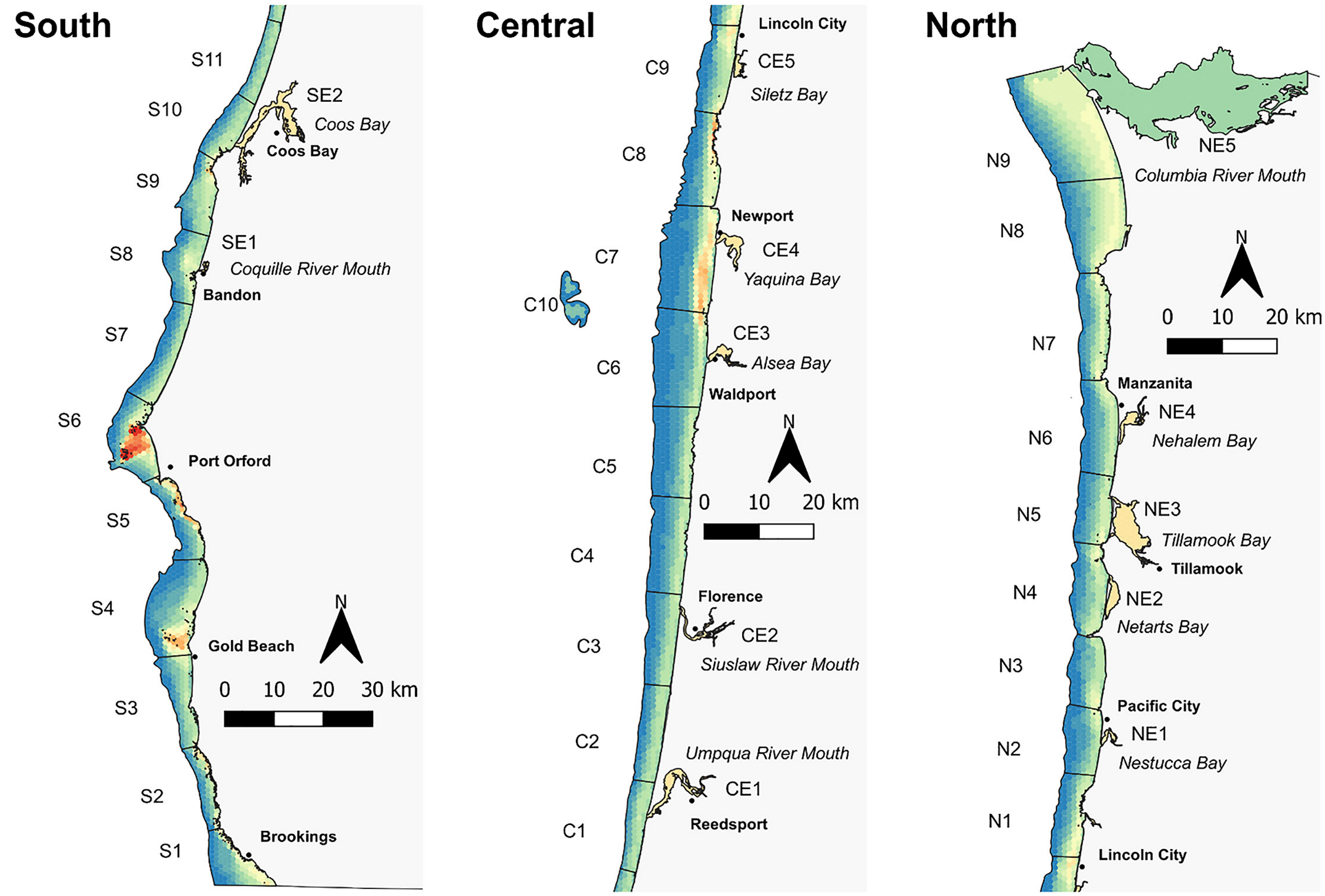
Note. The coastal area in this analysis is Section S6, as shown in Figure 3.4. The reintroduction's success is measured by the mean number of otters remaining after 25 years. The solid line indicates the mean expected value of all simulations, while the gray band represents the 80% CI.

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).

The SE Alaska translocation provided a concrete example of this principle. One reason that sea otter numbers in SE Alaska are so high today is that the original 450 animals were divided among six release sites (see Chapter 2 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 ORSO to compare a reintroduction scenario of 100 animals introduced to a single site (S6; Figure 3.6a) versus a scenario of the same number of animals divided between two spatially distant sites (SE2 and CE4; Figure 3.6b) resulted in almost two times more animals after 25 years under the latter scenario. 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).

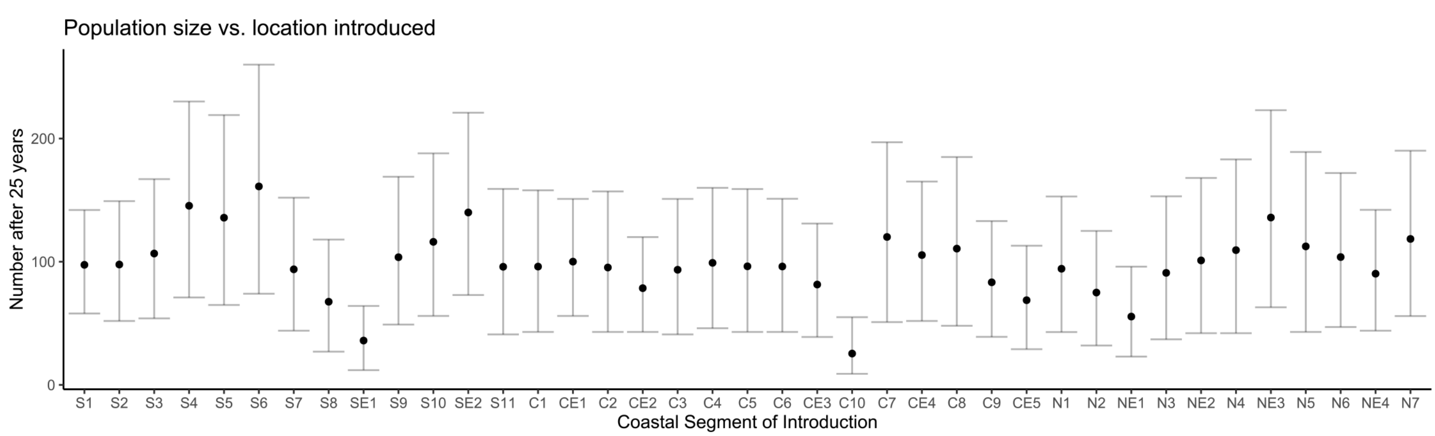
In summary, the ORSO population model provides an easy-to-use tool for exploring the factors that may affect the future viability of reintroduced sea otter populations in Oregon. Broadly speaking, the take-home message is that a reintroduced population (or populations) of sea otters in Oregon could indeed 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

Figure 3.4. Results of a habitat-based model of sea otter *K* to the Oregon coast (Kone et al. 2021).



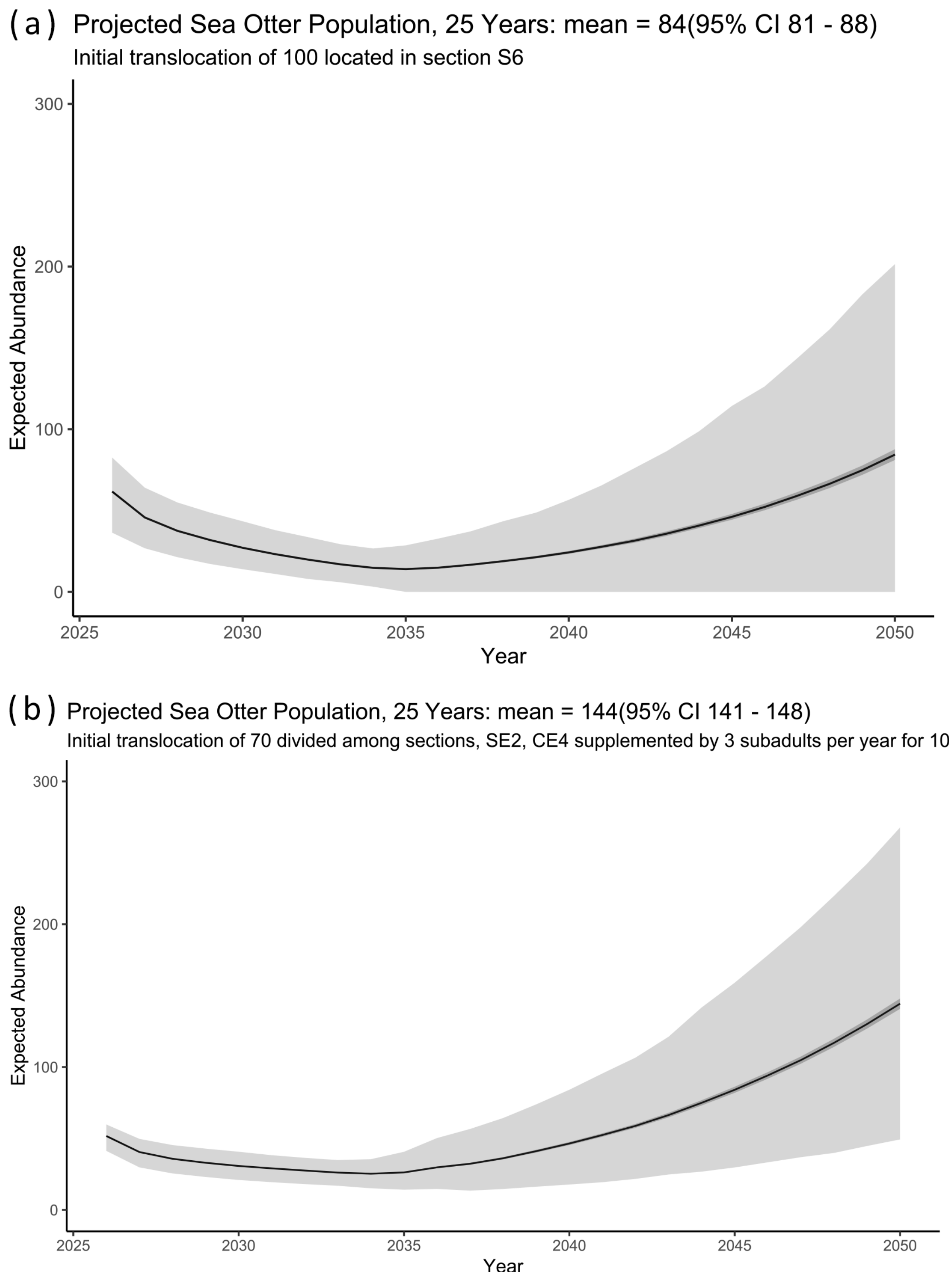
Note. These results show variation in the expected density of sea otters at *K* resulting from differences in habitat suitability.

Figure 3.5. Comparison of the expected number of sea otters after 25 years based on reintroductions of 100 sea otters to different coastal segments.



Note. See the map in Figure 3.4 for an explanation of the coastal segments, such as Segments S1, SE1, C1, CE1, N1, and NE1. Each scenario consisted of an initial reintroduction of 70 animals followed by supplementary additions of three otters per year for 10 years. The establishment phase was assumed to last for 10 years, with an elevation in mortality of 14% during that period and an average probability of post-introduction dispersal away from the translocation site of 75% for adults but only half that rate for subadults.

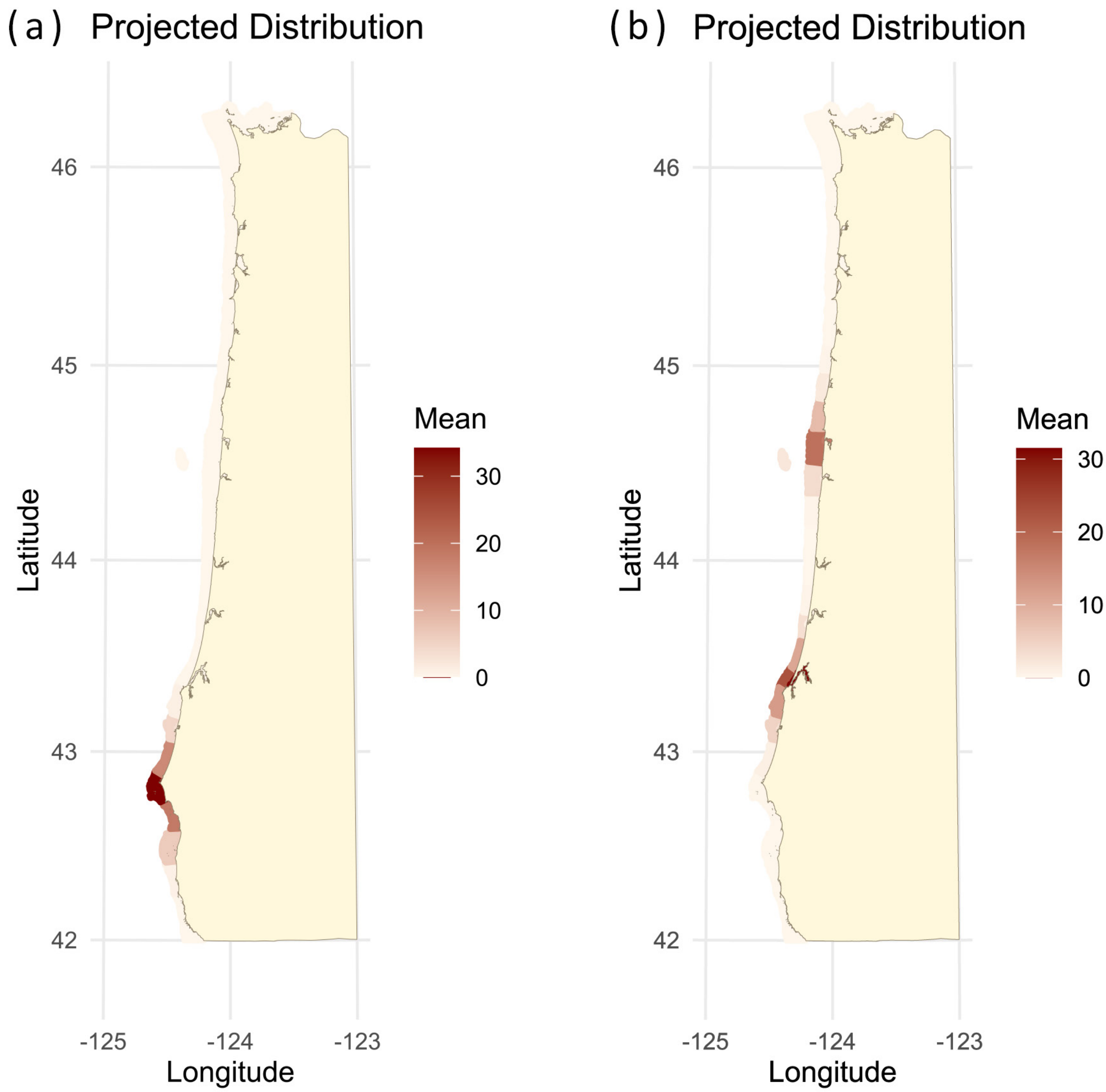
Figure 3.6. Comparison of projected sea otter trends after two reintroduction scenarios.



Note. The two reintroduction scenarios are (a) an initial translocation of 100 animals to a single coastal area (Section S6 per the map in Figure 3.4) and (b) an initial translocation of 70 animals divided equally among two sections (SE2 and CE4), with supplemental additions of three subadults per year for 10 years (also divided equally between the two areas). Despite the fact that both scenarios involved reintroducing 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 using multiple centers and supplementary additions of animals to improve the population viability at a given release site.

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 socioeconomic 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.

Figure 3.7. Comparison of the projected sea otter distribution after 25 years for two reintroduction scenarios.



Note. See Figure 3.6 for details about the related trends. The two reintroduction scenarios are (a) an initial translocation of 100 animals to a single coastal area (Section S6 per the map in Figure 3.4) and (b) an initial translocation of 70 animals divided equally among two sections (SE2 and CE4), with supplemental additions of three subadults per year for 10 years (also divided equally between the two areas). The second scenario resulted in two spatially disjunct population centers and a net abundance approximately two times that of the first scenario.

Sample Scenarios Evaluated with ORSO

For illustrative purposes, we conducted a suite of simulations using ORSO for five alternative reintroduction scenarios. We emphasize that these scenarios do not represent recommended strategies: Rather, they provide a set of "reasonable" scenarios useful for evaluating the range of potential outcomes resulting from different initial conditions. The first four scenarios represent potential future reintroduction plans. They have been used as the basis for a companion economic impact assessment provided in a separate document (Elakha Alliance 2022). The fifth scenario corresponds to the 1970–71 historical translocation to Oregon and is presented as a benchmark scenario to compare model simulation results with the "actual" historical results.

The key parameters for all scenarios are summarized in Table 3.1: For the four potential future scenarios, we initialized simulations with 180 otters, divided equally between the specified coastal sections and with a female/male ratio of 0.65 and an adult/subadult ratio of 0.25. We also assumed that otters were reintroduced in a single year, although we note that the same number of otters introduced over multiple years could achieve equal or greater rates of increase (see the previous discussion concerning Figures 3.6 and 3.7). For the fifth scenario, we initialized simulations with 93 otters (the total reintroduced in 1970–71) released over two years and spatially allocated to match the actual historical release locations (Jameson 1975). The age composition and sex ratio of the 1970s translocated population are unknown, but we assumed 50:50 ratios of females to males and adults to subadults. All other model parameters for the five scenarios (vital rates, dispersal probabilities, establishment period, rate of range expansion, etc.) were set to the default values (refer to Appendix A). For those parameters that determine reintroduction dynamics, default values were selected such that the model would closely reproduce the observed post-translocation trends at San Nicolas Island (Rathbun et al. 2000, Carswell 2008) when evaluated at that location.

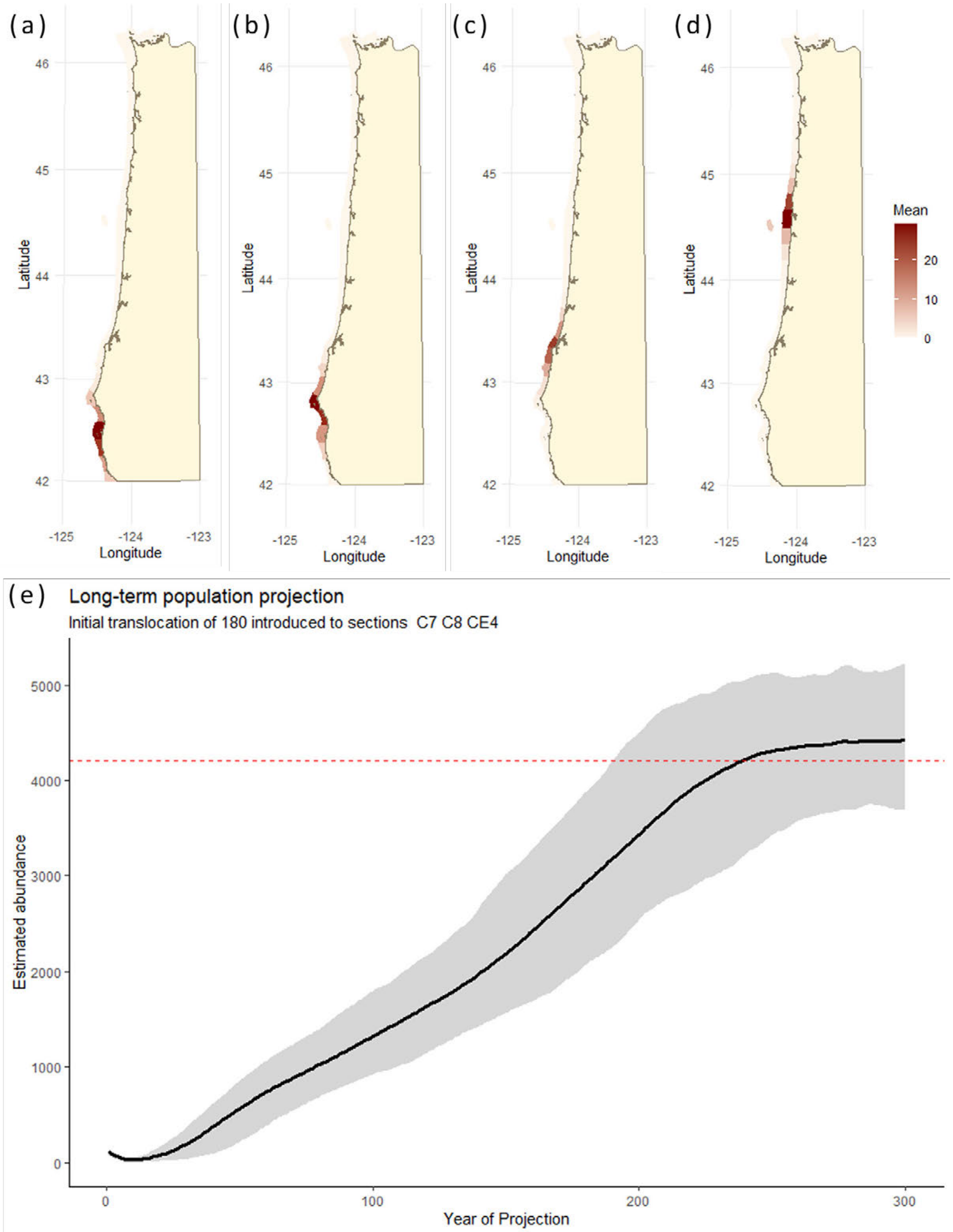
In the case of Scenarios 1–4, for which the initial number of otters introduced was 180, the average number of otters expected to persist after 25 years was greater than 100, although mean estimates varied from 117 to 144 depending on where the reintroduction occurred (Table 3.1), and the spatial distribution after 25 years also differed between scenarios (Figure 3.8). The probability that the reintroduced populations declined to extinction was less than 5% for future Scenarios 1–4. Interestingly, the scenario with the lowest probability of extinction also had the lowest mean expected population size, suggesting that a single scenario will not necessarily achieve the objectives of minimizing extinction risk and maximizing expected population size. In the case of Scenario 5, which corresponded to the historical 1970s reintroduction, the mean expected population size after 25 years was only 39 otters, and the probability of extinction (i.e., the percent of simulations declining to 0 within the first 25 years) was 34%. The 90% CI for projected

Table 3.1. Summary of parameters and results for five modeled scenarios of sea otter reintroductions to Oregon.

ID	Scenario	Initial sections	Initial otters	% Fm / % Ad	Avg. 25y	Qtl. 0.025	Qtl. 0.975	% extinct	Years to *K*
1	Rogue Reef / Crook Point	S3, S4	180	65% / 25%	124	0.4	259	3.4%	299
2	Port Orford / Cape Blanco	S5, S6	180	65% / 25%	144	2	317	3.2%	280
3	Cape Arago/ Coos Bay	S9, S10, SE2	180	65% / 25%	121	15	262	1.9%	245
4	Yaquina Bay / Otter Rock	C7, C8, CE4	180	65% / 25%	117	13	243	1.7%	190
5	Historical (1970–71)	S5, S9	93	50% / 50%	39	0	142	34%	270

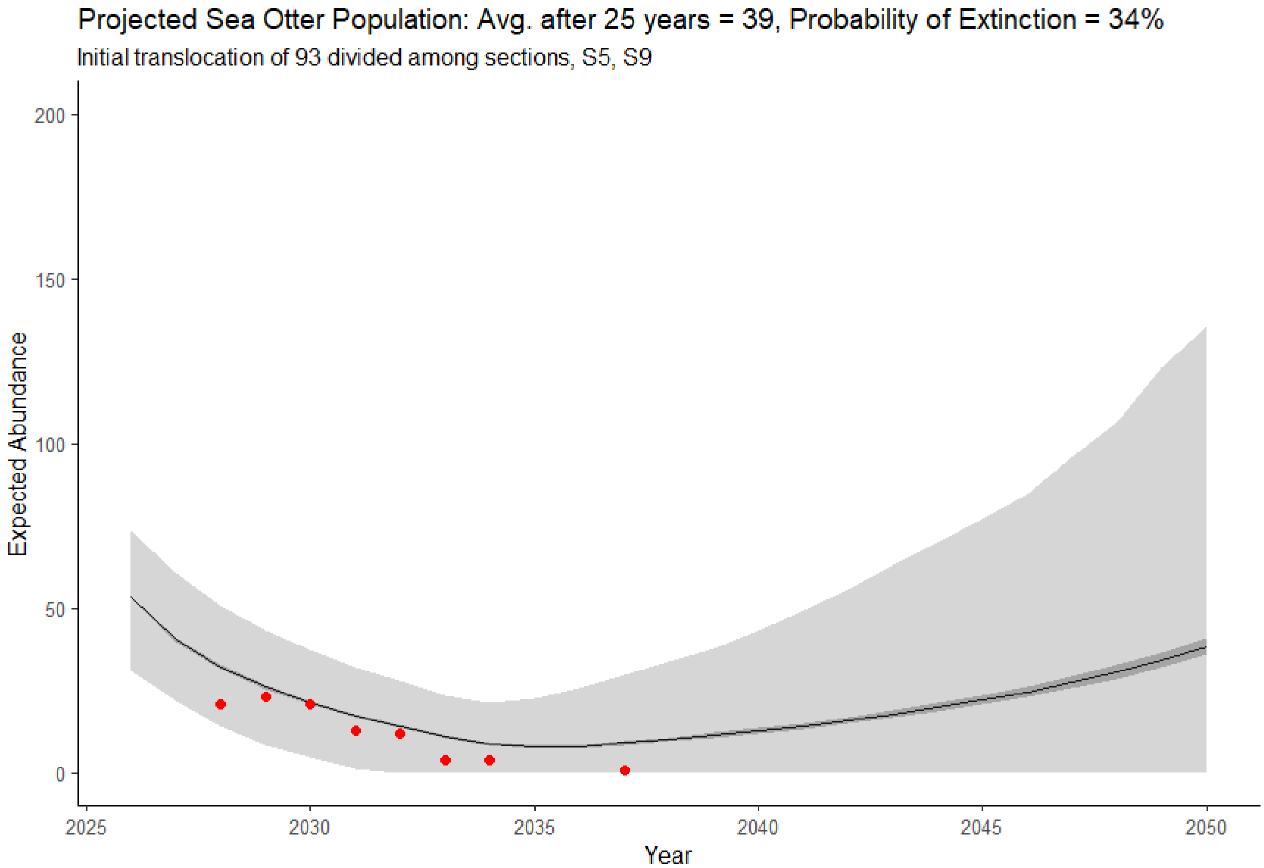
Note. Shown are the initial coastal sections (per Figure 3.4), number of otters introduced, sex composition (% Fm = the percentage female), age composition (% Ad = the percentage adult), expected abundance after 25 years (mean and 95% quantiles), percentage of simulations going to extinction within 25 years, and expected number of years to reach *K*.

Figure 3.8. Simulation results from ORSO modeling associated with four alternative reintroduction scenarios.



Note. Refer to Scenarios 1–4 in Table 3.1 for details about the reintroduction alternatives. Panels (a) to (d) in this figure show maps of the expected distribution and abundance (indicated by color intensity) of sea otters after 25 years based on reintroductions of 180 otters at each of four areas: (a) Rogue Reef/Crook Point, (b) Port Orford/Cape Blanco, (c) Cape Arago/Coos Bay, and (d) Yaquina Bay/Otter Rock. Panel (e) shows the model-projected population trends over 300 years after a reintroduction at Yaquina Bay/Otter Rock, with regional abundance approaching coast-wide *K* (the red dashed line) approximately 200 years after the initial reintroduction.

Figure 3.9. Plot of the model-projected trends in abundance associated with Scenario 5, corresponding to the historical Oregon reintroduction in 1970–71.



Note. Scenario 5 (in Table 3.1) used the initial abundance and location of reintroduced otters from the historical Oregon reintroduction in 1970–71. The dark gray band shows the 95% CI of the mean expected abundance (solid line), while the light gray band encompasses 90% of the simulated trajectories. The red points correspond to the observed survey counts made after the historical reintroduction (adjusted for the starting year) and fall within the 90% confidence band of model simulation results.

trends encompassed the observed outcome of the historical reintroduction (Figure 3.9), thus suggesting that ORSO projections are consistent with the dynamics of the previous reintroduction attempt (including its ultimate failure).

Finally, the simulation results for all scenarios indicated that the time from an initial reintroduction until the population approaches projected *K* coast-wide (Kone et al. 2021) would be relatively prolonged, in the 200- to 300-year range (Table 3.1, Figure 3.8e). While this extended period of recovery to equilibrium may seem long given the rapid growth rates reported for some northern populations, it is entirely consistent with the rate of population growth and range expansion observed in California. Recent analyses of the importance of spatial habitat complexity for sea otter population dynamics show that long, linear coastlines, such as California's, are associated with slow rates of growth and range expansion relative to regions such as SE Alaska and British Columbia that are defined by topologically complex habitats (Tinker 2015, Davis et al. 2019, Tinker et al. 2019). This pattern occurs because adult sea otters have restricted home ranges and are limited by local resource abundance. So, *K* (the density-dependent resource limitation) occurs at local scales. At regional scales, the growth rate is thus determined by the relative access of individuals within the population to habitats with abundant resources. In linear, "one-dimensional" coastal habitats, these conditions only occur near the two ends of the range. Conversely, in complex, "two-dimensional" habitats, many areas of population expansion and growth exist, and thus, a higher proportion of individuals have access to abundant resources. Because the network structure of coastal habitats in Oregon is essentially one-dimensional, like California, it is reasonable to assume that recovery patterns will be similar to California, and ORSO captures these dynamics. We note that the time to reach coast-wide equilibrium abundance would be reduced considerably by having multiple release sites (and thus multiple initial centers of growth) distributed throughout the state, as was the case in SE Alaska (Eisaguirre et al. 2021).

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 herein suggest that it is highly likely that such a tabulation exercise will result in a net-positive outcome: This outcome is because the negative impacts on 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 the susceptibility of the species to total extinction due to the demographic risks of a small population size, as well as the genetic consequences of population reduction and fragmentation (see Chapter 4). 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 managers face in facilitating the recovery of sea otters and the restoration of their functional roles in coastal ecosystems is that natural range expansion is extremely slow in this species. As discussed above, this slow expansion is due to inherent traits in sea otters: the limited mobility and high site fidelity of reproductive adults. Because of these traits, sea otters' natural recolonization of 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 southwestern 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 the acceleration of sea otters' return 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 requirement for allowing pre-fur trade levels of gene flow (Larson et al. 2002, Wellman et al. 2020) and would greatly enhance the potential for demographic rescue effects (the process by which natural dispersal from one area can "rescue" a neighboring subpopulation that has experienced a 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 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 restoring 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, 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 the likely viability of an established Oregon population under various reintroduction scenarios. Managers and a wide range of stakeholders can easily use the model framework developed for this assessment (the ORSO web app) to explore the 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 a reintroduction's success or failure.

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. They must be placed in a broader context of social and economic, legal and administrative, and logistical considerations (Reading et al. 2002). We believe ORSO can help in evaluating all these subject areas, as it provides a spatially and temporally explicit tool for visualizing the outcomes of a 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 CONSIDERATIONS OF OREGON SEA OTTERS

Shawn Larson and M. Tim Tinker

HISTORICAL CONSIDERATIONS

Sea otters (*Enhydra lutris*) 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). Their abundance across this range before 1750 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 remnant populations from the fur trade and those populations resulting from successful translocations.

Before the commercial fur trade extirpations, sea otters were hunted by the Indigenous populations of North America for at least 10,000 years for food and ceremonial purposes, as well as for the 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 honored tradition among coastal Indigenous 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 Indigenous Peoples, 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, otherwise known as 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).

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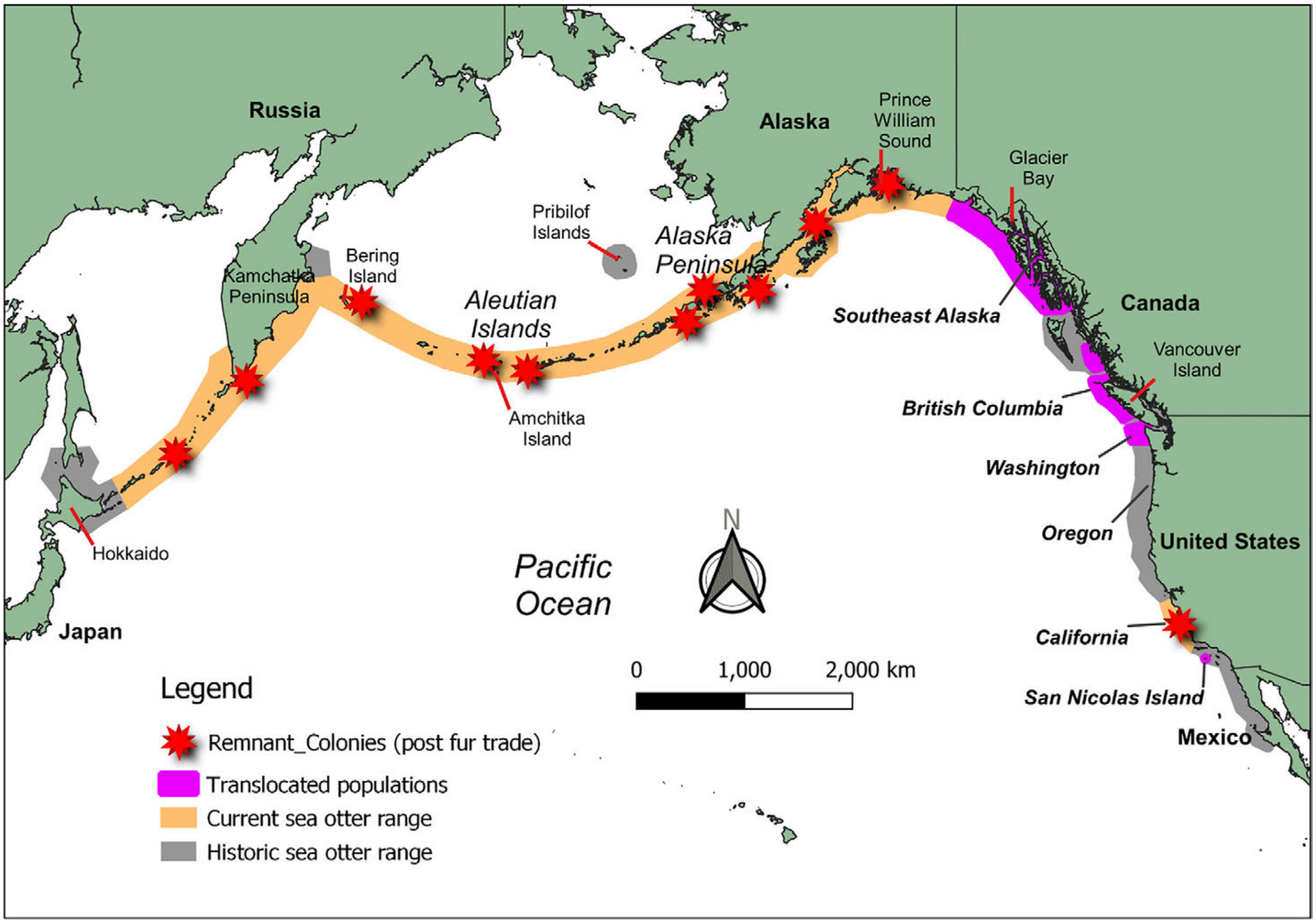
This scenario is supported by the fact that sea otter remains can still be found and investigated in curated Indigenous *middens* (layers of discarded animal bone, shells, and other artifacts from historical human occupation) throughout the west coast of North America that represent thousands of years of continuous occupation. Indigenous subsistence hunting was thus sustainable in the sense that sea otter populations persisted throughout their North American range before the arrival of Europeans, although genetic analyses have suggested one or more population

Figure 4.1. Map of the North Pacific showing historical and current sea otter ranges.



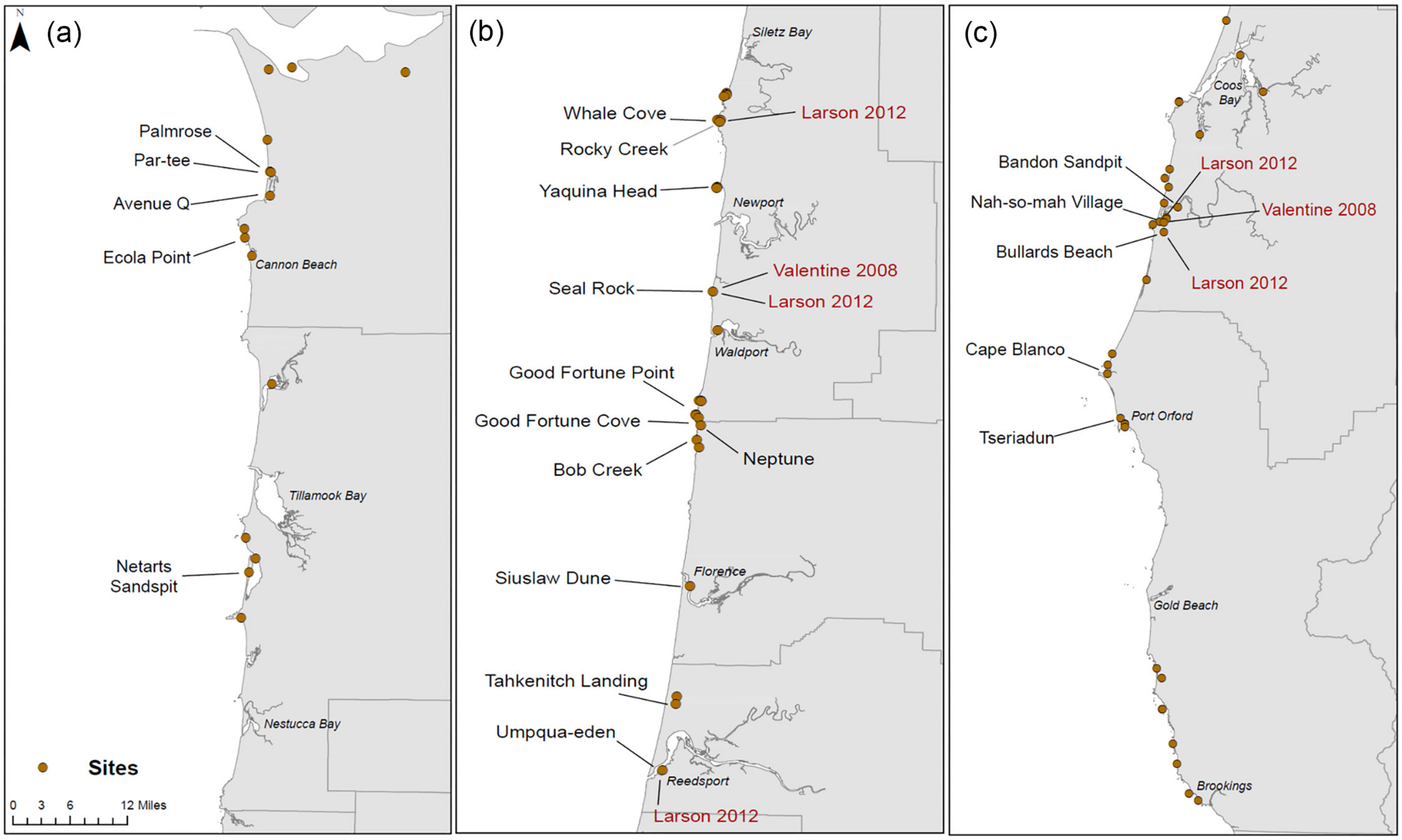
Note. This map includes the locations of remnant populations from the fur trade and those populations resulting from successful translocations.

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 Indigenous Peoples, the maritime fur trade continues to be 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).

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 kilometers), which were well within the range of 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 historical 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 America's west coast (see Chapter 2; 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 (SE) Alaska, Vancouver Island in British Columbia, Washing-

Figure 4.2. Coastal Oregon archaeological sites with known vertebrate faunal remains, plotted by region.



Note. The regions plotted are (a) North, (b) Central, and (c) South Oregon. Labeled sites are known to have held sea otter remains, and sites that were previously sampled for genetic studies are labeled in red. From Curran et al. (2019).

ton, and Oregon. An important detail from a genetic standpoint is that the SE 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). 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 before the fur trade, as evidenced by Indigenous Peoples' oral histories, sea otter remains in Oregon's Indigenous middens (Valentine et al. 2008, Hall 2009), and written accounts of sea otters by explorers such as Meriwether Lewis and William Clark and by fur traders (La Follette and Deur 2021). However, a clear account of the density and distribution of otters throughout Oregon before the fur trade extirpation is missing. Studies of Indigenous 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 these middens have not been analyzed. The Lewis and Clark Expedition in the winter of 1805–1806 mentioned that sea otters were "plentiful" along the northern Oregon coast yet 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 dearth of international trading ships that could easily make port along Oregon's coast, and 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).

GENETIC CONSIDERATIONS

Over this extensive history—from Indigenous communities' interactions 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 a loss of genetic diversity (Frankham 2005, Lankau and Strauss 2007, Ralls et al. 2018). Genetic studies focused on sea otters have used a variety of variable nuclear genetic markers and have demonstrated relatively low genetic diversity (average of 50% diversity within the genome) within all extant sea otter populations. Compare the otters to mammals that have no known population bottlenecks and typically have diversity metrics between 70% and 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. (2002b, 2012) used nuclear microsatellite markers and 600-year-old to more than 10,000-year-old sea otter bones found in Indigenous 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, indicating 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: SE Alaska (60%) and Vancouver Island, British Columbia (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, British Columbia, 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 in British Columbia, and SE 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 gene flow between neighboring sea otter populations spanning from the Alaska Peninsula to Prince William Sound to SE 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 1200 km) of unoccupied habitat from northern California to southern Washington. Recolonization 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. 2021), so managed reintroduction would clearly accelerate this goal's achievement. If such a management action were to be undertaken, a key question would be which sea otter population should be used as a source population.

The selection of a source population for a new reintroduction 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 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 Indigenous midden sites. The actual number of individual sea otters in Oregon Indigenous 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 location in north-central Oregon and the Nah-So-Mah Village 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 haplotypes not yet recorded. Valentine et al. (2008) found the dominant haplotype matching southern sea otters and suggested that one reason the translocation in the mid-20th century to Oregon failed was because the founders from Amchitka were not 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: (1) Little Whale Cove (site number: 35-LNC-43) on the northern Oregon coast; (2) near the mouth of the Umpqua River and (3) near Seal Rock State Park, both on the central Oregon coast; and (4 and 5) two sites near the mouth of the Coquille River near Bandon on the southern Oregon coast. They found that the 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 than in a southerly direction. This finding using nuclear markers contrasted with the earlier finding based on mtDNA (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 are unclear.

Finally, new research by Wellman et al. (2020) presented 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. The researchers 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 British Columbia haplotypes) that were substantially different from California haplotypes. The two fur-trade-era haplotypes from southern Oregon also clustered close to northern haplotypes (Wellman et al. 2020). These results are perhaps unsurprising 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, before sea otter extirpation in the fur trade, the Oregon coast 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 the sea otters' former range.

CONCLUSION

The history of sea otters in western North America—including information from Indigenous oral histories, archaeological remains, and genetic studies—suggests 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 would benefit from a design that keeps this history in mind and, thus, aims to recreate 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) pairing an Oregon reintroduction that uses a northern sea otter source population with a northern California reintroduction that uses southern sea otters as a source population. In the last scenario, the hybridization of northern and southern sea otters would reoccur naturally. Any one of these strategies would further the recovery of genetic diversity by restoring the 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.

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Photo by the Vancouver Aquarium.

Chapter 5

ECOSYSTEM EFFECTS OF SEA OTTERS

James A. Estes and M. Tim Tinker

The interplay between sea otters (*Enhydra lutris*) 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) effects of the ecosystem on otters and (2) 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 nonspecialists. We thus begin this chapter with a short primer about ecology's central concepts, goals, methods, and challenges (see the primer in the upcoming callout box). 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 study (Chapter 6 on habitat suitability considerations and Chapter 10 on health and welfare considerations).

How do ecologists determine a species' effects on its associated ecosystem? The most compelling approach is contrasting otherwise similar habitats in which the species is present and absent. For some species, an analysis 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 is 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 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. 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 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 changes 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.

Fourth is the ease with which other key elements of the interaction web (e.g., macroalgae, benthic macroinvertebrates, reef fish, etc.) can be observed and measured. This is due in large part to the sessile nature and spatially constrained distribution of these species (i.e., the narrow coastal zone defined by the intertidal and shallow subtidal depths).

A fifth is the capacity of these species to recover quickly following pulse perturbations (i.e., the addition or removal of sea otters).

A sixth and 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. Therefore, we have provided a brief introductory review of key ecological concepts in the following callout box. Readers already familiar with ecological concepts and terminology can skip this primer and go directly to the next section.

A PRIMER OF ECOLOGY

This primer provides interested or unfamiliar readers with further background on those dimensions of 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 nonspecialists, the subject is admittedly complex and often nuanced. Therefore, we refer readers to the referenced literature if they wish to obtain a more detailed or additional understanding.

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 are what they are). The description of pattern, while frequently tedious, is otherwise a relatively straightforward endeavor, attainable simply via "boots on the ground" observations and measurements. However, understanding the processes that underlay these patterns 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 environment (i.e., physical and chemical), 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: where any particular species **can live** (the species' so-called *fundamental niche*) versus where it actually **does live** (the species' so-called *realized niche*). The abiotic environment and species interactions largely determine a species' fundamental niche; the historical influences of biogeography further determine its realized niche.

Species interactions can be thought of most simply as how 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), *mutualism* (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 critical because it would be impossible for any species to exist anywhere without them (other than photosynthesizing plants and a few chemosynthetic autotrophs). The network of *trophic linkages* (interactions between consumers and prey) is known as a *food web* (Pimm 1982, Ch. 1), and the scientific enterprise of understanding how this network of linkages influences species distribution and abundance 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 were believed to be determined by what is known as *bottom-up forcing processes* (Hunter and Price 1992). Via these processes, the distribution and abundance of species are 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, species distribution and abundance are influenced by what has become known as *top-down forcing processes.* 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). See Figure 5.1. The *trophic level* of a species within a trophic cascade simply refers to the number of consumer-prey interactions between that species and the bottom of the food chain (thus, primary producers are Trophic Level 1, herbivores are Trophic Level 2, consumers of herbivores are Trophic Level 3, and so on).

In this top-down view of the 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 sea otters' ecological influences 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, while 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.

Drivers Versus Recipients

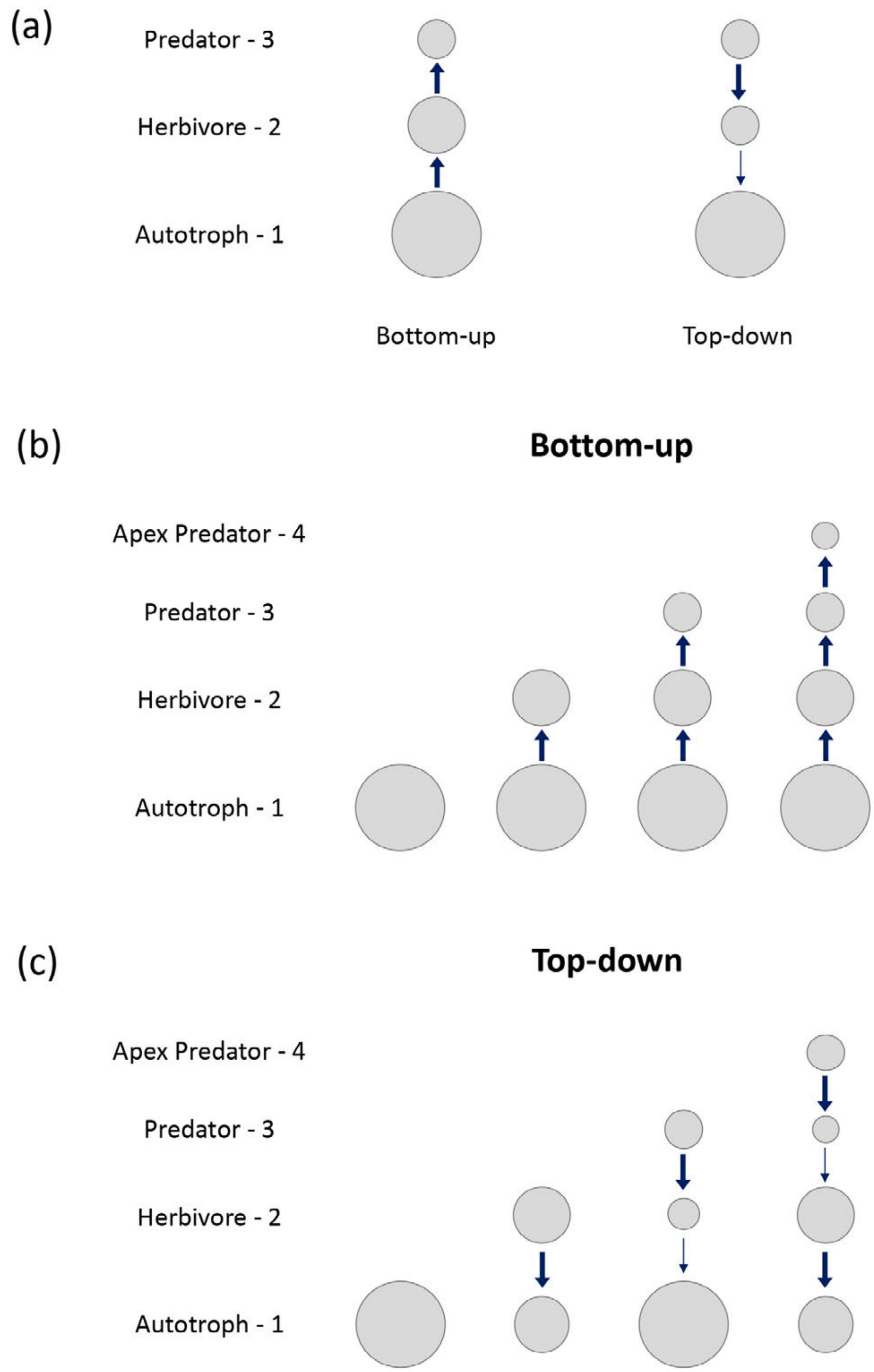
Many interactions among species and between species and the elements of their abiotic environments are asymmetrical, which means that one member of the interacting pair is the *driver* (i.e., its abundance is the primary determinant of pairwise dynamics) and the other the *recipient*. Adding or losing 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})

1 An interaction web is the network of linkages (interactions) among species and between species and their physical environment.

Figure 5.1. How bottom-up and top-down forcing differ and why it matters to species distribution and abundance.



Note. Panel (a) depicts how bottom-up and top-down forcing differ. See (b) and (c) for illustrations of why the differences matter to the distribution and abundance of species. In all panels, the trophic-level descriptors and numbers are indicated at left, the circles represent species in each trophic level, circle size indicates relative abundance, lines with arrows represent species interactions, arrows indicate the direction of forcing, and the arrow or line weight indicates interaction strength (thin [weak] vs. heavy [strong]). Differences in interaction strengths and abundances are shown between odd- and even-numbered food chains under (b) bottom-up and (c) top-down forcing.

versus when the driver is absent (R_{da}). Interaction strength is often calculated per capita: $(R_{dp} - R_{da})/D$, 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*. This operation implies 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 to eat, and which sizes of the chosen prey to eat. Prey size matters a great deal in a consumer's behavioral calculus 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 choices; one that is especially pertinent to this assessment is the tendency of 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 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 (Figure 5.1). Top-down influences by a species of a high trophic level 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 the directionality of the 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 that 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 *nonconsumptive 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. The 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 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 does not have to be common in the predator's diet for strong top-down effects to occur in nature (Creel and Christianson 2008, Heithaus et al. 2008).

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. Nonlinear 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). Nonlinear 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 when considering what can be reasonably predicted about the ecological, social, and economic consequences of repatriating Oregon's coastal ecosystem with sea otters.

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2 Ripple et al. (2016) define the 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).

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 predator species. These influences have been determined using the two-step procedure 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 and 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 the 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, appear 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 pathway 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-urchin-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 [SE] 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. 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 the previous primer).

Reef systems in SE 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 biphasic nature of the otter-urchin-kelp cascade (Foster and Schiel 1988). Indeed, adding sea otters to a southern California kelp forest at San Nicolas Island has shown that factors other than sea otter predation can drive community state transitions. Still, despite this complexity, sea otter predation at San Nicolas has shifted the subtidal community to a previously unobserved 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 (*Pycnopodia helianthoides*), 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. So, the abundance of kelp, as influenced by the abundance of otters, has an important influence on net primary production (NPP), which is elevated severalfold 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, Washington, 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) areas 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).

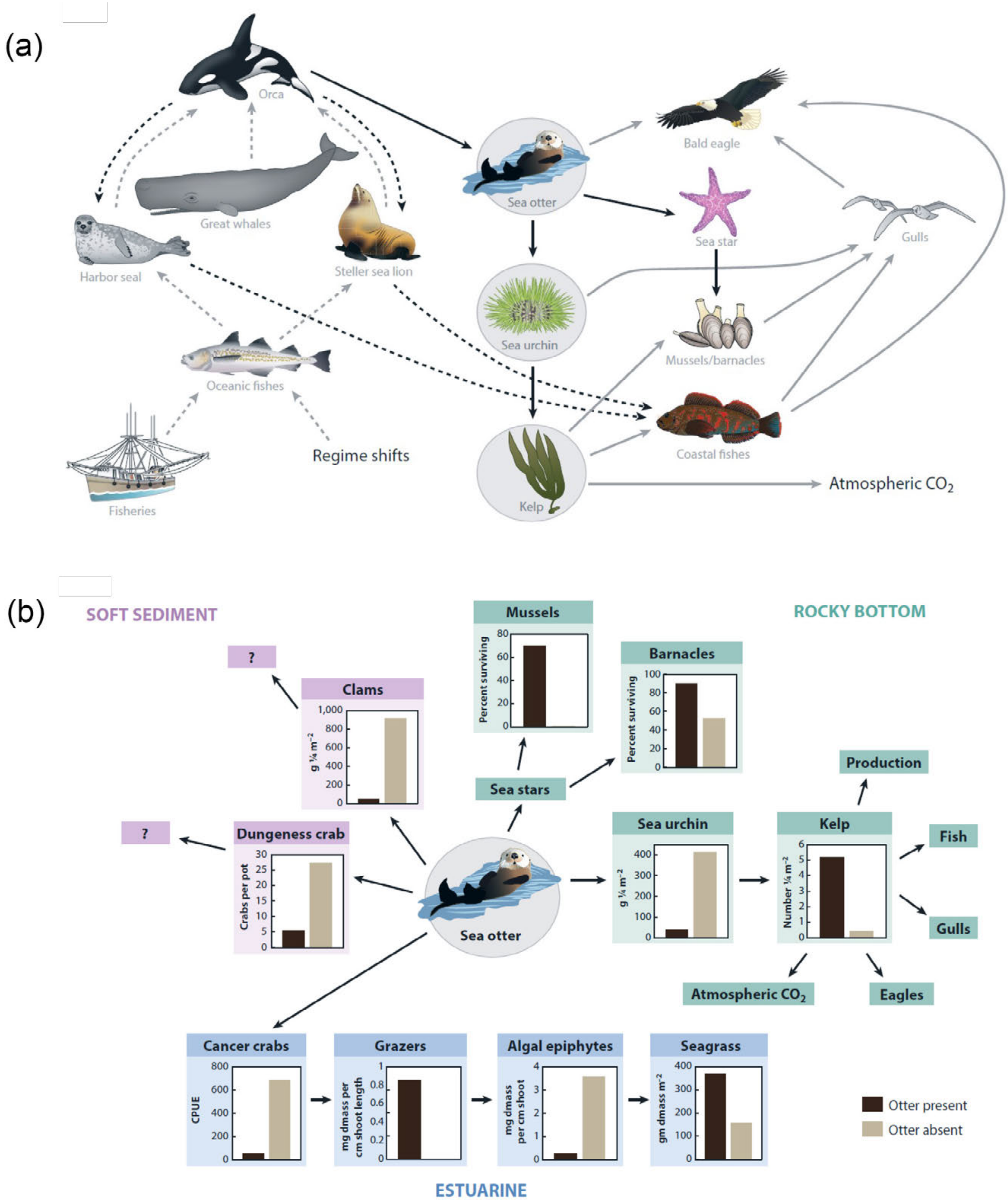
Kelp affects coastal marine ecosystems via three other known pathways: (1) structurally, by serving as habitat for other species; (2) by attenuating waves and currents; and (3) by absorbing carbon dioxide (CO2) from the surrounding seawater and overlying atmosphere (i.e., part of the supply side for increased NPP). In turn, these processes have a range of essential effects on both physical and biotic elements of the ecosystem. For example, microbes (bacteria) cycle energy and materials, decompose detritus, and remineralize organic matter—processes 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 CO2 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). Also, this drawdown potentially influences the CO2–bicarbonate balance and pH in the surrounding seawater. Wilmers et al. (2012) assessed 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 this data, they estimated a sea otter effect of 4.4 to 8.7 teragrams of carbon storage, a value that might be even larger depending on the 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. This interaction influences various species of piscivores (fish eaters) 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 feeding on fish to invertebrates when sea otters are lost from coastal ecosystems. 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 a diet dominated by seabirds where otters were absent.

Sea otters' indirect effects on coastal ecosystems can also follow interaction 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

Figure 5.2. Some known or suspected linkages between sea otters and coastal marine ecosystems.



Note. Panel (a) depicts key interactions between sea otters and other species or components of coastal and oceanic ecosystems of the North Pacific. Arrows with black lines represent top-down forcing, arrows with gray lines represent bottom-up forcing, solid lines represent interactions whose effects have been confirmed based on experiments or field studies, and dashed lines represent interactions that are suspected to be important based on indirect evidence. Panel (b) depicts statistical comparisons of the relative abundance of various species in systems with and without sea otters present, with the differences representing a measure of the direct and indirect food web effects of sea otters. Comparisons are shown for three types of coastal habitats: rocky bottom reef systems, soft sediment systems on the outer coast, and estuarine systems. See the original source (Estes et al. 2016b) for further explanation and detail.

predatory sea stars, thereby reducing sea star populations and associated mortality rates from sea star predation on filter-feeding mussels and barnacles.

Although the preceding narrative summarizes a diverse array of indirect ecological influences from the otter-urchin-kelp trophic cascade (Figure 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).

Soft-Sediment Coastal Ecosystems

Sea otters' effects in soft-sediment habitats along outer coasts result from their consumption of numerous prey species. The two prey groups 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 (*Metacarcinus magister*) 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 on other species and processes in these soft-sediment systems, though probably important, are largely unstudied and thus unknown. Still, they may include such factors as modifying substrate complexity and sediment turnover, facilitating clam recruitment rates on shell debris, modifying the 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), the 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 the 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 by male sea otters have been documented, the cost of deep diving probably results in reduced foraging efficiency, and the vast majority of foraging dives in this species are in less than 30 m 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 the larval supply. Dungeness crab populations in Alaska's inner waters appear to be locally recruiting or self-recruiting, whereas populations in northern California probably draw more extensively from vast larval pools in the offshore California Current ecosystem (A. Shanks, pers comm).

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 nonexistent in deeper-water habitats.

Estuarine/Seagrass Ecosystems

As with soft-sediment habitats on outer coasts, sea otters in estuaries have been shown to reduce the abundances of clams and crabs (Hughes et al. 2013, Grimes et al. 2020). Sea otters influence seagrass-dominated estuarine systems in various other ways, some of which have important conservation implications for these valuable but threatened ecosystems. For example, anthropogenic nitrogen inputs from agriculture and residential activities have 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 returning sea otters to the system. This unexpected positive effect resulted from a previously undescribed trophic 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. The 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, consequently increasing the 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. Otter reintroduction may conflict with the 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, so the possibility of conflicts 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.

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 contribute to this variation, some of which have already been alluded to. They include (a) learned behavioral differences among individual sea otters, especially as they relate to dietary preferences; (b) variation in water depth; (c) variation in the regularity and strength of recruitment by species like fish, invertebrates, and macroalgae commonly characterized by complex life histories with spores or larvae; and (d) 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 sea otters' important evolutionary influence in kelp forest and seagrass ecosystems.

The oldest and most well-known of these evolutionary studies is Steinberg et al.'s (1995) proposal for sea otters' influences on the coevolution 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 coevolution 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 to a poorly defended kelp flora and weakly resistant herbivores. They reasoned that the weaknesses would have been caused by a lack of necessity on the one hand and an otherwise high evolutionary cost of defense/resistance on the other.

They tested this hypothesis via comparative and experimental studies of North Pacific and Australasian kelp forests. They discovered that (a) Australasian kelps and their analogs were well defended by secondary metabolites, whereas their North Pacific counterparts were not; (b) North Pacific herbivores were strongly deterred by these metabolites, whereas their Australasian counterparts were not; and (c) kelps and herbivores lived in close association 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 coevolution of defense and resistance in Australasian kelp forests. In contrast, 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 (*Hydrodamalis gigas*; a kelp-eating mammal) in the North Pacific (Estes et al. 2016a) and the evolution of the unusually large body size in North Pacific abalones (Estes et al. 2005).

A final example of sea otters' evolutionary influence comes from recent work by Foster et al. (2021) on the 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 study) has resulted in sea otters digging for prey in these dense, asexually clonal eelgrass stands as populations have increased and spread, creating patches of open space on the seafloor for successful seed set and, 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 the 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 prey (including many shellfish species). Also, other species and ecological processes feel the effects indirectly through knock-on effects. 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. In turn, the macroalgae affect 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 are 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.

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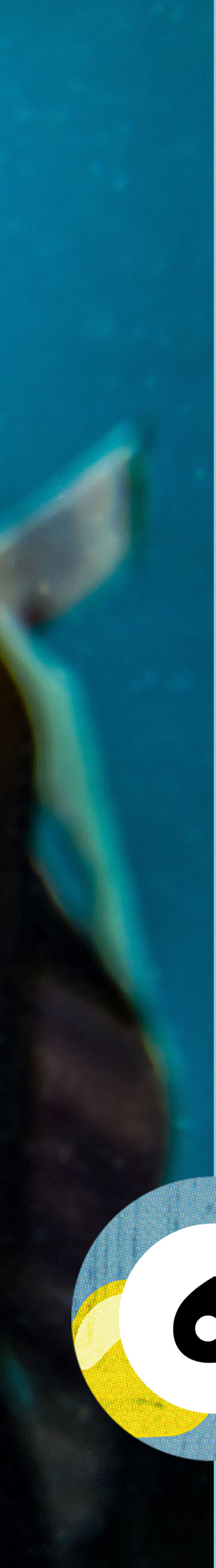
Photo by Laura Tesler.



Chapter 6

HABITAT SUITABILITY

Jan Hodder, M. Tim Tinker, and James L Bodkin

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

Sea otter occurrence in nearshore marine habitats depends on characteristics such as depth and slope, substrate composition, prey abundance and primary productivity, and coastal geography, as well as the otters' 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 unused by sea otters in regions where they have fully recovered since the fur trade. However, it is also essential to recognize that 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 this chapter, we explore what is known and unknown about how characteristics of sea otter habitat in Oregon might influence reintroduction efforts.

CRITICAL RESOURCES FOR SEA OTTERS

For sea otters, as with most carnivores with high trophic levels, the resource most critical for survival is access to sufficient and suitable prey. Sea otters are known to consume more than 150 species of prey, primarily bottom-dwelling marine invertebrates in the intertidal and subtidal zones (Riedman and Estes 1990, Estes and Bodkin 2002, Tinker et al. 2017). 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 versus unconsolidated substrate, or *soft sediments* (Newsome et al. 2015, Davis and Bodkin 2021).

In rocky reef habitats, the diet consists mostly of species living on the surface of the seafloor (i.e., *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).[1] In the early stages of sea otter population establishment in rocky reef habitats, urchins almost always represent a core part of the diet (Wild

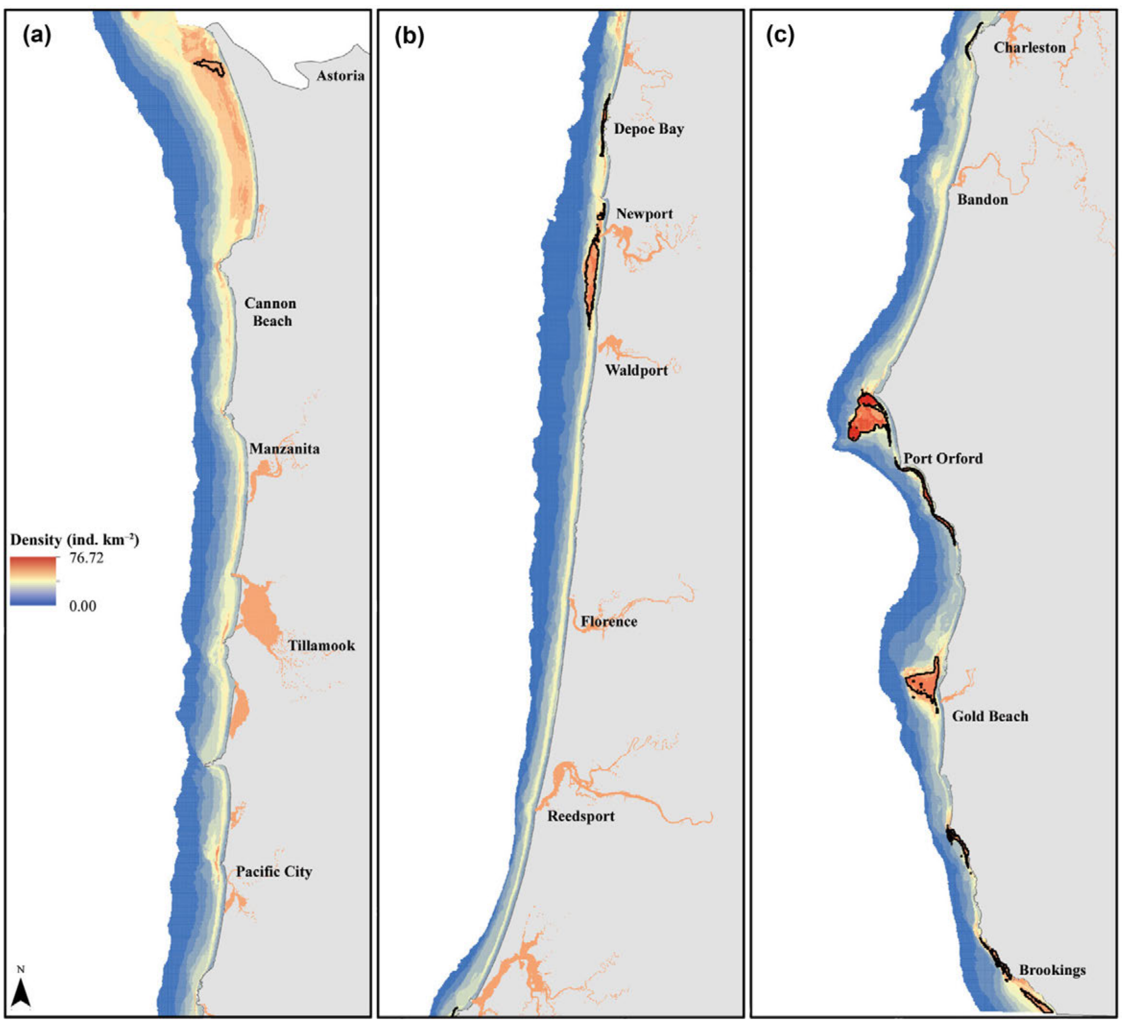
1 We omitted species' scientific names in this introductory section. Later in the chapter, we have provided the scientific names of those species that are the subject of a given section.

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 (*infaunal* 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 versus 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 the 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 providing adequate prey, habitats that protect otters from adverse environmental conditions, such as high seas, facilitate a range of behaviors that otters exhibit most often when aggregated in groups—such as resting, grooming, and social or reproductive behaviors (pup rearing). Examples of such habitat features 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 often attract high densities of animals. Not all kelp

Figure 6.1. Estimated potential densities of sea otters at equilibrium along the outer coast and in estuaries of Oregon.



Note. These potential densities assume a population reaches carrying capacity (K). The maps are for Oregon's (a) north, (b) central, and (c) south 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. Adapted from Kone et al. (2021).

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 giant kelp beds are more preferred than bull kelp beds, although both are used. The specific features that attract otters 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 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 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 south-central coast of Washington, where large expanses of relatively shallow water extend tens of kilometers offshore (Jeffries et al. 2017). Thus, sheltering features appear to be used by otters when available but may not be absolutely critical for an area to support otters. 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—help determine the relative degree of a coastal habitat's suitability for sea otters. Still, the former resource appears to be more limiting than the latter. Unfortunately, measuring these resources directly at spatial scales relevant for sea otters, especially prey availability, 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 subtidal sampling methods to directly measure the relative availability of this prey species (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 scuba-based methods cannot effectively measure 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 that can be more readily measured (e.g., substrate characteristics).

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 geographic information system (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.

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 a suitable substrate that supports a large enough prey base to allow sea otters to successfully colonize an area. Sea otters are typically found in the highest densities in shallow (< 20 m) 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 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 provided 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 that 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 Oregon's suitability to support reintroduced sea otters. The topics covered include nearshore substrate, kelp distribution, information on potential prey items, and biological resources in Oregon's estuaries.

SUBSTRATE

Oregon's nearshore subtidal zone consists of a mosaic of substrates, ranging from rock reefs to mud plains. Oregon's Nearshore Strategy website[2] provides an overview of substrate for approximately 53% of Oregon's territorial sea,[3] 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.

The Active Tectonics and Seafloor Mapping Lab at Oregon State University (OSU) made available a more detailed habitat substrate characteristic for some of Oregon's coastal waters. 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 maps on the right-hand side of Figures B.16 through B.18 in Appendix B, were not mapped as funds were not available to complete the work. However, the Oregon Nearshore Strategy maps (Figure 6.2(b)) show that considerable bedrock is 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 Oregon ocean planning tool.[4]

In addition to these statewide maps, more detailed substrate characteristics of Oregon's nearshore are available for the marine reserves and their comparison areas.[5] Only three of the five marine reserves contain any substantial rock substrate: Cascade Head, Otter Rock, and Redfish Rocks. Maps from the Oregon Department of Fish and Wildlife (ODFW) Data Dashboard for the substrate characteristics of these three marine reserves are provided in Appendix C.

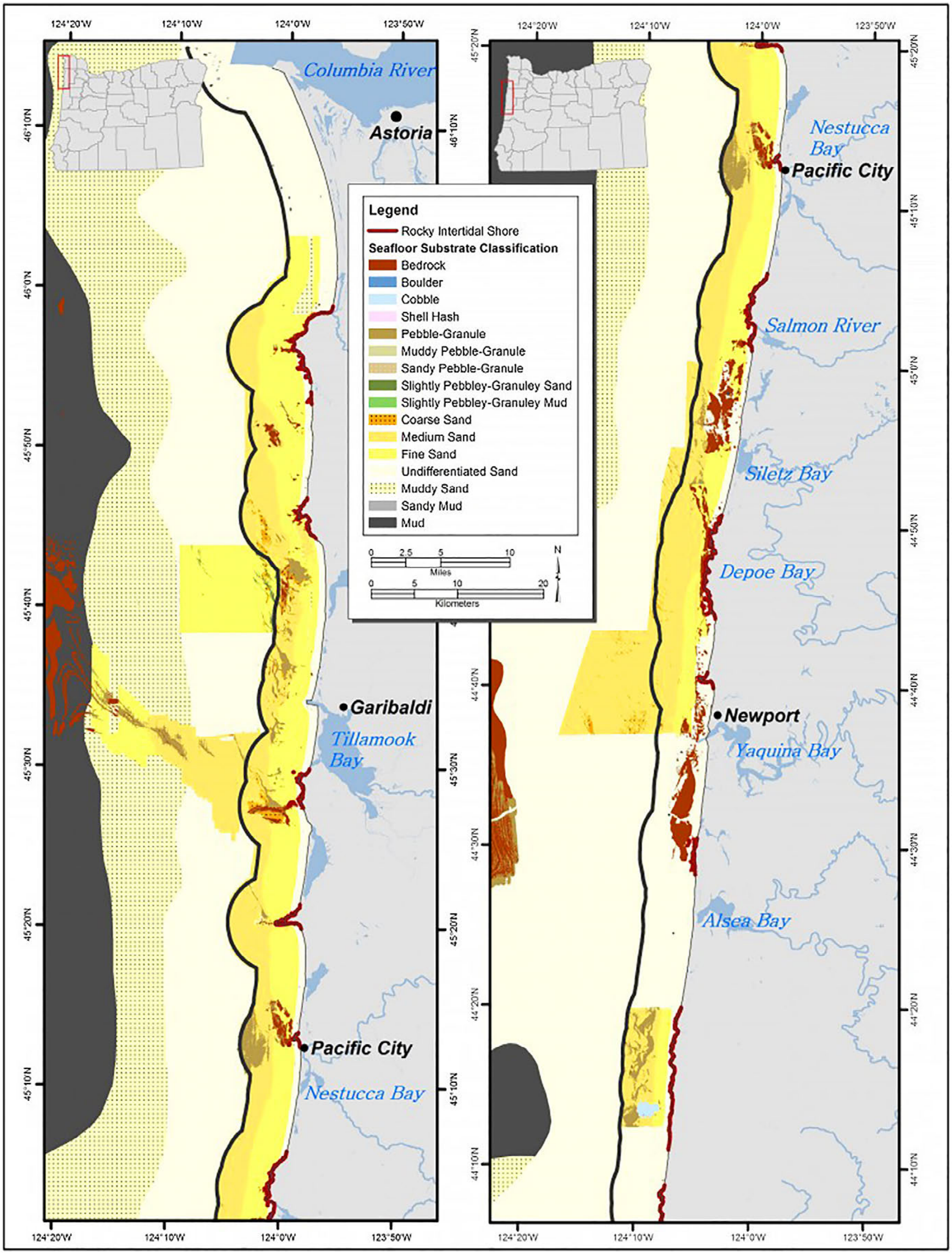
2 See https://oregonconservationstrategy.org/oregon-nearshore-strategy/habitats/.

3 Oregon's territorial sea is defined as the waters and seabed extending 3 geographical miles (4.83 km) seaward from the Pacific coastline.

4 See https://www.seasketch.org/#projecthomepage/5c1001699112e049f68fc839.

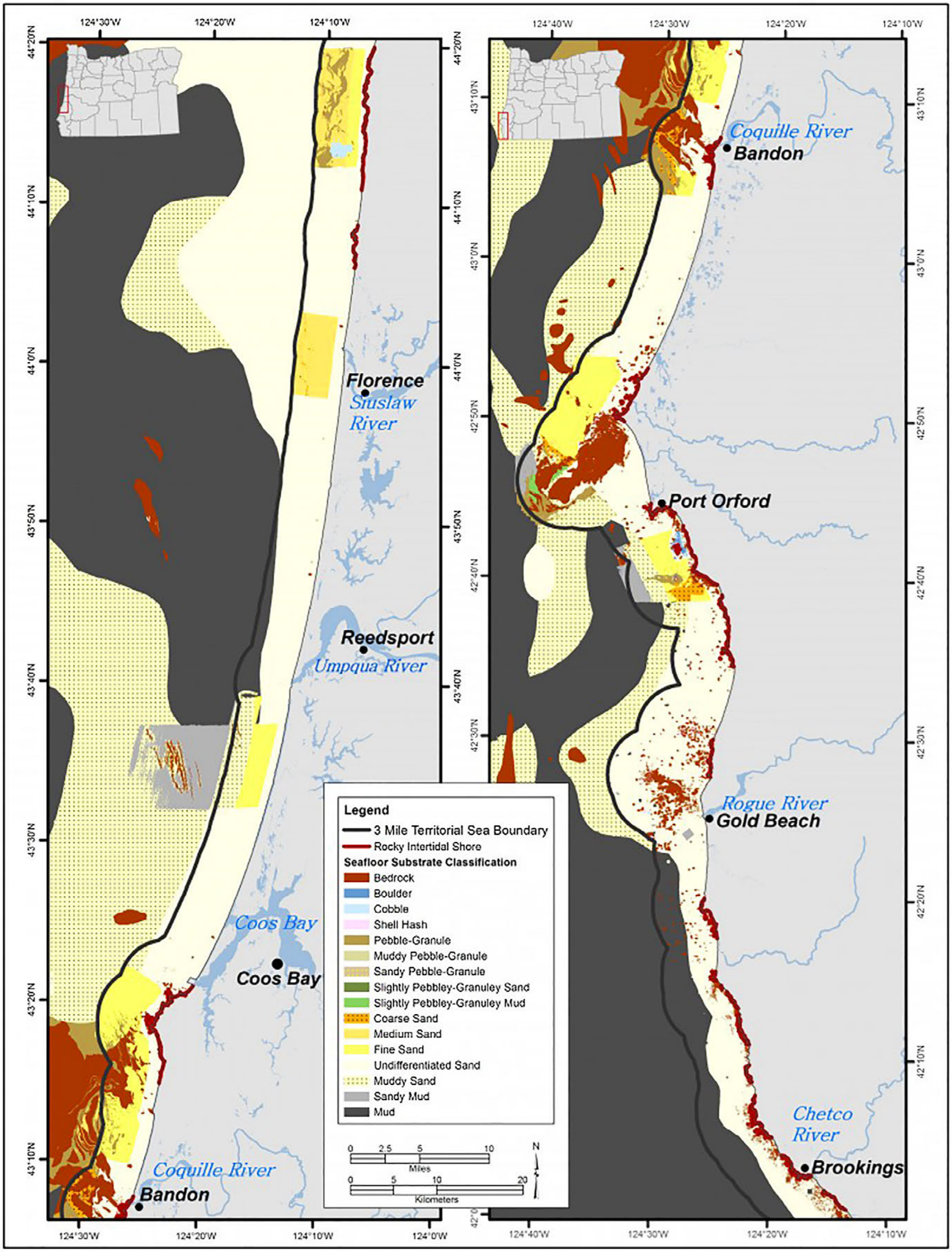
5 See the ODFW Marine Reserves Program Data Dashboard: https://odfwmarinereserves.shinyapps.io/Marine_Reserves_Shiny_App_v7/.

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



Note. From the Oregon Conservation Strategy: https://oregonconservationstrategy.org/oregon-nearshore-strategy/habitats/.

Figure 6.2, cont'd. (b) Benthic substrate classification for the southern half of the Oregon coast.



Note. From the Oregon Conservation Strategy: https://oregonconservationstrategy.org/oregon-nearshore-strategy/habitats/.

KELP DISTRIBUTION

Substrate characteristics, particularly bedrock, can provide some information on the suitability of habitat for sea otters. The presence of kelp beds can also inform habitat 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 giant kelp in Oregon is located at the south end of Simpson Reef in the North Cove of Cape Arago (Sanborn and Doty 1944), although it occurs along open coasts north to the Gulf of Alaska. Interestingly, Simpson Reef was one of the two core areas where 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 resources 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 their 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 more than 200 acres of kelp bed were documented:

- 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 infrared 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, ODFW initiated a five-year study that 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 the report *Kelp Canopy and Biomass Survey* (Merems 2011). It used survey information collected between 1990 and 1999 and supplemented it with data collected from 2011 aerial surveys off the southern coast of Oregon using a digital multispectral imaging system. Complete composite maps of kelp canopy extent from these surveys are provided in Appendix D.

More recently, Hamilton et al. (2020) used 35 years of Landsat satellite imagery (1984–2018) to track the population size of bull kelp in Oregon. Canopy-forming kelps, such as bull kelp, 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 30 m and thus can miss smaller kelp patches as well as kelp cover in the immediate nearshore. However, the imaging 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 before 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.

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

Area	Concentration (acres)					Harvestability (acres)		
	Not con-firmed	Thin	Mod-erate	Dense	Total	Un-known	Unhar-vestable	Harvest-able
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 Rock	--	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	1071	257	891	2709	373	1141	1195
Total for Lincoln, Coos, and Curry Counties	**508**	**1159**	**754**	**1283**	**3704**	**391**	**1307**	**2006**

Note. From the Fish Commission of Oregon's research briefs (Waldron 1955).

Table 6.2. Oregon coastal kelp resources, canopy areas by map number.

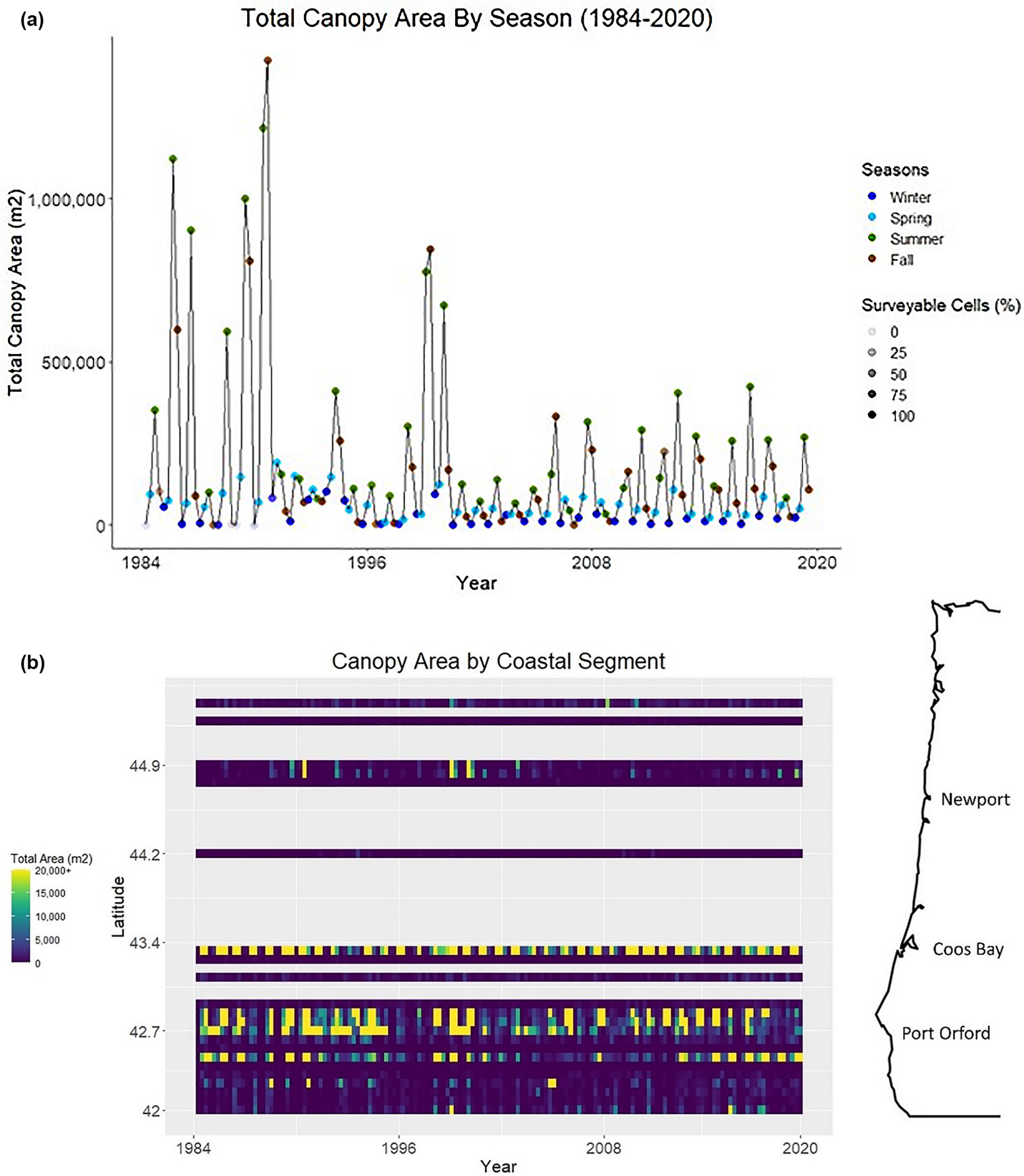
Map number	Map name	Kelp canopy area (ha.) *N. luetkeana*	Kelp canopy area (ha.) *M. integrifolia*	Total canopy area (ha.) Both species
1	Columbia River	0.00	0.00	0.00
2	Tillamook Head	0.00	0.00	0.00
3	Cape Falcon	0.00	0.00	0.00
4	Rockaway	0.00	0.00	0.00
5	Netarts Bay	0.00	0.00	0.00
6	Cape Lookout	5.03	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**

Note. N. luetkeana = bull kelp. *M. integrifolia* = giant kelp. From Ecoscan Resource Data (1991).

As with previous surveys, Hamilton et al. (2020) found that 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 Orford-Humbug Mountain area in Table 6.1), and Rogue Reef (Figure 6.4). Some areas' kelp canopies (e.g., Cape Arago near Coos Bay) have been remarkably stable over time, while others (e.g., Rogue Reef) have varied more.

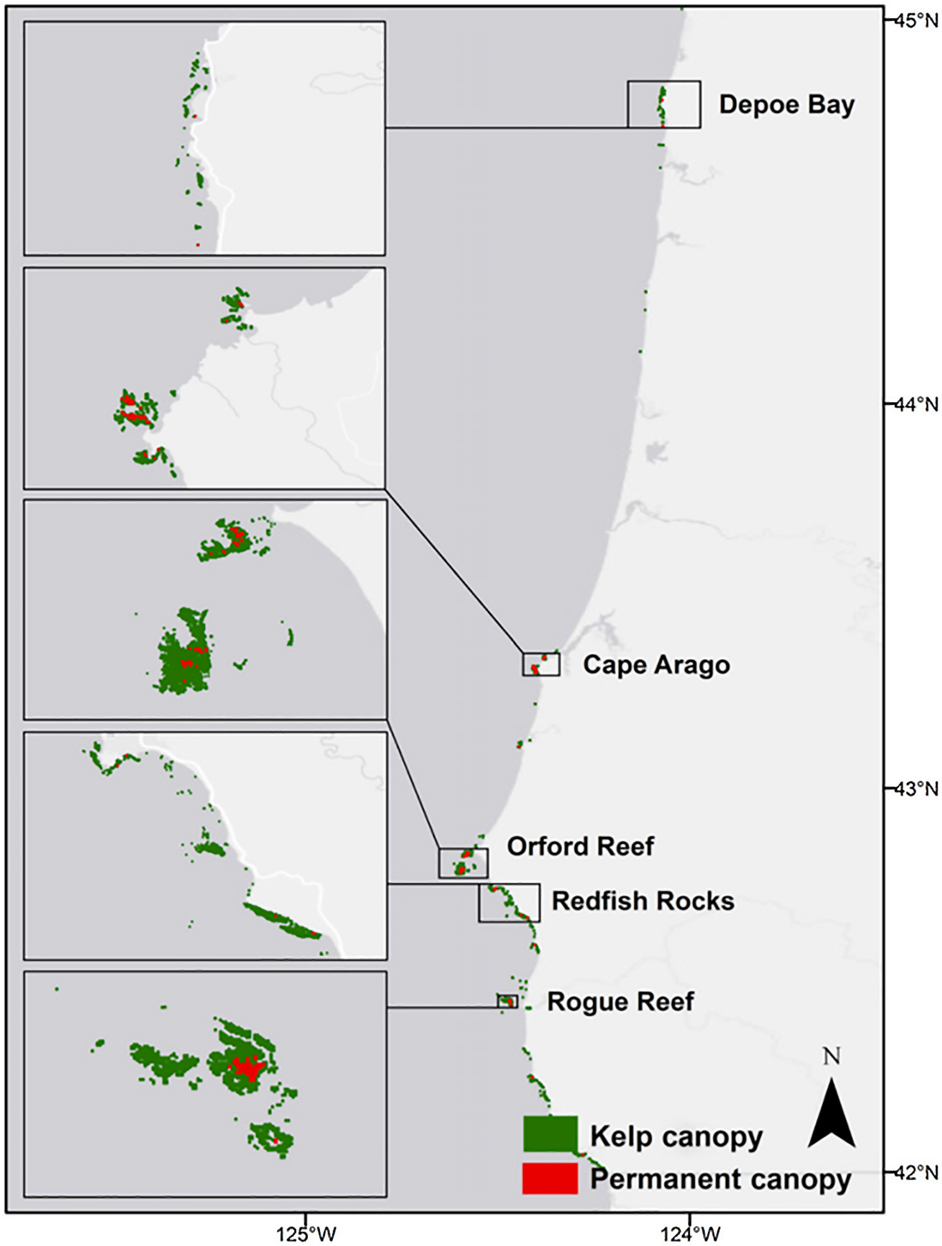
At the scale of individual reefs, Hamilton et al. (2020) found no consistent trend in the bull kelp canopy area or population trajectory over the last 35 years (Figure 6.5). At some sites, canopy area varied dramatically among years, although all five sites had what was described as a "permanent canopy" 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 population levels for the past 15 years.

Figure 6.3. Total kelp canopy in Oregon by season and by coastal segment, 1984–2020.



Note. (a) Total kelp canopy area by season across Oregon for every quarter from 1984 to 2020. Quarters are displayed as "seasons" using colors, and the transparency of the points indicates the percentages of all Oregon kelp pixels that could be surveyed during that quarter. (b) Total kelp canopy area by coastal segment for every quarter from 1984 to 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 the total canopy area was summed for each quarter in each segment. From S. Hamilton, pers comm.

Figure 6.4. Map of all kelp detected in Oregon.



Note. The map shows kelp detected in Oregon in at least 1% of the available Landsat images (green) and all "permanent" canopy (red), which is defined as kelp 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).

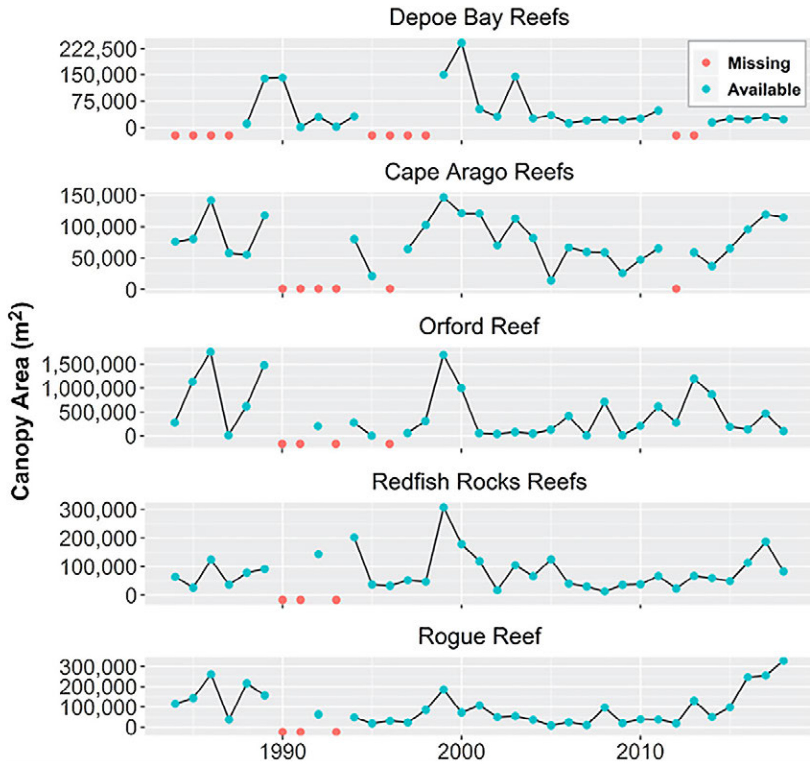
A notable example of variation is from Orford Reef, where the estimated maximum summer canopy extent in 1987 was 0.7% of the area present in 1986. Over the last 20 years, Orford Reef has shifted to a somewhat smaller, less variable population (Figure 6.5).

Hamilton et al. (2020) ran linear models of canopy extent against a number of variables, including the year. Two time periods were modeled: 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 1984–2018 model, indicating declining populations over the last 35 years. However, the 1996–2018 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, the canopy extent was positively related to the 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 the year. At both sites, population sizes over the last five years were within the range of sizes seen regularly over the last 35 years (Figure 6.5).

Hamilton et al. (2020) also looked at whether Oregon's bull kelp population sizes responded to a 2014 marine heat wave, which in northern California was accompanied by a large decline in the bull kelp 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 the maximum summer canopy area for 2015–2018 as compared to the prior 10 years. At Cape Arago, Redfish Rocks, and Rogue Reef, the kelp area increased in 2015–2018 as compared to the previous decade. During the 2014 marine heat wave, the 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.

Figure 6.5. Time series of the maximum detected summer kelp canopy area for Oregon's five largest reefs, 1984–2018.



Note. The map shows kelp detected in Oregon in at least 1% of the available Landsat images (green) and all "permanent" canopy (red), which is defined as kelp 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).

SEA OTTER PREY

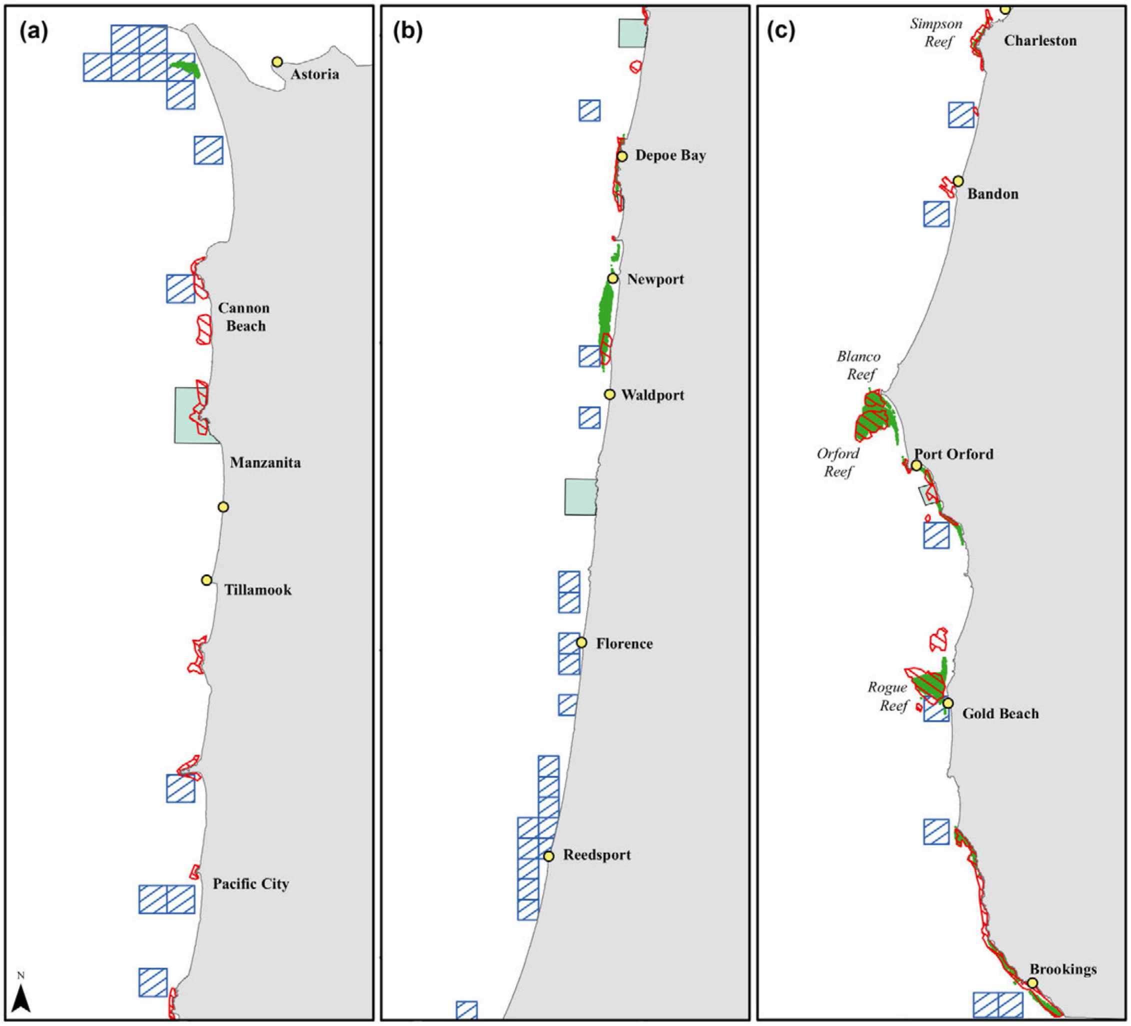
Intertidal Invertebrates

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[6] or the Multi-Agency Rocky Intertidal Network,[7] 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 gigantea*) are found under rocks and among 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 three to five per square meter in surveys conducted in 2010 and 2013.

6 See https://www.piscoweb.org/about-us.

7 See https://marine.ucsc.edu/overview/index.html.

Figure 6.6. Spatial location of predicted high-density sea otter habitat along Oregon's outer coast compared to high-catch crabbing grounds.



Note. The spatial locations of predicted high-density sea otter habitats are shown as green polygons. The map indicates these areas' potential overlap with and proximity 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 Oregon's (a) northern, (b) central, and (c) southern regions. Adapted from Kone et al. (2021).

Subtidal Invertebrates

For the majority of sea otters' potential subtidal prey species, there are no consistent monitoring efforts. As with intertidal prey, a few prey species are included in subtidal monitoring by the Partnership for Interdisciplinary Study of Coastal Oceans. 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[8] 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 (*Mesocentrotus franciscanus*) and Dungeness crab (*Metacarcinus magister*)—resulting in more extensive data available for these species, as summarized below. Two other taxa monitored by ODFW are not current fisheries but are potentially commercially important: abalone (*Haliotis* sp.) and rock scallops (*Crassadoma gigantean*).

8 Available at https://odfwmarinereserves.shinyapps.io/Marine_Reserves_Shiny_App_v7/.

Red Sea Urchins

Both purple urchins (*Strongylocentrotus purpuratus*) and red urchins (*M. 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 eight portions of the coast predicted to potentially support higher-than-average density in 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.

Dungeness Crab

As with urchin landings, Kone et al. (2021) evaluated the overlap between Dungeness crab (*M. magister*) fishing areas and eight portions of the coast predicted to potentially support higher-than-average density in sea otter populations (Figure 6.6). This analysis suggested that Dungeness crab are abundant throughout the state, including near 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 to the south. There was a short-lived commercial fishery from 1960 to 1962 and a recreational fishery from 1953 to 2017. Both were closed because of concerns about depletion, and 2015 surveys for red abalone conducted by ODFW showed that there were only 0.03 individuals per square meter (Groth and Rumrill 2019). Flat abalone (*Haliotis walallensis*) are found in vegetated rocky reefs throughout Oregon. They were commercially harvested from 2001 to 2008. There are no data on current population levels, but it is likely to be small, as the fishery's closure was the result of conservation concerns about the population's status. Pinto abalone (*Haliotis kamtschatkana*) is a small species that 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 the recreational harvest of rock scallops (*Crassadoma gigantean*). Figure 6.7 indicates that for the years 2013–2019, the annual recreational take ranged from 669 to 1154 scallops. The number of individuals participating in the fishery, based on permit returns, ranged from 58 to 195 per year. Half (50%) of the take was returned to the ports of Charleston, Port Orford, and Brookings, indicating they were collected along the southern Oregon coast (S. Groth, ODFW, pers comm, February 12, 2012).

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

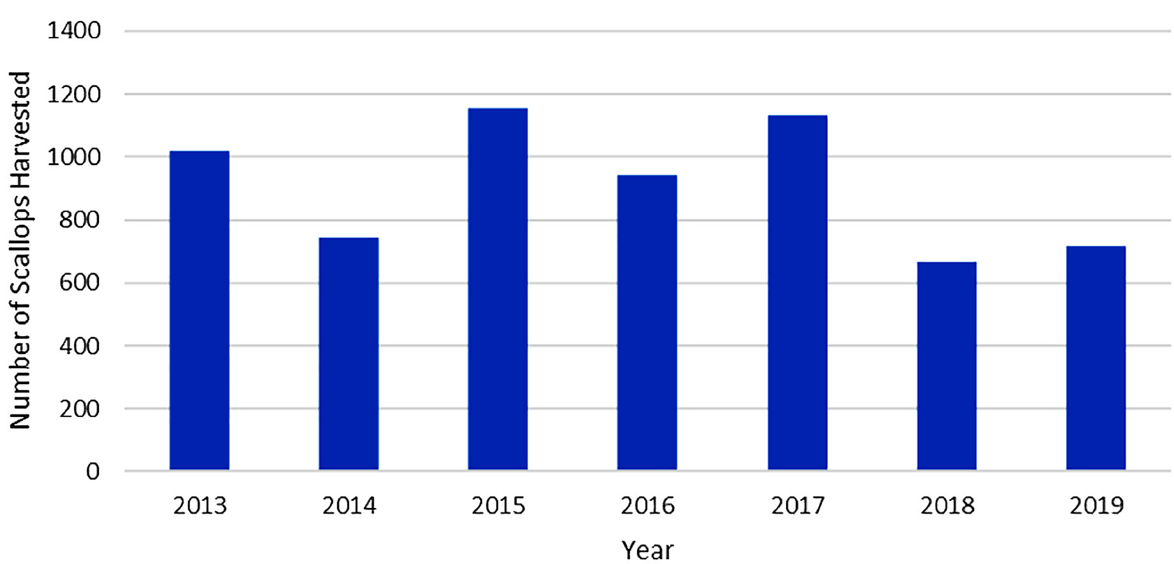
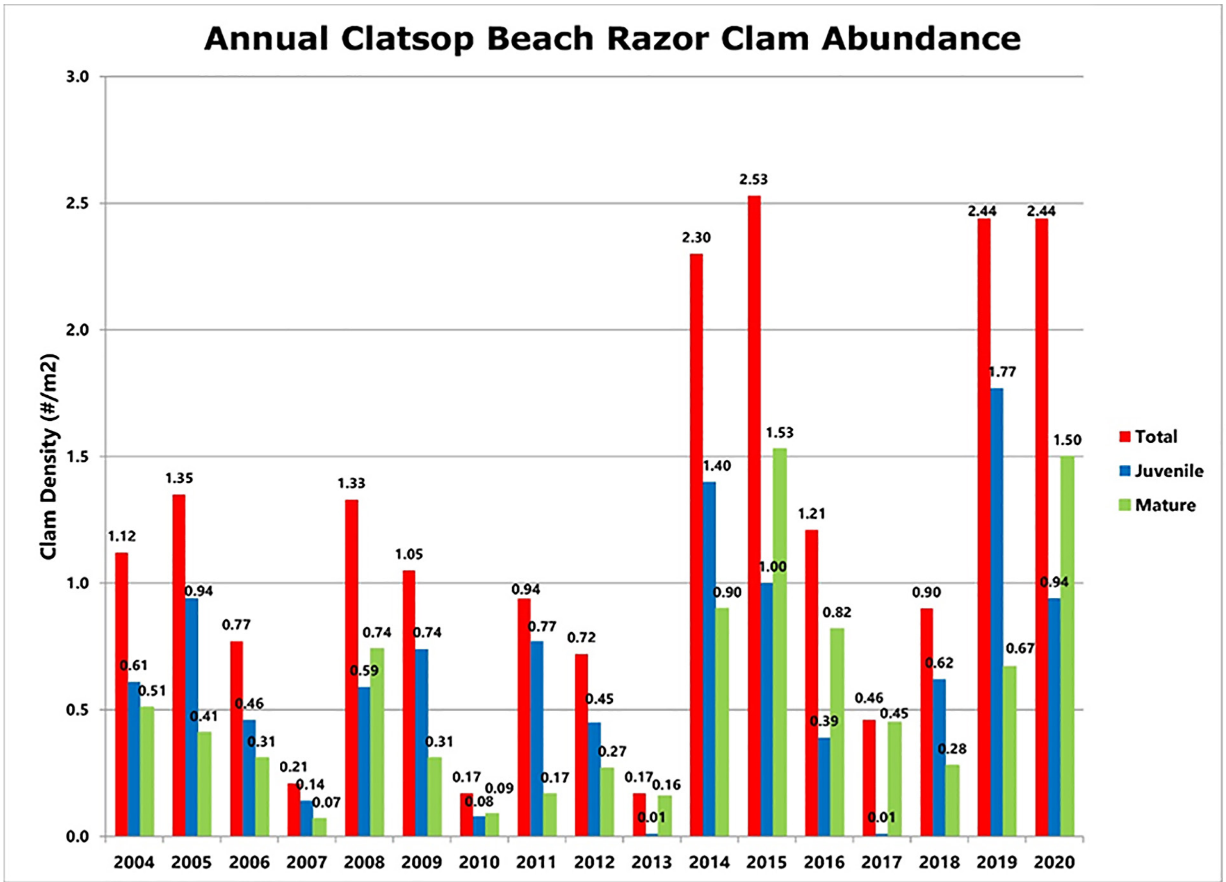


Figure 6.8. Annual abundance of intertidal razor clams in Clatsop County.



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 OSU Active Tectonics and Seafloor Mapping Lab (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) indicated that both gaper calms (*Tresus capax*) and cockles (*Clinocardium nuttallii*) occur in soft-sediment areas of the outer coast, though in smaller numbers than found in estuaries. Razor clams (*Siliqua patula*), another common prey species for sea otters, are found in sandy substrates both subtidally and in the low intertidal (McCrae and Daniels 1998). They 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 mi (28.97 km) 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 (DA) 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 DA effects on sea otter health.

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, sea otters' estuarine use 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 the 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 British Columbia 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 British Columbia eelgrass habitats (Hessing-Lewis et al. 2018).

The Kone et al. (2021) model for estimating sea otter population potential in Oregon 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. Thus, it 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 and, consequently, 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 rich invertebrate prey resources, not to mention serving as an indicator of good estuarine water quality. 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*, the latter of which also occurs subtidally. 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 surfgrass (*Phyllospadix* spp.; Harper et al. 2011). Based on the 2014 ShoreZone report (Harper et al. 2011), 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* (EPB; Cortright et al. 1987). The EPB identified eelgrass (*Zostera* spp.) in 13 estuaries in Oregon. An update to the EPB was made in the 1980s (Sherman and DeBruyckere 2018) and provided a limited synopsis of the extent of eelgrass in Oregon's estuaries, as summarized in Table 6.3.

The U. S. 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 given system's reported distribution of intertidal *Z. marina*. 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 online resources curated by the Pacific Marine and Estuarine Fish Habitat Partnership (PMEP): (1) The West Coast Estuaries Explorer and (2) the "Eelgrass Maximum Observed Extent" data layer from the West Coast USA Eelgrass Habitat tool.[9]

Each of these online resources used a different data source, but there were common conclusions: First, Coos, Yaquina, and Tillamook Bays have the most substantial eelgrass resources. Second, most other Oregon estuaries either are devoid of eelgrass or have only limited amounts.

9 Learn more about PMEP at https://www.pacificfishhabitat.org/. The West Coast Estuaries Explorer is available at https://estuaries.pacificfishhabitat.org/. The West Coast USA Eelgrass Habitat data tool is available at https://www.pacificfishhabitat.org/data/west-coast-usa-eelgrass-habitat/.

Figure 6.9. Distribution of seagrass biobands: Eelgrass (ZOS) and surfgrass (SUR) in the Oregon study area.

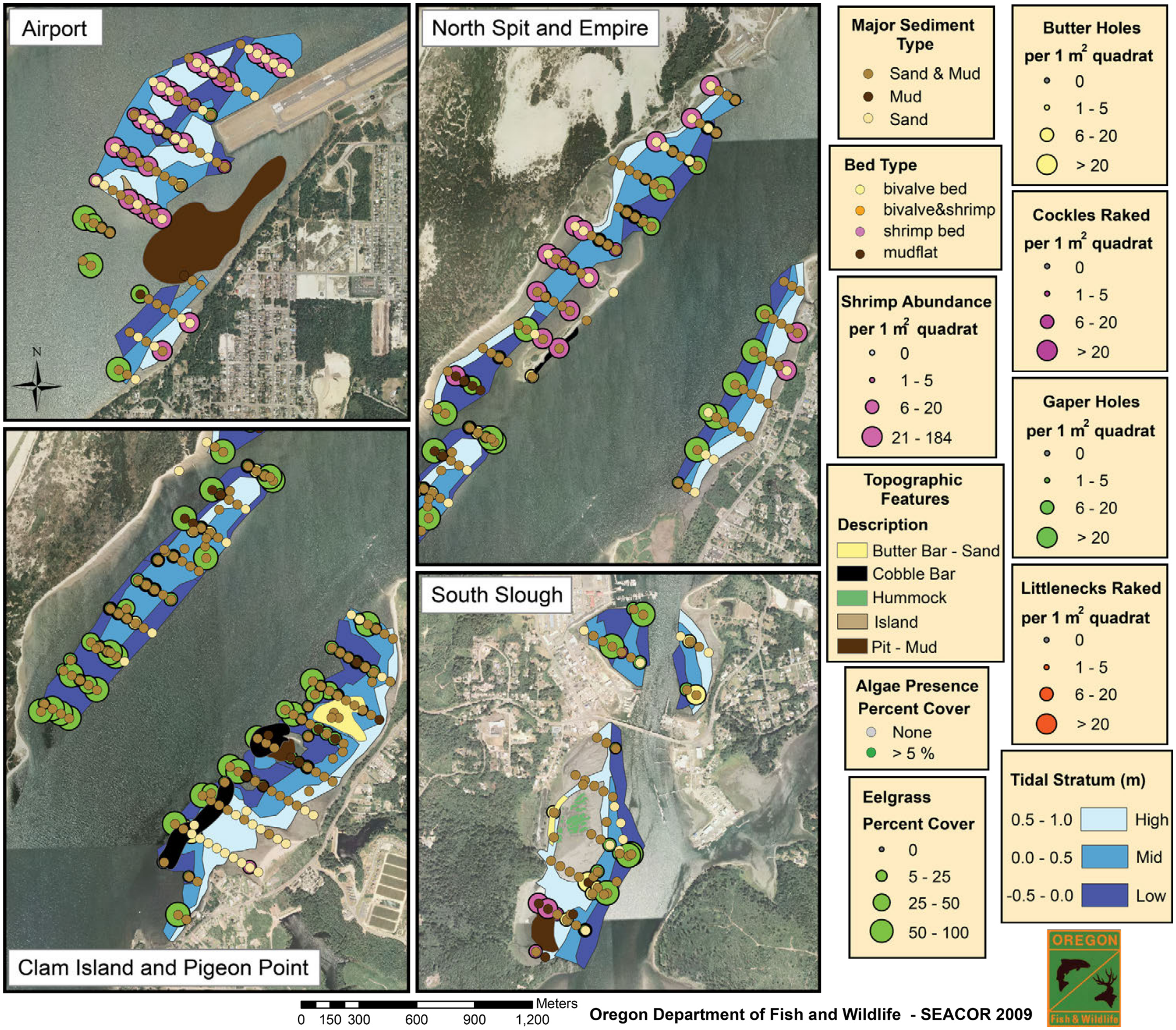
Note. From the 2014 ShoreZone report (Harper et al. 2011).

Table 6.3. Timeline of data collection depicting the current and historical extents of eelgrass in Oregon estuaries.

	Regional eelgrass extent summary data sets				**Other local data sources**	**Literature only**
PMEP estuary (with eelgrass present)	EPB	USEPA	ODFW (SEACOR)	ShoreZone (OR & WA)	Estuary-specific extent data source	Historical 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

Note. PMEP = Pacific Marine and Estuarine Fish Habitat Partnership. EPB = the Oregon *Estuary Plan Book* (Cortright et al. 1987). ESI = Environmental Sensitivity Index. SEACOR = Shellfish and Estuarine Assessment of Coastal Oregon. Cells surrounded by double-line borders indicate the presence of eelgrass, and the date in each cell indicates the survey year or range of years. The five cells without borders but with bold text indicate the absence of eelgrass and list the relevant survey year(s). Empty boxes indicate no available data. Adapted from Table 2 in Sherman and DeBruyckere (2018).

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



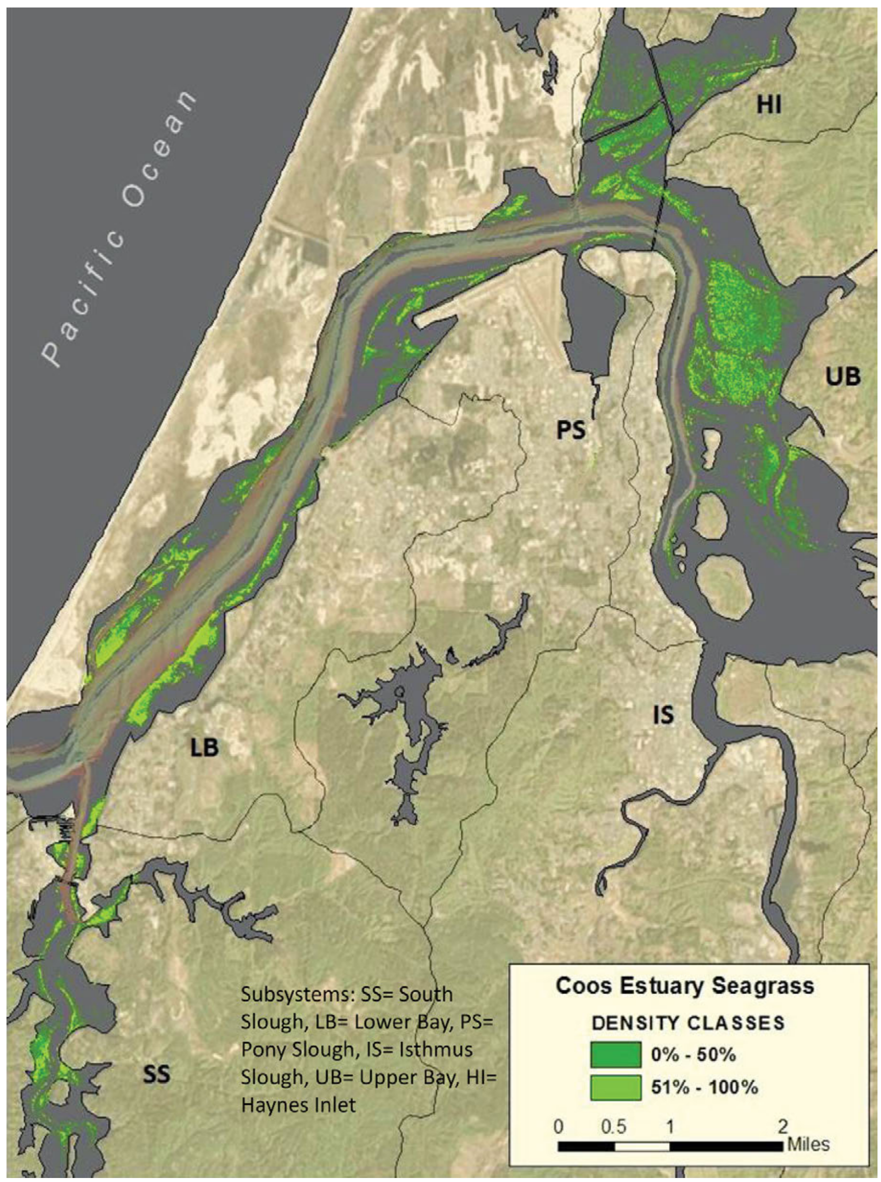
Note. From the SEACOR program (ODFW 2009). The Partnership for Coastal Watersheds (https://www.partnershipforcoastalwatersheds.org/vegetation-aquatic/) provides additional information on the extent of eelgrass in Coos Bay, with the caveat that the data set may not be complete or up-to-date. These data are shown in Figure 6.11.

Table 6.4. Seagrass abundance in seven Oregon estuaries.

	Native seagrass (*Z. marina*)		Non-native seagrass (*Z. japonica*)	
Estuary	Presence: # of sites with *Z. marina*	Coverage: % of total intertidal area	Presence: # of sites with *Z. japonica*	Coverage: % 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

Note. Sampling occurred between 2004 and 2006, with Coos estuary sampling occurring exclusively in 2005. The 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. From Lee II and Brown (2009).

Figure 6.11. Eelgrass extent in Coos Bay.



Note. From p. 11-85 in the Partnership for Coastal Watersheds' *Community, Lands, & Waterways Data Source* (2015).

The ODFW SEACOR data set (2010–2015) surveyed six estuaries for recreational clam populations and, in some cases, eelgrass distribution. There are clam species occurrence maps[10] for six estuaries: Tillamook Bay, Netarts Bay, Yaquina Bay, Siletz Bay, Alsea Bay, and Coos Bay. For Coos Bay, data are presented in an interactive map of substrate, clam abundance, and eelgrass cover (Figure 6.10).

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) documented an example of eelgrass decline in Yaquina Bay, comparing the maximum observed extent of eelgrass (based on the "Eelgrass Maximum Observed Extent" data layer from the West Coast USA Eelgrass Habitat tool[11]) with the ODFW SEACOR data set (Figure 6.12). This comparison documented a dramatic reduction in the extent of eelgrass beds in Yaquina Bay.

In Coos Bay, an available time series of eelgrass abundance allows for another examination of temporal trends in extent. The South Slough National Estuarine Research Reserve (SSNERR) monitored eelgrass density at four sites within the reserve from 2004 to 2020 (A. Helms, pers comm, December 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 nonmigratory 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.

Based on all the above data on eelgrass distribution, relative abundance, and trends, we can summarize the relative suitability of five 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 a habitat for the resting and reproductive behaviors of sea otters, as well as adjacency of the estuaries to nearby kelp habitats (Table 6.5).

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[12] 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 Bays). Commercially exploited bay clams (cockle, gaper, butter, and native littleneck clams) are present in Tillamook, Netarts, Yaquina, and Coos Bays (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, pers comm, January 11, 2021).

Oregon's estuaries are also important habitats for juvenile and adult Dungeness crabs (*M. 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) provided the most comprehensive information on recreational crabbing in Oregon. Annually recreational harvest accounts for approximately 5% of the commercial harvest. The European green crab (C*arcinus maenas*) has been present in Oregon's estuaries since the late 1990s and has increased in abundance in the estuaries of Tillamook, Netarts, Yaquina, and Coos Bays since 2016 (Behrens Yamada et al. 2020).

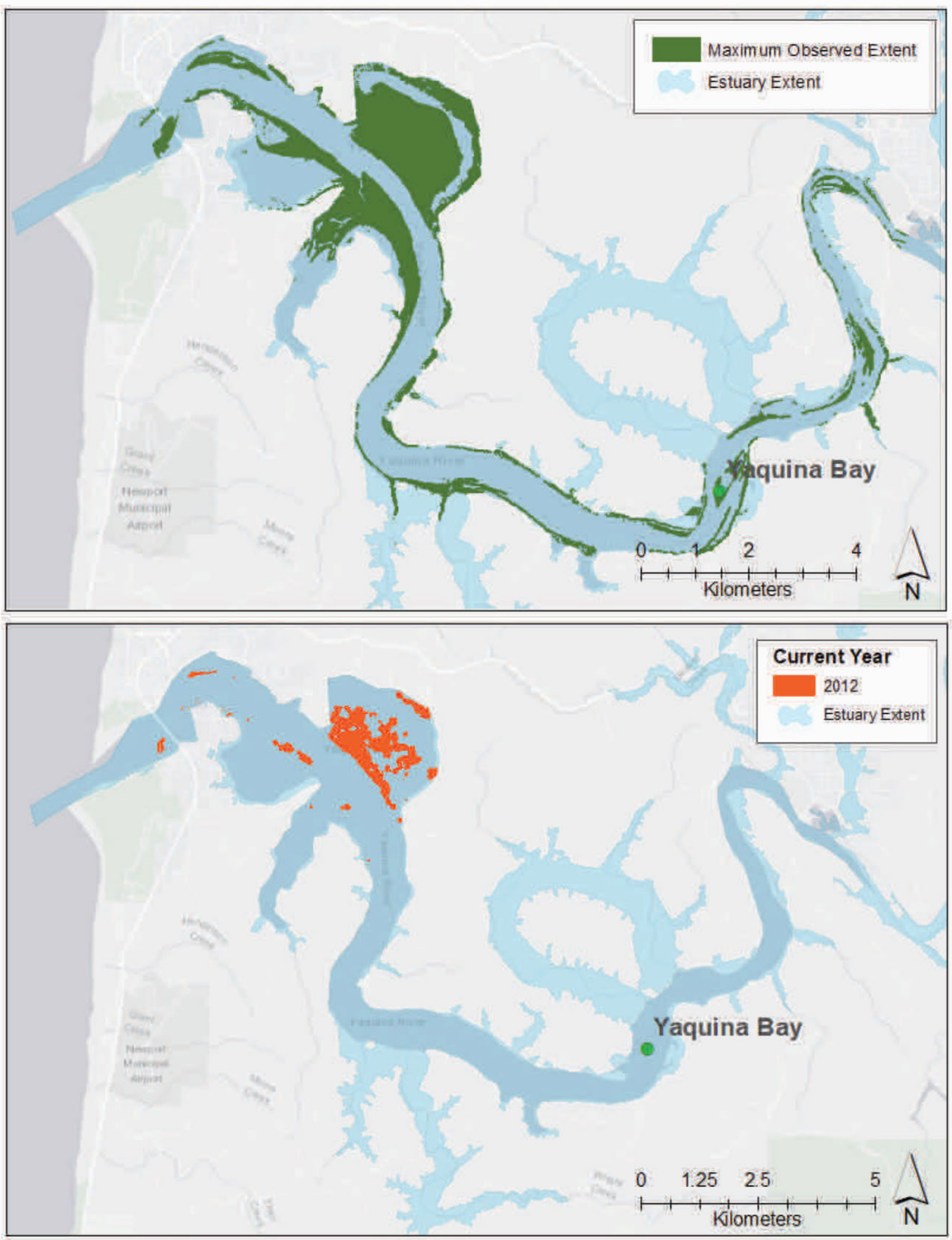
Several of Oregon's estuaries (Tillamook, Netarts, Yaquina, and Coos Bays) support commercial oyster (*Crassostrea gigas*) farms. The majority of oysters in Oregon are grown directly on the estuarine bottom rather than by rack or hanging culture, as is often seen in other areas. Native oysters (*Ostrea 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

10 See https://www.dfw.state.or.us/mrp/shellfish/seacor/maps_publications.asp.

11 See https://www.pacificfishhabitat.org/data/west-coast-usa-eelgrass-habitat/.

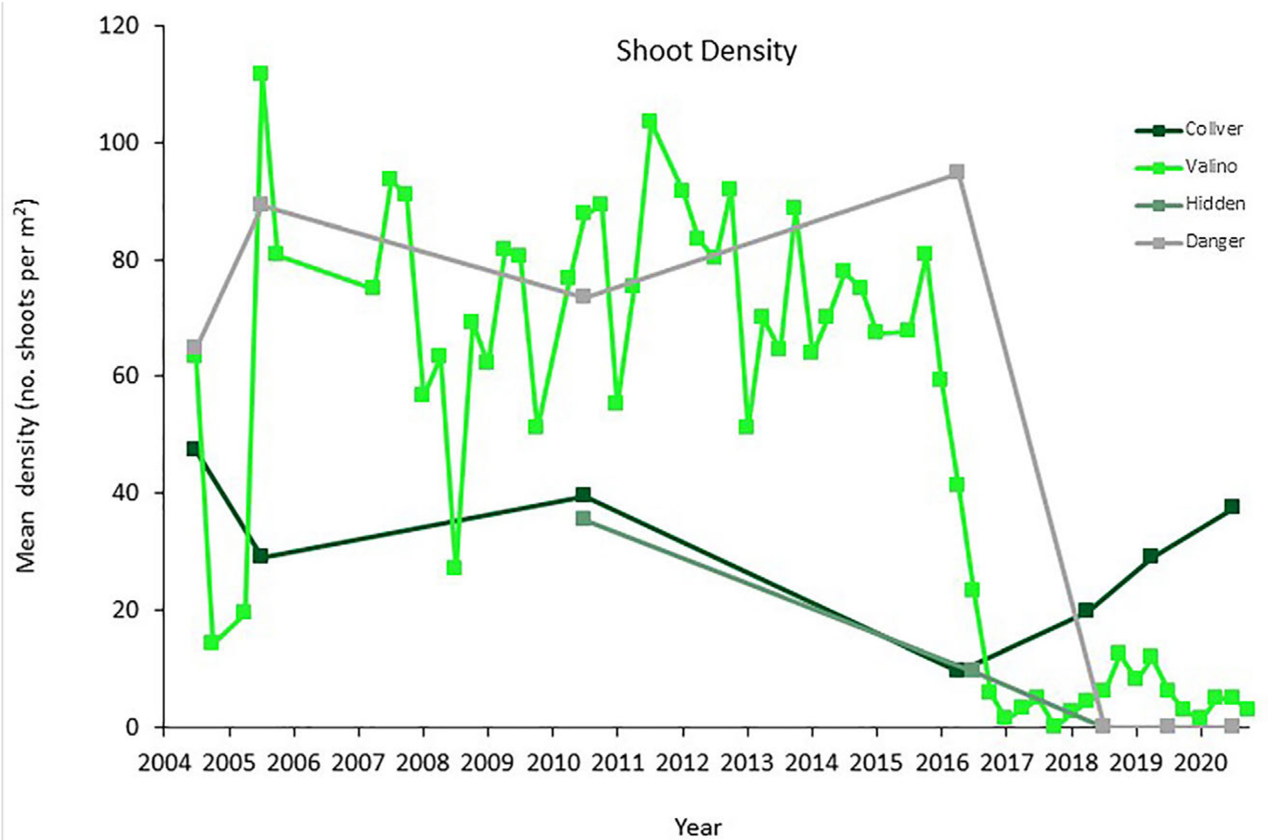
12 Available at https://www.dfw.state.or.us/MRP/shellfish/Seacor/maps_publications.asp.

Figure 6.12. Comparison of current eelgrass extent to the maximum extent for Yaquina Bay, OR.



Note. From Sherman and DeBruyckere (2018), see p. 83.

Figure 6.13. Shoot density of eelgrass from four SSNERR sites.



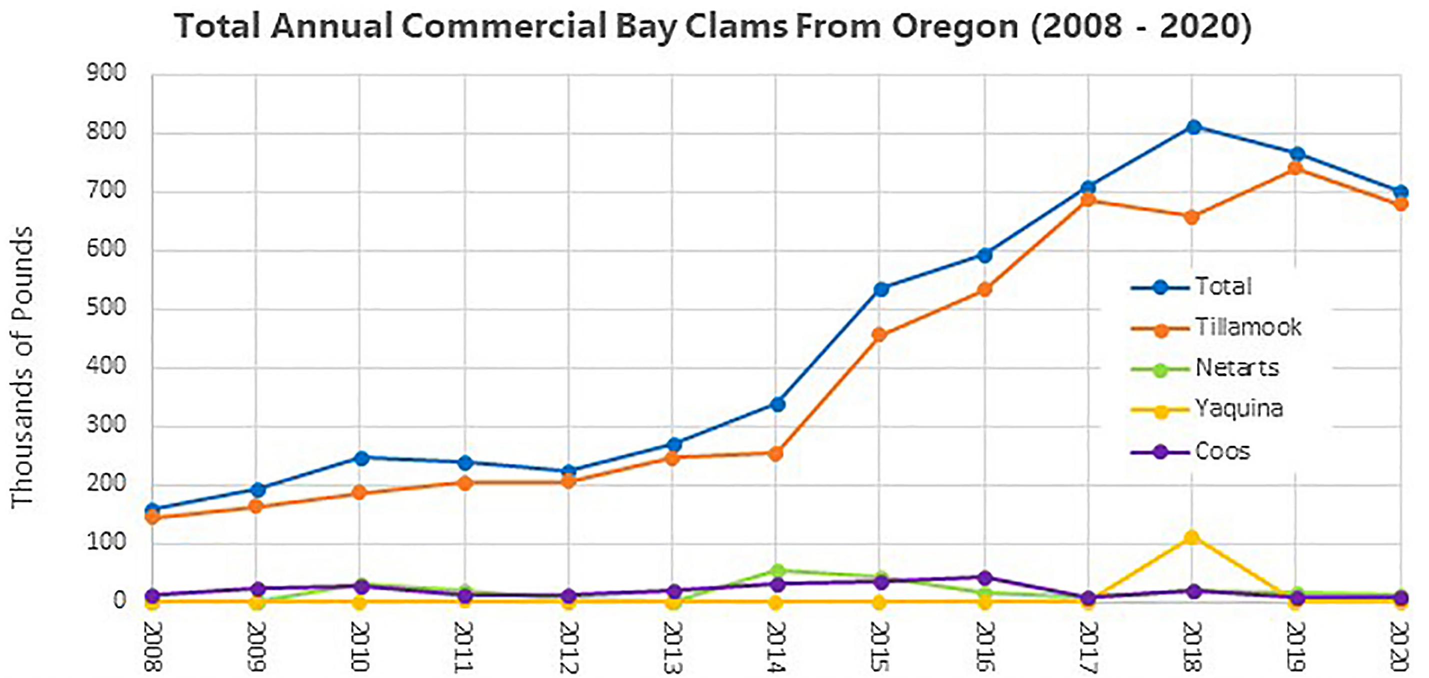
Note. Data were provided via personal communication with A. Helms, SSNERR, December 2021.

Table 6.5. Characteristics of eelgrass vegetation in five 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	6649	11	17.4	162	Yes
Alsea Bay	3562	"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

Note. * From Lee II and Brown (2009).
** From the West Coast Estuaries Explorer, an app created by the Conservation Biology Institute in partnership with the Pacific Marine and Estuarine Fish Habitat Partnership: https://estuaries.pacificfishhabitat.org/.
*** From Phillips (1984).

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



Note. From personal communication with M. Vance, ODFW, January 2021.

Table 6.6. Variables related to prey availability, threats, and eelgrass resting habitat for selected 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

Note. 1 ha = 10,000 m^2.

estuaries are currently underway, spearheaded by The Nature Conservancy, the Confederated Tribes of Siletz Indians, and the SSNERR.[13] Neither type of oyster is subject to recreational harvest. There is little published information about whether sea otters consume commercial or native oysters. Based on anecdotal reports concerning areas where sea otters and commercial oyster operations overlap in Alaska, there have been minimal interactions. However, unlike the Oregon fishery, Alaskan commercial oyster operations use hanging bags or enclosures that may discourage sea otter interactions.

13 As noted on the following ODFW web page, accessed May 20, 2022: https://www.dfw.state.or.us/mrp/shellfish/bayclams/about_oysters.asp.

Estuary Summary

Based on all the data described above, we provide a summary of characteristics for selected 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 a 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.

WATER QUALITY CONSIDERATIONS

As with any coastal marine species, sea otters can be affected by anthropogenic pollution that impairs water quality. In extreme cases, elevated pollutants can directly impact sea otter health (see Chapter 10), while in other cases, certain types or concentrations of pollutants may negatively affect prey populations. Thus, water quality is a factor that should be included in any assessment of the relative quality of Oregon habitats available for sea otters.

Water quality monitoring in Oregon's marine waters is conducted by several entities and involves surveying for bacteria and biotoxins harmful to human health. Reporting primarily involves issuing warnings of samples that exceed a regulatory level and/or closures of commercial and recreational harvest activities. The monitoring activities indicate that Oregon's ocean and estuarine water quality meet and, in most cases, exceed standards set by regulatory agencies.

Fecal Coliform Monitoring in the Marine Environment

The Oregon Department of Environmental Quality (ODEQ) partners with the Oregon Health Authority to monitor the waters along Oregon's coastline. Marine waters adjacent to beaches are tested for enterococcus bacteria, which can indicate the presence of other harmful microbes. Enterococci are present in human and animal waste and can enter marine waters from a variety of sources, such as streams and creeks, stormwater runoff, animal and seabird waste, failing septic systems, sewage treatment plant spills, or boating waste. It is important to note that there may or may not be any sea-otter-related health concerns associated with elevated levels of enterococcus bacteria (see Chapter 10).

The Oregon Beach Monitoring Program conducts regular evaluations of the enterococcus presence at beaches from Seaside to Brookings from mid-May to mid-September. In 2021, a total of 70 locations at 18 beaches were sampled: three in Clatsop County, four in Tillamook County, five in Lincoln County, one in Lane County, two in Coos County, and three in Curry County. The beach monitoring uses a testing method that estimates the number of colonies of bacteria in 100 ml of water. When water samples indicate the number of colonies has reached 130 per 100 ml, a health advisory is issued.[14] In 2020, eight (2.3%) samples exceeded the threshold. In total, since 2002, the Oregon Beach Monitoring Program has collected more than 17,061 samples, of which 1203 (7.1%) exceeded the 130-per-100 ml threshold. Overall, 68% of beach samples have had no detectable fecal bacteria during the past 19 years (ODEQ 2021).

The Blue Water Task Force is a citizen science program sponsored by the Surfrider Foundation that measures water quality at selected beaches in Oregon. Local Oregon Surfrider chapters partner with volunteers from schools, watershed councils, and nongovernmental organizations to operate seven labs that measure enterococcus bacteria levels.[15] Data available for each site are variable: Some have data from 2014 to 2021. For others, the data are more limited. But the vast majority of samples show that the ocean water adjacent to the sampled beaches meets the water quality standards set by ODEQ.

14 For current health advisory results, see https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/RECREATION/BEACHWATERQUALITY/Pages/index.aspx.

15 The results of this sampling can be seen at https://bwtf.surfrider.org.

Table 6.7. Fecal coliform levels in mid–Coos Bay, November 2017–September 2018, MPN per 100 ml.

	Coos			
Sample Date	**BLM 1 *E. coli***	**BLM 2 *E. coli***	**Empire Dock 1 *E. coli***	**Empire Dock 2 *E. coli***
11/7/2017	3.1	2.0	< 1	3.1
12/11/2017	< 1	< 1	2.0	< 1
1/16/2018	< 1	< 1	1.0	< 1
02/27/2018	< 1	2.0	2.0	< 1
04/09/2018	8.5	5.2	7.3	7.5
05/17/2018	< 1	< 1	< 1	1.0
06/20/2018	< 1	2.0	< 1	< 1
07/19/2018	< 1	1.0	< 1	< 1
08/23/2018	2.0	< 1	< 1	< 1
09/20/2018	1.0	< 1	< 1	1.0

Note. MPN = most probable number. Adapted from CTCLUSI 2018.

Fecal Coliform Monitoring in Estuaries

The Oregon Department of Agriculture conducts monthly surveys for fecal coliform bacteria in estuaries that support commercial oyster farms or clam harvest. In Coos Bay, for example, there are 16 monitoring stations. The closure criteria are met when samples indicate an average of 14 bacteria colonies per 100 ml. The state agriculture department also samples oysters during the summer months for the presence of *Vibrio parahaemolyticus*, a bacterium found naturally in the coastal waters that can infect oysters and cause illness if eaten raw by humans.

In addition to the Oregon Department of Agriculture samples, two other bacterial monitoring efforts take place in Coos Bay. The Confederated Tribes of Coos, Lower Umpqua, and Siuslaw Indians (CTCLUSI) conducts water quality monitoring at two sites in mid–Coos Bay. The tribal water quality assessment for October 2017 to September 2018 (CTCLUSI 2018) indicated low levels of fecal coliform bacteria in the two samples from each site (Table 6.7).

The SSNERR also takes water samples monthly to detect fecal coliforms at both high and low tidal levels at multiple stations in Coos Bay. The data are summarized in the Communities, Lands & Waterways Data Source provided by the Partnership for Coastal Watersheds.[16] They also consistently show low levels of fecal coliform bacteria (A. Helms, SSNERR, pers comm, January 7, 2022).

Biotoxin Monitoring

Naturally occurring biotoxins can also affect sea otter health (see Chapter 10). The Oregon Department of Agriculture monitors mussels, clams, and oysters for paralytic shellfish toxin and DA, two marine toxins that can affect shellfish and are toxic to humans. Monitoring takes place during low tides at several ocean sites and occurs at least twice per month during the colder months and weekly during the warmer months. If levels of paralytic shellfish toxin exceed 80 micrograms per 100 grams (µg/100 gm) or 20 ppm for DA, the recreational and/or commercial harvest is closed.[17]

In the summer of 2021, the SSNERR initiated a sampling program for the presence of harmful algae in Coos Bay at seven sites in South Slough and one in the middle of the bay. They also assessed whether the alga, mostly *Pseudo-nitzs-*

16 See https://partnershipforcoastalwatersheds.org/lands-waterways-data-source.
17 Data for marine biotoxin levels and the status of closures are at https://www.oregon.gov/oda/programs/foodsafety/shellfish/pages/shellfishclosures.aspx.

chia spp., were producing toxins. Only in one sample from the mid-bay site were toxin levels high enough that it was possible that shellfish were accumulating toxins (A. Helms, SSNERR, pers comm, January 7, 2022).

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 a 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 habitats 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). Also included is an area 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, tidal creeks), suggesting 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. Water quality monitoring data from these areas suggest the potential for some exposure to anthropogenic pollutants but likely no more (and possibly less) than equivalent estuarine habitats in California, where sea otter populations are thriving.

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Photo by Patrick Webster.

Chapter 7

SOCIOECONOMIC CONSIDERATIONS

James A. Estes, Jan Hodder, and M. Tim Tinker

Sea otters (*Enhydra lutris*) 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 of these effects). Accordingly, the nearshore coastal ecosystems within this region that now lack sea otters are qualitatively different than what they would have been before 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). Therefore, modern human societies in the Pacific Northwest developed, for the most part, in an environment without otters. People often perceive these otter-free systems as the "pristine" or "natural" state because it 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 are central to this socioeconomic analysis.

The value of anything can be defined in terms of its "relative worth, utility, 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 sociopolitical system operates. However, humans also use other currencies (e.g., existential, 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 assembling 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 nonmonetary 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 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 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

1 The definition of "value" is from the *Merriam-Webster.com Dictionary:* https://www.merriam-webster.com/dictionary/value.

2 The definition of "capitalism" from the *Merriam-Webster.com Dictionary* is "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." See https://www.merriam-webster.com/dictionary/capitalism.

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 have 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 completed for the Oregon coast (Curran et al. 2019, 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 before the species' reestablishment in Oregon. This chapter includes a synopsis of some of the specific commercial activities in Oregon that may be affected. We also note that a more comprehensive economic impact assessment of the potential return of sea otters to Oregon has been completed (Elakha Alliance 2022) and is available as a companion piece to this feasibility study.

DIRECT EFFECTS

Sea otters are predators, and as such, their main direct effect is via prey limitation. In such cases where 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 Southeast (SE) Alaska (Kvitek et al. 1993, Hoyt 2015). The magnitude and timing of these negative effects will depend on the pattern and rate of sea otter recovery and the relative availability of alternative (noncommercial) 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 Endangered Species Act 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 have 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 seem 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 2 cm 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 British Columbia (Burt et al. 2018) and California (Smith et al. 2021) and on cancroid 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. Adding 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, because of their mobility, adult crabs 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 (Shanks and Roegner 2007). 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 this industry's economic and social importance, 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 the 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; however, the impacts of sea otters on abalone population health and viability are 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 (due to 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 lingcod) 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 positively impact 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 Bays, herring spawn on eelgrass. Currently, eelgrass abundance in Oregon's estuaries is in decline (see Chapter 6), but a case study from a California estuary where sea otters have recovered (Elkhorn Slough) showed that the return of sea otters to estuaries could 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 a nursery habitat. In turn, people value herring directly as the target of fisheries and indirectly as forage fish supporting 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 (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 they impart 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, Gregr et al. (2020) conducted the first comprehensive effort to measure these effects in monetary terms. The researchers 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 CAN 9.4 million, CAN 2.2 million, and CAN 42.0 million from finfisheries, carbon sequestration, and ecotourism, respectively; and a loss of CAN 7.3 million from shellfisheries.

NONMONETARY EFFECTS

Although Gregr et al.'s (2020) analysis of sea otter economic impacts in British Columbia was both unprecedented and transformative, it also involved an extraordinarily complex issue beset by at least two limitations. One of these limitations was the incomplete breadth of indirect effects 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 understood well enough to be included in such an analysis (the aforementioned possible effects on herring, salmon, and whales are cases in point).

The other limitation of the Gregr et al. study (2020) was the singular currency (i.e., monetary value) used in the analysis. It 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. 2022), thereby enhancing shellfish availability. 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 the socioeconomic impacts of sea otter recovery must provide a comprehensive accounting of the social values of the relevant communities, including both monetary and nonmonetary 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 using a monetary value system is the single most common way of conducting such a socioeconomic analysis, it is important to keep in mind the nonmonetary 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 our expertise. Some of the differing views and values of various stakeholders are discussed in Chapter 11. The full suite of socioeconomic consequences has been taken up separately by more qualified experts in the areas of resource economics and the social sciences and presented in a companion economic impact assessment undertaken by the Elakha Alliance (2022).

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, as previously mentioned, a full economic impact assessment is available as a companion to this study). 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 the impact varies greatly among species and habitats (see above). Most of the indirect effects will probably be positive, although here, one should also recognize the likely variation among species, ecosystem types, and specific areas. In Oregon, the invertebrate species fished commercially and taken by recreational harvesters that could potentially be affected by sea otter recovery include Dungeness crabs (*Metacarcinus magister*), red rock crabs (*Cancer productus*), Pacific razor clams (*Siliqua patula*), butter clams (*Saxidomus gigantea*), gaper clams (*Tresus capax*), littleneck clams (*Leukoma staminea*), cockles (*Clinocardium nuttallii*), mussels, ghost shrimp (*Neotrypaea californiensis*), and red and purple sea urchins (*Mesocentrotus franciscanus* and *Strongylocentrotus purpuratus*, respectively). 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).

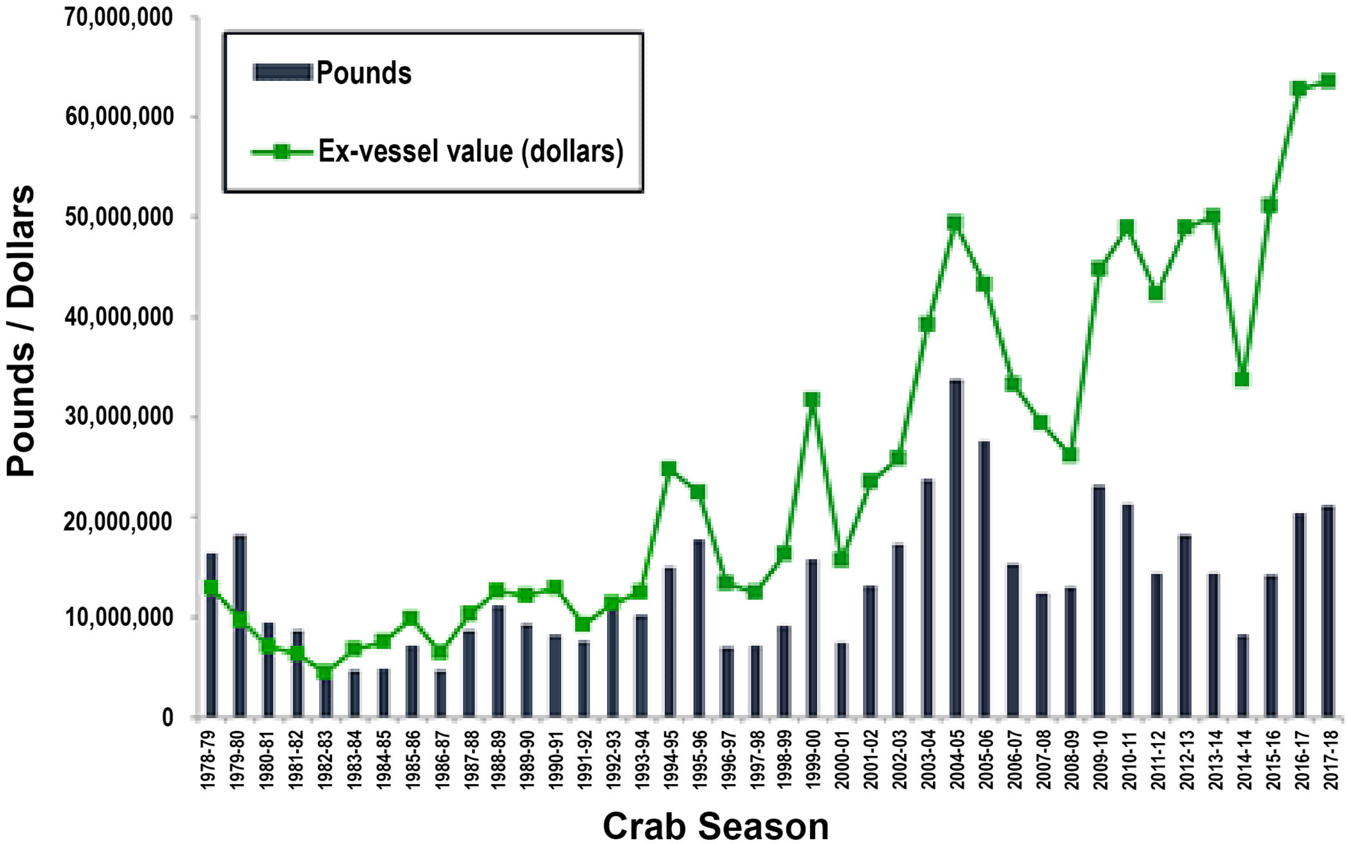
Commercial Invertebrate Coastal Fisheries

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 (7,847,148.00 kg) 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 (4,218,409.04 kg) 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 (Chapter 3 and Chapter 6 of this study; Kone et al. 2021). Nearshore areas of Brookings, Cape Arago, and reefs off of Depoe Bay account for the remaining 25% of the harvest. Purple sea urchins account for less than 1% of the 43 million pounds (19,504,471.91 kg) of sea urchins harvested from Oregon since 1986. California sea cucumbers (*Apostichopus californicus*) are also covered by an urchin permit, though harvest of this species has been minimal.

Data from the Oregon Department of Fish and Wildlife (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

Figure 7.1. Annual Dungeness crab landings in Oregon over time.



Note. 1 lb = 0.454 kg. Data from ODFW commercial crab landings: https://www.dfw.state.or.us/MRP/shellfish/commercial/crab/landings.asp.

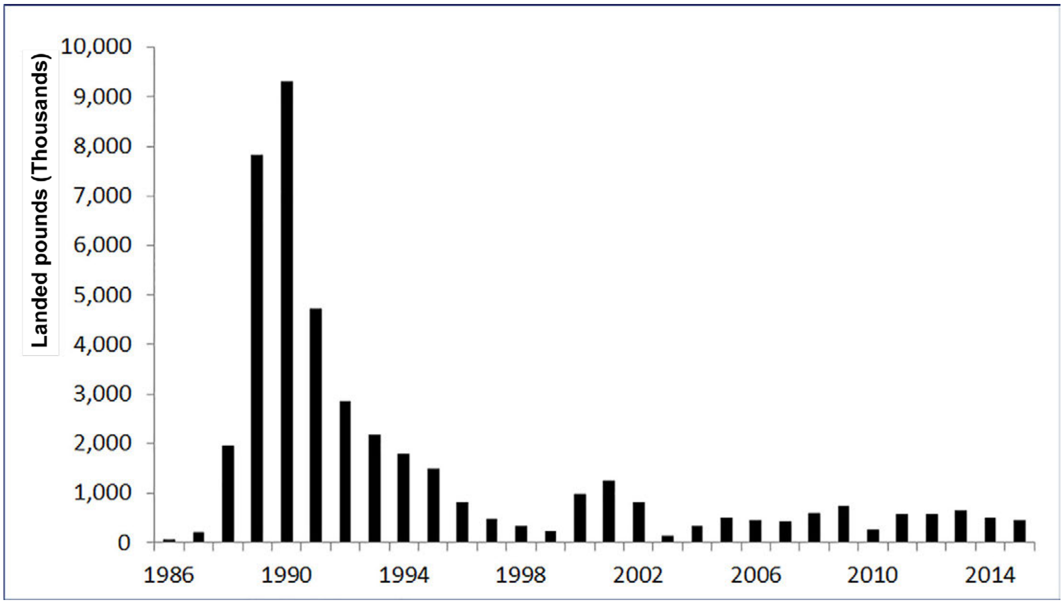
Table 7.1. Commercial catch statistics for ASTORIA (Columbia River mouth).

Species		January	February	March	April	May
Crab, box	lb $					
Crab, Dungeness, bay	lb $					
Crab, Dungeness, ocean	lb $	2,750,269 8,353,683	429,965 1,757,282	148,577 656,774	35,752 179,121	20,050 126,638

Note. This table spans the two facing pages. 1 lb = 0.454 kg. Adapted from ODFW 2019 landing data in "2019 Final: Pounds and Values of Commercially Caught Fish and Shellfish Landed in Oregon – Astoria" at https://www.dfw.state.or.us/fish/commercial/landing_stats/2019/ (data as of 4/14/2020 11:01:59 a.m.).

are summarized below (Tables 7.1–7.8).[3] 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 ft; 73.15 to 228.60 m) 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 Tables 7.1–7.8 are harvested in estuaries.

Figure 7.2. Annual red sea urchin landings in Oregon over time.



Note. 1 lb = 0.454 kg. Data from ODFW commercial red sea urchin landings: https://www.dfw.state.or.us/mrp/shellfish/commercial/urchin/landings.asp.

The commercial landings summarized in Tables 7.1–7.8 are somewhat reflective of where the catch occurs, although the location is not always certain. For example, depending on the 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.

3 See https://www.dfw.state.or.us/fish/commercial/landing_stats/2019/index.asp for the ODFW landing statistics used for Tables 7.1–7.8.

June	July	August	September	October	November	December	Total
1 0							1 0
				206 1330	200 1000		406 2330
6889 32,931	3108 14,383	253 980	2 0	1 0	818 0	22,953 68,501	3,418,637 11,190,293

Table 7.2. Commercial catch statistics for GEARHART to NEHALEM BAY.

Species		January	February	March	April	May
Barnacle, gooseneck	lb $					
Crab, Dungeness, bay	lb $					
Crab, Dungeness, ocean	lb $	533,515 1,723,504	106,735 454,265	60,438 281,900	23,705 161,185	19,395 142,834
Crab, rock	lb $					
Shrimp, ghost	lb $	3 5	2 3	17 28	6 10	34 51
Clams, butter	lb $	8023 6590	13,537 10,083	11,288 8300	3770 3016	1671 1374
Clams, cockle	lb $	81,681 110,000	52,345 71,541	78,142 108,491	18,928 25,261	16,123 18,346
Clams, gaper	lb $	198 139	506 424	413 344	158 126	374 507
Clams, razor	lb $			590 1760	5380 16,789	15,365 47,071
Mussel, bay	lb $					
Octopus	lb $					

Note. This table spans the two facing pages. 1 lb = 0.454 kg. Note that razor clams are harvested commercially from the intertidal area of Clatsop County 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. Adapted from ODFW 2019 landing data in "2019 Final: Pounds and Values of Commercially Caught Fish and Shellfish Landed in Oregon – Gearhart – Seaside – Cannon Beach – Garibaldi – Nehalem Bay" at https://www.dfw.state.or.us/fish/commercial/landing_stats/2019/ (data as of 4/14/2020 3:17:37 PM).

June	July	August	September	October	November	December	Total
33 330	47 430	60 510	43 391	41 335	20 158	15 105	259 2259
			554 3244	476 2644	866 4814		1896 10,702
11,931 67,762	10,861 51,937	3786 17,888			403 403	797 797	771,566 2,902,475
			107 321	49 147	14 28		170 496
28 44	18 27	27 41	16 24	38 57	3 5	3 5	195 300
2146 1717	6490 5185	4187 2987	7712 5171	13,519 8265	19,392 12,392	19,712 12,619	111,447 77,699
18,841 22,832	26,704 23,425	16,528 15,870	1707 935	41 78			311,040 396,779
46 37	302,372 264,600	8323 4377	3063 1729	2204 1873	131 105		317,788 274,261
12,032 35,500	7078 20,368			2571 7740	1594 4771	474 1460	45,084 135,459
	54 81	36 36	33 33	18 18	3 3		144 171
				11 11			11 11

Table 7.3. Commercial catch statistics for NETARTS to DEPOE BAY.

Species		January	February	March	April	May
Crab, Dungeness, bay	lb $					
Crab, Dungeness, ocean	lb $	11,393 37,327	1024 3773	3038 14,700	700 3929	1633 11,640
Crab, rock	lb $					
Shrimp, ghost	lb $	394 603	410 625	513 781	383 581	961 1452
Shrimp, mud	lb $					
Clams, butter	lb $					
Clams, cockle	lb $				2888 1444	6093 3453
Sea urchin, purple	lb $			1500 1500		
Sea urchin, red	lb $			302 302		

Note. This table spans the two facing pages. 1 lb = 0.454 kg. Note that the urchins would have been harvested close to Depoe Bay. Adapted from ODFW 2019 landing data in "2019 Final: Pounds and Values of Commercially Caught Fish and Shellfish Landed in Oregon – Netarts – Pacific City – Siletz – Salmon River – Depoe Bay" at https://www.dfw.state.or.us/fish/commercial/landing_stats/2019/ (data as of 4/14/2020 3:21:11 p.m.).

Table 7.4. Commercial catch statistics for NEWPORT.

Species		January	February	March	April	May
Barnacle, gooseneck	lb $					
Crab, box	lb $		8 8			
Crab, Dungeness, bay	lb $					
Crab, Dungeness, ocean	lb $	5,212,577 16,684,187	1,090,288 4,815,557	365,302 1,725,540	115,570 795,027	47,102 369,676
Crab, rock	lb $				4 4	
Shrimp, ghost	lb $					

Note. This table spans the two facing pages. 1 lb = 0.454 kg. Adapted from ODFW 2019 landing data in "2019 Final: Pounds and Values of Commercially Caught Fish and Shellfish Landed in Oregon – Newport" at https://www.dfw.state.or.us/fish/commercial/landing_stats/2019/ (data as of 4/14/2020 3:22:43 p.m.).

June	July	August	September	October	November	December	Total
			18 108	1781 11,051	1980 9879		3779 21,038
938 5600	1653 10,277	1264 7850					21,643 95,096
				18 54	5 15		23 69
572 874	449 693	422 654	590 915	837 1284	514 793	229 351	6274 9606
		4 8					4 8
					871 697		871 697
7677 4929							16,658 9826
							1500 1500
							302 302

June	July	August	September	October	November	December	Total
			15 60	57 228			72 288
							8 8
			4 16	101 808	1138 5218		1243 6042
19,271 122,864	11,154 72,481	3404 24,235	19 0		2852 0	61,121 183,423	6,928,660 24,792,990
					82 123		86 127
	19 38						19 38

Table 7.5. Commercial catch statistics for WALDPORT to WINCHESTER BAY.

Species		January	February	March	April	May
Crab, box	lb $				257 900	
Crab, Dungeness, bay	lb $					
Crab, Dungeness, ocean	lb $	499,276 1,754,393	170,487 748,777	69,810 330,492	26,286 177,589	16,349 130,661
Shrimp, ghost	lb $	1514 4119	1521 4178	2560 7192	2380 7222	3447 9265

Note. This table spans the two facing pages. 1 lb = 0.454 kg. Note that ghost shrimp are harvested for bait in the intertidal area of bays. Adapted from ODFW 2019 landing data in "2019 Final: Pounds and Values of Commercially Caught Fish and Shellfish Landed in Oregon – Waldport – Yachats – Florence – Winchester Bay" at https://www.dfw.state.or.us/fish/commercial/landing_stats/2019/ (data as of 4/14/2020 3:24:23 p.m.).

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

Species		January	February	March	April	May
Crab, box	lb $					6 12
Crab, Dungeness, bay	lb $					
Crab, Dungeness, ocean	lb $	2,282,972 7,109,328	1,565,359 6,056,058	287,609 1,197,934	121,259 809,955	55,257 432,775
Crab, mole	lb $					3 3
Shrimp, ghost	lb $		42 84	110 220	66 132	283 566
Clams, butter	lb $		255 290	703 778		91 91
Clams, cockle	lb $		648 890	1730 2539	2246 3247	63 95
Clams, gaper	lb $					
Octopus	lb $				43 65	
Sea urchin, red	lb $					

Note. This table spans the two facing pages. 1 lb = 0.454 kg. Adapted from ODFW 2019 landing data in "2019 Final: Pounds and Values of Commercially Caught Fish and Shellfish Landed in Oregon – Charleston" at https://www.dfw.state.or.us/fish/commercial/landing_stats/2019/ (data as of 4/14/2020 3:27:56 p.m.).

June	July	August	September	October	November	December	Total
							257 900
				7659 34,845	17,091 80,418		24,750 115,263
7585 44,218	3372 18,290	1609 9163				969 555	795,743 3,214,138
2247 5804	1890 5281	1378 3958	3067 8320	3238 8533	1071 3124	1066 3262	25,379 70,258

June	July	August	September	October	November	December	Total
							6 12
				926 4017	1801 7638		2727 11,655
19,059 107,911	10,735 52,583	2210 12,924	19 0		1840 0	63,405 186,584	4,409,724 15,966,052
							3 3
434 868	192 384	90 180	111 209	157 312	144 285	113 226	1742 3466
199 239	59 59						1307 1457
77 116	1569 2354				95 143	134 201	6562 9585
				44 55	108 135	520 650	672 840
	25 13					52 78	120 156
1998 3497	9277 13,545						11,275 17,042

Table 7.7. Commercial catch statistics for BANDON/PORT ORFORD.

Species		January	February	March	April	May
Crab, Dungeness, bay	lb $					
Crab, Dungeness, ocean	lb $	1206 0	555,476 1,851,104	83,219 334,093	30,063 150,928	30,418 167,306
Octopus	lb $		689 456	1103 671	154 99	117 69
Sea cucumber, California	lb $				566 2264	1184 4736
Sea urchin, purple	lb $				66 66	
Sea urchin, red	lb $	18,213 64,122			3441 6215	

Note. This table spans the two facing pages. 1 lb = 0.454 kg. The majority of these landings would have been from Port Orford. Adapted from ODFW 2019 landing data in "2019 Final: Pounds and Values of Commercially Caught Fish and Shellfish Landed in Oregon – Bandon – Port Orford" at https://www.dfw.state.or.us/fish/commercial/landing_stats/2019/ (data as of 4/14/2020 3:29:15 p.m.).

Table 7.8. Commercial catch statistics for GOLD BEACH/BROOKINGS.

Species		January	February	March	April	May
Crab, Dungeness, ocean	lb $		1,508,179 5,251,980	166,088 665,809	36,501 213,825	18,150 106,731
Sea urchin, red	lb $	15,498 55,193	11,943 43,651	21,099 69,966		23,755 60,897

Note. This table spans the two facing pages. 1 lb = 0.454 kg. The majority of these landings would have been in Brookings. Adapted from ODFW 2019 landing data in "2019 Final: Pounds and Values of Commercially Caught Fish and Shellfish Landed in Oregon – Gold Beach – Brookings," available at https://www.dfw.state.or.us/fish/commercial/landing_stats/2019/ (data as of 4/14/2020 3:32:09 PM).

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 (*N. 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 (*T. capax*), butter (*S. gigantea*), cockle (*C. nuttallii*), littleneck (*L. 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).

The subtidal clam dive fishery is a limited-entry fishery (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, and Nehalem Bay represent the Tillamook harvest; these landings are shown in Table 7.9. Cockles are the only species shown in landings reported from Netarts, Pacific City, Siletz Bay, Salmon River, and Depoe Bay, as well as 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 bottomlands leased from the state or, in the case of some regions in Coos Bay, owned by the port or Coos County.

June	July	August	September	October	November	December	Total
				67 335			67 335
17,602 96,295	15,520 63,906	7364 30,793			268 0	66,121 196,554	807,257 2,890,979
95 98		24 12				31 16	2213 1421
							1750 7000
							66 66
						14,052 59,310	35,706 129,647

June	July	August	September	October	November	December	Total
6940 37,938	3014 15,599	1123 6286			253 0	106,955 321,780	1,847,203 6,619,948
22,708 58,161				16,455 55,778	21,965 79,696		133,423 423,342

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

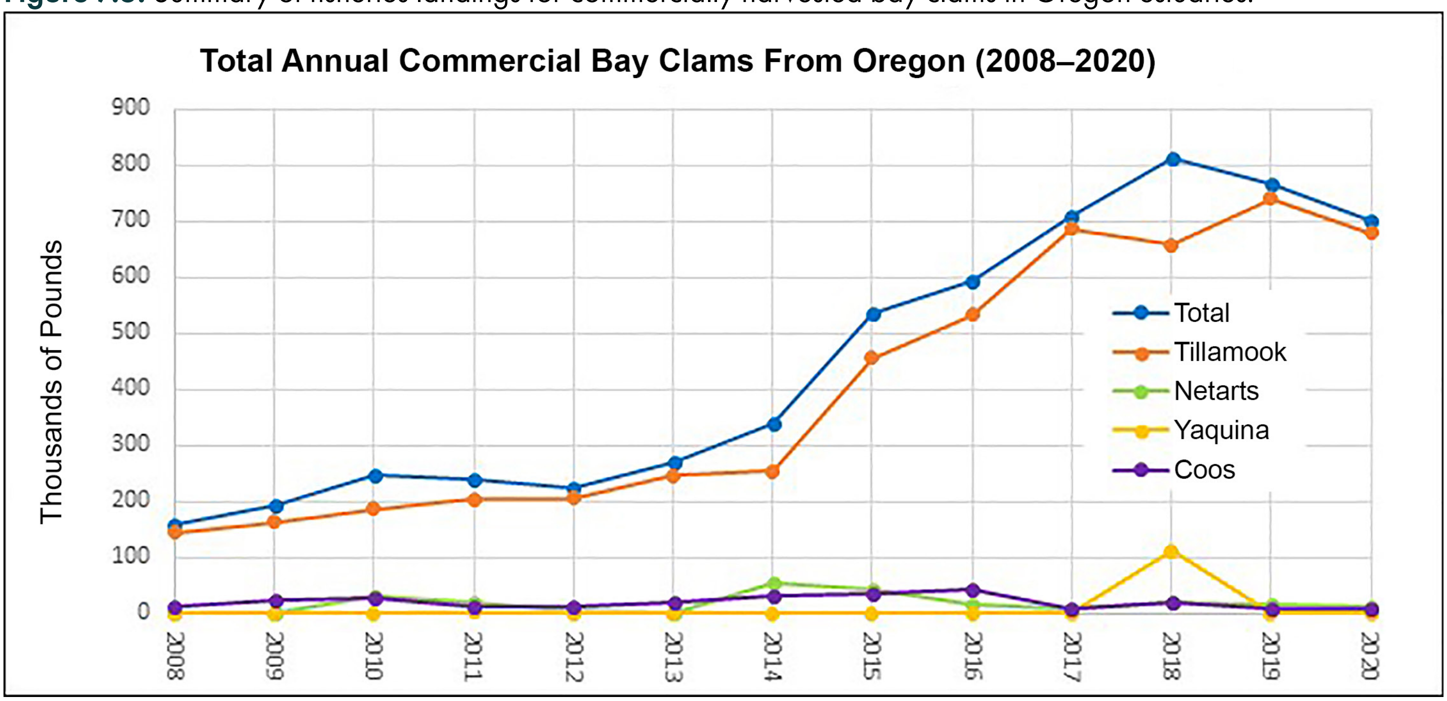


Table 7.9. Summary of 2020 landings of clams from the Tillamook Bay estuary and nearby areas.

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

Note. 1 lb = 0.454 kg. Data from https://www.dfw.state.or.us/fish/commercial/statistics.asp.

Table 7.10. Summary of 2020 landings of clams from Netarts, Pacific City, Siletz Bay, Salmon River, and Depoe Bay, as well as from Charleston.

Port	No. of lb.	Value ($)
Netarts, etc.	14,519	8277
Charleston	11,462	10,554

Note. 1 lb = 0.454 kg. Data from https://www.dfw.state.or.us/fish/commercial/statistics.asp.

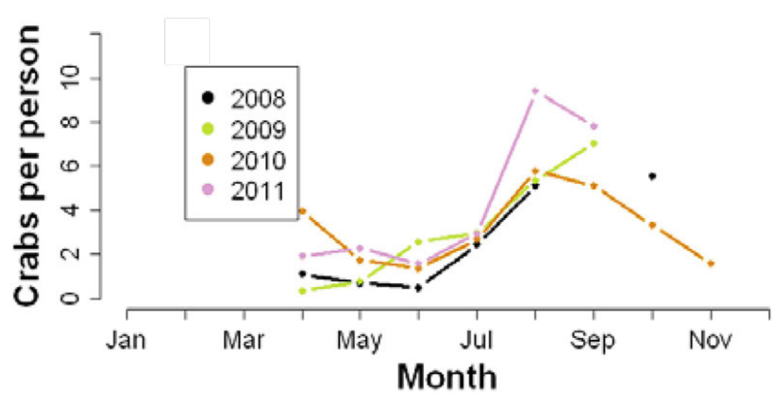
Table 7.11. 2020 commercial oyster production on Oregon state-leased lands in five estuaries.

Estuary	Acres leased	Gallons shucked	Bushels raw	Total production	Production value	Lease/fees collected
South Slough	240.13	245.00	8218.17	8463.17	$507,790.00	$4093.83
Netarts Bay	425.22	38.00	5514.17	5552.17	$333,130.00	$6605.53
Tillamook Bay	2605.14	2833.75	27,943.00	30,826.75	$1,849,605.00	$36,961.92
Umpqua River	60.00	0.00	28.83	28.83	$1730.00	$843.46
Yaquina Bay	517.00	5805.00	3053.55	8858.55	$531,513.00	$7164.71
Totals	3847.49	8971.75	44,757.72	53,729.47	$3,223,768.00	$55,669.45

Note. 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. Data from the Oregon Department of Agriculture, Food Safety Program, https://www.oregon.gov/oda/programs/FoodSafety/Shellfish/Pages/ShellfishPlat.aspx — on this web page, see "Shellfish plat production annual report (2020)," accessed in December 2021.

Figure 7.4. Estimated number of crabs harvested recreationally, by month and year from 2008–2011, for TILLAMOOK BAY.

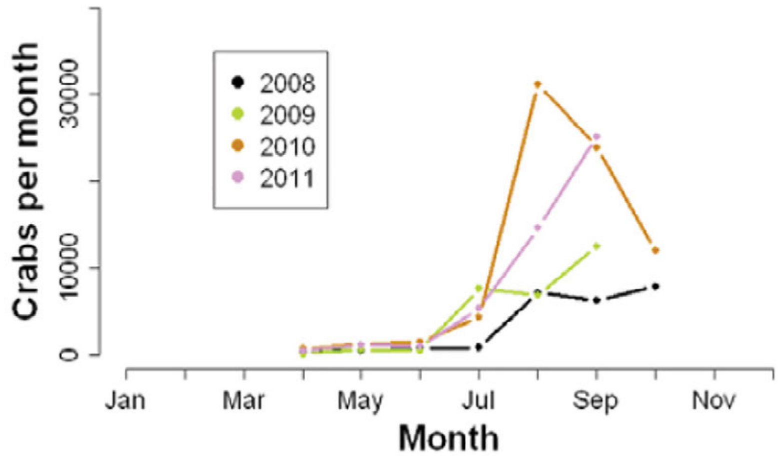
	2008	2009	2010	2011
April	89	663	451	320
May	229	1108	814	641
June	378	479	630	203
July	575	1958	788	631
August	1373	1721	1589	1330
September	1426	1536	1531	2512
October	2370	NS	1276	NS
Total (95% CI)	**6440** (4635-8245)	**7465** (5829-9102)	**7080** (5503-8657)	**5637** (4355-6919)



Note. NS = not sampled. Adapted from Ainsworth et al. (2012).

Figure 7.5. Estimated number of crabs harvested recreationally, by month and year from 2008–2011, for NETARTS BAY.

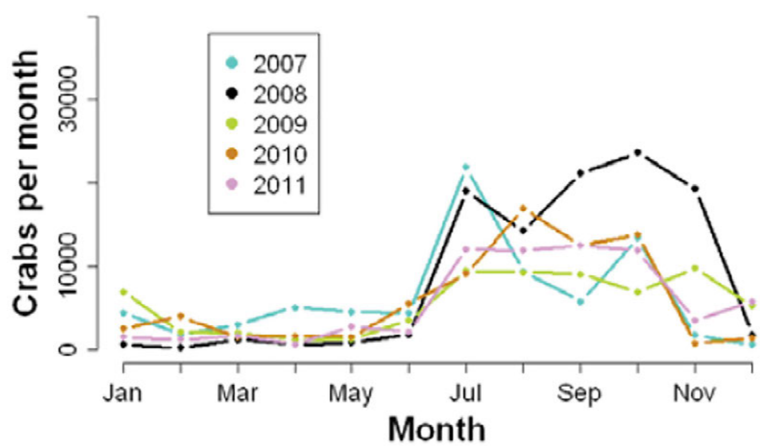
	2008	2009	2010	2011
April	299	333	434	553
May	406	559	467	694
June	285	267	455	510
July	360	1928	1240	1042
August	801	1612	2745	1297
September	930	1664	2767	1924
October	1871	NS	2140	NS
Total (95% CI)	**4951** (3485-6418)	**6363** (5001-7724)	**10,248** (8131-12,364)	**6020** (4666-7375)



Note. NS = not sampled. Adapted from Ainsworth et al. (2012).

Figure 7.6. Estimated number of crabs harvested recreationally, by month and year from 2007–2011, for YAQUINA BAY.

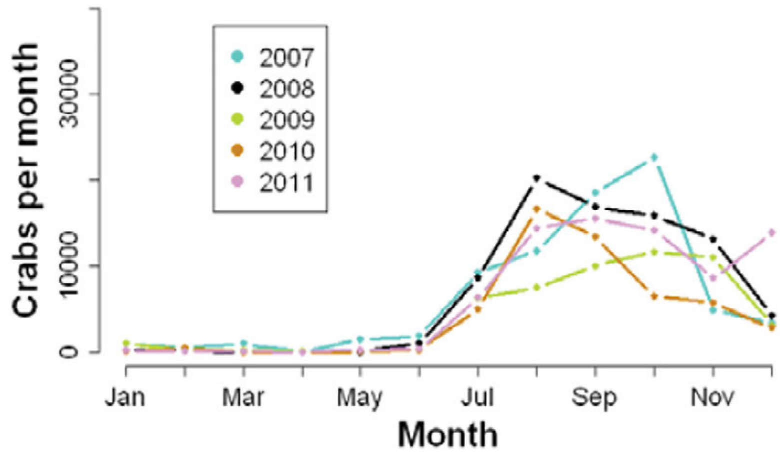
	2007	2008	2009	2010	2011
Jan.	927	251	1435	656	684
Feb.	923	644	1127	1397	645
Mar.	1264	658	1031	1054	578
Apr.	738	601	1061	1154	423
May	1181	1040	869	497	853
June	1301	976	1084	1311	716
July	4210	2599	1817	2307	2169
Aug.	2617	2285	1966	2240	1927
Sept.	1356	3658	2572	2144	2065
Oct.	4038	3506	2161	3730	2125
Nov.	972	3390	1335	695	596
Dec.	406	474	1126	566	936
Total (95% CI)	**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)



Note. Adapted from Ainsworth et al. (2012).

Figure 7.7. Estimated number of crabs harvested recreationally, by month and year from 2007–2011, for ALSEA BAY.

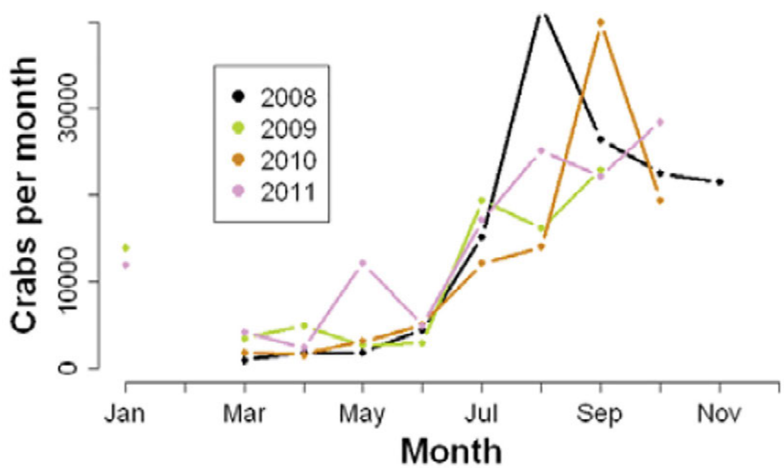
	2007	2008	2009	2010	2011
Jan.	300	169	553	54	252
Feb.	400	163	275	295	90
Mar.	286	276	209	48	80
Apr.	180	133	168	99	64
May	292	145	500	191	497
June	460	437	380	161	299
July	2519	1455	1462	1077	1312
Aug.	2613	3724	2109	2721	2055
Sept.	3296	3715	3363	2913	2136
Oct.	3077	3306	2821	1719	2503
Nov.	901	2418	1314	896	1048
Dec.	486	675	773	577	1221
Total (95% CI)	**14,810** (9698-19,923)	**16,615** (13,059-20,171)	**13,929** (10,775-17,082)	**10,752** (8318-13,186)	**11,558** (8951-14,269)



Note. Adapted from Ainsworth et al. (2012).

Figure 7.8. Estimated number of crabs harvested recreationally, by month and year from 2008–2011, for COOS BAY.

	2008	2009	2010	2011
Jan.	NS	1845	NS	1530
Feb.	NS	NS	NS	NS
Mar.	351	1329	319	928
Apr.	683	1143	359	375
May	877	864	1000	920
June	638	663	1153	874
July	1834	2033	2021	2000
Aug.	6155	2136	3085	2481
Sept.	3468	2572	2476	2671
Oct.	3616	NS	2126	2431
Nov.	1886	NS	NS	NS
Dec.	NS	NS	NS	NS
Total (95% CI)	**19,507** (14,076-24,939)	**12,584** (8264-17,106)	**12,540** (8657-16,422)	**14,209** (10,337-18,081)



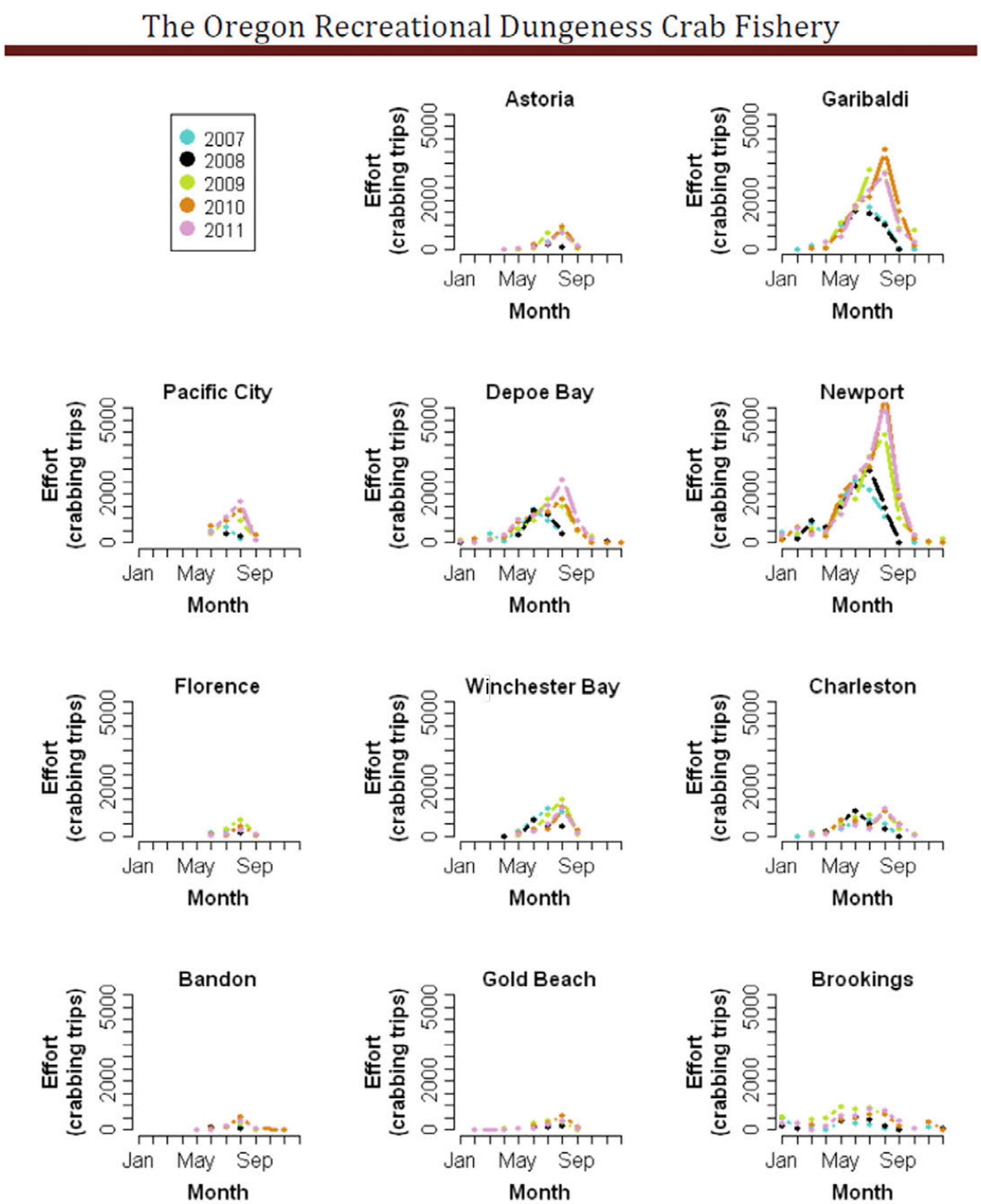
Note. NS = not sampled. Adapted from Ainsworth et al. (2012).

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 (*C. productus*) are harvested. Ainsworth et al. (2012) provided 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 study, we have included the estimates of the number of recreational crabbing trips and the estimates of the 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) showed the number of trips taken from Oregon ports to the open ocean in 2007–2011 (Figure 7.9).

Figure 7.9. Estimated monthly recreational ocean crabbing trips, including charter and private boats.



Note. From Ainsworth et al. (2012).

Recreational clamming is also a popular activity in Oregon estuaries. Surveys from ODFW's Shellfish and Estuarine Assessment of Coastal Oregon (SEACOR[4]) 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 to 2012, ODFW conducted surveys of the number of recreational clam-digging trips to these bays, with the exception of Alsea Bay (Table 7.12). The time periods covered for each bay differ. 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.

The 2019–2023 Oregon Statewide Comprehensive Outdoor Recreation Plan (SCORP; officially titled *Outdoor Recreation in Oregon: Responding to Demographic and Societal Change*; Oregon Parks and Recreation Department 2019) contains the results of a survey of 3069 randomly selected Oregonians. It assessed their participation in outdoor recreation activities. Crabbing and clamming were included as recreational activities, and an estimate of their economic value is reported in Table 7.13.

4 See https://www.dfw.state.or.us/mrp/shellfish/seacor/maps_publications.asp.

Table 7.12. Number of recreational clam-digging trips for each of four estuaries in Oregon, 2008–2012.

Bay	2008	2009	2010	2011	2012
Tillamook	9832	9818	6207	6134	11,018
Netarts	12,081	23,262	11,177	9786	13,653
Yaquina	6114	13,002	11,961	7363	7052
Coos Bay	13,598	15,428	13,030	11,113	9729

Note. Data from ODFW's SEACOR program: https://www.dfw.state.or.us/mrp/shellfish/seacor/maps_publications.asp.

Table 7.13. Estimate of the economic value of recreational crabbing and clamming activity in Oregon.

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

Note. SCORP = Statewide Comprehensive Outdoor Recreation Plan. 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. User occasions are the number of times individuals participated in outdoor recreational activities in 2017. An activity day is defined as one person recreating for some portion of a day.

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 is diverse; however, they can generally be divided into two categories: (1) direct effects of sea otter predation, which are generally negative from a human perspective insomuch as they involve shellfish species harvested commercially, recreationally, or as part of subsistence fisheries, and (2) 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 fished commercially or recreationally that could 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 tens of millions of dollars in the case of Dungeness crab. Thus, the potential economic impacts of even a small reduction due to sea otter recovery are consequential. However, the impacts are not always clear. For some fisheries (e.g., urchin dive fisheries), there is good reason to project a substantial negative impact from sea otter recovery. But for 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 negative impacts associated with sea otter recovery—in fact, there was actually a positive correlation (though likely not a causal relationship) between sea otter abundance 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 have often been associated with reductions in herbivores and corresponding increases in primary producers (plants), which in coastal marine ecosystems include kelp and seagrass. 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, thus stabilizing and protecting shorelines. Sea otters can also impact human welfare through wildlife viewing opportunities and the benefits imparted to 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 nonmonetary values to people. In the case of Indigenous 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 the socioeconomic impacts of sea otter recovery should therefore provide a comprehensive accounting of the social values of the relevant communities, including both monetary and nonmonetary variables.

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Photo by the crew and officers of the NOAA ship *Fairweather*.

Chapter 8

ADMINISTRATIVE AND LEGAL CONSIDERATIONS

Shawn Larson and M. Tim Tinker

Sea otters (*Enhydra lutris*) 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 work is not only to restore sea otter populations into previously occupied habitat to increase the 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 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 in this chapter, 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 been compiled by the U.S. Fish and Wildlife Service (USFWS; Zwartjes 2020) and should also be consulted. All relevant regulations must be followed, and approvals must be obtained from the relevant agencies before any actual sea otter reintroduction to the Oregon coast.

We restrict our attention here to laws and regulations that pertain to wild populations and the translocation and reintroduction of sea otters. We do not address here a related issue, the management and care of sea otters in captivity, consideration of which would be required prior to engaging in the transport of wild otters or rehabilitation of stranded juveniles. The topic of animals' captive care is addressed in Chapter 10: We emphasize that there are multiple legal requirements and considerations associated with captive care, such as those identified by the federal Animal Welfare Act and Animal Welfare Regulations (APHIS [Animal and Plant Health Inspection Service] 2020). Legal oversight of captive care for wild animals in the United States is typically provided by the Institutional Animal Care and Use Committee associated with the relevant institution (e.g., Aquarium or University), and this committee would ensure that all necessary procedures are in place and legal permissions obtained.

INTERNATIONAL PROTECTIONS

Sea otter populations have varying levels of protection, triggering different legal considerations. At the international level, the sea otter is listed as endangered by the International Union for Conservation of Nature (IUCN) due to decreasing populations in portions of its range and the unknown effects of climate change (Doroff et al. 2021). 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 of Wild Fauna and Flora (CITES), which specifies requirements for permits for international trade.

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Sea otters are classified taxonomically into three subspecies based on skull morphometric variation: the Russian sea otter (*E. l. lutris*) found in Japan and Russia; the

Table 8.1. 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	*Enhydra lutris lutris*	NA	Appendix II [a]	Protected	--
Northern sea otter	*E. l. kenyoni*	↓	Appendix II [a]	Protected	--
		Southwest Alaska stock/DPS		Protected/ strategic stock	Threatened DPS
		South-Central Alaska stock		Protected/ nonstrategic stock	--
		Southeast Alaska stock		Protected/ nonstrategic stock	--
Southern sea otter	*E. l. nereis*	Southern sea otter	Appendix I [b]	Protected/ strategic stock	Threatened subspecies

Note. MMPA = Marine Mammal Protection Act of 1972. DPS = Distinct Population Segment. ESA = U.S. Endangered Species Act of 1973. CITES = Convention on International Trade of Endangered Species of Wild Fauna and Flora. NA = not applicable.
[a] Appendix II – International trade is controlled.
[b] Appendix I – International trade is prohibited unless under certain circumstances for research.

northern sea otter (*E. l. kenyoni*) found throughout Alaska, British Columbia, and Washington; and the southern sea otter (*E. l. nereis*) found in California (Wilson et al. 1991). There are no behavioral or ecological differences between the subspecies, nor is there genetic data (to date) supporting these specific subspecies designations, and genetic differences between and within these identified subspecies are complex (Cronin et al. 1996; Larson, unpublished data). However, there are three distinct genetic stocks in Alaska recognized under the Marine Mammal Protection Act of 1972 (MMPA): a Southwest (SW) stock includes the Aleutian Islands, the Alaska Peninsula, the Katmai Peninsula, and Kodiak Island; a South-Central (SC) stock includes Prince William Sound, the Kenai Peninsula, and Cordova; and a Southeast (SE) stock includes the Alexander Archipelago (USFWS 2013; see Table 8.1).

The southern sea otter is listed in CITES Appendix I, which lists the most endangered species among CITES-listed animals and plants.[1] Species on the CITES Appendix I list 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.[2]

The northern sea otter and the Russian sea otter are included on the Appendix II list, which concerns species "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 are only 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.

1 Interpretations of Appendix I through Appendix III are available from the following CITES web page, where you may also download a PDF version of the interpretations: https://cites.org/eng/app/appendices.php.
2 Learn more about CITES import and export permits on this web page: https://cites.org/eng/app/index.php.

FEDERAL MANAGEMENT AND PROTECTIONS

Sea otters are managed in the United States at the federal level by the 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, under the U.S. Endangered Species Act of 1973 (ESA; 16 U.S.C. 1531 et seq. of the U.S. Code), protections apply to the southern sea otter subspecies in California (listed as threatened under the ESA in 1977; 42 FR 2965 of the Federal Register) and to the SW Alaskan Distinct Population Segment (DPS) of the northern sea otter in SW Alaska (SW stock listed as threatened under the ESA in 2005; 70 FR 46366). Further details about the 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. Its protections remain regardless of whether the animal is listed under the ESA. Any species of marine mammal 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.

Marine Mammal Protection Act (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 United States. The MMPA defines *take* as follows: "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)THE(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 MMPA provisions, 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 the protection of marine mammals under the MMPA within the state (16 U.S.C. 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 104the of the MMPA. The USFWS Division of Management Authority issues these permits.

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, which are used to evaluate the progress of commercial fisheries toward 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 8.1). 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, Definitions, sec. 1 and sec 19).

National Environmental Policy Act (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 before making decisions, and an assessment under NEPA is required for any federal action that has the potential to significantly affect the quality of the human environment ("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 those cases, the issuance of a USFWS permit for reintroducing 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. These effects include 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.[3]

Endangered Species Act (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 the transport of listed species across state lines.) This permit would be required for the capture, handling, 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 the USFWS and/or NOAA's National Marine Fisheries Service (NMFS) to ensure 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, USFWS issuance of any permits 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 would affect other listed species or critical habitat, and if so, whether it would 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 before 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 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 "nonessential, 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 nonexperimental 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.

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3 The NEPA process involves several steps: (1) Scoping 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) An EA or EIS is drafted and followed by public comment. (3) The final EA or EIS is then issued and 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.

NEPA compliance is also required to establish 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. A NEPA assessment will also need to take into account potential impacts on the source populations.

Coastal Zone Management Act (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 the national policy to preserve, protect, develop, and where possible, restore or enhance the resources of the nation's coastal zone for this and succeeding generations. The CZMA also provides for coastal states to prepare 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 be carried out in a manner consistent, to the maximum extent practicable, with the enforceable policies of approved state management programs. The federal agency must provide a *consistency determination* to the relevant state agency in the form of a certification that the proposed action is consistent with any such enforceable policies. This requirement 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 the 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 United States 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 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 to coordinate 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 on the source population (see Chapter 3). As discussed above, the SW Alaska stock of northern sea otters is listed as threatened under the ESA 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. However, it 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, British Columbia population (Larson et al. 2021). However, the Washington population is still believed to be well below its potential carrying capacity (Hale et al. 2022), 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, since this population is listed as threatened under the ESA, capturing animals from the mainland would entail some additional administrative hurdles (as described above) and could negatively impact the source population (but see 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 stranded juveniles 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; thus, consultation with the California Department of Fish and Wildlife would also be required.

Oregon

The Oregon Department of Agriculture's 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 prohibition could be addressed by either changing the language of Division 62 of the Oregon Administrative Rules, creating a special exception for sea otters, or 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.

CONCLUSIONS

Reintroducing a marine mammal protected by international, federal, state, and tribal laws requires careful consideration, planning, and the documentation of legislation, including the acquisition of multiple permits. Internationally, there are CITES permits required for trade between countries. In the United States, sea otters are managed at the federal level by the USFWS and are protected under the MMPA. The southern sea otter subspecies and the SW 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. Reintroducing sea otters from non-ESA-listed U.S. stocks, such as sea otters in SE 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 require extensive documentation and permits under federal law, as well as careful adherence to state laws and regulations, local ordinances, and 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 of Wild Fauna and Flora (CITES) — http://www.cites.org/

Endangered and Threatened Wildlife and Plants; Termination of the Southern Sea Otter Translocation Program; Final Rule (USFWS) — https://www.fws.gov/species-publication-action/endangered-and-threatened-wildlife-and-plants-termination-southern-sea

Endangered Species Act of 1973 (provided by USFWS) — https://www.fws.gov/sites/default/files/documents/endangered-species-act-accessible.pdf

Marine Mammal Protection Act of 1972 (provided by NOAA) — https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-protection-act

Marine Mammal Protection Act – Permits
— https://www.fws.gov/law/marine-mammal-protection-act
— https://www.fisheries.noaa.gov/insight/understanding-permits-and-authorizations-protected-species

National Environmental Policy Act flowcharts (provided by the U.S. Department of the Interior's Bureau of Reclamation) — https://www.usbr.gov/gp/nkao/ainsworth/flowcharts.pdf

Oregon Administrative Rules 635-062-0020 – concerning the prohibition on rehabilitating marine mammals — 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, the Animal Health Unit's import and export information — https://www.oregon.gov/ODA/programs/AnimalHealthFeedsLivestockID/Pages/AnimalImportExport.aspx

Permits for Native Endangered and Threatened Species (USFWS) — https://www.fws.gov/library/collections/permits-native-endangered-and-threatened-species

Public Law 99-625 – about the translocation of southern sea otters — https://www.govinfo.gov/content/pkg/STATUTE-100/pdf/STATUTE-100-Pg3500.pdf

Secretarial Order No. 3355 – from the Secretary of the U.S. Department of the Interior, an order concerning NEPA streamlining — https://www.doi.gov/sites/doi.gov/files/uploads/3355_-_streamlining_national_environmental_policy_reviews_and_implementatio.pdf

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Chapter 9

IMPLEMENTATION AND LOGISTICAL CONSIDERATIONS

James L. Bodkin and M. Tim Tinker

Based on a review of the translocation history of the sea otter (*Enhydra lutris*; refer to 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 reintroducing sea otters to the waters of Oregon. One follows the strategy employed by all but one historical reintroduction. It 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 sequentially reintroducing 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 offer the underlying rationale and discuss the pros and cons. Presenting 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 selecting source or donor populations. The protocols may differ for capture/holding, transport, and to some extent, release and monitoring, depending on release strategies and source population alternatives. 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. They include (a) suitable and appropriate habitats, (b) the availability of appropriate and sufficient prey, (c) access to suitable resting habitats, either protected waters or canopy-forming kelps, and (d) refuge from disturbance or sources of injury or mortality. We will briefly consider each of these habitat requirements in the discussion below as it relates to potential sea otter release strategies. A more comprehensive assessment of habitat suitability is provided in Chapter 6 of this study.

The present distribution and abundance of sea otters in the coastal North Pacific suggest that all coastal habitat types less than about 50 m in depth represent potential habitats for sea otters. At the same time, there is a growing body of evidence that suggests 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 soft-sediment habitats (Kenyon 1969, Riedman and Estes 1990), with reported densities in rocky habitats in California more than five times greater than along sandy shorelines (Laidre et al. 2001, Tinker et al. 2021). However, relatively high densities of sea otters can also be found in mixed-substrate habitats, particularly along complex shorelines that provide sheltered habitats, including bays,

1 The published example of estuarine release occurred in Elkhorn Slough, an estuarine habitat in California that was already occupied by sea otters, although they were mostly male otters and had a density well below the local carrying capacity. Therefore, this example might reflect a different outcome than a similar release to an unoccupied estuary in Oregon.

lagoons, sounds, and estuaries. Examples of such include Kachemak Bay, Prince William Sound, Izembek Lagoon, and Glacier Bay in Alaska, as well as 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 due to elevated prey abundances achieved during the otters' absence. These high otter densities may subsequently decrease 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) suggested that Oregon coastal habitats could still support over 4000 sea otters.

Our primary goal in this chapter is to identify options for reintroducing sea otters to Oregon that will maximize the potential for the successful establishment of a self-sustaining population (Chapter 3) while minimizing potential human–otter conflicts over competition 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 coastal ocean habitats where sea otters had occurred historically but had been absent for decades, sometimes up 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 living 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. What is less clear from historical information and published accounts is the rationale used to determine exactly where translocated sea otters would be released. In most cases, if not all, logistics based on methods of transport 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 to be preferred habitats, supporting relatively high densities (four to six 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) suggested that the Oregon coast could support about 4500 sea otters (a range of 1742–8976), with most of them 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. Elsewhere in this study, more detailed analyses are provided on 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 scenario was the case in the initial Oregon release but also in all other open-coast release attempts (excepting perhaps portions of Southeast [SE] Alaska), despite the presence of abundant and preferred prey and proximity to established kelp beds. It may be possible to improve the 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 conditions 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 ranges they were removed from, although there is little data on age and sex composition in most reintroductions. This likelihood is evident from the rapid diminishment in abundance post-release and from 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 in post-release movements was presented in SE Alaska. 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 sea otter populations has been the release of large numbers of individuals at multiple release sites over several years. This approach is best exemplified in the reintroduction of 403 sea otters over five years into six separate areas of SE Alaska (Esslinger and Bodkin 2009) that ultimately resulted in three or possibly four distinct populations across coastal SE Alaska. Annual rates of increase by 1987–1988, about 20 years after the final reintroduction, averaged about 20% per year, and total abundance had approached 5000 sea otters (Pitcher 1989, Tinker et al. 2019a). It is possible that the loss rate to emigration or mortality in the SE 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 a high reproductive output of animals at some release sites compensated for lower survival at others, thus explaining early increases in regional abundance. Unfortunately, a lack of detailed post-release animal tracking in SE 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 ocean's seawater with the freshwater draining 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 1947/1962, Kenyon 1969) focused on open coastal 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) identified the sea otter as a predominant marine mammal in estuarine habitats, 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 have encountered them (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 km2) 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 underutilized habitat in the Elkhorn Slough within Monterey Bay (Mayer et al. 2019). This work in Elkhorn Slough provides an example of a previously unused strategy for releasing 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 both be considered in reintroducing sea otters to the coast of Oregon.

The details of the Elkhorn Slough reintroduction are important, and distinctions from releases on the open coast require consideration. First, Elkhorn Slough had already been occupied by sea otters for several decades at the time that the reintroduction of juveniles began. However, the number of preexisting otters was well below carrying capacity (Tinker et al. 2021), and they were mostly 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 four 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, source, age, and sex composition of sea otters, as well as 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, the Oregon Sea Otter Population Model) and is described in Chapter 3 (also see Appendix A). To demonstrate the feasibility of a proposed reintroduction plan, we somewhat arbitrarily considered 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 showed 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 with supplementary additions of three 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 compositions to determine when and where subsequent releases occur. This recurrent strategy would continue 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 versus 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 the failure of one of the releases, thereby reducing the overall failure risk of the reintroduction program.

Perhaps more important 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 recovery rate in SE Alaska, which was facilitated by having several spatially distinct nodes of population growth resulting from multiple release sites (see Chapter 2

and Chapter 3 of this study; 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).

SOURCE POPULATION CONSIDERATIONS

Several options exist for source populations for reintroduction to Oregon, including SE Alaska, Washington, and California. Each, 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), and logistical factors. In the following paragraphs, we primarily consider the logistical considerations but include relevant information on the 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 (> 8000) 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 an open-coast reintroduction to Oregon based on their abundance, proximity, and state-protected status and based on the assumption that the State of Washington and the U.S. Fish and Wildlife Service (USFWS) would be cooperative. Washington sea otters currently number approximately 3000 individuals and occupy about 100 km of the 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). Transporting animals captured in Washington would be relatively straightforward 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 situation 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 possible that the State of Alaska would be another willing donor of sea otters to a reintroduction effort into Oregon. SE Alaska likely supported 30,000–40,000 sea otters as of 2020, occupying thousands of kilometers 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 be sustainable at a subregional scale depending on the specific capture locations (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 the protected nature of the habitat occupied in SE 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 SE Alaska from habitats that are qualitatively similar to the habitats at proposed release sites in Oregon, thereby maximizing the potential for the 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 multistate collaboration could increase the availability of crucial resources needed to implement the capture and translocation of animals.

Based on long-term positive rates of increase in abundance, animals residing in Washington and SE Alaska appear to have readily adapted to the habitats, prey assemblages, and environments along those coastlines. 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 SE Alaska. One additional difference between Washington and SE Alaska is that SE Alaskan (and British Columbian) otters 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, this two-donor approach restored 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 SE Alaska as a source population might best achieve the goal of maximizing genetic diversity near the southern end of the sea otter distribution (Chapter 4).

Given the ESA listing and demographic status of sea otters in California, taking a large number of animals annually (≈ 100) from the population—a number adequate to establish a viable population in Oregon—would likely have measurable negative impacts on the California population's conservation and recovery, depending on where the captures were conducted (see Chapter 3). However, depending on the preferred release strategy, a case could be made for including 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 in Oregon would likely aid in the recovery of lost genetic diversity that resulted from the maritime fur trade. This would theoretically provide future benefits to sea otters in both California and those further north, as Oregon could become a bridge reuniting the long-fragmented sea otter species (Larson et al. 2012, Larson et al. 2015, Wellman et al. 2020). In turn, this connection 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 a 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 in an Oregon reintroduction strategy. Such a strategy would partly depend 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 by 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 strandings in California, which sometimes 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 (a) help reduce euthanasia of sea otters in California, (b) demonstrate a mechanism for stranded pups in other U.S. and possibly Canadian populations to contribute to the Oregon population, (c) aid in the recovery of lost genetic diversity within sea otters, potentially across much of their range in the eastern Pacific, and (d) potentially improve the retention rate of reintroduced sea otters in Oregon beyond that expected based on past translocation efforts.

In the following text, we present options for the capture, transport, holding, and release of animals into the coastal waters of Oregon. This effort would be sizeable but not insurmountable and would require 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 for 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 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 method. 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 the sea otter's injury or death exists during capture, although the probability varies among methods (discussed below). Additionally, capture and handling present the potential for 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 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 ft ; 5.18–6.10 m) skiff with a 50–100 hp outboard motor and with a team of two people, 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 and 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 as in translocation to San Nicolas Island.

One advantage to dip-netting is that the equipment is rather simple and requires only two people. 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 lb (6.80–11.34 kg; often recently weaned pups), and if juvenile sea otters are a target age group, some individuals may be captured this way.

There are at least three potential disadvantages to dip netting. One is that the catch rate can be relatively low, perhaps zero to four animals per day per team under good conditions. The second disadvantage 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 the risk of serious injury or death possible. 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.

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

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 ft (100.58 m) long, about 9–15 ft (2.74– 4.57 m) deep, constructed of #15 monofilament line with a 9.25 in. (23.50 cm) stretch mesh size, and commonly adapted from commercial king salmon fishing gear. Nets are kept afloat with a "cork-less" foam core float-line with a 1.5 in. (3.81 cm) 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, nets used for sea otter captures over the past 30 years, and we recommend that organizers of future capture efforts talk with Research Nets Inc. to benefit from their expertise.

The nets are set in proximity to aggregations of sea otters at rest or in areas where sea otters are known to forage or travel between resting and foraging locations. Typically, one to three 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 rode line. A large float is on one or both ends, and the nets are usually set in waters from 20–60 ft (6.10– 18.29 m) deep in or 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 float continuously. Where sea otters are abundant, nets might be deployed only during daylight hours and be watched continuously by a shore-based observer(s) with a telescope. Where densities are low and sea conditions allow, nets may be allowed to remain overnight but should still be checked periodically.

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

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 five to 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 the 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 a tangled animal. It is therefore essential that the nets are 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 a tangled animal 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 a tangle-net hazard is an unexpected 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 proximity were they able to bring the net to the surface and release an animal submerged for several minutes. It usually takes a crew of three to operate one to three 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 resetting, and there is also the risk of bycatch of fishes, birds, and other mammals. These incidences can result in injury or death to the bycatch, with the potential for 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 them to capture sea otters, and even then, not all risk can be eliminated. Compared to SE Alaska or British Columbia, the Washington coast probably provides the least amenable habitat, environment, and access to capturing sea otters with tangle nets.

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

Wilson Traps

In large part because of the risk presented by floating tangle nets, in 1972, the State of California 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 the disturbance would be to dive into the trap. The trap would immediately be closed by the purse string, entrapping the otter, and the dive tender would soon pick it up.

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 it the preferred capture method in many cases. These improvements include a shift to oxygen rebreathers (a closed-circuit scuba system) that remove the scent and disturbance created by divers' bubbles; waterproof very-high-frequency (VHF) radios that allow spotters to communicate with the divers; and the replacement of the wooden rod with a battery-powered underwater propulsion device that extends the range and speed of the divers. Under average to good capture conditions—including abundant animals and clear and calm seas—expected capture rates by a team of three to four should be approximately three to six animals per day.

Regardless of the method of sea otter capture, it is essential that once a sea otter is captured, it be placed in a container that will restrain its 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 proven to meet these needs (Figure 9.1). It is constructed of marine-grade plywood and fitted with a sliding lid and holes for drainage and air or water exchange. It can hold ice to keep animals cool. A frame of tubular polyvinyl chloride (PVC) can be placed on the bottom to keep the sea otter off the bottom of the box, thereby reducing the potential for soiling the fur. If animals are required to be held for any period of time before 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, depends on locations, distances, and available logistics. In this section, we discuss the advantages and disadvantages of the modes of transport likely to be used in a translocation in Oregon.

Small, trailered skiffs, 5–7 m 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 space is needed for two to four people and capture equipment that might include nets, dive equipment, and at least two capture boxes. The 17 ft and 20 ft (5.18 m and 6.10 m) 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 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, 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 helps the sea otter maintain 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 the animal's 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 depend 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 for any future Oregon reintroduction, 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 the water level and 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 the sea otters' recapture when needed. It may be advisable to acquire the capacity to hold adult female sea otters at the release site to rear juvenile sea otters under rehabilitation for release.

Figure 9.4. Photos of floating net pens for holding sea otters at a release site.

Note. TOP: A view of a floating net pen deployed for testing in Monterey Bay. BOTTOM: Releasing a captured sea otter into a floating net pen deployed at San Nicolas Island. Photos courtesy of Colleen Young (California Department of Fish and Wildlife) and Mike Kenner (U.S. Geological Survey).

RELEASE

Based on evidence from the earliest (Barabash-Nikiforov 1947/1962) 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, which may be facilitated by allowing for recapturing and holding 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 of or the core of a reintroduction in Oregon, a single individual or small groups of individuals may come from one or more captive sea otter institutions. They will require a holding facility at (or near) the release site to provide local acclimatization and bond development between individuals from different sources. Such a release 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 the animals move from the release site and the more erratic those movements. However, the use of remote sensing tags on each individual can help locate 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 the U.S. Geological Survey and the U.S. National Aeronautics and Space Administration (J. Tomoleoni, pers comm) 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 released on the open coast compared to those released in estuaries (assuming that animals stay within the estuary). Frequent monitoring, daily or multiple times per day, can improve the reintroduction's chances of success, particularly if recapture is required. Full-time teams of two to four trained and experienced observers may be required for initial monitoring.

Depending on movements and the 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. Float-equipped aircraft may provide increased margins of safety for pilots and observers if tracking occurs more than a few kilometers offshore.

DATA NEEDS

The primary data need before a reintroduction is the assessment of appropriate and adequate food and habitat resources (see Chapter 6). Such assessments depend 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. So, rapid assessments of food and 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 (geographic information system, or 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, allowing for informed assessments of ecological and socioeconomic impacts (Chapter 5 and Chapter 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 descriptions of communities, species, and ecological relations expected to be influenced by reintroducing a long-absent predator. Published data from other established and recolonizing sea otter populations can provide an excellent reference for the types of changes to be expected. Monitoring studies aimed at detecting changes in sea otter behavior, physiology, and population dynamics in newly established populations can also provide insights into population status and ecological impacts. In addition to long-term monitoring studies, comparative studies that utilize a *space for time substitution* (i.e., comparisons of sites that differ in terms of the duration of sea otter occupation used as a proxy for longitudinal data from a single site that becomes occupied by sea otters and changes slowly over time) have been shown to be a powerful approach for elucidating ecological dynamics associated with sea otter recovery (Rechsteiner et al. 2019).

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 SE Alaska. Sea otters from California may be considered to supplement animals from northern populations, which would potentially benefit the conservation and recovery of southern sea otters as well as establish a genetic bridge between California and northern subspecies. Evidence from historical reintroductions suggests that 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. The 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 the 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 kilometers 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 that 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. The ORSO application (Chapter 3) can be used to evaluate the likely effects of varying the age/sex ratio 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 captured animals' health status during transport and holding is critically important, and intensive post-release animal monitoring will also help ensure success.

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Chapter 10

ANIMAL HEALTH AND WELFARE CONSIDERATIONS

Michael J. Murray

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

This chapter's animal welfare section is more subjective and speculative. While animal welfare is becoming more science-based, it evaluates an animal's state at any one point in time, is described on a continuum from good to poor, and varies, often dramatically, within a group of animals and over time. The subject is addressed through the lens of a modified list of the Five Freedoms described by Britain's Farm Animal Welfare Council (FAWC) in 1965 and subsequently released in 1979 (FAWC 2009) and the Association of Zoos and Aquariums' (AZA's) Five Opportunities, outlined in their accreditation standards (AZA 2020). The modified list considers whether animals have the following when assessing their welfare:

1. nutritionally complete diets—in quantity, familiarity, safety, and accessibility
2. comfortable living experiences—that are appropriate for the species, provide the ability to rest, offer haul-out opportunities, and prevent anthropogenic risk
3. good physical health—humans help to mitigate known disease risk and provide live-stranding responses, carcass recovery and processing, and potential rehabilitation opportunities
4. adequate social structure—per group size, sex ratio, age range, and site fidelity
5. freedom from chronic stressors—e.g., boat traffic, ecotourism disturbances, inadequate refugia, interspecies interactions

Lastly, a discussion of health and welfare would be incomplete without including animal transportation and post-arrival conditioning. A number of federal agencies provide regulatory oversight for interstate animal transportation, and the list becomes longer albeit less specific when dealing with wildlife, especially marine mammals. Regardless of the source population, any 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 maintaining the otters' health and well-being.

ANIMAL HEALTH

As previously described, animal health includes both infectious and noninfectious diseases. For this chapter, a rather stringent definition of infectious disease has been applied. *Infectious diseases* are those 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 transmitted directly between animals are described as transmissible, communicable, contagious, or transmitted horizontally. An exception to that definition is the diseases known to be transmitted in utero, such as toxoplasmosis, for which transplacental or vertical transmission is used. While many infectious diseases are transmitted directly between animals, not all are. Examples include both toxoplasmosis (excepting the vertical transmission between dam and fetus) and sarcocystosis. Both are caused by living organisms, specifically 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 is selective in its inclusion of noninfectious diseases. An attempt was made to address those considered to potentially impact the success of a sea otter reintroduction program at a population level and are typically considered an individual animal malady. Of the 11 major groups of *noninfectious 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. Refer to Chapter 4 for further information on genetics and disease.

Aspects of this discussion are necessarily speculative. The information provided is based upon a combination of published data, works in progress, personal communications with colleagues, and my experience in clinical sea otter medicine. In addition, inferences were drawn from other members of the otter's family, *Mustelidae*, for which a fair bit of information is known about infectious and noninfectious 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. Before 2001, all sea otters tested for morbilliviruses were seronegative (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 seropositive (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 the 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 have been reported. Serologic evaluation of live-captured sea otters in the eastern Aleutians and Kodiak archipelago in 2004–2005 identified 40% seropositivity 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 to 2012 identified three cases of putative morbillivirus infection (3/560) as the primary cause of death (COD) and five cases (5/560) as a 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 said, the potential exposure of naive sea otters to canine distemper virus from terrestrial carnivores, such as canids and raccoons, and marine-foraging river otters cannot be ignored. Additionally, the ongoing loss of sea ice and the opening of the Northwest Passage may facilitate the 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 for 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 seropositive. The source of the infection was unclear; however, serologic evidence supported the notion that the sea otters' source of infection was the northern elephant seal (*Mirounga angustirostris*).

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

Bacterial Diseases

Morbidity and mortality associated with bacterial infections are common in the sea otter. From 1998 to 2012, bacterial infections were the primary COD in 33 out of 560 southern sea otters and the contributing COD in 35 out of 560 (Miller et al. 2020). The examined death assemblage from the 2002–2015 evaluation of Washington State otters identified 14 out of 93 cases of bacterial infection (including six 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. A review of the list of more than 15 species recovered at necropsy (Brownstein et al. 2011) suggests that the vast majority of bacterial species are, in fact, opportunistic. They rely on a breach of the host's intrinsic immune system (skin, mucus membranes), immunosuppression, or coinfection with a primary pathogen to gain access to the body. Notably, several pathogens identified have significant zoonotic potential and may pose a public health risk: *Brucella* spp., *Coxiella burnetii*, *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 wounds likely associated with intraspecific 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 gigantea*), Dungeness crab (*Metacarcinus magister*), and black turban snails (*Tegula funebralis*)—are capable of bioaccumulating *S. phocae* (Rouse et al. 2021). It is unclear whether this bacterium is capable of breaching the gastrointestinal mucosa or if food-borne exposure requires a preexisting break in the gastrointestinal tract, such as ulceration or a wound associated with prey handling.

Other beta streptococcus species, *Streptococcus bovis/equinus* and *Streptococcus infantarius* ssp. *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 cause of the unusual mortality event declared in 2006 in Kachemak Bay, either partially or entirely, to 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 what is commonly known as 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 seropositivity rate of one in 30 in 2001 (Brancato et al. 2009); five in 103 in California in 2003 (Hanni et al. 2003); and three in 161 in Alaska and Russia in 2004–2006 (Goldstein et al. 2011). In 2002, six beach-cast sea otter carcasses were evaluated, and COD was attributed to leptospirosis (Knowles et al. 2020). While the incidence seems to remain low, there may be some degree of concern for the 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 interspecies transmission on the Oregon coast.

Overall, bacterial infections are unlikely to pose a significant, population-level threat to a reintroduced sea otter population along the Oregon coast. Recent mortality studies of southern and Washington sea otters identified 68 out of 560 (12%) and 14 out of 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 immitis*. 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 nine of 560 were identified by Miller et al. (2020), all of which were found at the southern end of the sea otter range.

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 people in 2008 to 54.7 cases per 100,000 in 2018 (Monterey Health Department 2019). 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 posed by coccidioidomycosis to a sea otter reintroduction. That said, 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, it is probably unwise to assume that infection is impossible.

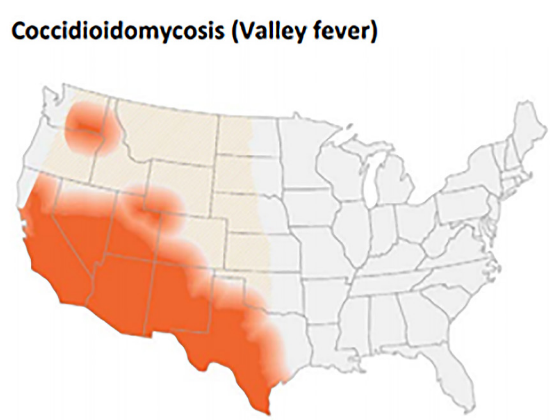
Parasitic Diseases

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

Sarcocystosis

Sarcocystosis is caused by a sporozoan protozoan, *Sarcocystis neurona*. It has a rather complicated life cycle, employing a number of endotherms—including dogs, cats, raccoons, and sea otters—as intermediate

Figure 10.1. Map of the distribution of Valley fever in the United States



Note. Source: Information from the U.S. Centers for Disease Control and Prevention about the estimated areas with blastomycosis, coccidioidomycosis (Valley fever), and histoplasmosis in the United States: https://www.cdc.gov/fungal/pdf/more-information-about-fungal-maps-508.pdf.

hosts, in which it forms tissue cysts. The definitive host, the species in which sexual reproduction occurs and oocysts are produced and shed, is the Virginia opossum, *Didelphis virginiana*.

In the sea otter, positive antibody titers are more common than clinical disease. It is suspected that encysted parasites may not cause significant symptoms. The 2002–2015 Washington State study found that sarcocystosis accounted for 28 of 93 primary CODs (White et al. 2018), while the California study identified protozoal infection (*Sarcocystis* and *Toxoplasma*) as the primary and contributing COD for 50 of 560 cases and 58 of 560, respectively. While numbers were not provided, sarcocystosis outnumbered toxoplasmosis as a primary COD by a factor of five (Miller et al. 2020). The 2004 mass mortality event in Morro Bay, California, was attributed to sarcocystosis as the primary COD in 15 of 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 titers, with terrestrial features (wetlands, croplands, and high human-unit density), soft-sediment substrate, and the predominance of clams in the diet (Burgess et al. 2020).

A transmission pathway has been proposed in which oocysts accumulate over time and remain viable in the environment for months to years. Freshwater runoff into the nearshore system allows for concentration by the local marine habitat features, ocean physical processes, and subsequent invertebrate bioaccumulation. 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 the late winter and early fall and subsequent disease peaks in sea otters in the spring and early summer. This trend 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 runoff (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 in 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 periods. The method of transmission from land to sea is now well understood, as is the bioconcentration 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 a fatal disease in sea otters. Type II, while causing seroconversion, 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 *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 perinatal 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 a 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 results from 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*, is different from that of other gastropods, such as abalone. The net result is greater 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 sheds large numbers of oocysts into the terrestrial watershed adjacent to sea otter habitats, ensures 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 nearshore marine environment, and the ability of benthic filter feeders, such as bivalves, to accumulate infectious stages for eventual consumption by sea otters (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 reintroduced sea otter population. Even with the less virulent types, significant infection may impact 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 associating sea otters' well-described *Toxoplasma* relationship with any publicized human cases.

Acanthocephalan Peritonitis (AP)

AP is not an uncommon primary or contributing COD in southern sea otters (127/560), but it 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 AP's causative agent, *Profilicolis* spp. The normal life cycle is complex, with a free-living stage, an arthropod as an intermediate host, and a vertebrate as a definitive host. In the case of *Profilicolis*, the intermediate hosts are the sand crab, *Emerita analoga*, and the spiny mole crab, *Blepharipoda 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 presence of the intermediate hosts is somewhat more inconsistent 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 restocked by larvae drifting northward on the currents, with the highest numbers identified during El Nino years (Sorte et al. 2001).

The disease is most often diagnosed in recently weaned pups, subadults, 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 food source. When food is plentiful, hunting is less demanding, and even the less physically fit otters can 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 by thoughtfully selecting the release site and physically conditioning the animals prerelease. Ample food availability (at least in the early years after reintroduction) may result in otters avoiding predation upon some of the high-risk food sources, such as *Emerita* and *Blepharipoda*.

Larva Migrans

In this venue, *larva 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 AP.

Larva 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 to be clinically insignificant. 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 risks of pathogen pollution of the nearshore habitat.

NONINFECTIOUS DISEASE

Toxic Diseases

Domoic Acid (DA) Intoxication

While DA intoxication was not identified as a COD in the recent Washington death assemblage, it was a significant primary or contributing COD (probable/possible) in the California study (White et al. 2018, Miller et al. 2020). DA is a water-soluble neuronal glutamate receptor analog that is produced by certain strains and species of the diatom *Pseudo-nitzschia* (PN). It is 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 known or suspected to enhance 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 to better understand the relationship between oceanographic conditions and HAB along the coast of Oregon.

PN blooms tend to be seen during the spring and summer months, which align with the early period to the midpoint of the 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 DA production.

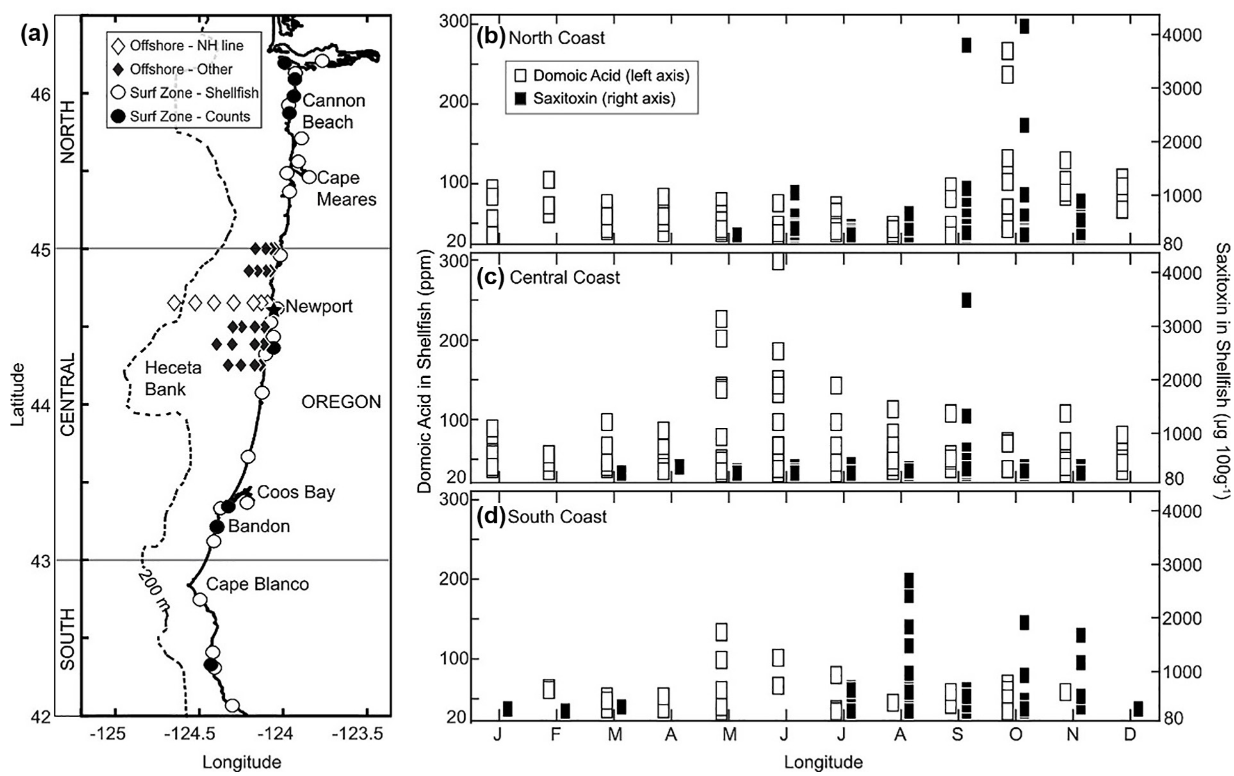
An important cautionary note is that reliance on offshore PN and DA monitoring may not reflect the degree to which benthic sea otter prey are exposed to the biotoxin. Exposure is dependent upon the movement of the algal bloom into the shallower surf zone. This movement is, in turn, affected by surf zone 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 offshore 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 are exposed to DA 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 DA intoxication occurs in humans, as well as marine mammals and birds, state and local agencies carry out active monitoring programs. Several sentinel species are used, as well as an evaluation of the water column for PN. Mussels are a common bio-accumulator that is easily managed; therefore, they are commonly used as sentinel species for evaluating the presence of DA. 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 DA levels in razor clams may represent an acute, high-level exposure or, alternatively, a chronic, low-level exposure over time (McKibben et al. 2015). Using established monitoring systems has limited applicability to predicting sea otter exposure because (a) monitoring efforts vary from region to region, (b) bioaccumulation mechanisms differ between species, (c) the systems use human-centric toxicity thresholds, and (d) the systems emphasize human-consumed species (Figure 10.2).

Other potential sea otter prey items have been evaluated as potential DA depositories. One study looked at eight benthic invertebrate species representing four feeding groups: filter feeders (*Emerita analoga*, *Urechis caupo*), a predator (*Citharichthys 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 DA exposure are likely to be directly related to how various prey species respond to the toxin, local and regional environmental factors, and the age and size of the prey (Egmond et al. 2004). Mussels, one of the primary sentinel species for DA, accumulate it in the digestive gland. As a result, it depurates quickly but does accumulate to high levels. DA accumulates in different body tissues of the razor clam: the mantle and foot. This accumulative 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 DA levels in a short time; acute intoxication is the result. Prey species with slower depuration rates, such as razor clams (Blanco et al. 2002), may cause sea otters to accumulate high DA levels from either profound PN blooms or exposure to low, persistent levels of the toxin (McKibben et al. 2015).

Figure 10.2. Oregon map illustrating domoic acid (DA) and saxitoxin (STX) monitoring activities and related data.



Note. In the map of coastal Oregon (a), the area to the right of the solid black line is land. The dashed line shows 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 the coast represent surf zone sampling locations for shellfish DA and STX (white) or *Alexandrium* and PN cell counts (black). Surf zone data are binned into north (45–46.58N), central (43–458N), and south (42–438N) regions. Monthly STX and DA samples are shown as black squares (right axis) and white squares, respectively, for north (b), central (c), and south (d) 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).

DA intoxication is difficult to diagnose antemortem. 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. There are three major postmortem presentations of DA intoxication based on the dose consumed over time. Acute intoxication is primarily a neurological disease with seizures dominating the clinical presentation. A subacute disease with doses 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. 2021).

Given the significance of known or suspected DA-related mortality, as well as 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 high in an Oregon coast reintroduction 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.

Saxitoxin (STX) Intoxication

A second marine biotoxin warranting discussion is saxitoxin (STX), the causative agent of paralytic shellfish poisoning, which is produced by some species of the dinoflagellate *Alexandrium*. STX is not a single compound. Instead, it is a group of neurotoxins produced by species of dinoflagellates, including *Alexandrium* (Horner et al. 1997). Based on regional Indigenous customs and the apparent ability of some marine mammals to proactively reject toxin-bearing prey, it appears that paralytic shellfish poisoning has been present on the West Coast for centuries (Fryxell et al. 1997). For this reason, the Oregon Department of Agriculture 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 toward shore, exposing nearshore invertebrates to biotoxins. Dinoflagellate blooms, including *Alexandrium*, are classically seen later than DA-associated blooms, traditionally peaking in June through November (McKibben et al. 2015).

The marine biotoxin sampling program for DA/STX and PN/*Alexandrium* is inconsistent along the Oregon coast, with the north coast most heavily monitored, followed by the central coast, and the south coast at the lowest level (Figure 10.2). Mussels are sampled more commonly than razor clams, and the sampling frequency decreases from north to south. Significant STX and *Alexandrium* have been reported. In 2010, the Oregon Department of Agriculture 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 of closures concerning commercial and recreational shellfish harvesting along the eastern Pacific coast, the incidence of STX intoxication in sea otters is low. Recent comprehensive analyses of CODs 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 gigantea*, 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).

After consuming toxic STX levels, 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 finding 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 reintroduced sea otters. Sea otters appear to be able to detect and develop an aversion to STX at levels above a certain threshold (Kvitek and Bretz 2004). It is unclear how this detection 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 subadult otters may be at greater risk of saxitoxicosis.

Microcystin Intoxication

Microcystin intoxication is an uncommon 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 biomagnified up to 107 times in the tissues of bivalves (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 bioaccumulate 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 reintroduced sea otter population. It does, however, warrant some degree of consideration during the evaluation of release sites. The Oregon Health Authority's Public Health Division publishes guidelines for cyanobacterial blooms in freshwater bodies, a potential resource for this evaluation (Oregon Health Authority 2019).

Tributyltin (TBT) or Organotins

Tributyltin (TBT) was employed as an antifouling agent in marine paint for boat hulls from 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 TBT effects 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 bioaccumulate primarily in the liver; however, significant levels are also found in the brain and kidney. Likely due to 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 COD for southern sea otters recovered from 1992 to 1996 did not demonstrate a strong association between TBT levels and immunosuppression, as evidenced by disease as COD (Kannan et al. 1998). This finding was supported by a study of organotins in sea otter carcasses from California, Washington, Alaska, and Kamchatka, Russia, from 1992 to 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. The 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

A significant amount of work has been done to look 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. 2006b, 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 bioaccumulation and slow depuration in benthic invertebrate prey (Rudebusch et al. 2020). Unfortunately, except for localized PCB concentrations 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.

Considering the degree to which a release site is polluted, compromised, or nutrient-enriched should be a part of the decision-making process. Still, its importance should not be overemphasized relative to other factors. As with many, if not most, estuarine habitats in coastal North America, Oregon's estuaries are likely to suffer negatively from anthropogenic impacts, including high levels of pollution (see Chapter 6). However, published evidence from a large California estuary, Elkhorn Slough, does not support the notion that polluted ecosystems and thriving sea otter populations are necessarily mutually exclusive. Despite having the most elevated levels of the organic contaminants DDT and DDE recorded within the southern sea otter range (Jessup et al. 2010)—pollutants that are known to have deleterious effects on sea otters (Kannan et al. 2006a)—Elkhorn Slough supports some of the highest sea otter densities in California (Tinker et al. 2021c). The Elkhorn Slough sea otter population has been found to have high survival and growth rates even in the presence of these high pollutant levels (Mayer et al. 2019). Perhaps more importantly, the net result of this thriving sea otter population has been the contribution of significant ecosystem services, such as positive effects on eelgrass and salt marsh habitats (Hughes et al. 2013, Hughes et al. 2019). It thus seems apparent that one should not consider the sea otter to be a benign occupant of an ecosystem and a passive recipient of negative effects from pollution. Rather, one should consider the sea otter to be a functioning component of a resilient ecosystem that can help mitigate problems like pollution through positive effects on habitats such as eelgrass (M. T. Tinker, pers comm).

Oil Spills

A discussion of anthropogenic contaminants would be incomplete without including oil spills. While the incidence of direct oil-associated impacts on sea otters is uncommon, the experiences surrounding 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 a life-threatening loss of thermoregulatory capacity due to the fouling of the fur with oil. Thermoregulatory loss causes a cascade of metabolic events associated with not only the toxicity of the petroleum compounds but also the animal's inability to meet caloric and fluid needs, either through the active loss of heat or inability to hunt. Acute toxic effects observed during the 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. They include the animals' exposure to sublethal amounts of oil, effects of oil on prey populations, and exposure to petroleum compounds bioaccumulated 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 areas, and population growth slowed significantly due to 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 reintroduced sea otter population in Oregon cannot be ignored. It seems 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 the EVOS, spills such as the New Carissa spill of as much as 70,000 gallons in Coos Bay in February and March 1999 [1] 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 hydroelectric 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 is responsible for working together with the 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 reintroduction program becomes more likely, a proactive, 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 to 2012 (Miller et al. 2020), with dramatic increases recorded since 2003 (Tinker et al. 2016). A recent analysis indicated that shark-bite mortality has a greater impact on overall population recovery in California than any other COD (Tinker et al. 2021b). The reported incidence in Washington State otters is not nearly as common, with only two of 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 has been attributed to bites from the white shark (*Carcharodon carcharias*) based on recovered tooth fragments and parallel scratches on sea otter bones (Tinker et al. 2016). Unlike other marine mammal bites, sea otter attacks are nonconsumptive, probably exploratory bites. The nature of the resulting wound occurs later because of blood loss, tissue trauma, or the loss of thermal integrity and subsequent metabolic collapse.

The nature of shark-bite-related mortalities involving northern sea otters has not been provided; however, the pathogenesis of the ultimate death was likely similar to that observed in southern sea otters (White et al. 2018). There is an increasing body of anecdotal evidence to suggest that shark-related sea otter mortality may be important in coastal Oregon. Reports involving beach-cast sea otter carcasses for the first 11 months of 2021 (USFWS [U.S. Fish and Wildlife Service], unpublished data; T. Waterstrat, pers comm.) suggest that seven of eight had evidence of shark bites, although the timing of the shark bites, ante- or postmortem, could not be reliably determined.

The potential threat posed by shark predation to a reintroduced 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) has suggested 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 trend would mirror a hypothesized northward shift in white shark distribution along the U.S. East Coast (Bastien et al. 2020).

1 Read more about the New Carissa spill here: https://www.cerc.usgs.gov/orda_docs/CaseDetails?ID=992.

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 (< 200 m), including bays and estuaries. Except for 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 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. A well-described and documented migration pattern of this shark species exists between the continental shelf and the shallow nearshore and estuarine habitats (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 the white shark. It also uses social facilitation, in which a pack of sharks surrounds its victim to prevent escape before subduing it—a strategy employed at depth (Ebert 1991).

Unfortunately, the risk posed by shark attacks on sea otters in a reintroduction program is unknown and unlikely to be known before embarking on such a program. Similarly, it is purely speculative to predict the broadnose sevengill's potential impact 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 reintroduction 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 road map 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 CODs 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.

These two forms of direct anthropogenic trauma—gunshot and blunt trauma to the skull—are most assuredly malicious in nature (trauma from boat strikes is discussed in the next section; 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 an adequate basis, it suffices to say that public reaction to a sea otter reintroduction program is unlikely to be universally embraced. It is incumbent upon project managers to recognize the potential for this type of trauma and take necessary steps to mitigate its occurrence, if possible. Public outreach and education may be the most effective mitigation strategies.

Vessel Traffic

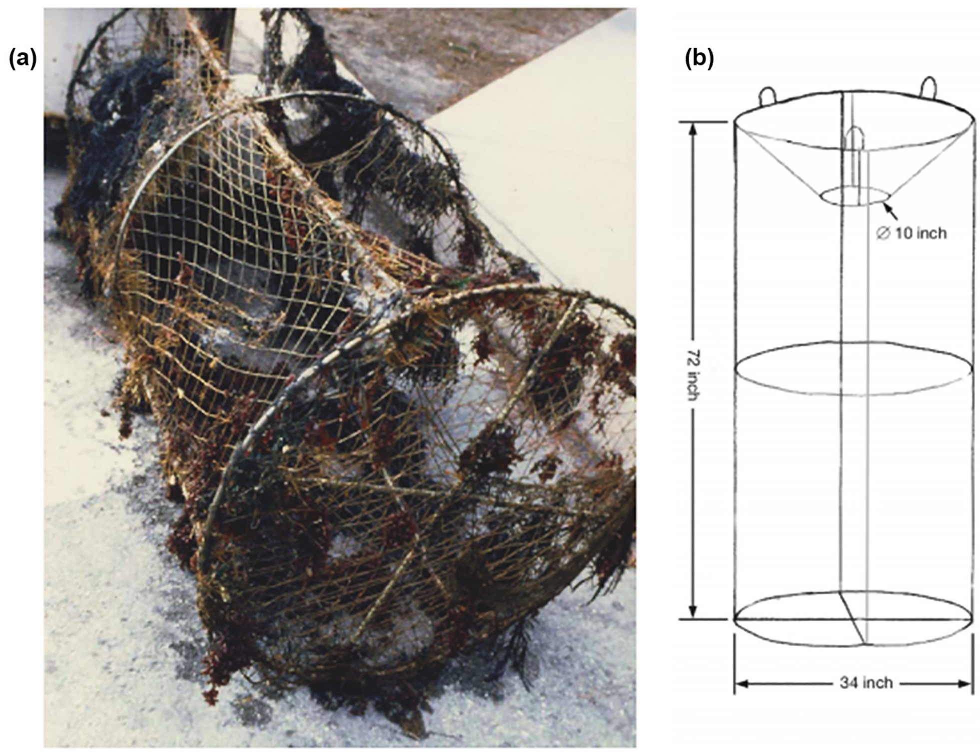
The incidence of boat-strike-related mortality was low in both the California and Washington State studies: 25 out of 560 and one out of 93, respectively (White et al. 2018, Miller et al. 2020). The negative effects of vessel traffic are not limited to boat strikes. Any disturbance of resting or grooming otters, normal social structure, and foraging efforts may 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). A consideration of anthropogenic disturbance should include not only commercial boating and fisheries traffic but also recreational fishing, watersports such as kayaking, 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.

Trauma Involving Fishing Gear

Trauma in sea otters associated with commercial and recreational fisheries is most frequently attributable to net entanglement, fishhook injuries or consumption, or entrapment in fish or invertebrate traps (Figure 10.3). Since fishing regulations in California were changed to move gillnet fisheries into deeper water, the incidence of net entanglement has decreased significantly (Wendell et al. 1986). However, it still occurs occasionally, either due to illicit fishing practices or entanglements in lost, abandoned, or damaged nets. By mandating gillnets be set at depths deeper than sea otter dives (40 m), the hazard seems avoidable.

Rigid traps, especially those used for Dungeness crabs, have been recognized as a potential entrapment threat, especially for younger sea otters that 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 in. (25.4 cm) circle to a 3 in. by 9 in. (7.6 cm by 22.9 cm) rectangle, most independent sea otters were excluded from the traps, and yet, crab capture rates were not significantly impacted (Hatfield et al. 2011).

Figure 10.3. A derelict fish trap that drifted into Monterey Harbor in 1987.



Note. (a) A photograph of the derelict fish trap containing two drowned sea otters (one adult female and one large male pup). (b) A line drawing of the same trap. Note the 10 in.-diameter (25.4 cm) fyke opening. The figure is from Hatfield et al. (2011).

ANIMAL WELFARE

Animal welfare and its application to free-ranging wildlife is a challenging subject. Welfare assessments tend to focus on individual animals, while conservation goals tend to focus on populations. 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 remain predominantly subjective, and by the nature of welfare, they are not static. In fact, they change frequently.

Original concepts of animal welfare were based on the FAWC's Five Freedoms (FAWC 2009). The AZA subsequently modified these freedoms, renaming them the Five Opportunities for its animal welfare and accreditation standards (AZA 2020). 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, a paraphrased version of the Five Opportunities provide the structure upon which welfare considerations are outlined. By their nature, they are subjective, and attempts have been made to apply them to a reintroduced population whenever possible. At times, however, it is necessary to consider the individual animal within the context of the opportunities:

- Nutritionally complete diets
- Comfortable living experiences
- Good physical health
- Adequate social groupings
- Freedom from chronic stress

Animal welfare is a hot-button topic in the public's eyes, especially as it applies to marine mammals. Including animal welfare in this feasibility study may be of benefit if and when a reintroduction project in Oregon is formally proposed. Considering not only the scientific and model-based aspects of a reintroduction but also the humane and welfare issues could help the Elakha Alliance gain public support with any future project it pursues.

Nutritionally Complete Diets

Several aspects of nutrition and diet need to be included in release site selection to help protect sea otters' welfare. Prey availability is important, to be sure, but so too is the spectrum of species and the otters' recognition of them as food. The availability of a variety of prey may provide some degree of insulation from naturally occurring recruitment cycles. Prey also needs to be present in sufficient quantities at depths attainable by reintroduced otters.

The wholesomeness (or health risks) of food items also warrants consideration. Areas with large aggregations of *Emerita* and *Blepharipoda,* the intermediate hosts of the cause of AP, may be problematic. Similarly, food-based risk factors associated with toxoplasmosis and those known to bioaccumulate DA effectively are noteworthy.

Comfortable Living Experiences

A great deal of effort has been made in identifying appropriate habitat suitable for the 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).

Moreover, the release site is not the only living experience that is a factor. As plans for pre-release holding and conditioning are developed, animal welfare will be an important consideration. The federal Animal Welfare Act and Animal Welfare Regulations (APHIS [Animal and Plant Health Inspection Service] 2020) have established minimum standards for marine mammal enclosures for exhibition and research animals based on animal size (sec. 3.104(f)), but their applicability to animals in a reintroduction program is doubtful. Regardless, 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 (6.10 m) in diameter and 3 ft (0.91 m) deep. Animal comfort appears to decrease significantly with group sizes exceeding six animals. Population density within holding facilities will be an important consideration.

Good Physical Health

Much of the discussion about health-related welfare considerations is found in the first section of this chapter. Still, several additional considerations are not disease-specific. First, there should be a protocol developed to describe 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 reintroducing them to a new site is essential.

After otters have been released, program managers must be prepared to answer this question: What is 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 reintroduction program. Some preexisting coastal marine mammal rehabilitation centers may be able to provide some support for developing and implementing a stranding response program. However, facilities, protocols, and even regulatory agencies will be different for sea otters.

One of the confounding knowledge gaps in reviews of the previous Oregon reintroduction program has been the lack of information about why it failed. To better understand the outcome of any future program, 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.

Adequate Social Groupings

Sea otters tend to be social animals, aggregating in cohorts of varying sizes up to hundreds of otters. These rafts are typically segregated by sex, and females tend to demonstrate the greatest site fidelity, with individuals spending nearly their entire lives in a relatively small area. Males tend to more loosely aggregate with the formation of bachelor rafts, and some become solitary, dominant territorial males. Males have been known to travel long distances and typically occupy otter-less areas well before females and pups arrive. Successfully reintroducing sea otters into sea-otter-free habitats may be difficult because the area has no existing otters with which the newly released individuals can socialize and bond. The critical mass for reintroduction is unknown, but data from the previous sea otter translocations may be informative. The number of otters available for the project will depend upon the source populations (see Chapter 3 and Chapter 9).

Success 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 after transportation. Maintaining natural social groupings is confounded by the males' tendencies toward aggression if held in the same tank or net pen. Necessarily, only one male is held per tank/pen. Holding times will be directly proportional to the distance traveled.

The Monterey Bay Aquarium has occasionally released pairs of juvenile animals that 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 have re-encountered one another, but no evidence suggests that the bond was retained. In some cases, there was a loose re-association at common rafting or feeding areas, or they might have remained separated but within the same general location (M. Staedler, K. Mayer, S. Hazan, pers comm). It is important, however, to recognize that these observations were made in release sites already occupied by sea otters, possibly serving as anchors for recently released individuals.

While not causally related to social groupings, some consideration should be made to animal age and experience. First, younger animals are less likely to have strong site fidelity and the desire to swim back to their original territory. Second, young animals may not be as athletic or physically conditioned to swim back, and 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. A future reintroduction program can help ensure the welfare of the subject otters by considering their varying needs based on age and proficiency in living in the wild.

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 limited and involve a series of trade-offs.

Freedom From Chronic Stress

This animal welfare consideration is a bit oxymoronic in this study's context. There is no way to avoid stress during a reintroduction, and some of it may be prolonged. Every aspect of any project will be associated with some degree of stress for the otters. A more realistic goal is to minimize stress whenever possible during the process. Minimizing both direct and indirect human contact, managing isolation, and segregating sexes are examples of actions that can reduce stress. Other stressors are likely to be mitigated by paying attention to the other four welfare opportunities. A reintroduction program should be designed to maximize opportunities for success. 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 reintroducing sea otters to the Oregon coast would be incomplete without some discussion of the potential for failure. While population-level metrics determine the success or failure of the project, 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 decisions to continue reintroductions, reevaluate release sites, and modify methods for animal capture, transportation, and release.

The preceding sections have attempted to identify, summarize, and extrapolate information regarding sea otter health and welfare from known circumstances to an anticipated reintroduction site. It is impossible to predict all 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 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 the most substantial threat to sea otters living along the Oregon coast is likely to be DA intoxication. Its presence in shellfish has been recognized as a potential human health threat for well over a decade—a concern mostly directed toward the 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 deep concern, though 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 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 diseases will have population-level impacts on the reintroduction program, they may have significant impacts in specific areas and may 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).

Noncontagious infectious diseases, such as sarcocystosis 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 health and/or selecting suboptimal prey species (Johnson et al. 2009, Burgess et al. 2018, Tinker et al. 2021b). Such diseases may also significantly impact 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 bioaccumulation by sea otter prey may result. This scenario would be unlikely to have a significant impact on an established population but may be devastating to a recently introduced one.

Table 10.1. Summary of health threats for sea otters in the case of a reintroduction to Oregon, by a subjective ranking of potential population impact.

Health concern	Category	Contagious	Population impact	Likelihood	Source	Site specificity
Domoic acid (DA)	Noninfectious, toxic	No	High	High	Prey, HAB	Possible
Shark bite	Trauma	No	Medium-high (med-high)	Med-high	White shark, sevengill shark	No
Morbillivirus, phocine	Infectious, viral	Yes	Med-high	Medium (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	Noninfectious, toxic	No	Med-high	Medium-low (med-low)	Vessels, land-based runoff	Site-specific increase
Streptococcus phocae	Infectious, bacterial	Possible	Med	Med-high	Bite wounds, prey	No
Acanthocephalan peritonitis (AP)	Infectious, parasitic	No	Med	Med	Prey, sandy substrate	Sandy seafloor
Microcystin	Noninfectious, toxic	No	Med	Med	Freshwater runoff	Freshwater runoff
Saxitoxin (STX)	Noninfectious, toxic	No	Low	Med-high	Prey, HAB	Widespread
Tributyltin (TBT)	Noninfectious, toxic	No	Low	Low	Prey, sediment association	Marinas, large harbors
Influenza	Infectious, viral	Yes	Low	Low	Pinnipeds	No
Leptospirosis	Infectious, bacterial	Yes	Low	Med-low	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
Larva migrans	Infectious, parasitic	No	Low	Low	Land–sea, runoff, prey	Freshwater runoff
Vessel traffic	Anthropogenic, trauma	No	Low	Low	Commercial, recreational	Heavily traveled, populated areas
Contaminants	Anthropogenic	No	Low	Low	Sediments, water column	Yes
Streptococcus bovis/equinus	Infectious, bacterial	Possible	Uncertain	Med	Probable prey	No
Bacterial infections, not specified	Infectious, bacterial	Possible	Uncertain	High	Multiple	No

Note. This table includes a subjective ranking of each health concern's potential population impact and the relative likelihood of each threat occurring, as well as other attributes. The rows are listed in descending order from a high to low potential population impact, with uncertain likelihoods listed at the end.

The animal welfare issues associated with reintroduction 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. Their importance will be most notable during the otters' time under human care, including the capture (if that is needed as an animal source), transportation, acclimation, and release of sea otters in Oregon. During these activities, it would be best to consider the animals individually. Each of the five opportunities concerning animal welfare—nutritionally complete diets, comfortable living experiences, good physical health, adequate social groupings, and freedom from chronic stress—will need to be addressed. Many of the considerations and recommendations are not well defined, as they depend on animal numbers, sources, and release plans. Once these parameters have been set, it will be important to address them.

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

Although not necessarily a population-level health consideration, plans for managing 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 retrieving beach-cast otter carcasses is important. A component of the carcass program will be the postmortem examination of dead animals. The development of a standardized necropsy protocol is recommended. Again, the questions of who, where, and what need to be answered before a reintroduction begins.

No glaring concerns suggest that reintroducing sea otters to the Oregon coast would likely face insurmountable health and welfare issues. There are known diseases and conditions that may be somewhat problematic, but such is the case for every extant sea otter population. Also, several unknowns should be recognized. The effects of climate change through direct impacts on weather patterns, oceanographic parameters, and sea level rise will affect otters' welfare at some point in time. Indirect effects, such as changes in prey species, pathogen distribution, and animal movements, also exist. Lastly, if the COVID-19 pandemic of the early 2020s has taught us anything, it may be that there are things out there that can have devastating effects on animal (and human animal) populations—things not yet known that are difficult to predict. While there are no fail-proof insurance policies for such unknowns, the most prudent strategy for reducing the 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 unanticipated risks emerge.

FINAL CONCLUSIONS

The discussion above is not intended to be an all-inclusive list of the potential diseases, infectious and noninfectious, that may impact sea otters or of animal welfare considerations. It is an attempt to present information on those shown to have the potential for population-level effects on a reintroduced sea otter population. Much of the information provided was interpreted via data extrapolation concerning California's southern sea otter and the Washington northern sea otter populations. Alaskan otters also warrant consideration; however, that region's mortality investigations are problematic due to the nature of the Alaskan coast; subsequent access to otters, especially distressed or dead otters; and the incidence of scavenging upon dead and moribund beach-cast otters.

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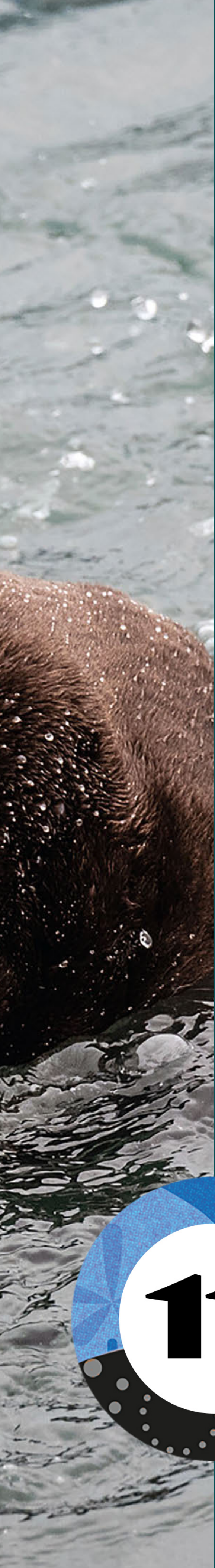

Chapter 11

STAKEHOLDER CONCERNS AND PERSPECTIVES

Shawn Larson and M. Tim Tinker

The potential return of sea otters (*Enhydra lutris*) 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 the 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 the stability and productivity of kelp forests and eelgrass beds and enhancing the abundance of nearshore fish species like rockfish and salmon and various invertebrates, even abalone, that use these kelp and eelgrass habitats (refer to Chapter 5 for a full discussion of the ecological effects of sea otter recovery). This well-studied trophic cascade is often considered a conservation success story for those supportive of returning 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 nonmonetary 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) illustrated 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 (> CAN 9.4 million), carbon sequestration (> CAN 2.2 million), and ecotourism (> CAN 42.0 million), which all combined to offset an associated estimated economic loss to invertebrate fisheries (< CAN 7.3 million). Nevertheless, these economic considerations fail to address other equally important issues, such as social impacts on the communities that support (and are supported by) those invertebrate fisheries and the challenges to food security and self-governance of the First Nations communities in the areas in Canada that are affected (Salomon et al. 2015, Burt et al. 2020).

Inevitably, some would gain and some 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 on nearshore fisheries, it is also important to recognize and address nonmonetary costs to people's livelihoods, lifestyles, and futures. Given these challenges, it is extremely important that decisions about sea otter reintroduction efforts fully consider all stakeholder and title-holder opinions, both positive and negative. Doing so can help foster consensus and stakeholder engagement in decisions 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 while the return of sea otters to Oregon will likely involve some unique costs and benefits, some commonalities exist in the types of concerns and human responses that have been raised in previous examples of sea otter recovery. 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 (SE) Alaska (Jameson et al. 1982). Over 450 animals were distributed among seven 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 (2010–2012) was more than 25,000 and is likely now closer to 40,000 given a 5%–10% estimated annual increase rate (Tinker et al. 2019, Eisaguirre et al. 2021). Based on the wide range of social and economic concerns about the impacts of sea otter recovery on commercial activities and local communities in SE Alaska, the U.S. Fish and Wildlife Service (USFWS) convened a workshop in November 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.[1] A final report from that meeting has also been released ("Southeast Sea Otter Stakeholder Meeting," USFWS Report MMM 2020-01). Below, we highlight some key points from the meeting and report, illustrating the range of stakeholder concerns regarding the impacts of the return of sea otters to SE Alaska.

STAKEHOLDER VIEWS IN SOUTHEAST ALASKA (2019)

Subsistence Harvest of Sea Otters

Sea otter harvest has been an important component of Indigenous communities' cultural practices for thousands of years. Under the exception of the Marine Mammal Protection Act (MMPA), specified in 50 CFR 18.23 of the Code of Federal Regulations, Alaskan Natives are allowed to continue to harvest sea otters for their pelts and the creation of handicrafts. This exception is most clearly enacted in SE Alaska, where the expansion of sea otters across the region has created economic opportunities for individuals involved in harvesting sea otters, tanning the hides, and modifying the hides for artistic purposes and the 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. First, for those who do have access, the blood quantum policy is a concern, including whether non-Native individuals can be on harvest vessels and whether Alaska Native individuals from communities outside of SE 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, concerns exist about misperceptions by the public about the legality and ethical/historical underpinnings of the subsistence harvest of sea otters.

While subsistence harvest considerations 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

1 Learn about the Southeast Sea Otter Stakeholder Meeting, held on November 6, 2019, in Juneau, Alaska, at https://www.seaotterstakeholders.com/. Among other things, the meeting agenda, presentation slides, and a video of the meeting are available from this website.

humans can and should interact, as well as differing cultural practices and traditions associated with sea otters. It is clear from the SE Alaska example that local communities, including Indigenous communities, should have significant involvement 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 the availability of shellfish for harvest. Shellfish collection continues to be an important component of Alaska Native community cultural practices and an important component of food security for many communities, but the situation since sea otter reintroduction and range expansion has become complicated, with additional legal considerations and stakeholder interests.

Modern commercial shellfisheries emerged in SE Alaska during an "abnormal" historical period when sea otters were entirely absent. Without sea otter predation, certain shellfish populations thrived and allowed productive fisheries to develop based on these species. 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, the productivity of many shellfish fisheries has 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 SE Alaska), but their impacts are apparent at a much smaller, localized scale. For this reason, subsistence and commercial fishery stakeholders expressed interest (at the 2019 stakeholder meeting in Juneau) in exploring ideas for more local spatial management of sea otters in a coordinated manner. This type of management could potentially be accomplished if Alaskan Native subsistence harvests were focused locally to protect the subsistence harvest of fisheries. However, it was also recognized that such local harvests would likely be infeasible at a larger scale sufficient to protect many commercial fisheries.

Sea Otter Population Ecology and Ecosystem Status

The USFWS is responsible under the MMPA for collecting data on sea otter population size, distribution, and trends. These population surveys are to be carried out regularly and use standardized and reliable methods to accurately document population trends. Stakeholders at the 2019 meeting in Juneau requested further clarification on how values for Optimum Sustainable Population, carrying capacity, and Maximum Net Productivity Level 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 over 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 the 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 and on 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 all stakeholders accept.

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, including past reintroductions of wolves and grizzly bears. Sea otter reintroductions have also caused conflict with other ocean users in California, British Columbia, and Alaska (Carswell et al. 2015). Experiences in SE Alaska and British Columbia (Burt et al. 2020) have suggested that it is important that all concerned stakeholders be engaged early in the process before any management decisions about reintroduction.

Stakeholder interests specific to Oregon were 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 et al. 2019). 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 who 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 the 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 reported that they anticipated one or more negative outcomes, 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. The authors reported the most common negative outcomes identified were harm to fisheries or reductions in 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 SE 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 finfish (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* (i.e., carbon captured by ocean and coastal ecosystems; n = 3)

» cultural benefits to Indigenous tribes (*n* = 2)
» 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 such an effort.

Table 11.1. Summary of stakeholder perceptions about the return of sea otters to Oregon, based on survey results.

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
Indigenous 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

Note. Respondents could self-assign to more than one stakeholder group among those listed in the "stakeholder affiliation" column. Adapted from Curran et al. 2019.

Key Positive Outcomes Identified by Stakeholder Survey Respondents

Increased Ecosystem Health and Ecosystem Services

When sea otters reclaim their 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. Stakeholder accessibility to these sites is a potential *confounding variable*, as it 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 and Conservation

Survey responses suggested that respondents could appreciate the historical context of a sea otter reintroduction, such as increasing the 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 the 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 Indigenous midden remains demonstrates their place in Indigenous culture for thousands of years (Hall et al. 2012). Indigenous 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 also the cultural connection between Indigenous 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 the 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 the overlap of sea otters and important commercial fishing areas (e.g., crabbing grounds), which itself would be determined by the reintroduction's location 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), and tribal agencies to carefully monitor the growth of the sea otter population and recreational and commercial benthic fisheries. They would need to maintain a balance and report survey results effectively to ensure that all stakeholders are engaged and their concerns are addressed.

Quantifying sea otter effects on economically important fisheries can be achieved by 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.[2] Kalaloch is the area where the Washington sea otter population has seen 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 for kelp forests, an important habitat for some finfish species. Also, 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 undertaken by the government. Others may share this perception, and it could potentially be made into a political narrative to oppose reintroduction. It is clear that, in each location, there will be people 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 likewise identified negative consequences and expressed opposition to reintroduction. One of the negative outcomes of sea otter reintroduction that respondents identified 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.

2 See the Washington Department of Fish and Wildlife's information on razor clam management: https://wdfw.wa.gov/sites/default/files/publications/02168/wdfw02168.pdf.

Some Indigenous community members may welcome the return of the sea otter to reestablish the relationship that Indigenous Peoples 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. 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 people will perceive as positive and some as negative. As has been the case in other regions, a reintroduction in Oregon will evoke both positive and negative responses from stakeholders. Therefore, engaging and continuing a constructive dialogue with all affected stakeholders and community groups should be a fundamental component of the decision-making process.

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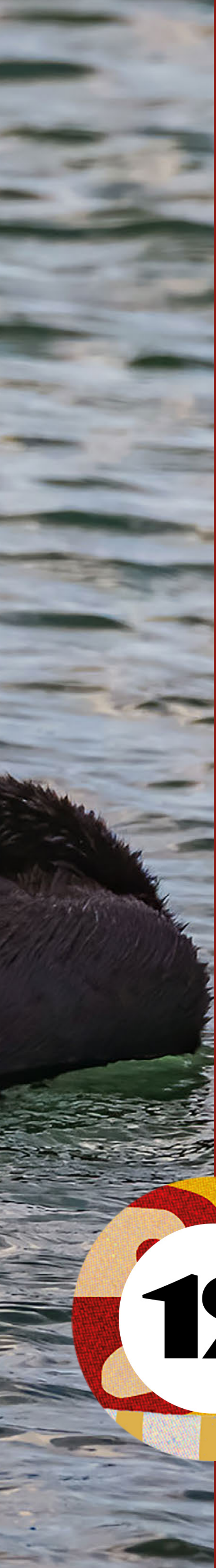

Chapter 12

CONCLUSIONS

M. Tim Tinker

FIVE KEY TAKEAWAYS

The previous 11 chapters provide an extensive review of the available data and scientific literature relevant to the consideration of a managed reintroduction of sea otters to coastal Oregon. There are, of course, a great many questions to address and issues to resolve before any final decision can be made as to whether such a reintroduction should be attempted. As emphasized in the introduction, the purpose of this feasibility study is not to make recommendations for or against any specific course of action, but rather to provide a useful resource document to aid resource managers and the various stakeholders who will be contributing to discussions and decisions about sea otter reintroduction. Each chapter of this feasibility study takes an in-depth look at a particular element or consideration relevant to the broader question of feasibility. Here, we summarize some of the most important takeaway messages that have emerged from this work.

1. Reintroductions are a successful conservation tool.

*The reintroduction of sea otters (*Enhydra lutris*) 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 today's global sea otter abundance 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 unsuccessful, 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 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 for future reintroduction efforts (Chapter 9).

Potentially important future genetic consequences could result from reintroducing 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

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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 the potential recovery of genetic diversity, especially for southern sea otters. Reestablishing sea otters in Oregon could reestablish such a genetic hybrid zone, aiding in the recovery of genetic diversity by restoring the 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 likely to support a successful reintroduction, mostly along Oregon's southern coast. The model also suggests that multiple release locations may be more effective than a single release site. The population model used in this feasibility study can guide alternate reintroduction strategies, including determining the appropriate numbers, demographic structure, sequencing, and location of reintroduced populations.

The most critical resource for a sea otter population's survival is access to sufficient and suitable prey. The sea otter's diet is determined largely by the type of habitats in which it forages, which include rocky reefs (where kelp forests can occur) and unconsolidated substrate, or soft sediments, with the latter further divided into outer coast areas versus protected estuaries. Suitable prey species can occur in all these habitats, though their abundance and productivity can differ. In addition to habitats with adequate prey, sea otters 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. Using estuarine release sites could increase the potential for the successful establishment of a population center, especially when close to a 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 rehabilitated juvenile sea otters into Elkhorn Slough in central California demonstrated the potential for a successful release of sea otters into an estuary. Specifically, it appeared that a small number of juveniles released into an estuarine environment were more likely to remain in place and contribute to an established population than the same number released to the outer coast. Moreover, it was easier to monitor them within an enclosed estuary and recapture them for further rehabilitation and later re-release if necessary. Thus, reintroducing 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), suggesting they could 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. The 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 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 seagrass, overall biodiversity and productivity, and carbon capture and fixation. The 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 direct influences on their macroinvertebrate prey, including some shellfish species of commercial and social consequence. Importantly, sea otters also have significant indirect influences on other species and ecological processes. The most well-known sequence of indirect effects occurs through what we refer to as the *otter-urchin-kelp cascade*. Via this pathway, sea otters limit the abundance of herbivorous sea urchins. In turn, the abundance and persistence of kelps and other macroalgae can flourish because fewer urchins are feeding. More macroalgae subsequently affect numerous other species and ecological processes. Sea otters are characterized as a *keystone species* because of this phenomenon.

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 the first to be documented, in part because sea otter diets have the highest proportion of commercially valuable species during the initial stages of recovery. In contrast, indirect effects of sea otter recovery are more difficult to quantify but often result in changes perceived as positive, such as the otter-herbivore-kelp pathway previously mentioned, enhanced biodiversity overall, increases in some nearshore finfish species, reduced wave energy, the 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. Socioeconomic 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 also be weighed. Outreach and engagement with a broad array of stakeholders and community groups likely to be impacted are essential to ensure that reintroduction decisions address all the relevant socioeconomic factors and have a broad base of support.

Social and Economic Considerations

In Oregon, the invertebrate species fished commercially or recreationally that could be affected by sea otter recovery include the following: 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 fisheries (e.g., urchin dive fisheries), there is good reason to project a substantial negative impact from 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. Conversely, in California, no measurable impacts were 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 those for direct effects, as they involve complex suites of interactions with other species. In cases where indirect effects have been measured, they have often been associated with increases in primary producers (plants), including kelp and seagrass, 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 analyzed a broad array of socioeconomic changes attributable to sea otter recovery on the west coast of Vancouver Island. It found a net positive economic impact (Gregr et al. 2020).

However, monetary considerations are not the only way to measure human values. Communities based around fishing activity provide people with many important nonmonetary values. In the case of Indigenous Peoples, subsistence shellfisheries often provide cultural and economic value. At the same time, the return of sea otters to the ecosystem may have cultural importance. Any assessment of the socioeconomic impacts of sea otter recovery should therefore provide a comprehensive accounting of the relevant communities' social values, including both monetary and nonmonetary variables.

Chapter 11 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 protected by international, federal, state, and tribal laws requires careful consideration, planning, and documentation of legislation, including acquiring multiple permits (see Chapter 8). Internationally, permits are required for trade between countries. In the United States, 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 Southwest 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 (SE) Alaska or Washington, would require the least regulatory oversight, legal documentation, and permitting. However, even for these non-ESA-listed source populations, a reintroduction would require extensive documentation and permits under federal law, as well as careful adherence to state laws and regulations, local ordinances, and 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, many other logistical considerations need to be addressed in any future reintroduction proposals. Selecting a suitable source population is the first of these considerations. As discussed above, this decision involves demographic and genetic questions as well as legal and 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 the recapture, 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); or
6. any of the above methods (or a combination) used at multiple, geographically distinct locations to achieve more than one founding node of population growth, as was the case for the SE 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. the selection of the appropriate sex and age composition of captured animals (to maximize the founding population's reproductive potential as well as the likelihood of animals remaining in their new habitats);
3. animal holding, care, and transport methods;
4. pre-release ecosystem monitoring and 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; and
6. recapture and rehabilitation 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 mostly directed toward the 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 great concern, but one with uncertain potential in Oregon, is shark-bite trauma. Shark bites are a significant cause of mortality for southern sea otters. 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 is present in high numbers in Oregon's 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, in the case of density-dependent diseases, may increase over time as sea otter numbers increase (Tinker et al. 2021). They include contagious diseases such as morbillivirus infections, noncontagious infectious diseases such as sarcocystosis and toxoplasmosis, and bacterial infections and toxicosis associated with nutrient-rich or contaminated freshwater inputs to coastal habitats. Such diseases may significantly impact small populations in localized areas, especially those associated with river mouths or estuaries in watersheds 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, along with 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 in Oregon. During these 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, logistical, 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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Photo by Brent McWhirter, Oregon Coast Aquarium.

Appendices

- » Appendix A. Oregon Sea Otter Population Model (ORSO, Version 1.0), User Interface App
- » Appendix B. Maps of Surficial Geologic Habitats for Coastal Oregon
- » Appendix C. Substrate Maps for Oregon's Marine Reserves
- » Appendix D. Kelp Canopy Extent

Appendix A

OREGON SEA OTTER POPULATION MODEL (ORSO, VERSION 1.0), USER INTERFACE APP

M. Tim Tinker

INTRODUCTION/CONTEXT

The Oregon Sea Otter Population Model (ORSO; Version 1.0[1]) has been developed as a user-friendly interface for community members and managers to explore possible sea otter recovery patterns after a reintroduction. The model can contribute to responsible stewardship of sea otters and other nearshore marine resources. ORSO's overall goal 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 or reintroduction. This information will help in evaluating management options and anticipating ecological and socioeconomic impacts in a spatially and temporally explicit way. However, experience from prior reintroductions has demonstrated 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. Therefore, this model is not intended to predict specific outcomes but rather to explore a range of outcomes that may be most likely given an extensive scope of model inputs and assumptions.

METHODS

Overview

ORSO 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 Southeast (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 tailored to Oregon's habitat configuration.

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

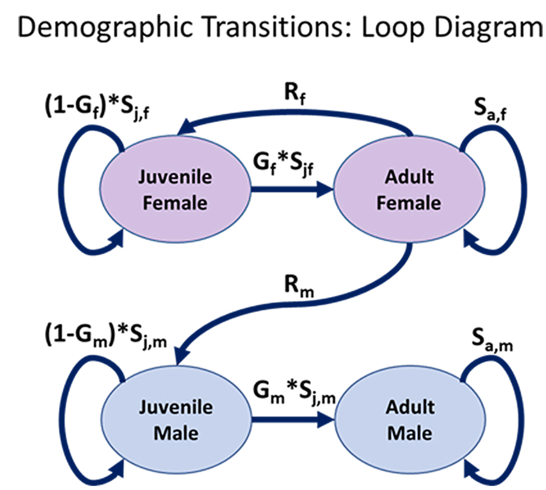
Spatially structured population models have been constructed for other sea otter populations in North America and have proved effective at predicting patterns of population recovery and range expansion in diverse habitats (Udevitz et al. 1996, Monson et al. 2000a, Tinker et al. 2008, USFWS [U.S. Fish and Wildlife Service] 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 projection updates and modifications to monitoring methods; in essence, ORSO aims to be a quantitative tool for conducting adaptive management.

Using data from comparable sea otter populations and geographic areas, primarily California (but augmented by data and models from SE Alaska and Washington), we developed a spatially explicit, simulation-based population model for evaluating a range of realistic scenarios of sea otter reintroduction to 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 a spatial diffusion approach to model range expansion over time.

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 to three years old), (2) adult females (three to 20 years), (3) juvenile males (weaning to three years), and (4) adult males (three to 20 years). Transition probabilities are described by three 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 A.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 A.1. Loop diagram of demographic transitions for sea otters in a population model.



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

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

where b is the birth rate (held constant at 0.98; Tinker et al. 2006) and w is the 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 have suggested that much of the variation in age-specific survival and weaning success is explained by density with respect to carrying capacity (*K*), 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 *K*) 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. Resampling 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 the "Estimating K and Habitat Effects" section), Θ allows for nonlinear effects of density-dependence, and ε represents the effect of environmental stochasticity. Furthermore, ε_t is drawn randomly from a normal distribution with a 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 reintroduction as a new population becomes established. Thus we allow for modified dynamics during this establishment phase, as described below (see the Establishment Phase section).

Spatial Processes

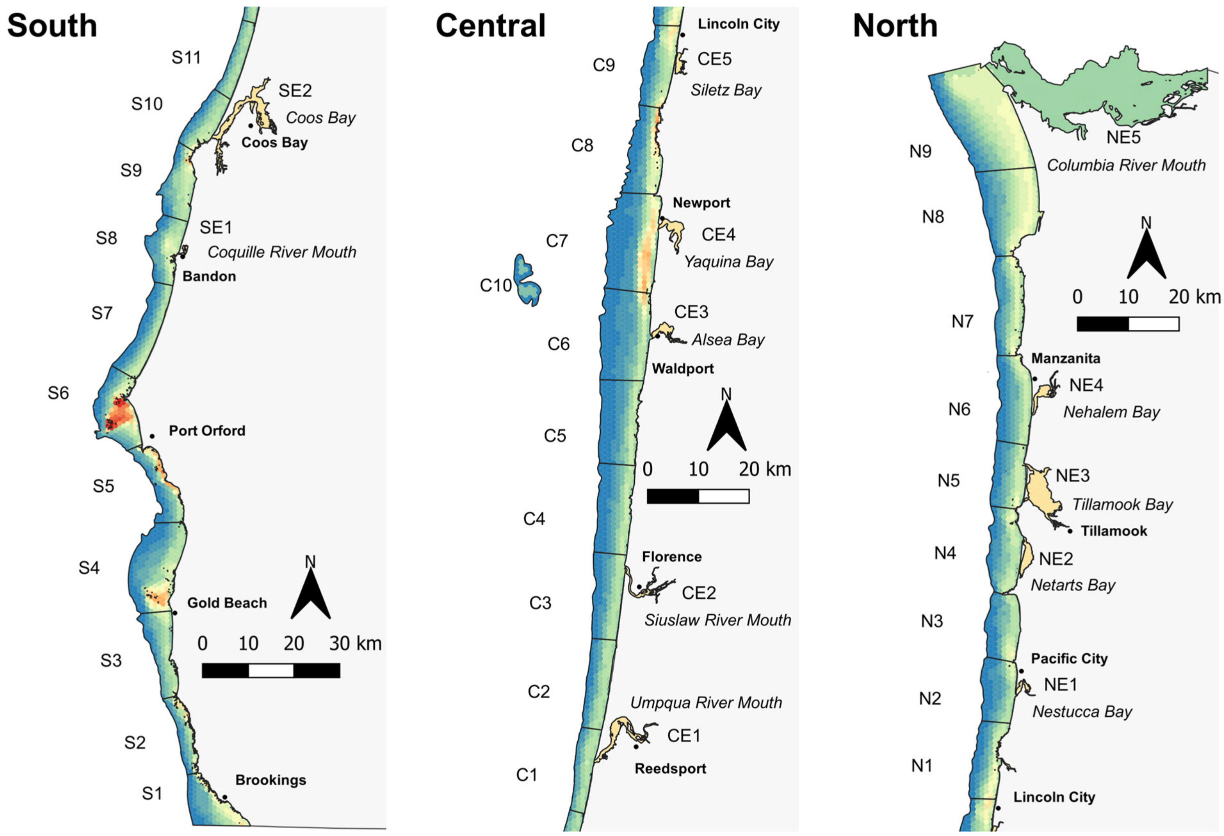
The processes of population dynamics and regulation (as described by Equations 3 and 4) occur at relatively small scales in sea otter populations, resulting in potentially divergent population trends and densities at different locations within a regional population (e.g., Laidre et al. 2001, Bodkin et al. 2002, Tinker et al. 2017). To accommodate this demographic structure, previous modeling efforts have divided regional populations into subpopulations and tracked demographic processes within each subpopulation, as well as the movement of animals between subpopulations (Tinker 2015). The use of spatially structured models facilitates the incorporation of range expansion, as new subsections 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 and parameter estimation, 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 subsections such that demographic processes vary between subsections 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 A.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 subpopulations is embedded within a range-wide meta-population that allows for the dispersal of animals between occupied sections. Range expansion of the meta-population along the coast is incorporated into the model by allowing unoccupied sections to be "colonized" by animals from neighboring occupied sections, with the rate of new sections' colonization constrained to maintain a prespecified rate of the population front's advancement along the coast (henceforth v, the asymptotic frontal wave speed, measured in km/year; Figure A.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).

The 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 did 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 the *net annual linear displacement* (NLD; 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.[2] 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 the "R" software application). 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.

2 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 overland. 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 the "R" software application), 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 overland, we ensure that the Least Coast Path distance is the shortest distance through water only.

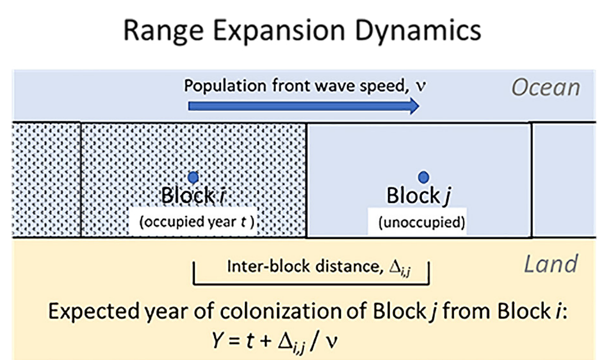
Figure A.2. Results of a habitat-based model of sea otter *K* to the Oregon coast (Kone et al. 2021).



Note. This figure is the same as Figure 3.4 in Chapter 3. It illustrates the spatial configuration of coastal habitat in Oregon used for population modeling. Coastal habitat sections (labeled polygons) show the basic geographic unit for modeling demographic processes, while the colored spatial grids within these polygons show the relative expected density at *K* based on a previously developed model of habitat-density relationships (Kone et al. 2021, Tinker et al. 2021).

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, $j \neq i$), rescaled 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 (see the upcoming Establishment Phase section).

Figure A.3. Schematic drawing illustrating how the model incorporates range expansion of a sea otter population from occupied habitat into unoccupied habitat.



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 square kilometer of *benthic habitat* (defined as a benthic substrate between the low tide line and the 40-m depth contour) to over 20 sea otters per square kilometer.

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 were 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 believe California habitat-density relationships provide the best starting point for predicting these relationships in Oregon. Therefore, a recently developed model predicting local K as a function of biotic and abiotic habitat variables (Tinker et al. 2021) has been applied to the equivalent spatial layers of habitat variables in Oregon to project potential K at fine scales throughout the state (Kone et al. 2021).

We use this projected K data layer to parameterize ORSO, interpolating projected equilibrium densities from Kone et al. (2021) at each cell h of a hexagonal grid laid over the study area (Figure A.2). The absolute number of otters expected within the grid cell h at K 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). Dividing by A_i (the total area of habitat in section i) gives the mean expected density at K for coastal section i:

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

Establishment Phase

Previous sea otter translocations and reintroductions 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 this population *establishment phase*, there is limited population growth and often a significant decline in abundance, associated with elevated mortality and the 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 of having occurred for some animals in the Oregon translocation, believed to have moved north to join the Washington or British Columbia populations). Notably, 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 five to 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 (S) 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 a mean of M and coefficient of variance 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) 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 reintroduction, we assume that a substantial number will disperse a significant distance away from the reintroduction 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 dispersals 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 (subadults) 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

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

where $R_{Ad,i}$ is the ratio of adults to subadults 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 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 A.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.

An ORSO user may adjust all the above-described parameters to explore assumptions about the establishment phase and its implications for the success of a proposed reintroduction. We note that setting parameters to values close to their defaults ($E = 10$, $M = 0.15$, $\varphi = 0.9$, $\omega = 0.5$, $\psi = 0.5$, $\Omega = 0.7$) will produce dynamics that match, on average, the observed population dynamics at San Nicolas Island during the three decades after that translocation (see Table 2.1 in Chapter 2 for details).

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 reintroduction scenarios and under varying sets of assumptions about population dynamics, as reflected by different combinations of user-specified parameters. See Table A.1 for a 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 reintroducing sea otters and specify the numbers of animals ($N_{0,i}$) to be introduced to each section, both during the initial translocation year 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. Adjust the expected values of other parameters to investigate their effects. Parameters that can be adjusted include the maximum population growth rate (r_{max}), the environmental stochasticity in growth rates (σ), the functional shape of density-dependence (Θ), the asymptotic wave speed for population range expansion (v), the number of years required for the population to become established (E), the excess annual mortality rate during the 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 (which ORSO calls "*reps*"), each one describing "*Nyrs*" years of population dynamics. Both *reps* and *Nyrs* are user-adjustable; the default is 100 *reps* of 25 years.
4. Step through the processes of population dynamics for $t = 1, 2, \ldots$ *Nyrs*. For each year of each simulation, the model conducts the following steps:
    a. During the establishment phase ($t \leq E$), calculate the proportion of animals that disperse away from the release site (accounting for age and estuary effects), stochastically choose 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 the establishment phase is 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 v, as illustrated in Figure A.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 them to parameterize projection matrix $\mathbf{P}_{i,t}$ following Equation 3. If the establishment phase is ongoing ($t \leq E$), 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 a mean of 0 and covariance 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 the establishment phase is complete ($t > E$), draw randomly from a 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 a 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 the 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. Downscale 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, as well as the associated data files needed to parameterize it, are available upon request (email ttinker@nhydra.com).

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 A.1.

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 reintroduction event. The outcome after 25 years (in terms of the magnitude of growth and extent/pattern of range spread) depends upon the reintroduction scenario and the various assumptions implicit in the user-specified parameters (Table A.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 A.2).

Table A.1. Default values for user-specified parameters.

User parameter	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 reintroduction
$N_{0,i}$	50	Number of otters introduced to each specified coastal section
O_i	3	Number of 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 the 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 the 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 (i.e., die or move out of study area)
v	2	Asymptotic wave speed of range expansion, km/yr, minimum
rr_{max}	0.18	Maximum instantaneous rate of growth: default r_{max} = 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 the theta-logistic model; for the standard Ricker model, theta = 1; for delayed onset of D-D effects, use theta > 1

Note. NA = not applicable.

Running model simulations with "typical" values for user-specified parameters (Table A.1) revealed that an initial translocation of 50 otters to Coastal Section S6 (assuming 60% female and 25% adult), with supplemental additions of three juveniles per year for five years, could grow to a population of approximately 78 sea otters after 25 years (Figures A.4 and A.5), although there is considerable uncertainty around this value (between 17 and 190 otters within a confidence interval [CI] of 95%). Range expansion over this period is projected to be limited to the southern portion of the Oregon coast (Coastal Sections S1–S11; Figures A.5 and A.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 (v = 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 A.4. Map of coastal Oregon showing projected sea otter abundance and distribution after 25 years.

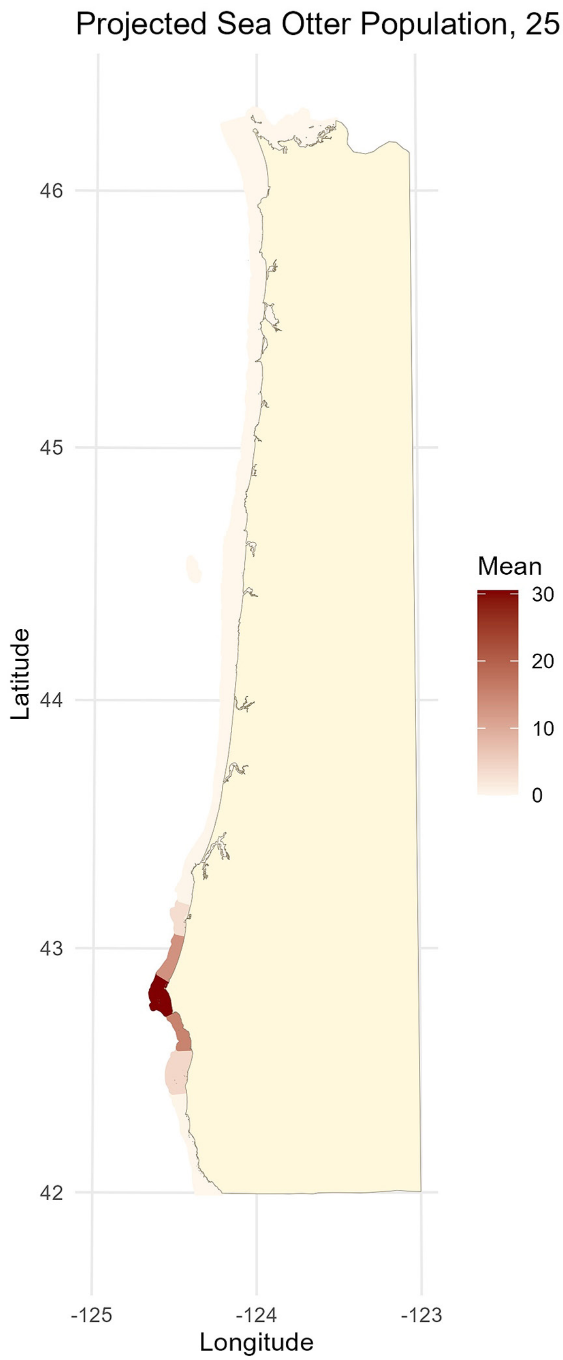
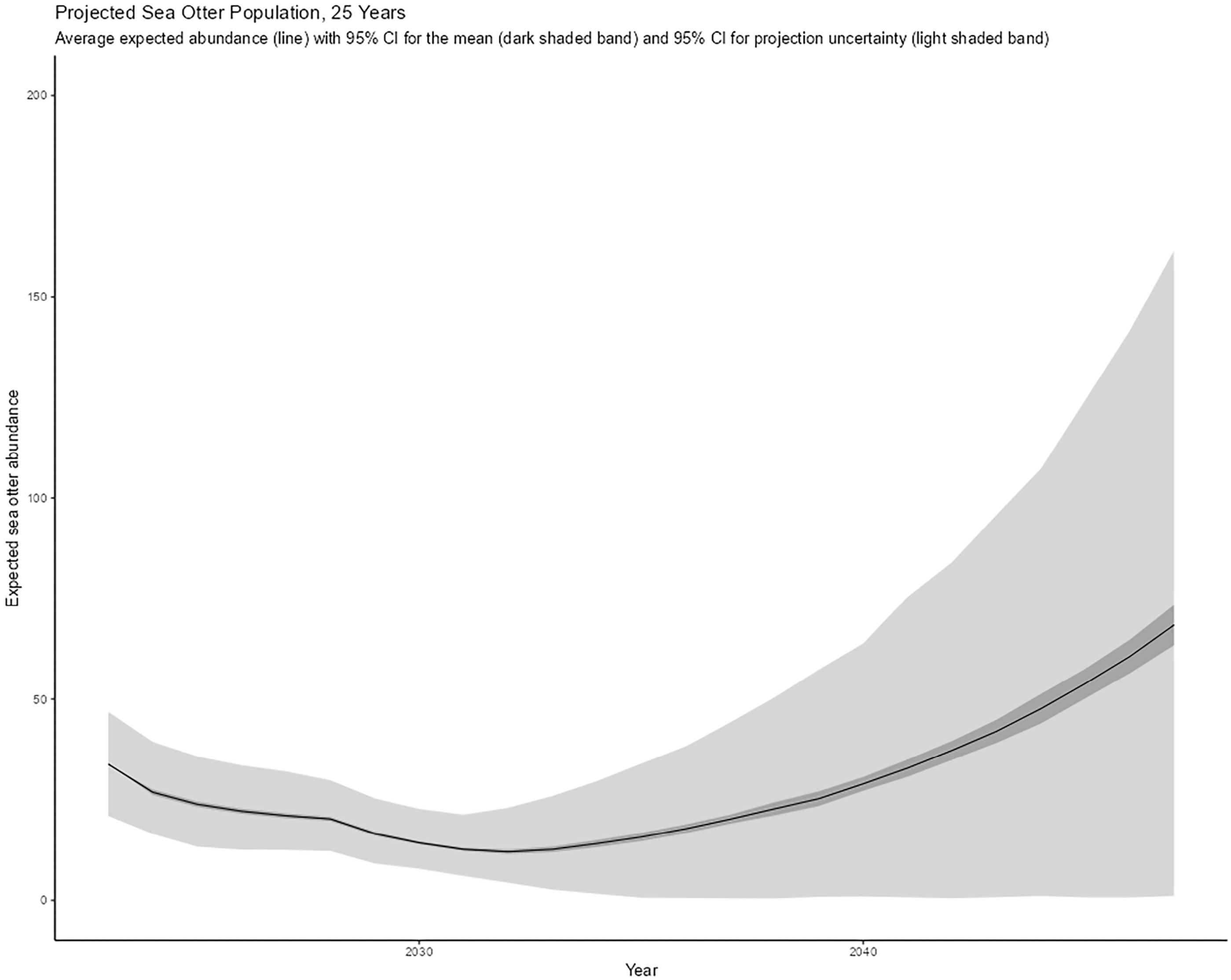


Figure A.5. Results from model simulations of sea otter population dynamics over 25 years in coastal Oregon, showing projected population trends.



Note. The light gray band shows the 95% CI for simulations; the dark gray band shows the 95% CI for the mean.

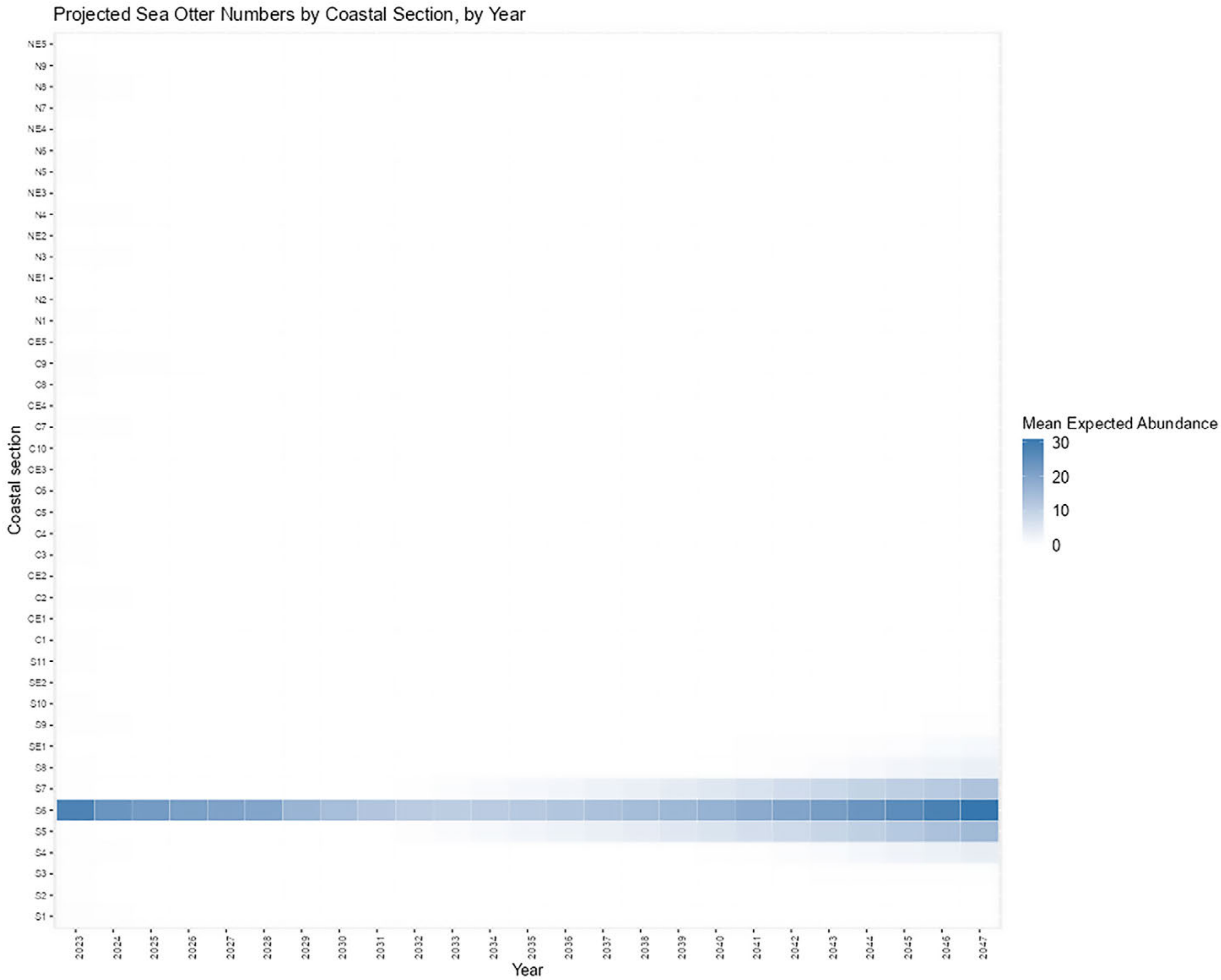
COMPONENTS OF THE ORSO APP

Overview

The web-based ORSO app is organized into several panels, which the user can navigate by clicking any of the three selection tabs embedded in the title bar at the top of the screen, as shown in Figure A.7 as 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 accessed 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 (Figure A.7d), where the user can adjust various parameters and run the simulations, and an information panel at right (Figure A.7e), 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

Figure A.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.



Note. Refer to Figure A.2 for the locations and boundaries of each coastal section.

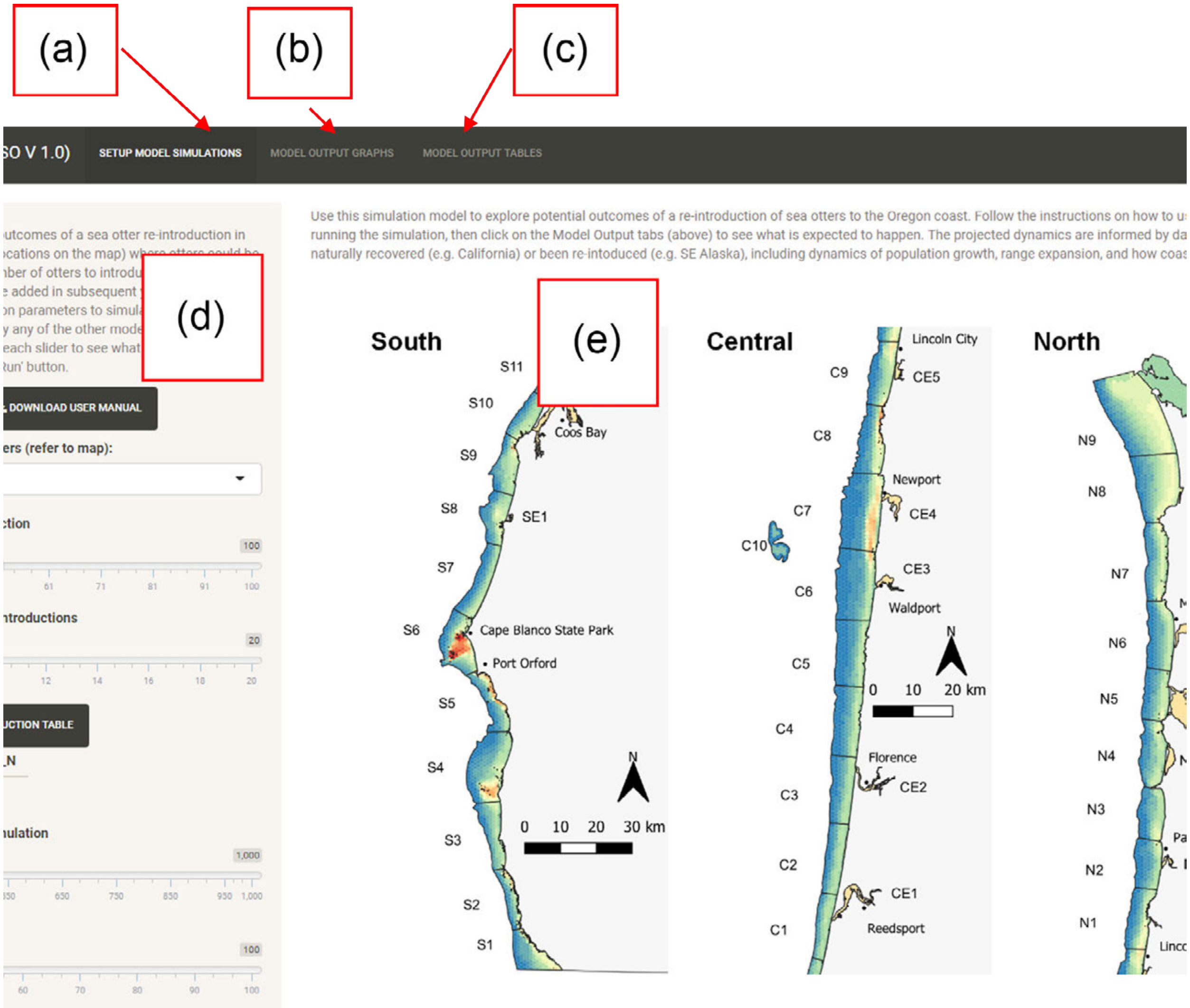
tracking sea otter abundance and distribution over time: The map allows the user to see the location of specific sections, as needed, to initiate simulations and interpret model results.

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** (Figure A.8).

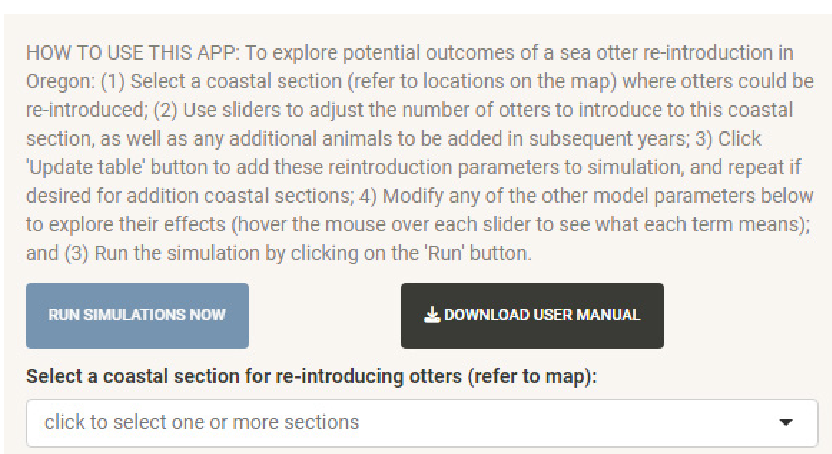
The **Download User Manual** button at right allows the user to download the same manual presented here, in Appendix A, at any time. The **Run Simulations Now** button at left is ORSO's primary action button, used to run a set of simulations. However, this button should only be clicked **AFTER** having first selected one or more coastal sections under consideration for a sea otter reintroduction and setting the user-adjustable parameters in the sidebar panel that describe the reintroduction details and control the underlying assumptions about the nature of population growth and range expansion. A description of each user-adjustable parameter will appear when the user moves the cursor over

Figure A.7. Three tabs in ORSO's title bar to select viewing panels.



Note. (a) The **Setup Model Simulations** selection tab in ORSO's title bar. (b) The **Model Output GRAPHS** selection tab. (c) The **Model Output TABLES** selection tab. (d) The sidebar panel in **Setup Model Simulations**, which allows a user to adjust parameters and run simulations. (e) The information panel in **Setup Model Simulations** with a map of Oregon divided into 42 numbered coastal sections.

Figure A.8. Buttons in the left sidebar panel of **Setup Model Simulations**.

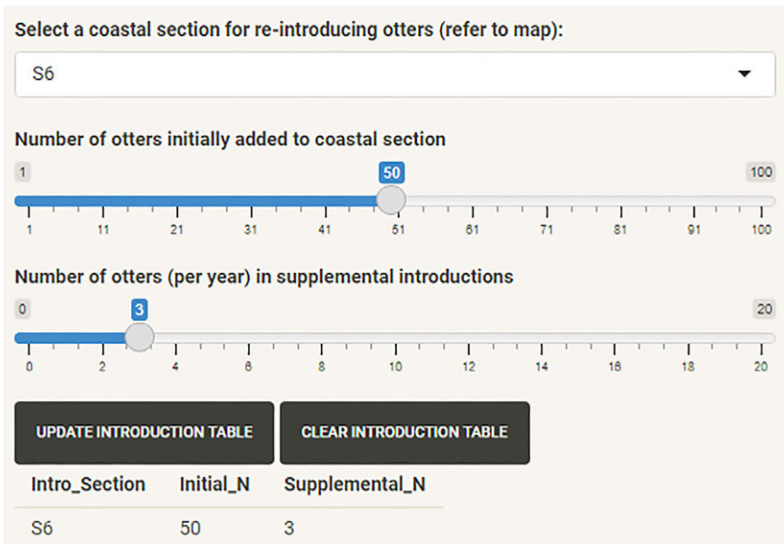


the parameter's name, and default values for each parameter are set based on data from other sea otter populations. These user-parameter adjustment controls are illustrated and explained below:

Select Coastal Sections for Reintroduction and Numbers of Otters to Be Added

Clicking on the selection box labeled **Select a coastal section for re-introducing otters** (Figure A.9) 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.

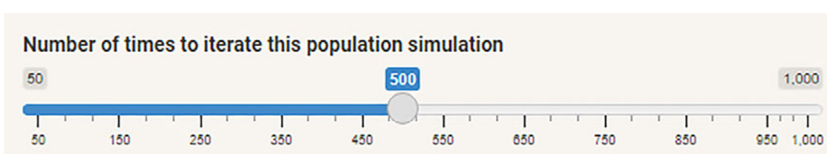
Figure A.9. ORSO controls to select coastal sections and numbers of otters for a reintroduction



Adjust Number of Iterations

This slider control (Figure A.10) 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.

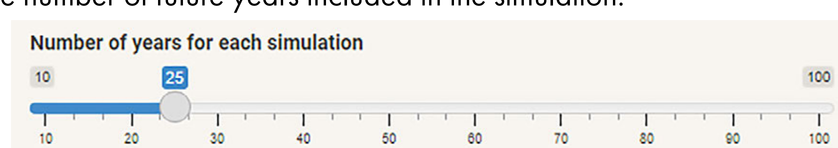
Figure A.10. Change the number of simulation iterations.



Adjust Number of Years

This slider control (Figure A.11) 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.

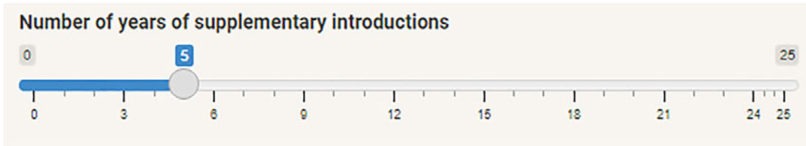
Figure A.11. Change the number of future years included in the simulation.



Adjust Number of Years That Supplemental Introductions Occur

This slider control (Figure A.12) 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 the success of the reintroduction by stabilizing the population during the establishment phase. These additional otters could be wild otters or juvenile rehabilitated otters from captivity.

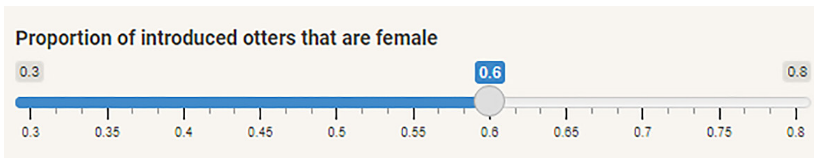
Figure A.12. Change the years between the initial translocation and supplemental reintroduction(s).



Adjust Sex Ratio of Reintroduced Otters

This slider control (Figure A.13) 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.

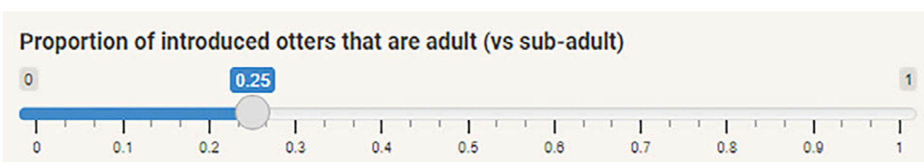
Figure A.13. Specify how many introduced otters are female.



Adjust Age Composition of Reintroduced Otters

This slider control (Figure A.14) allows the user to specify the proportion of introduced otters that are adult (vs. subadult or juvenile). Only adult sea otters produce pups, so introducing adults can hasten reproduction. However, in past translocations, it has been found that subadults may be more likely to successfully "take to" their new habitat, so a higher ratio of subadults may improve success.

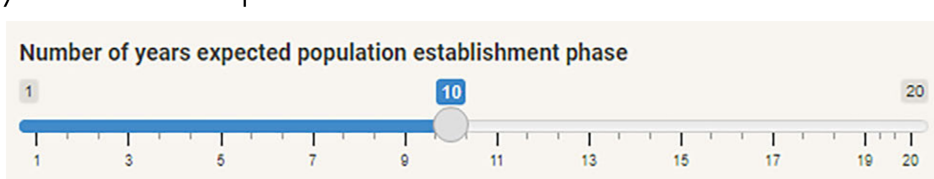
Figure A.14. Specify how many introduced otters are adults.



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 five to 15 years in previous reintroductions and natural return events. This slider control (Figure A.15) 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.

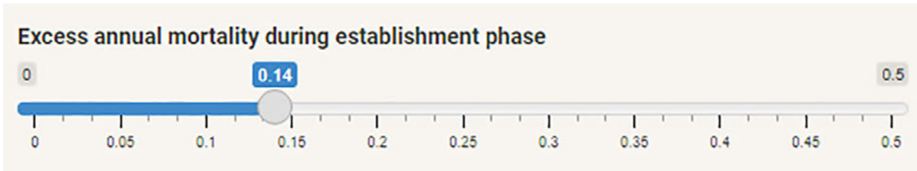
Figure A.15. Specify the establishment phase's duration.



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 10%–25% (expressed as 0.1–0.25 in the ORSO interface slider) have caused translocated populations to decline substantially during the establishment phase. This slider control (Figure A.16) allows the user to set the establishment phase's anticipated excess mortality rate.

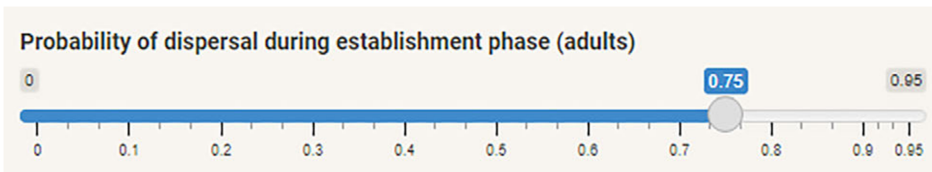
Figure A.16. Specify the establishment phase's anticipated mortality rate.



Adjust Probability of Dispersal During Establishment Phase for 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 destinations of post-release dispersal are impossible to predict, but the user can set the mean expected proportion of otters to disperse (Figure A.17).

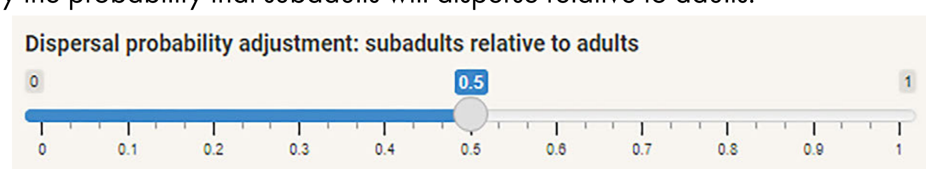
Figure A.17. Specify the number of otters (adults) expected to disperse during the establishment phase.



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 (Figure A.18) adjusts the likelihood of dispersal for subadults compared to adults: A value of 0.25 would mean that subadults are one-quarter as likely to disperse as adults.

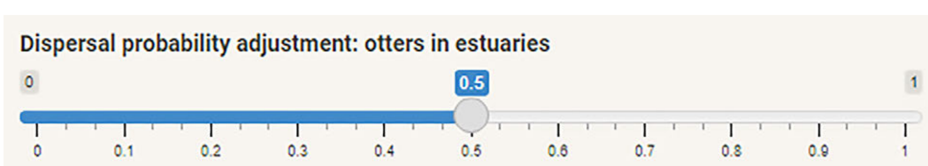
Figure A.18. Specify the probability that subadults will disperse relative to adults.



Adjust Probability of Dispersal During Establishment Phase for Otters in Estuaries

Based on several lines of evidence, it has been suggested that otters reintroduced 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 (Figure A.19) adjusts the likelihood of dispersal for estuaries compared to open coast: A value of 0.25 means otters in estuaries are one-quarter as likely to disperse post-introduction.

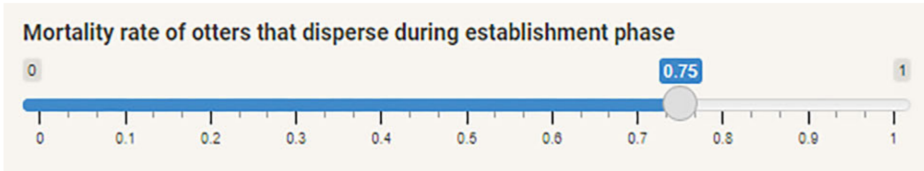
Figure A.19. Specify the probability that otters reintroduced to estuaries will disperse relative to those in outer coast habitats.



Adjust Mortality Rate for Otters That Disperse During Establishment Phase

The fates of otters that disperse away from a reintroduction site are 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 (Figure A.20) sets the expected loss rate for the dispersers: that is, the proportion of the dispersing group that dies (or moves entirely out of the study area and is effectively lost to the Oregon meta-population).

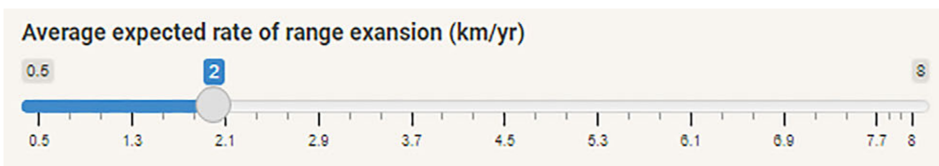
Figure A.20. Specify the mortality rate for otters that disperse during establishment.



Adjust Rate of Range Expansion

This slider control (Figure A.21) allows the user to adjust the expected rate at which the growing population spreads into new habitat. The 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, its distribution (range of occupancy) will spread outwards along the coastline, encompassing more area. The *rate of range expansion* is measured as the speed at which the frontal edge of the population moves along the coastline (see Figure A.3, several pages earlier in this appendix). In other populations, this range expansion speed has varied from 1 to 5 km/year.

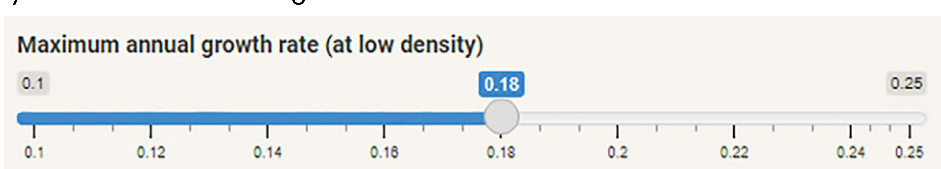
Figure A.21. Specify the rate of range expansion.



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 *K*. This slider control (Figure A.22) 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.

Figure A.22. Specify the maximum rate of growth.



Adjust Environmental Stochasticity

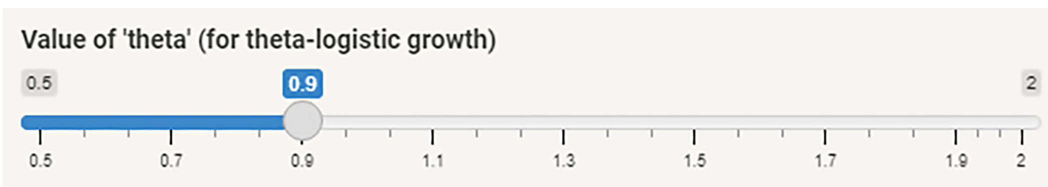
The average rate of growth for a reestablishing sea otter population in a given area can be predicted as a function of the local density with respect to *K*. However, year-to-year variation in environmental conditions and prey population dynamics can lead to unpredictable deviations in the growth rate, referred to as *environmental stochasticity*. This slider control (Figure A.23) can be used to adjust the degree of annual variation in growth rates: Typical values are 0.05–0.15.

Figure A.23. Specify the maximum rate of growth.

Adjust the Theta Parameter for Theta-Logistic Growth

The average rate of growth for a reestablishing a sea otter population in a given area can be predicted as a function of the local density with respect to *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 less than 1 lead to the onset of reduced growth rates at fairly low densities, while theta values greater than 1 mean that significant reductions in growth occur only at higher densities. This slider control (Figure A.24) 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.

Figure A.24. Define the nature of the onset of a reduced growth rate (i.e., theta).



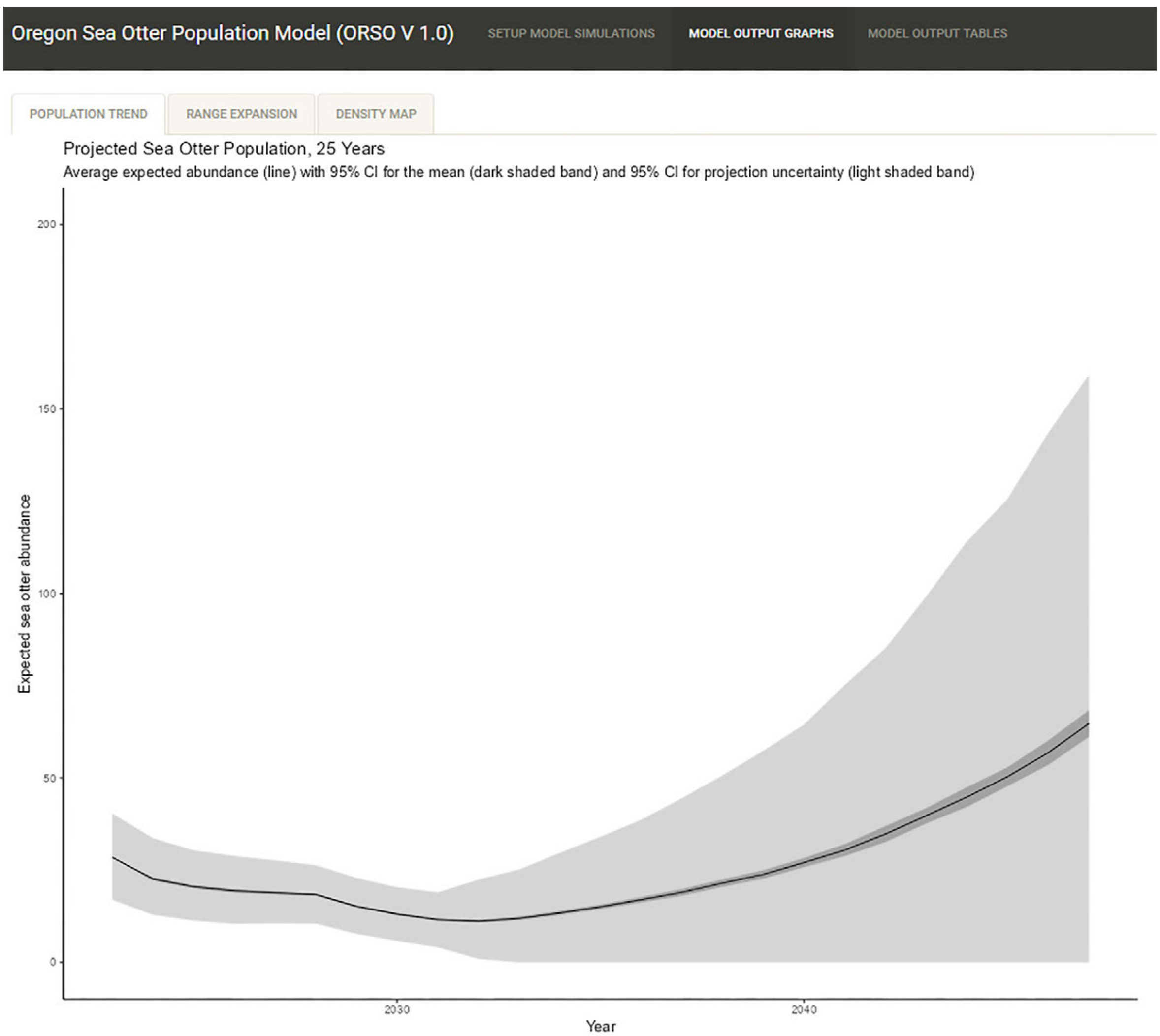
Model Output GRAPHS Panel

After setting up and running simulations, the user can navigate to the **Model Output GRAPHS** panel to view graphical results from model simulations. Three separate graphs can be viewed, and the user can move between them 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 (THE EXAMPLE SHOWN IN FIGURE A.25 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 gray band shows the 95% CI for the mean trend (i.e., uncertainty about the true average), and the light gray band shows the 95% CI for the full distribution of results (i.e., uncertainty about the range of possible outcomes).

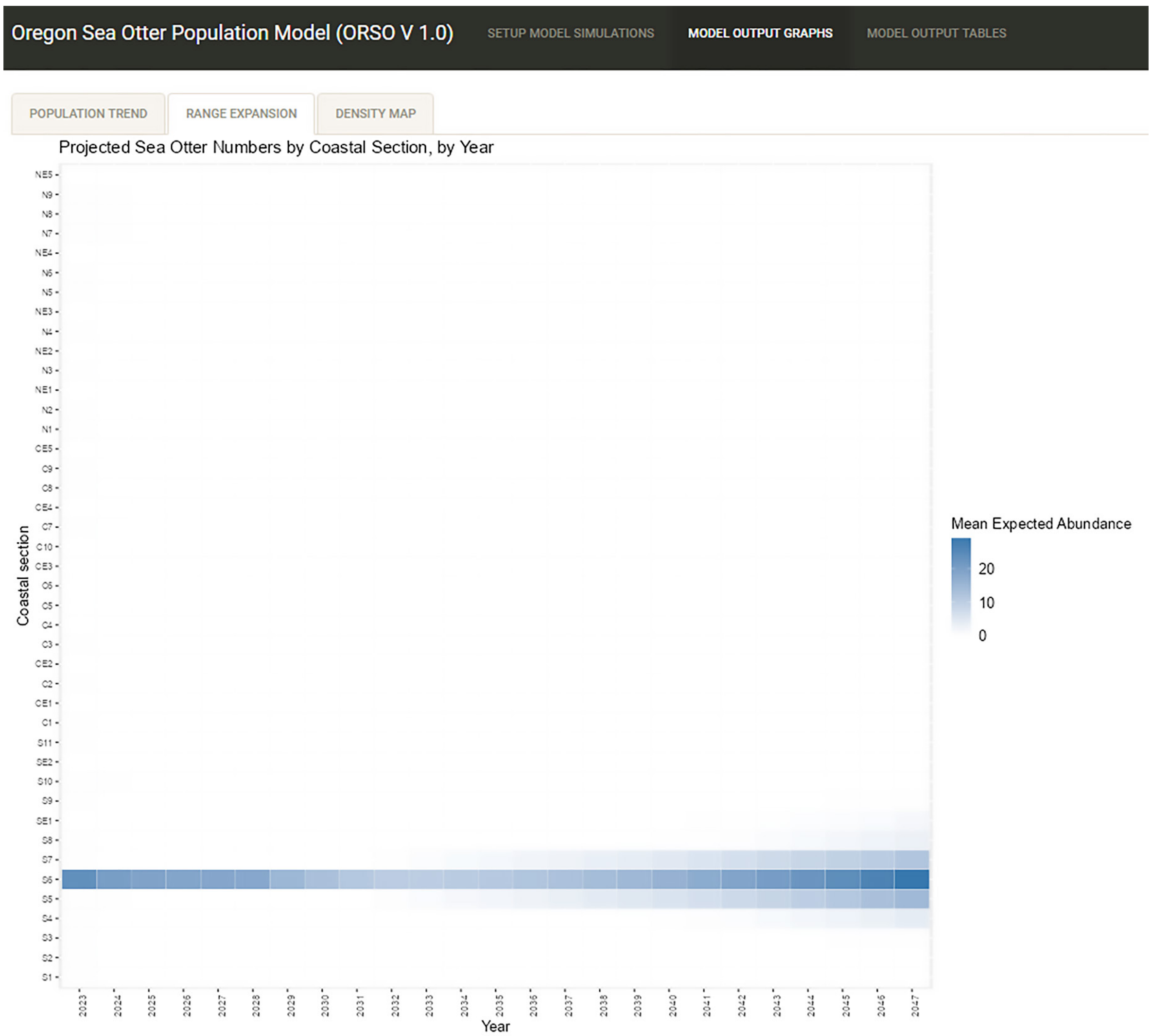
Figure A.25. An example of a population trend graph generated from ORSO simulations.



Range Expansion Graph

This heatmap graph shows the average projected abundance and spatial distribution of sea otters over time (THE EXAMPLE SHOWN IN FIGURE A.26 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 indicates 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. On 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.

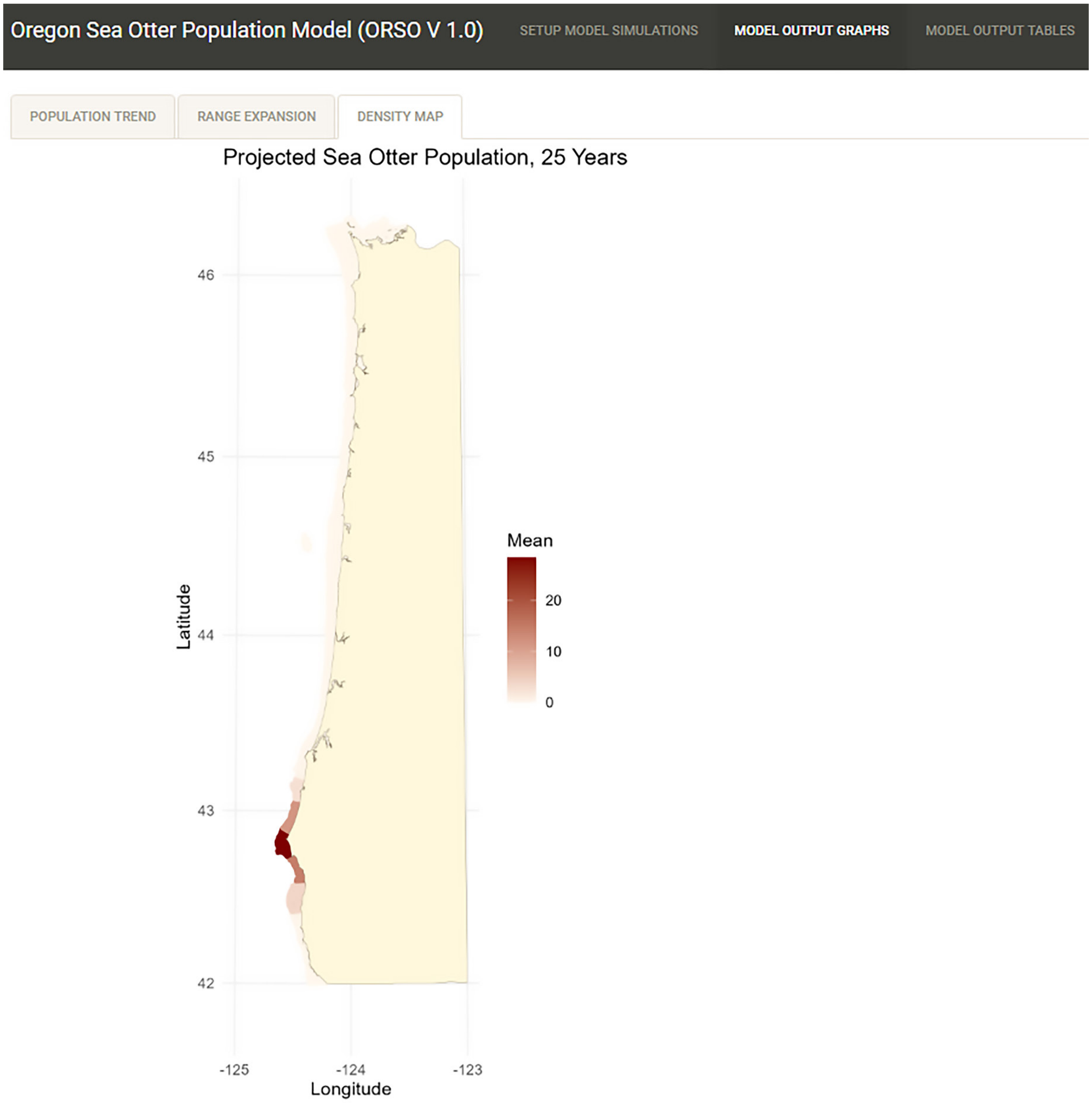
Figure A.26. An example of a range expansion heatmap graph generated from ORSO simulations.



Density Map

This map of coastal Oregon shows the average projected abundance and distribution of sea otters at the end of the simulation period (THE EXAMPLE SHOWN IN FIGURE A.27 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.

Figure A.27. An example of a range expansion heatmap graph generated from ORSO simulations.



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 the **Model Output TABLES** panel, where two standardized tables can be viewed and/or downloaded as *.csv files: one for abundance by year (Table A.2) and the other for abundance by coastal section in the final year (Table A.3).

Table A.2 summarizes the total projected abundance across all of coastal Oregon for each year of the simulation and includes six metrics: (1) average projected abundance, (2) lower bound of the 95% CI for the distribution of projected abundance estimates, (3) upper bound of the 95% CI for the distribution of projected abundance estimates, (4) estimation uncertainty expressed by the standard error (SE) of the mean projected abundance (ORSO uses the abbreviation SE to mean "standard error" though it means "southeast" in the rest of this study), (5) lower bound of the 95% CI for the average expected abundance, and (6) upper bound of the 95% CI for the average expected abundance.

Table A.2. Projected sea otter abundance by 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

Note. In this table only, SE = standard error. CI = confidence interval.

Table A.3 summarizes the projected abundance and density in each coastal section in the simulation's final year. Columns include the (1) area of benthic habitat in each section (km2), (2) average projected number of sea otters, (3) lower bound of the 95% CI for the distribution of projected abundance estimates, (4) upper bound of the 95% CI for the distribution of projected abundance estimates, (5) average density (number of sea otters/km^2), (6) lower bound of the 95% CI for the distribution of projected density estimates, and (7) upper bound of the 95% CI for the distribution of projected density estimates.

Table A.3. Projected sea otter abundance by coastal section in the 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 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

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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MAPS OF SURFICIAL GEOLOGIC HABITATS FOR COASTAL OREGON

Figure B.1. Surficial geologic habitat map near Seaside, Oregon (OSU [Oregon State University] 2011).

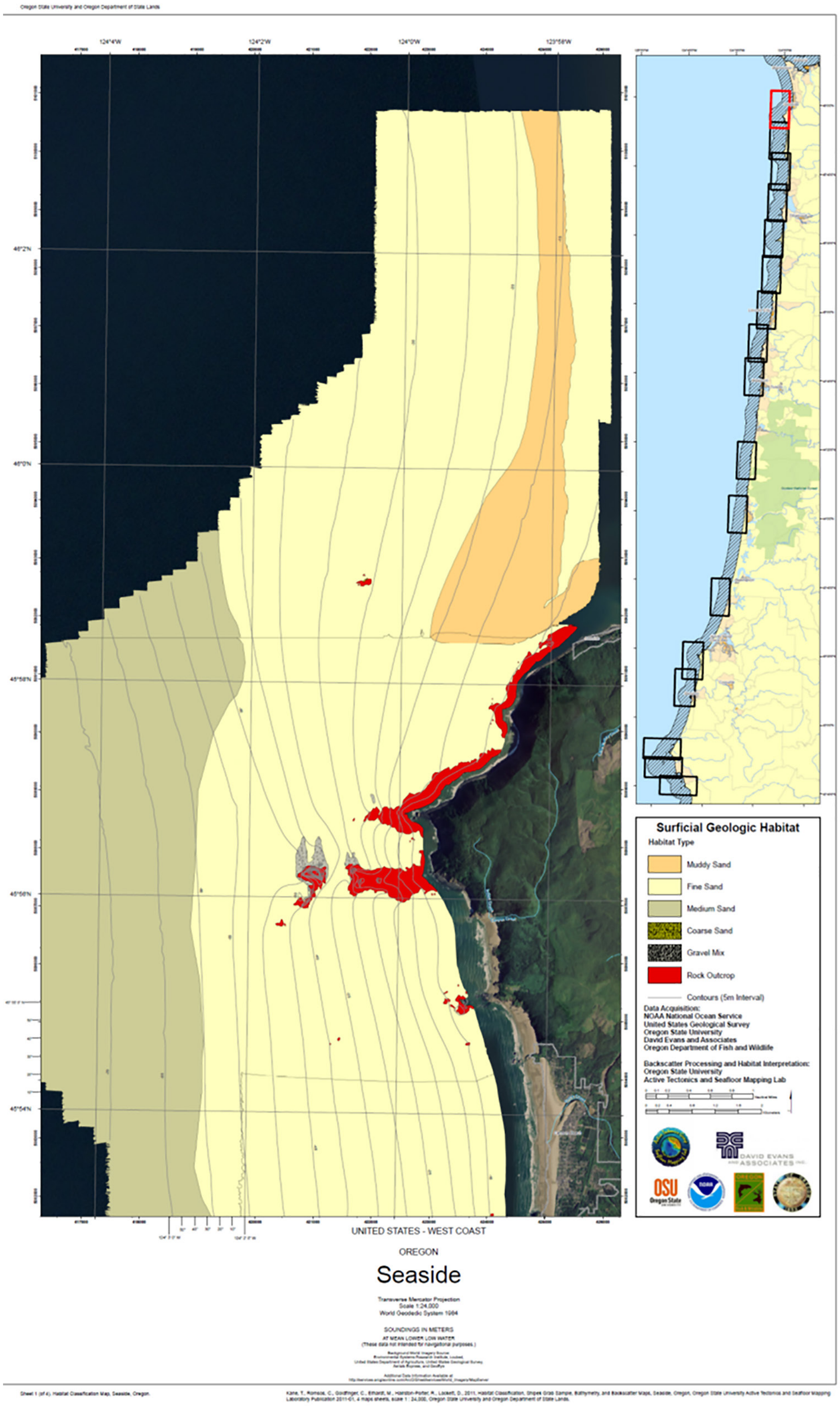


Figure B.2. Surficial geologic habitat near Hug Point, Oregon (OSU 2011).

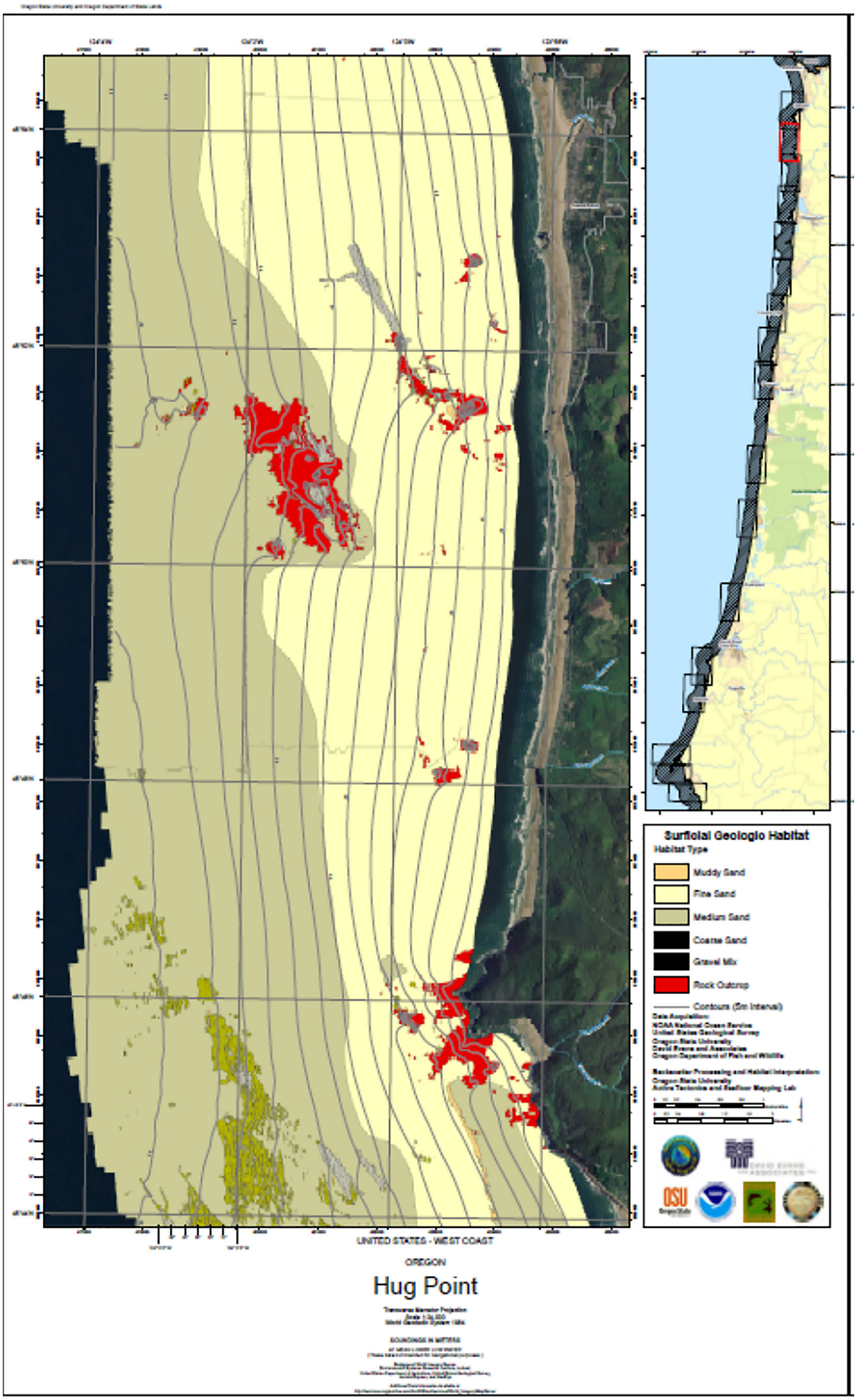


Figure B.3. Surficial geologic habitat near Nehalem, Oregon (OSU 2011).

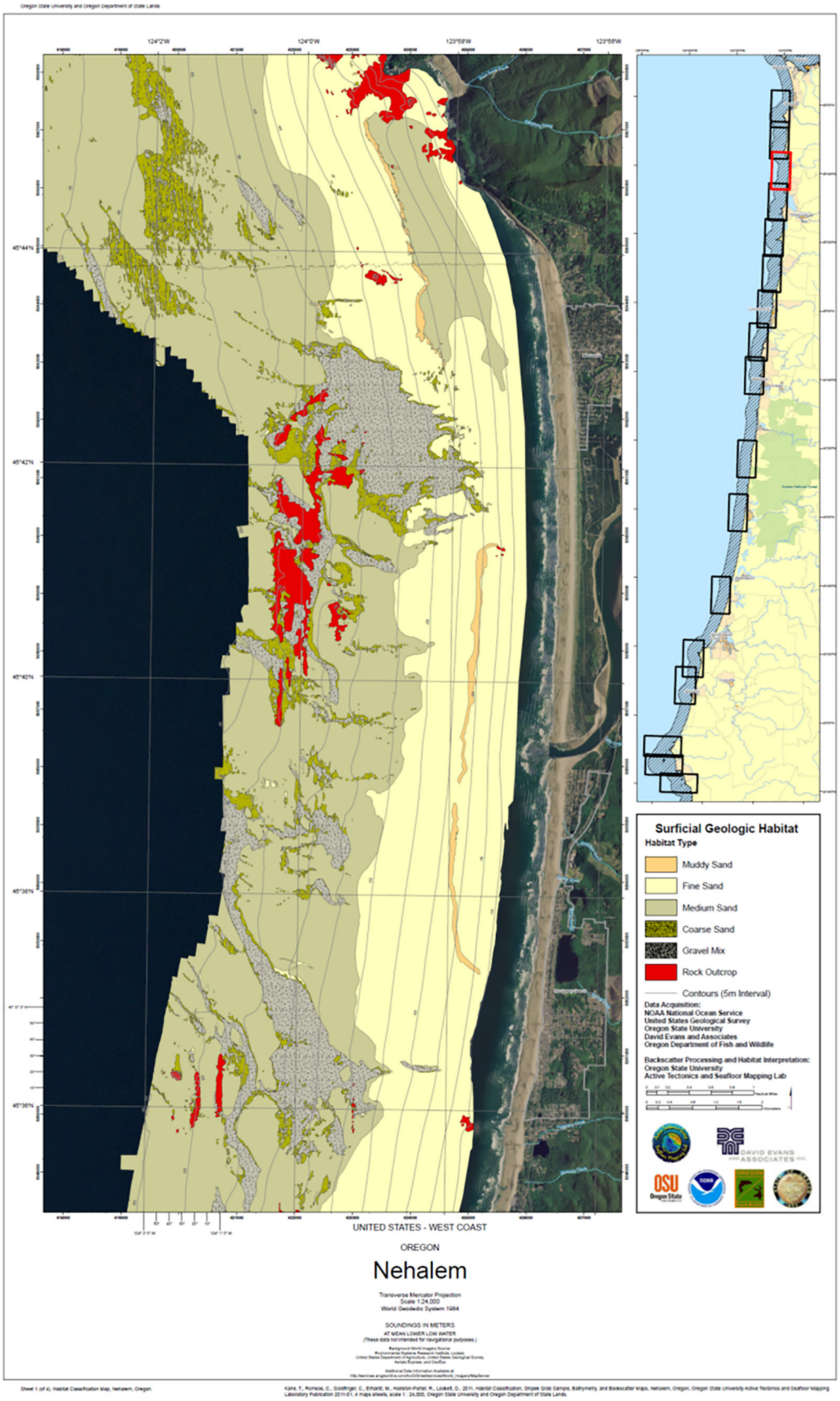


Figure B.4. Surficial geologic habitat near Cape Mears, Oregon (OSU 2011).

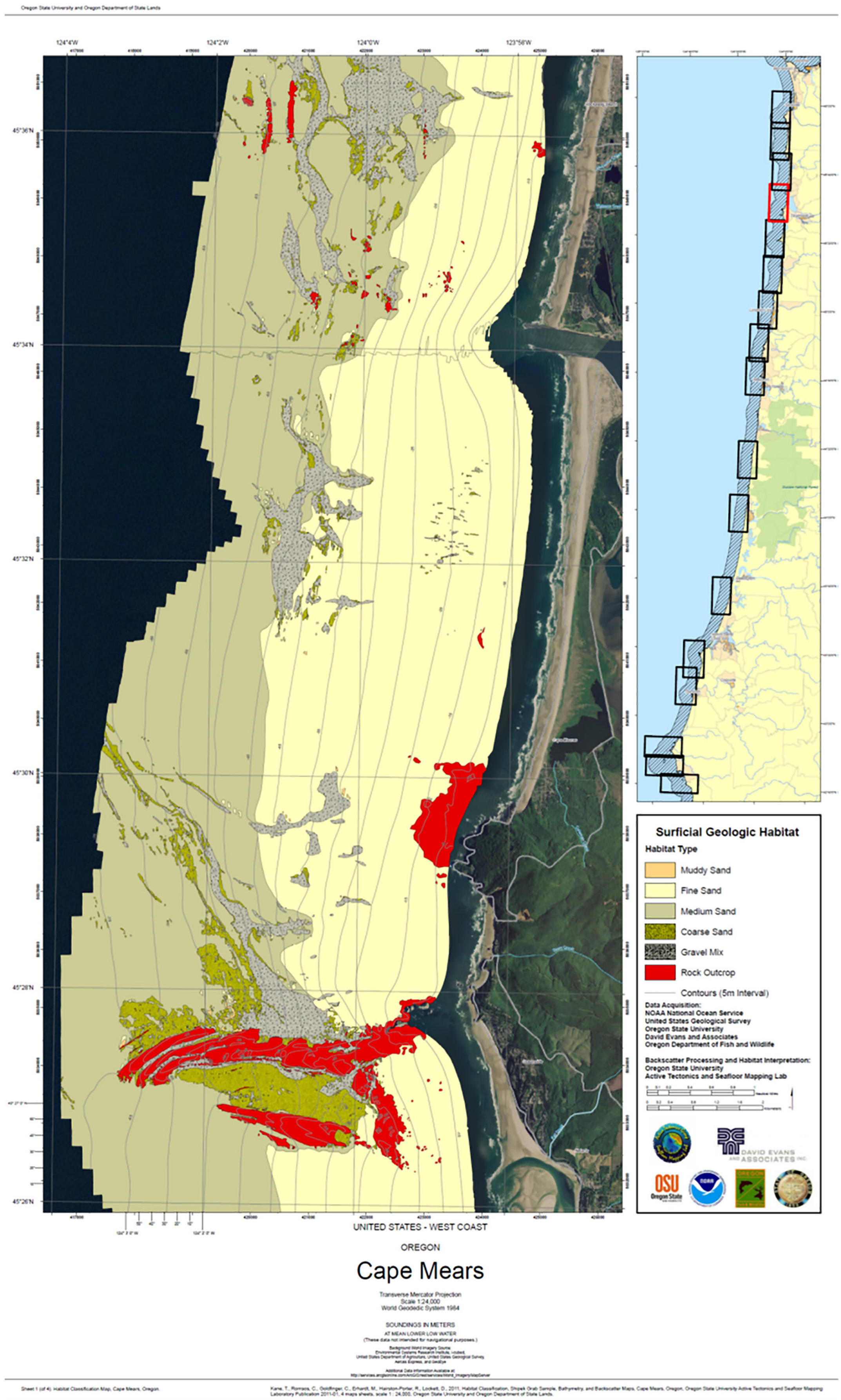


Figure B.5. Surficial geologic habitat near Cape Lookout, Oregon (OSU 2011).

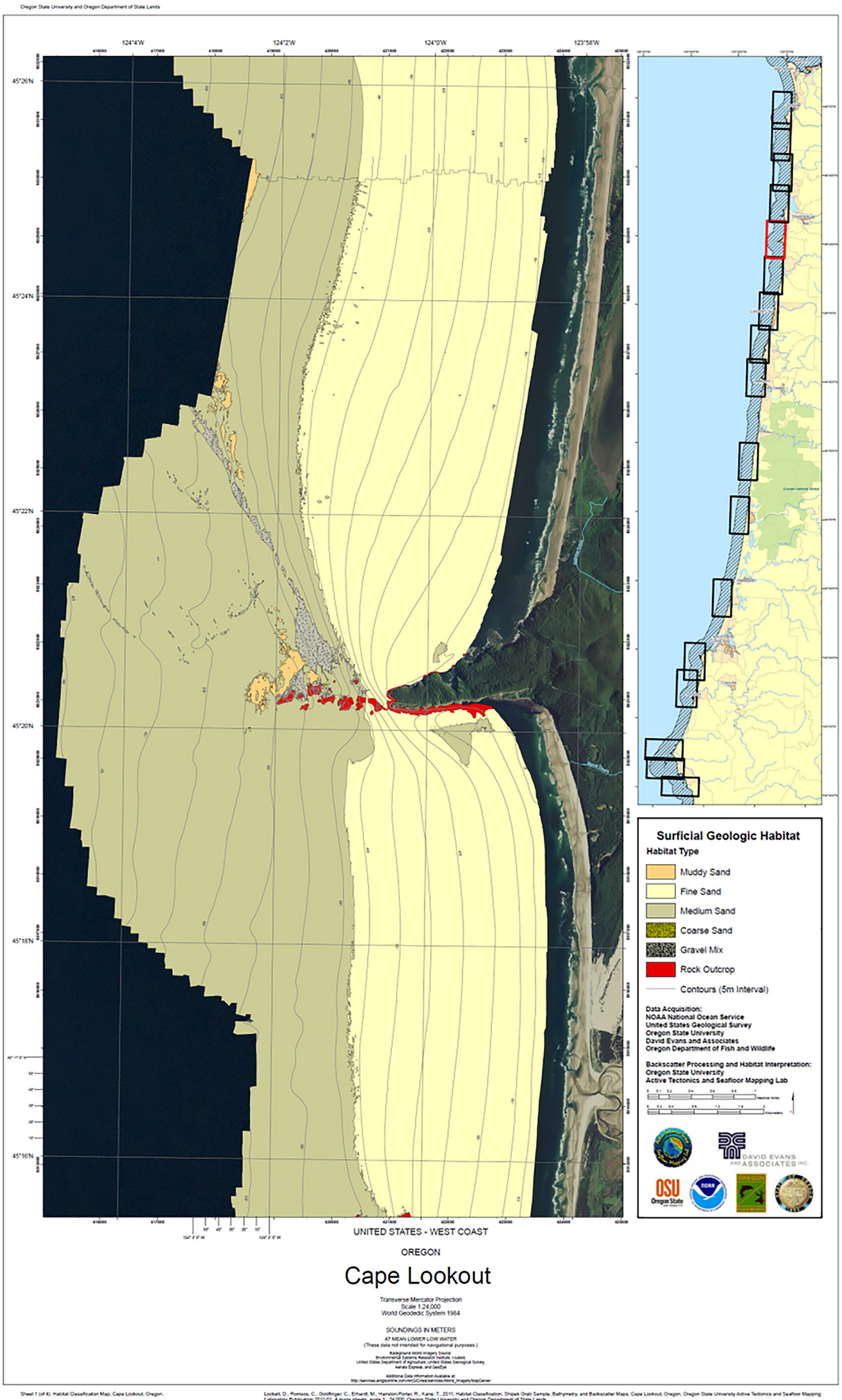


Figure B.6. Surficial geologic habitat near Cape Kiwanda, Oregon (OSU 2011).

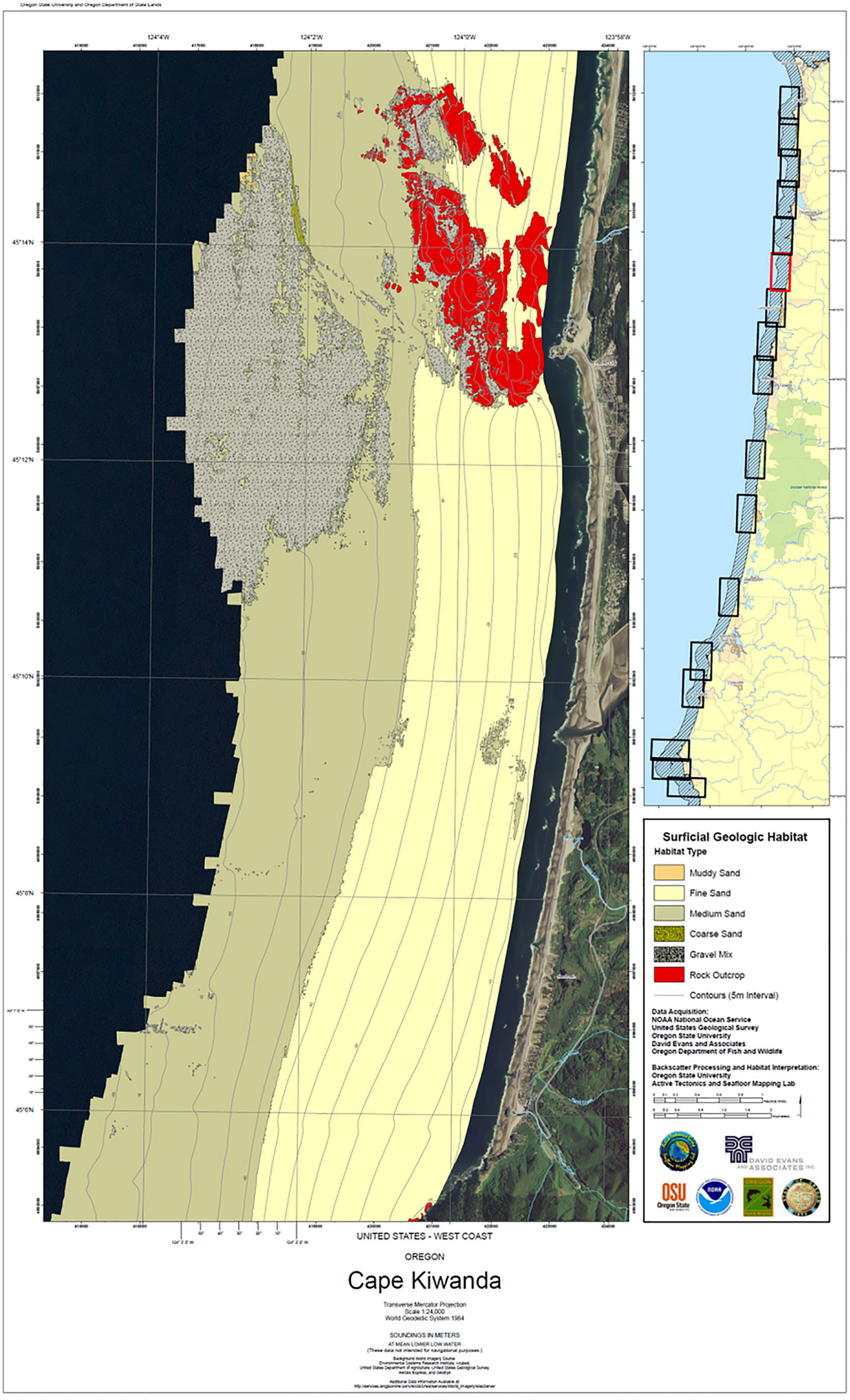


Figure B.7. Surficial geologic habitat near Lincoln City, Oregon (OSU 2011).

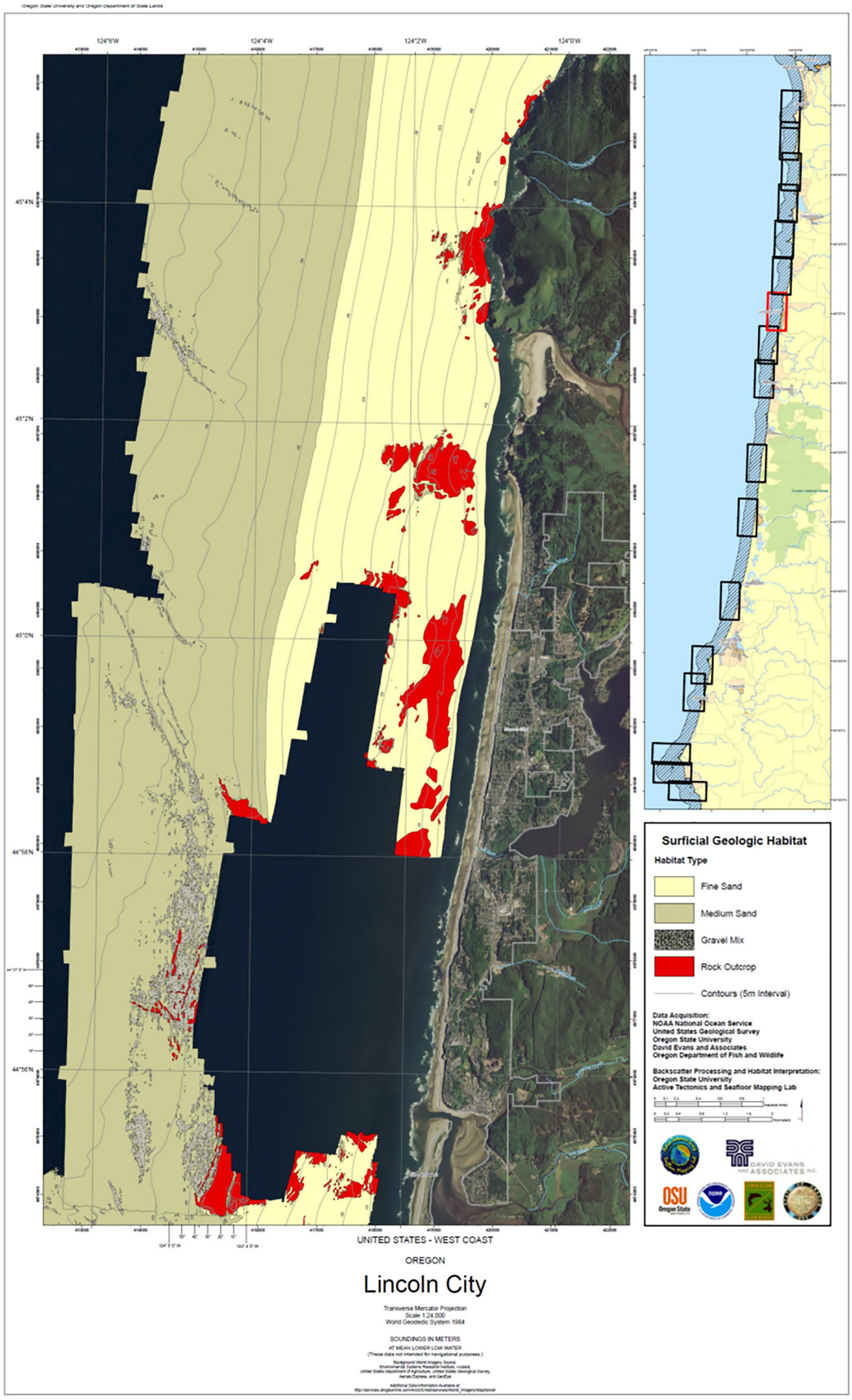


Figure B.8. Surficial geologic habitat near Depoe Bay, Oregon (OSU 2011).

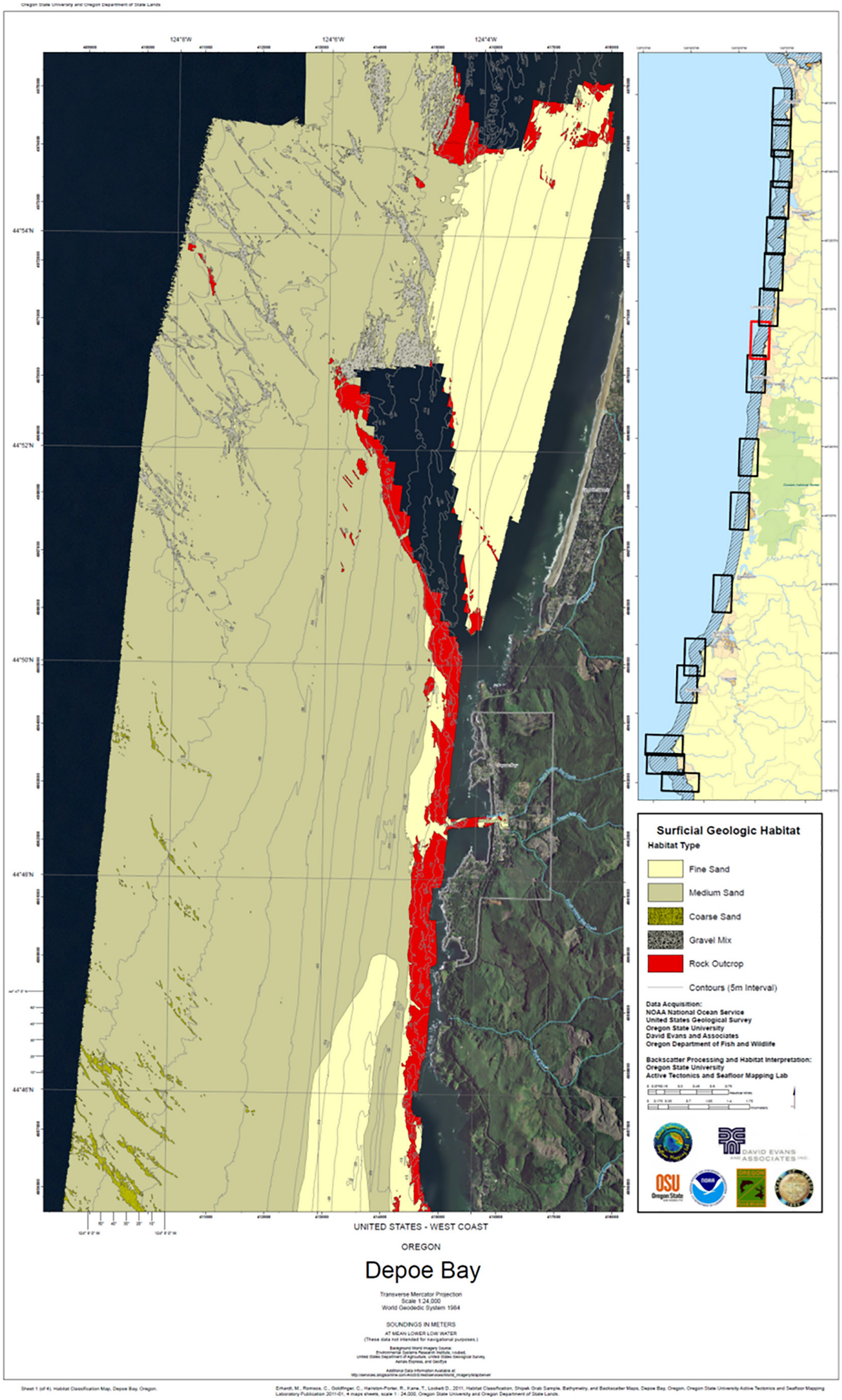


Figure B.9. Surficial geologic habitat near Newport, Oregon (OSU 2011).

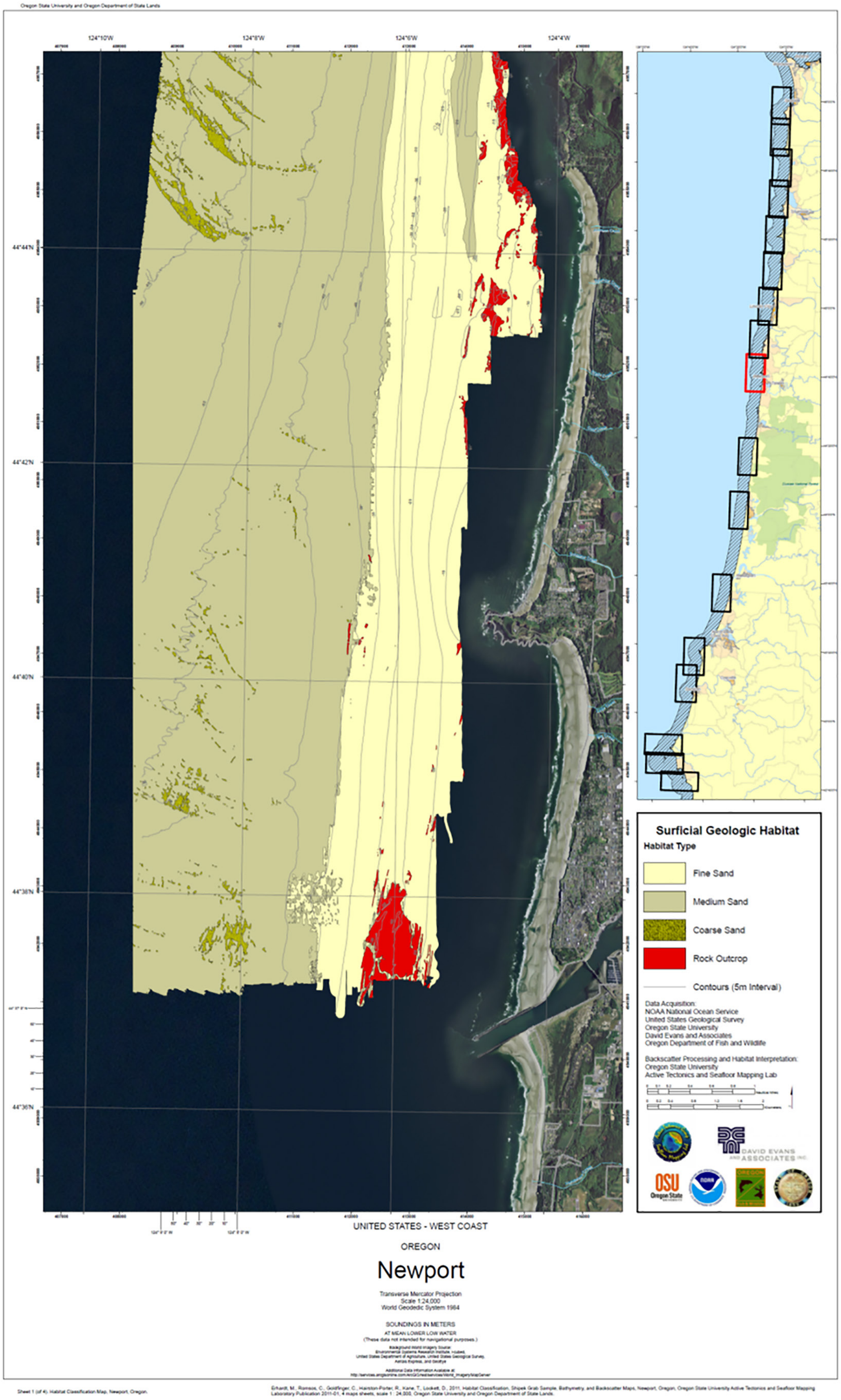


Figure B.10. Surficial geologic habitat near Cape Perpetua, Oregon (OSU 2011).

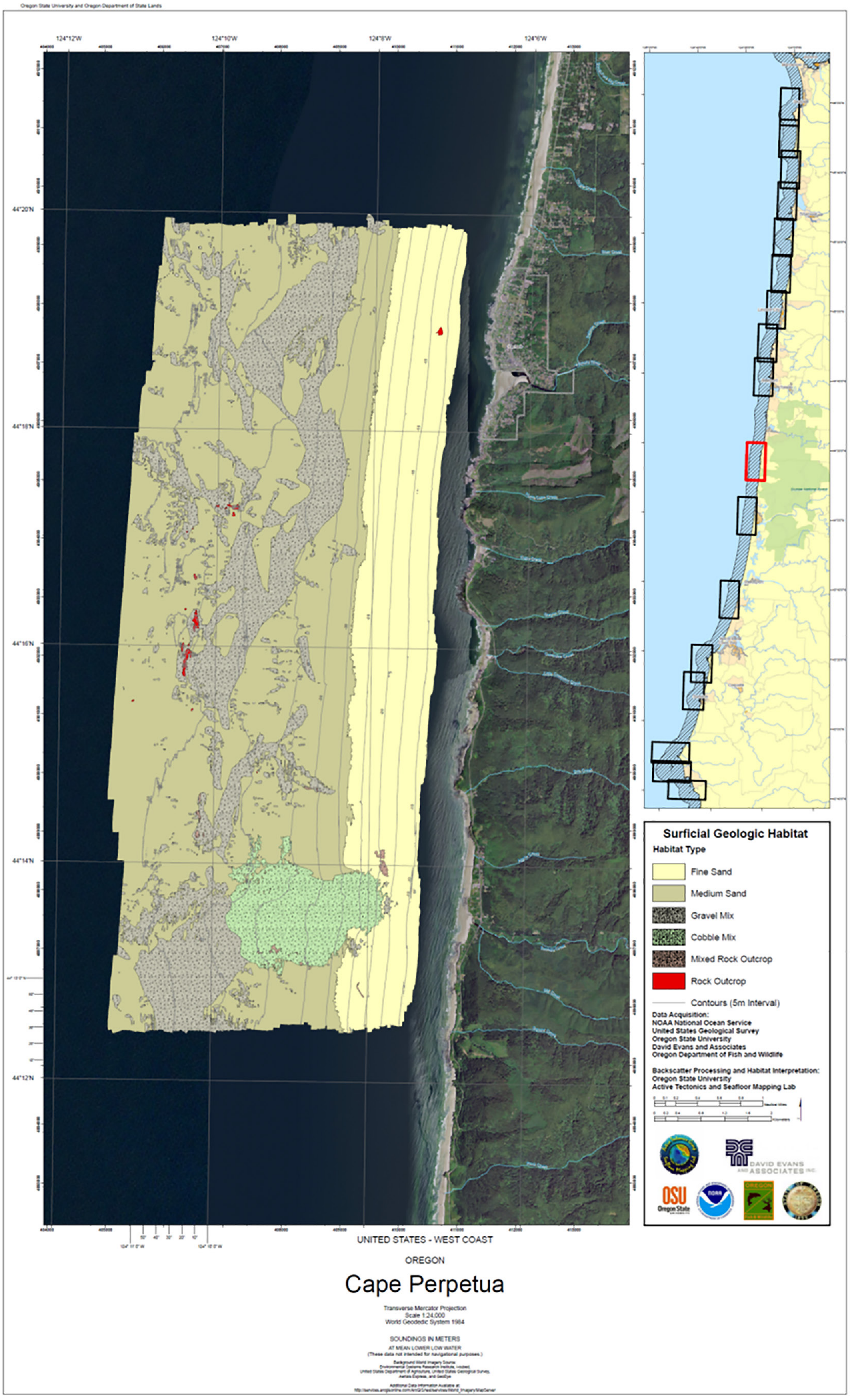


Figure B.11. Surficial geologic habitat near Florence, Oregon (OSU 2011).

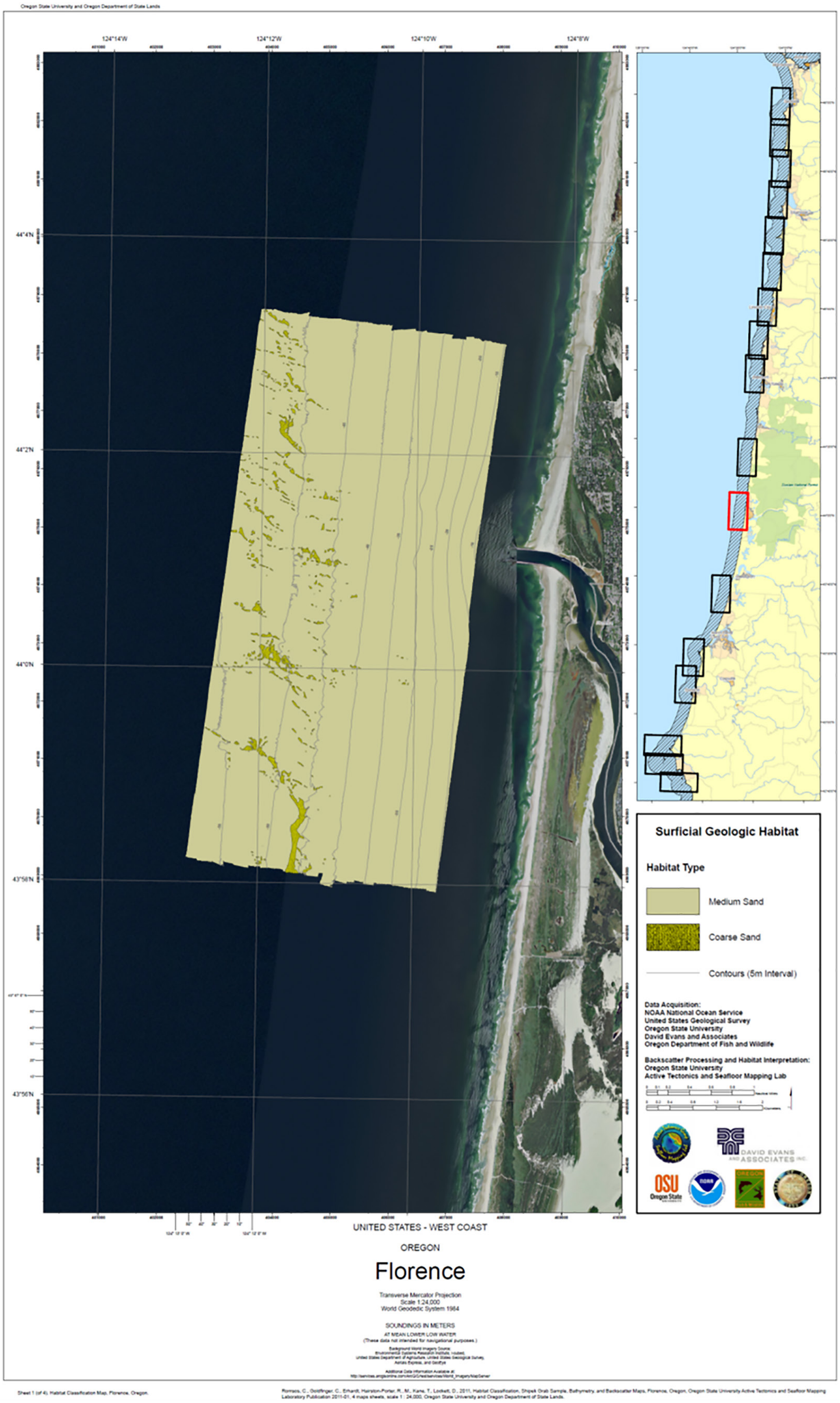


Figure B.12. Surficial geologic habitat near Lakeside, Oregon (OSU 2011).

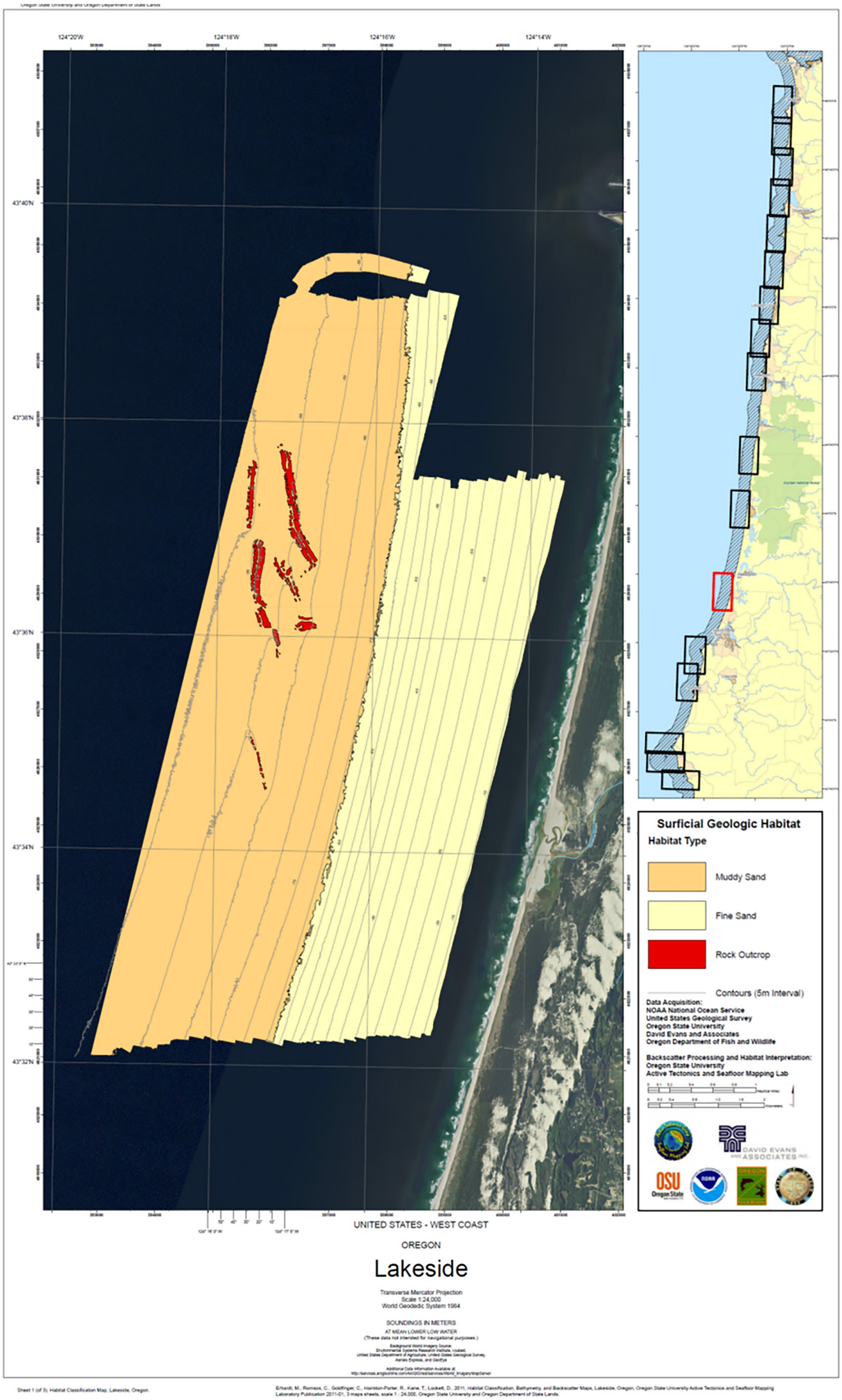


Figure B.13. Surficial geologic habitat near Cape Arago, Oregon (OSU 2011).

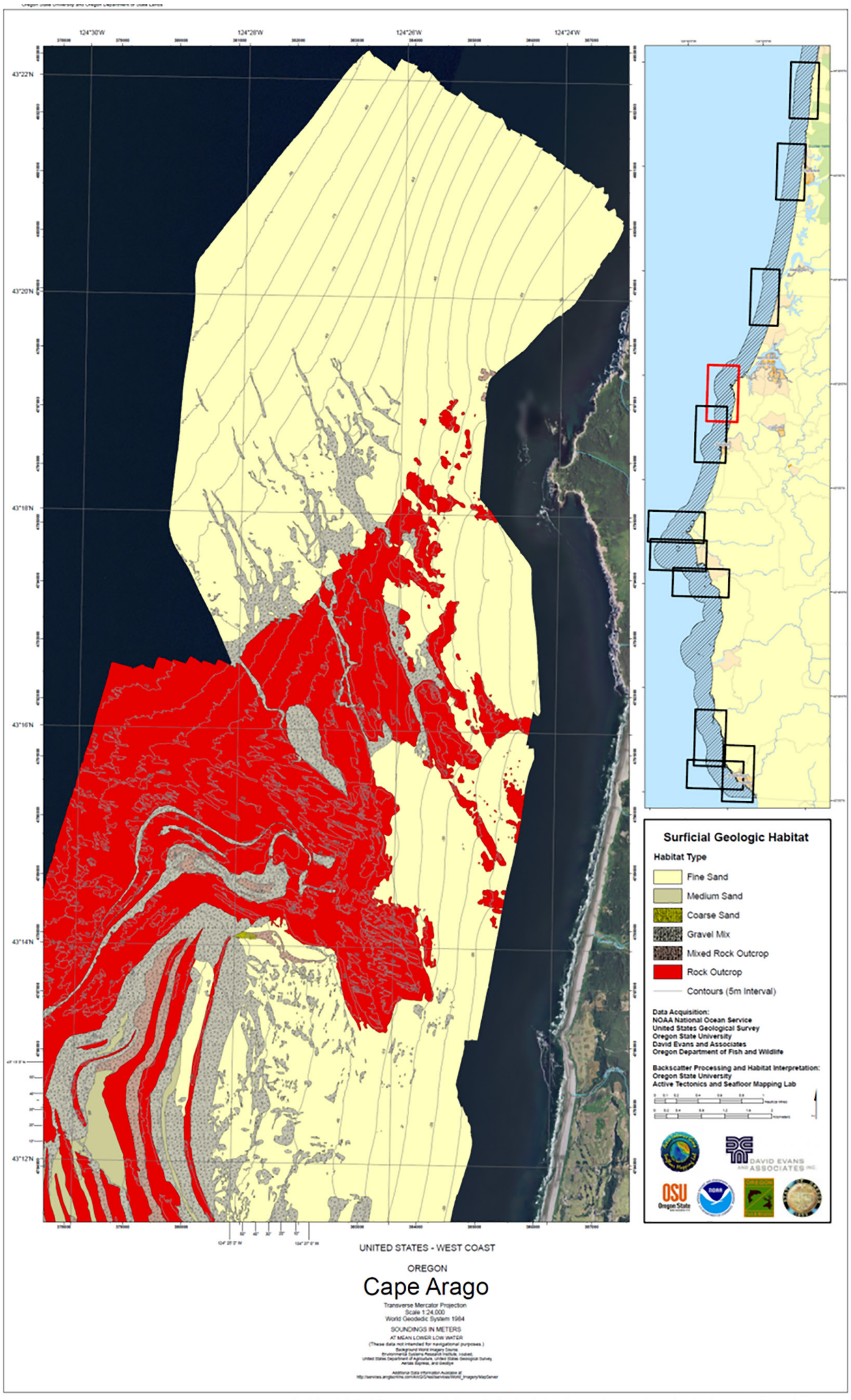


Figure B.14. Surficial geologic habitat near Bandon, Oregon (OSU 2011).

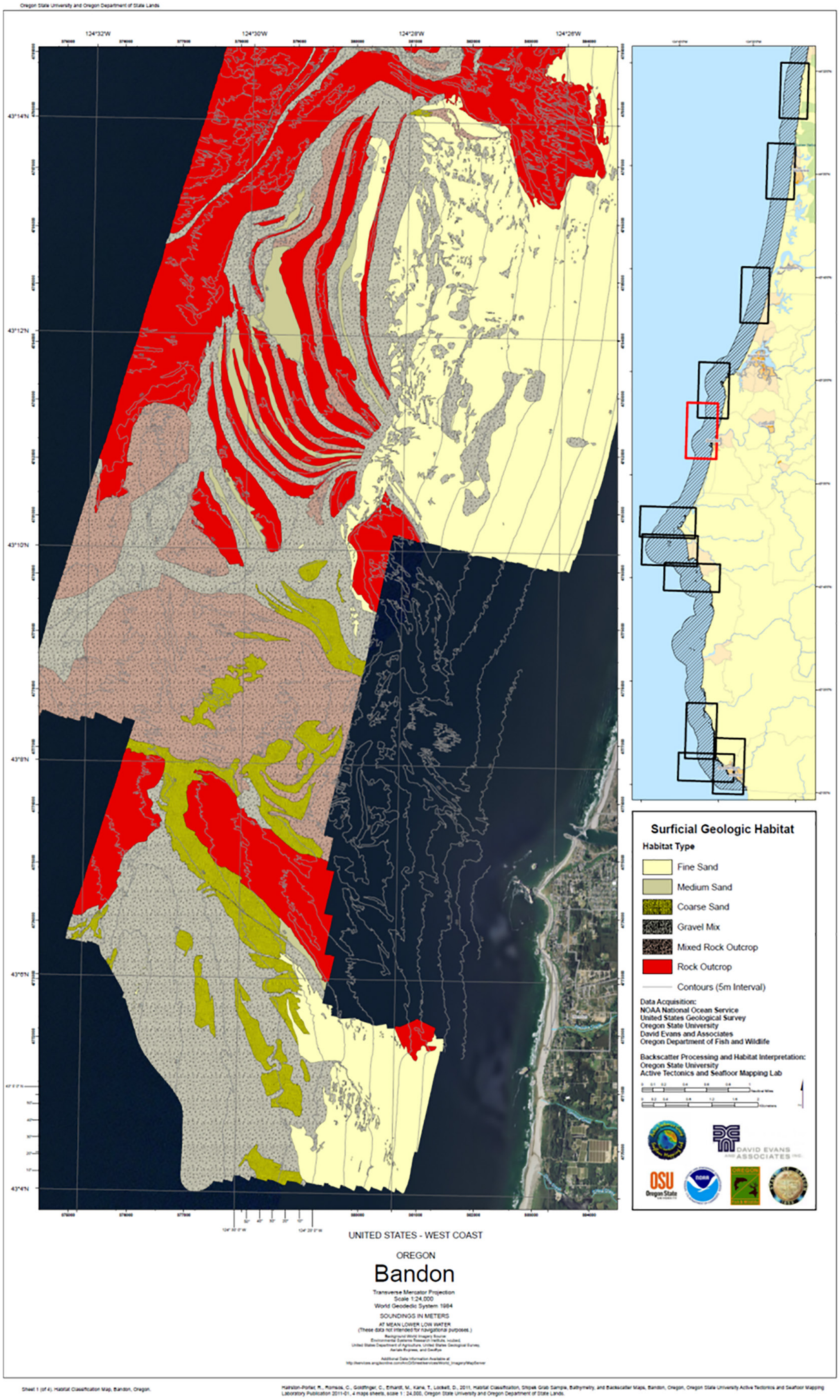


Figure B.15. Surficial geologic habitat near Blacklock Point, Oregon (OSU 2011).

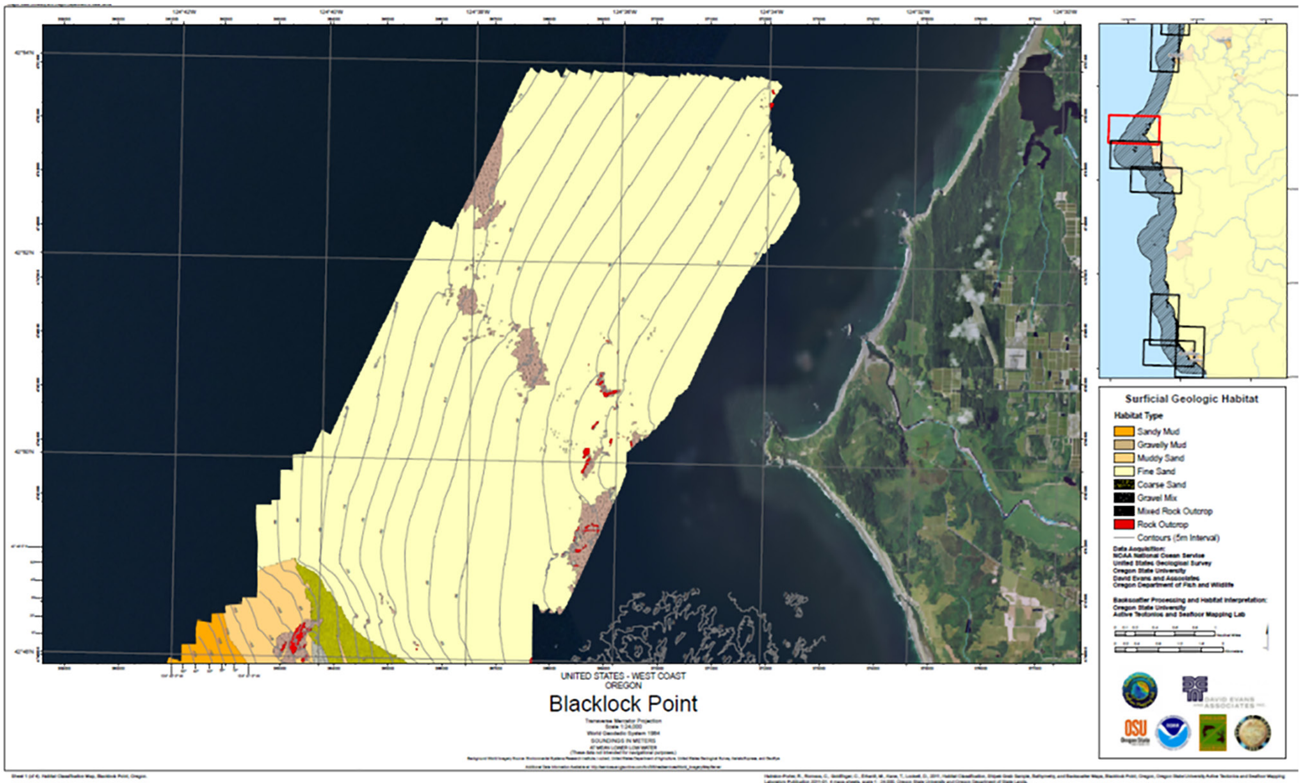


Figure B.16. Surficial geologic habitat near Cape Blanco, Oregon (OSU 2011).

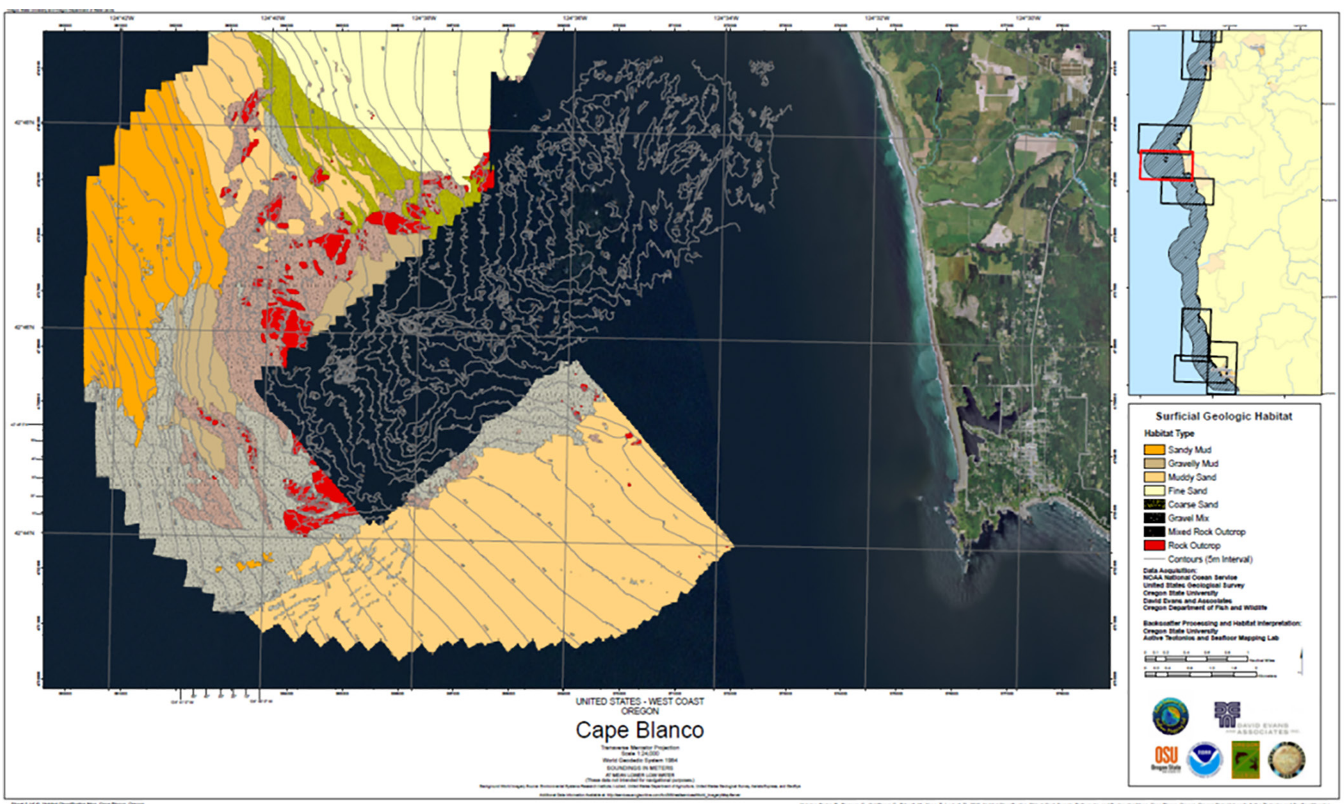


Figure B.17. Habitat types at Orford Reef and McKenzie Reef (ODFW 2006, p. 64).

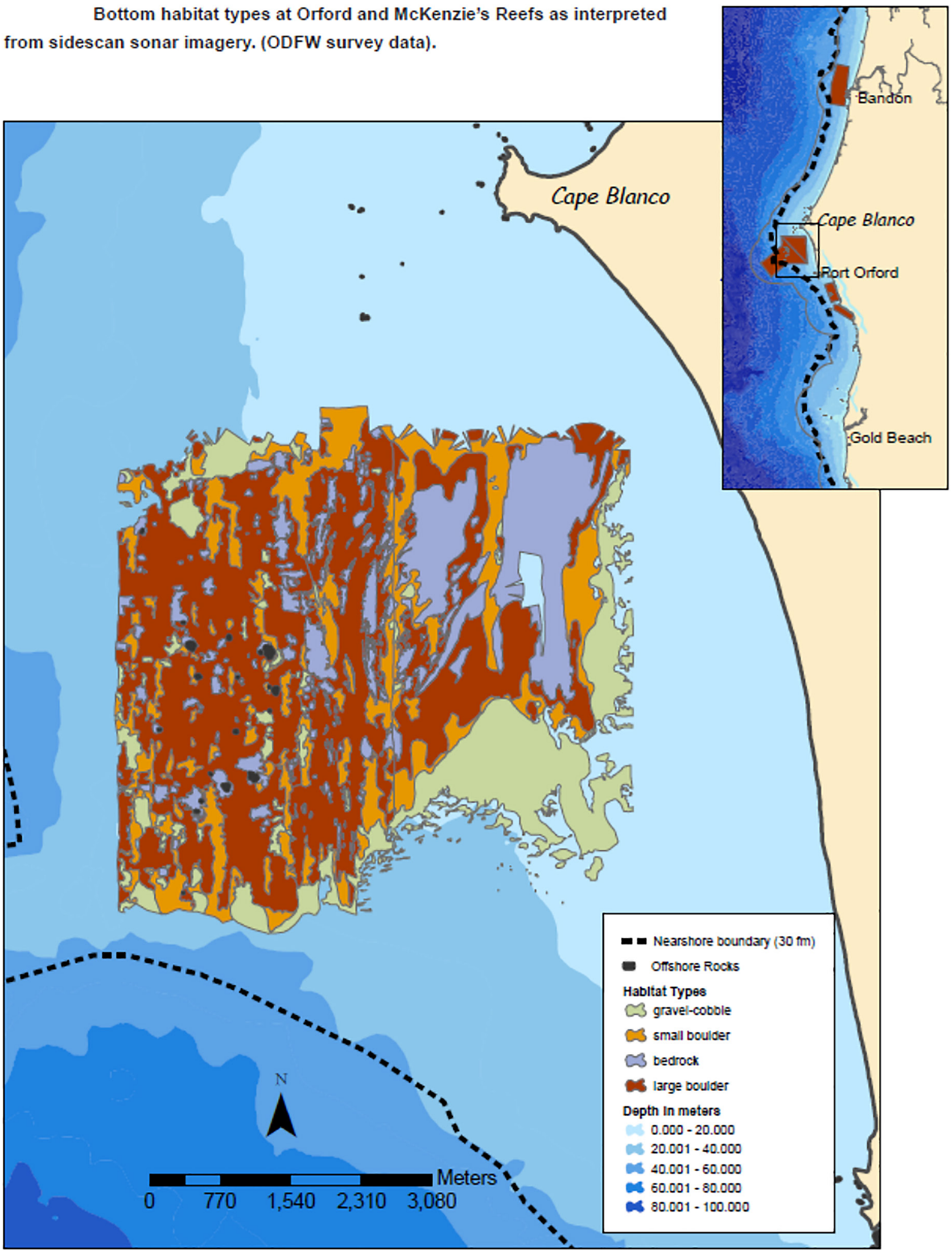
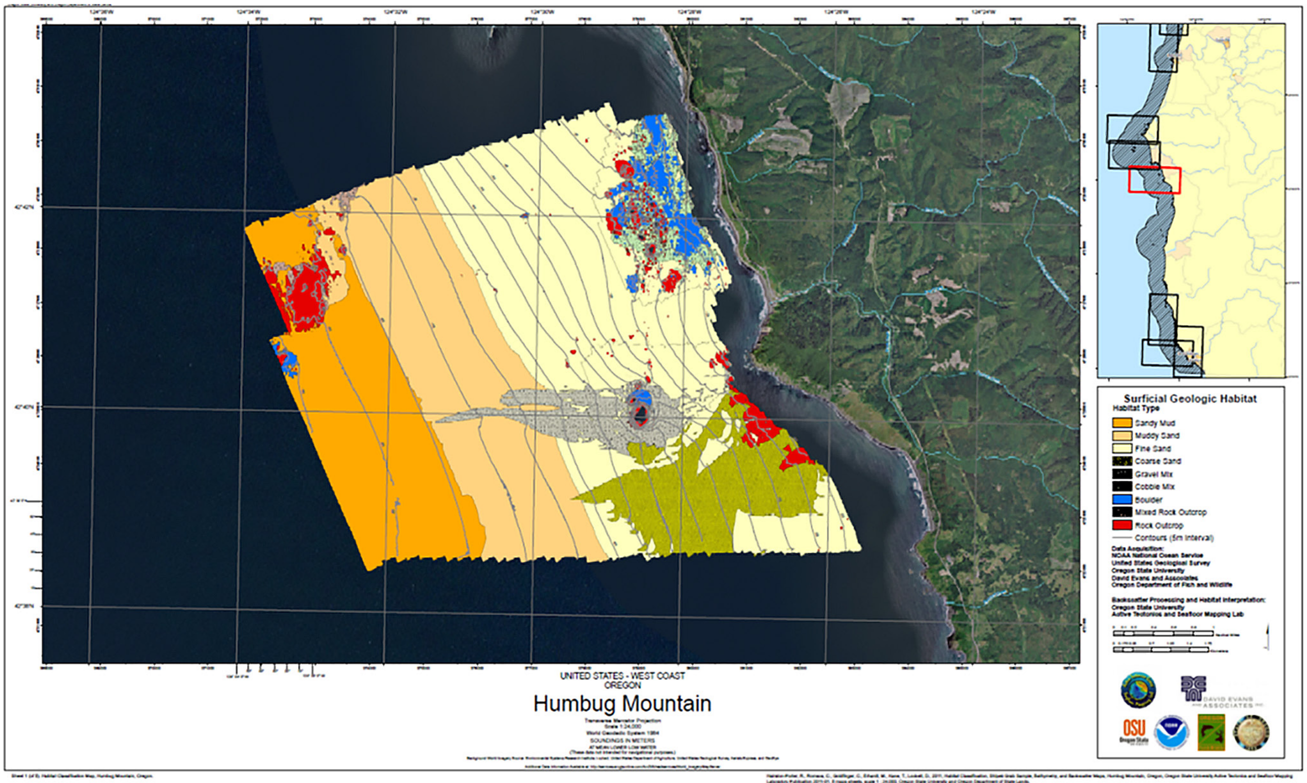


Figure B.18. Surficial geologic habitat near Humbug Mountain, Oregon (OSU 2011).



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SUBSTRATE MAPS FOR OREGON'S MARINE RESERVES

Figure C.1. Substrate maps for the area near Cascade Head, Oregon (ODFW [Oregon Department of Fish and Wildlife] Marine Reserves Program 2022).

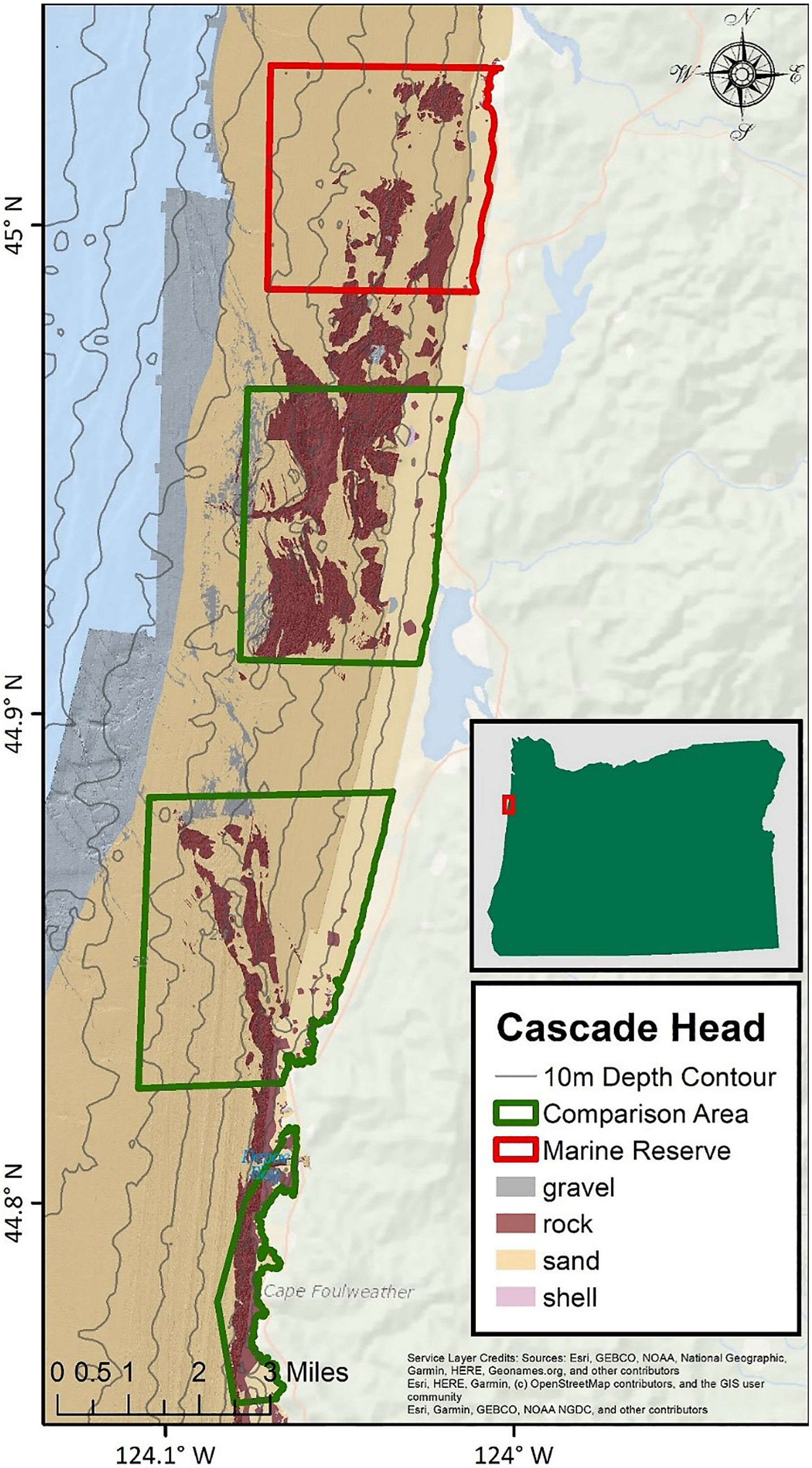


Figure C.2. Substrate maps for the area near Otter Rock, Oregon (ODFW Marine Reserves Program 2022).

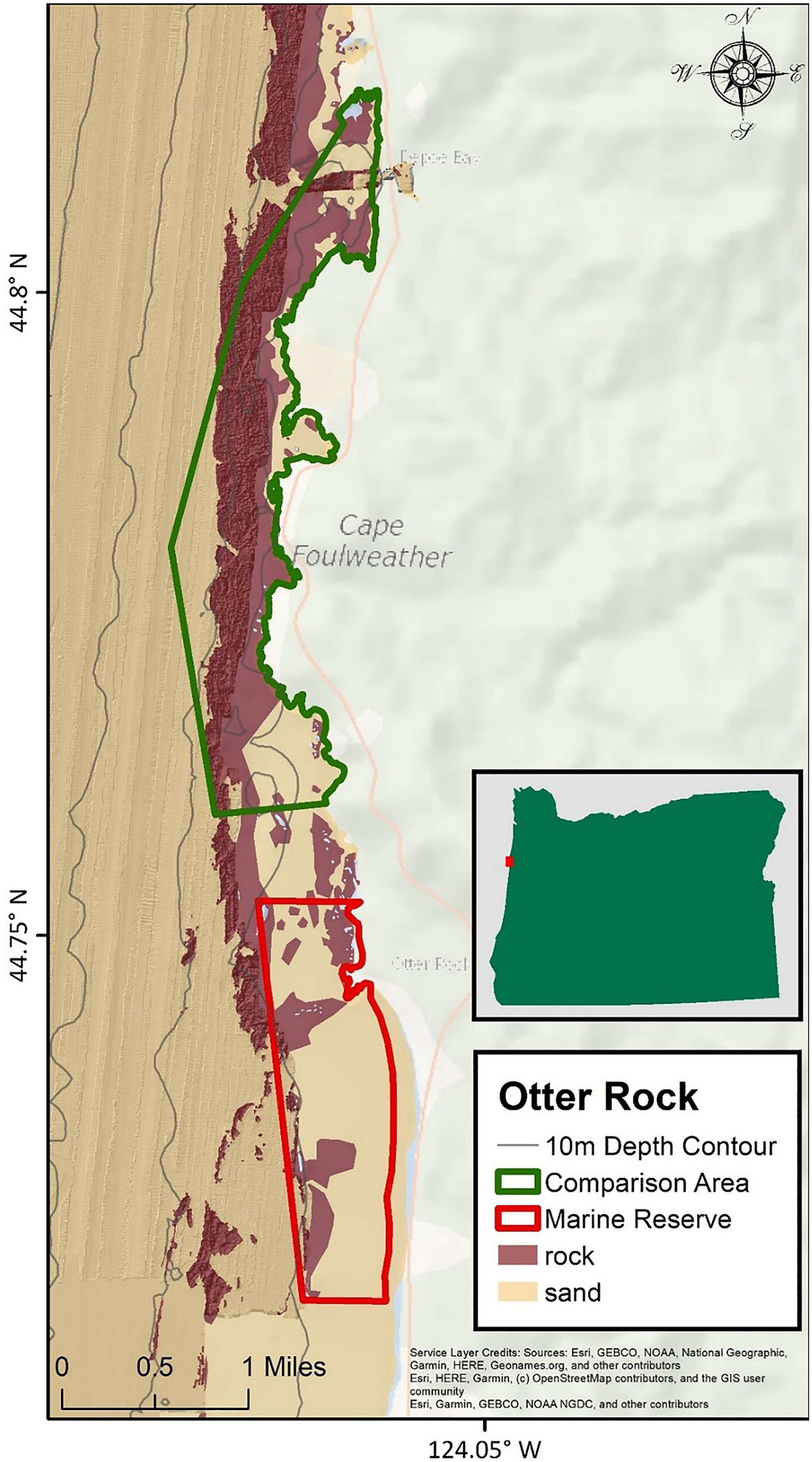
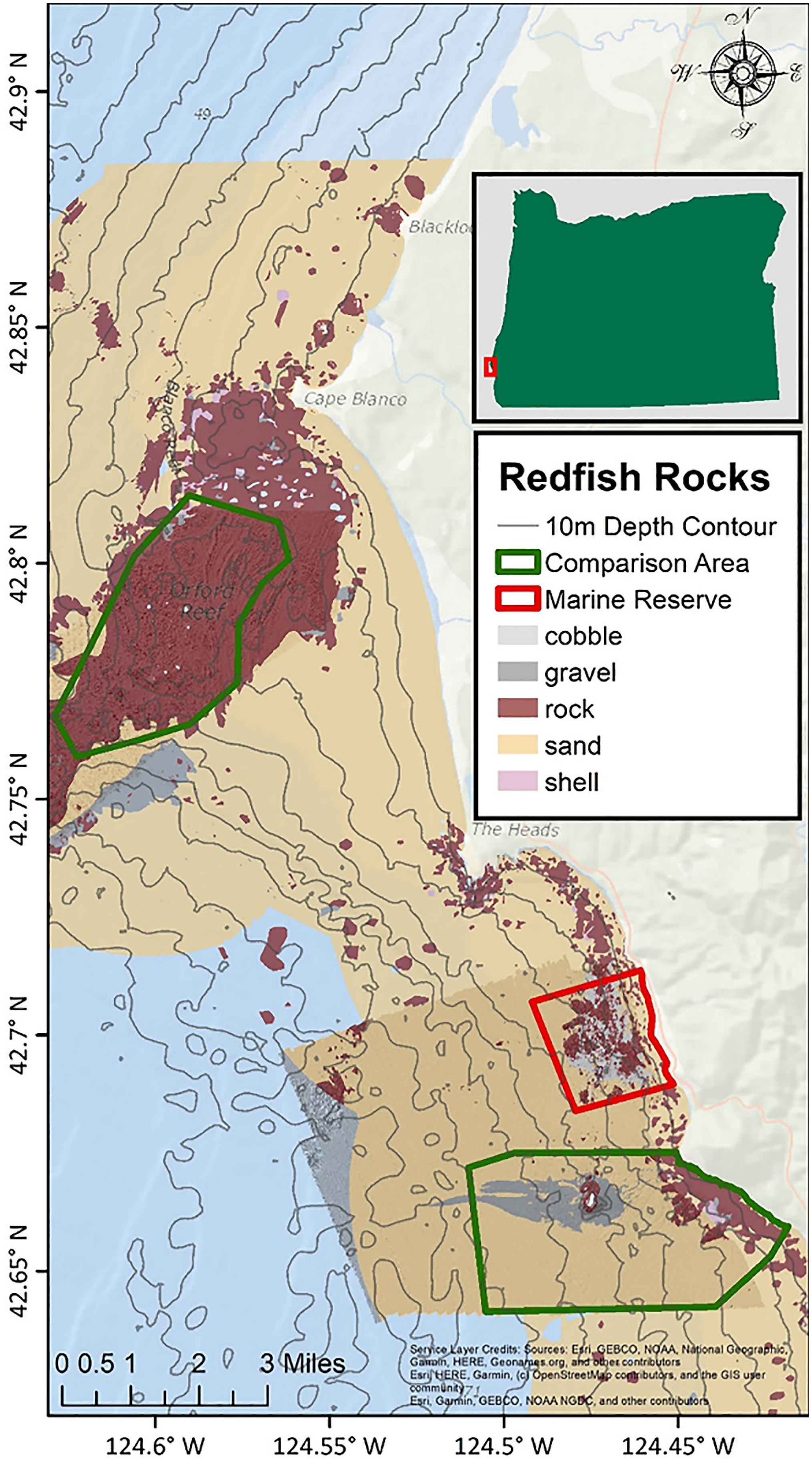


Figure C.3. Substrate maps for the area near Redfish Rocks, Oregon (ODFW Marine Reserves Program 2022).



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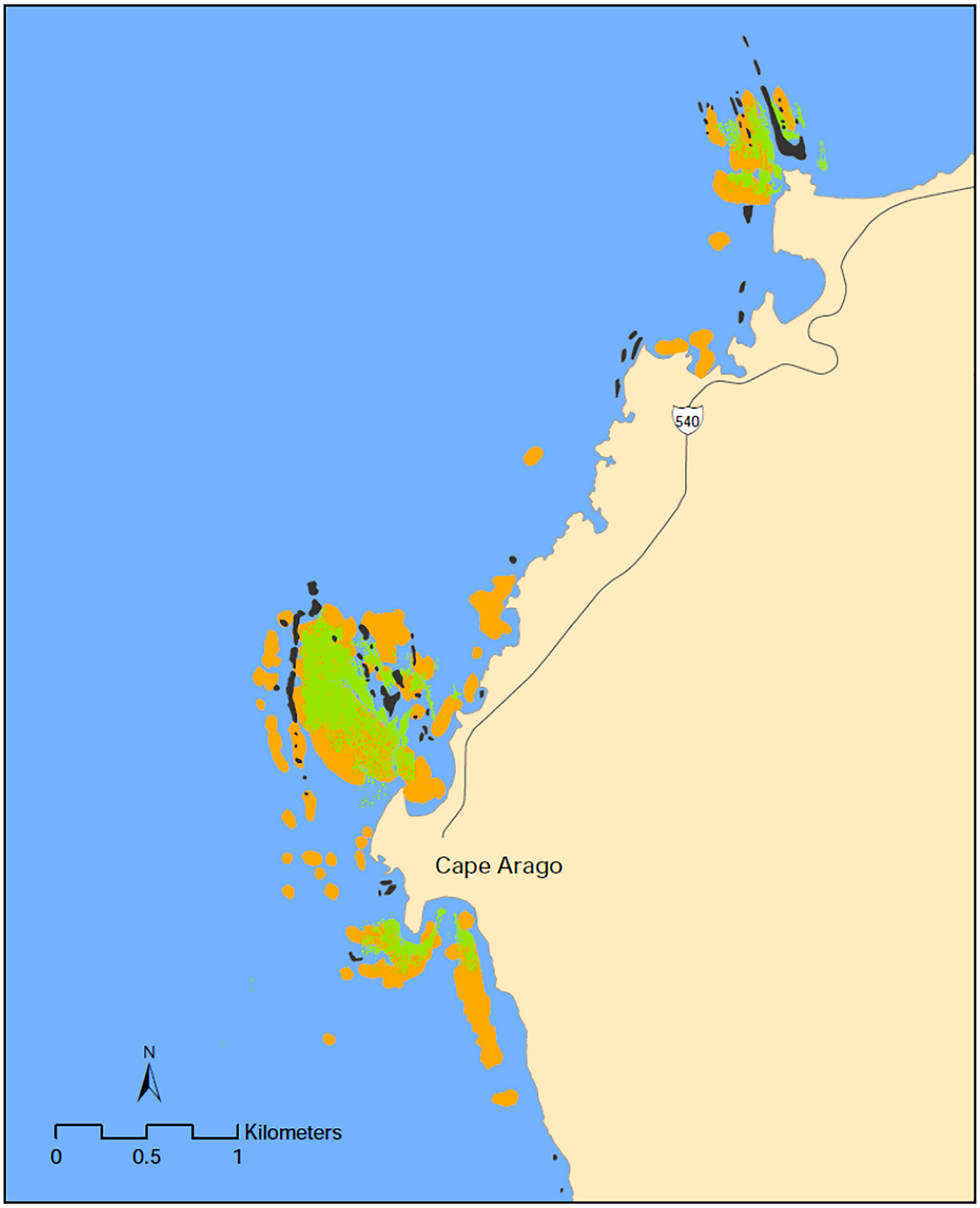
Appendix D

KELP CANOPY EXTENT

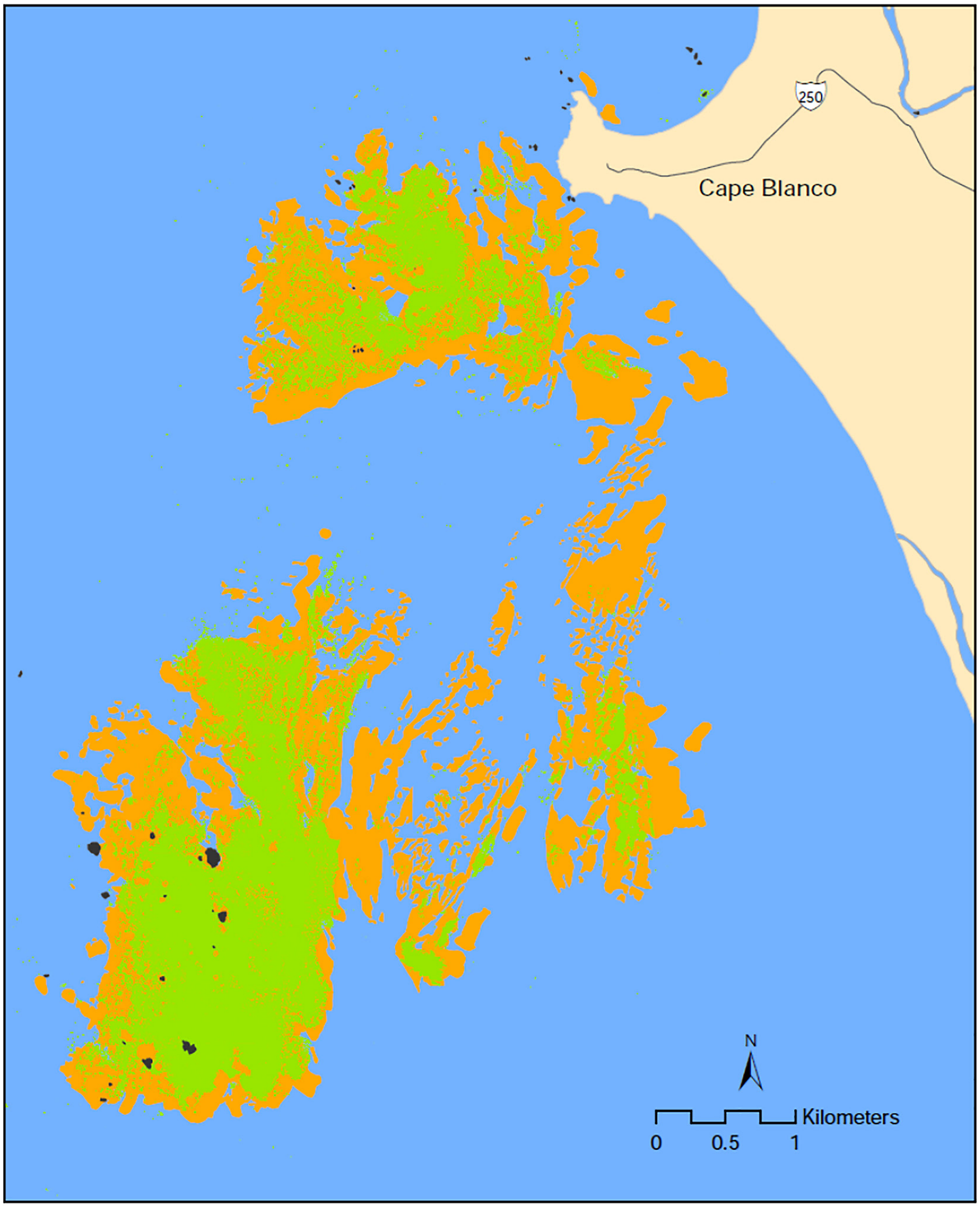
Figure D.1. Kelp canopy map for the area near Cape Arago, Oregon (Merems 2011).



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.

Note. This region was not included in the 1996–1999 surveys. DMSI = digital multispectral imaging.

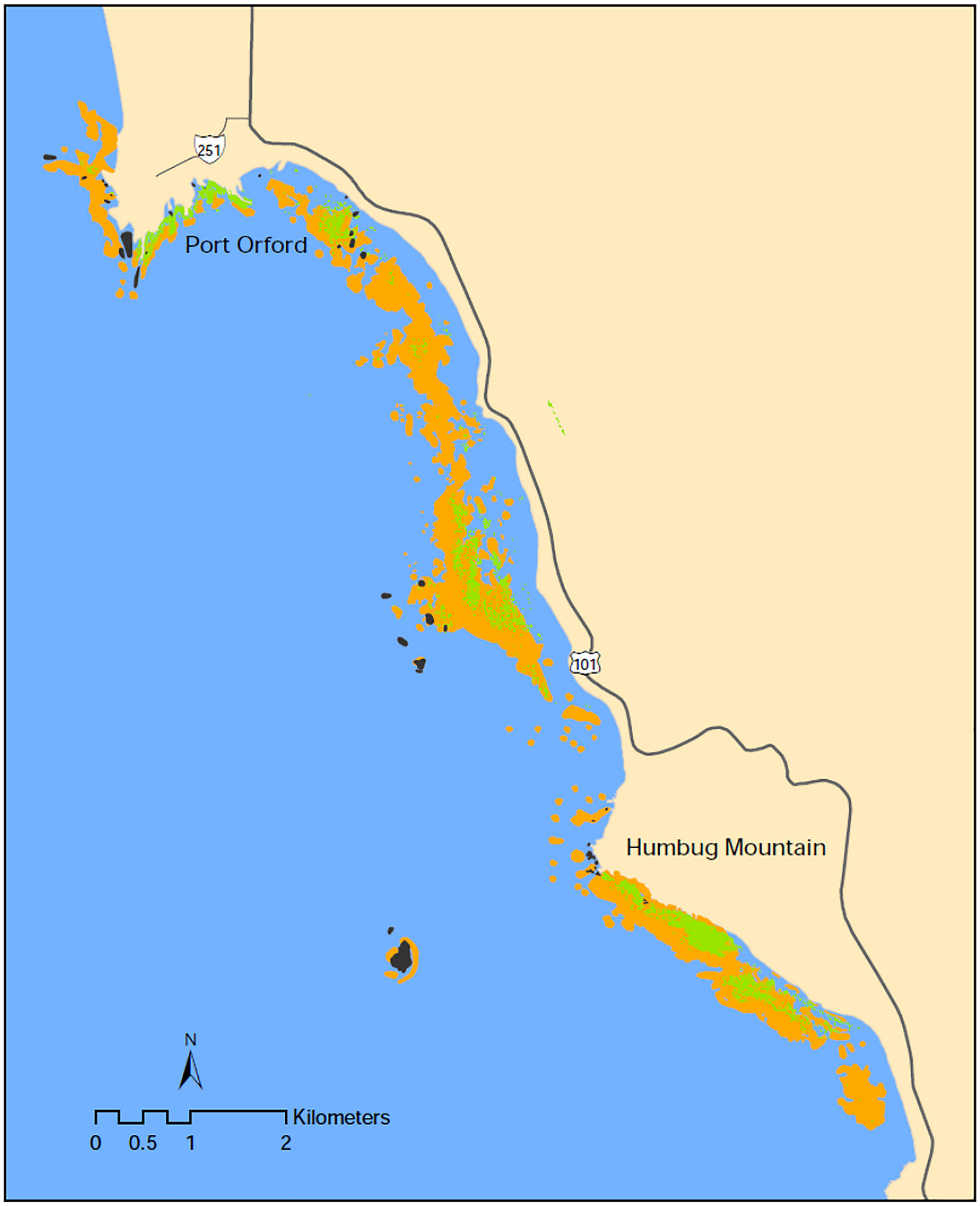
Figure D.2. Kelp canopy map for the area near Blanco and Orford Reefs, Oregon (Merems 2011).



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.

Note. DMSI = digital multispectral imaging.

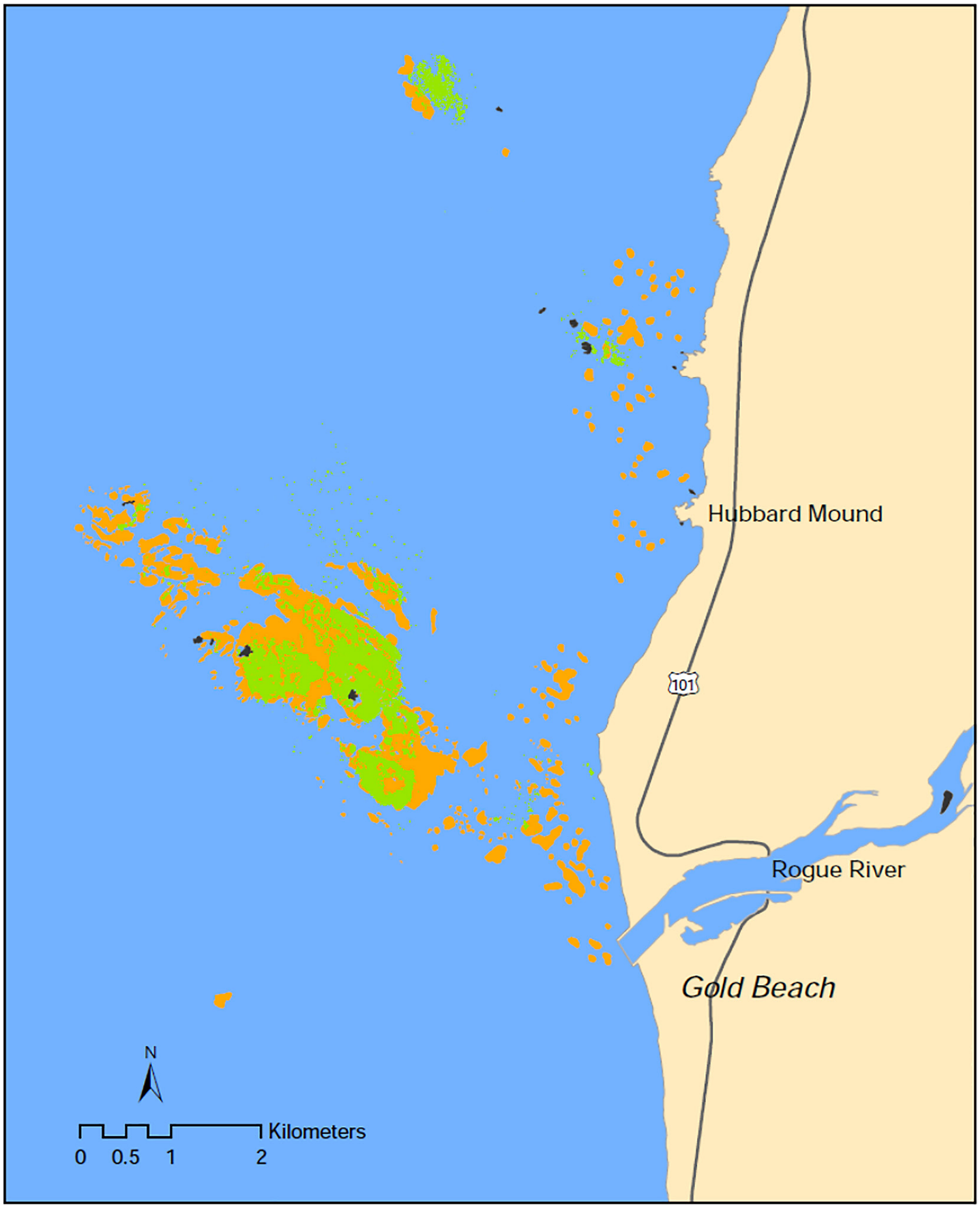
Figure D.3. Kelp canopy map for the area near Port Orford, Redfish Rocks, and Humbug Mountain, Oregon (Merems 2011).



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.

Note. DMSI = digital multispectral imaging.

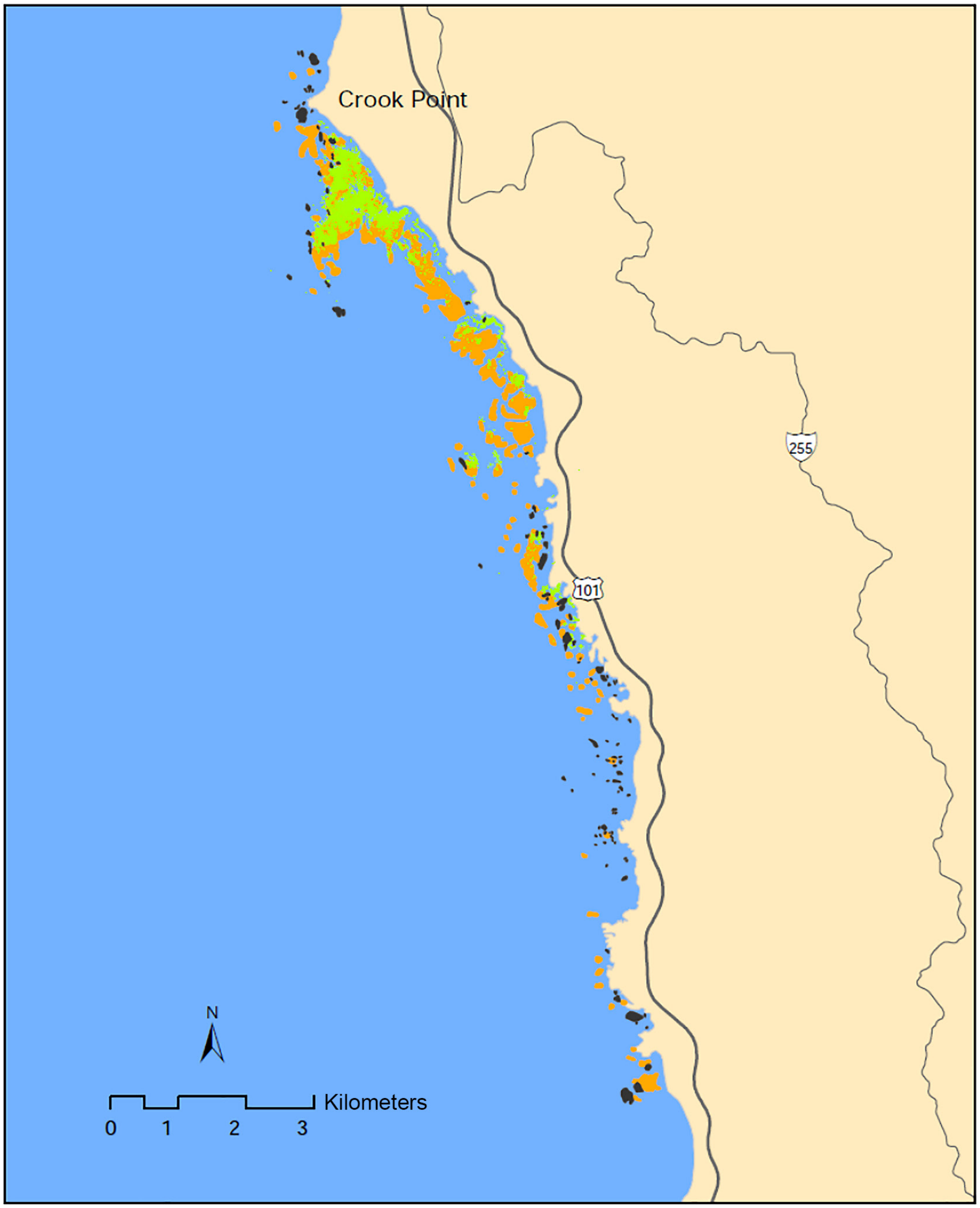
Figure D.4. Kelp canopy map for the area near Rogue River Reef, Oregon (Merems 2011).



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.

Note. DMSI = digital multispectral imaging.

Figure D.5. Kelp canopy map for the area near Crook Point and the Mack Arch Complex, Oregon (Merems 2011).



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.

Note. This region was not included in the 1996–1999 surveys. DMSI = digital multispectral imaging.

Figure D.6. Kelp canopy map for the area near Cape Ferrelo, Oregon (Merems 2011).

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.

Note. This region was not included in the 1996–1999 surveys. No scale bar was provided for this map. DMSI = digital multispectral imaging.

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AUTHORS

M. Tim Tinker

Dr. Tim Tinker, principal author; Research Wildlife Biologist, U.S. Geological Survey (retired); Adjunct Professor, University of California, Santa Cruz; Nhydra Ecological Research

James A. Estes

Dr. James Estes, contributing author; Ecologist, U.S. Geological Survey (retired); Distinguished Professor Emeritus, University of California, Santa Cruz

James L. Bodkin

Dr. James Bodkin, contributing author; Research Wildlife Biologist (retired), U.S. Geological Survey Alaska Science Center

Shawn Larson

Dr. Shawn Larson, contributing author; Curator of Conservation Research, Seattle Aquarium

Michael J. Murray

Dr. Mike Murray, contributing author; Jane Dunaway Director of Veterinary Services, Monterey Bay Aquarium

Jan Hodder

Dr. Jan Hodder, contributing author; Emeritus Professor, University of Oregon, Institute of Marine Biology

Photo courtesy of Peter Hatch

Elakha Alliance
PO Box 704, Siletz, OR 97380
www.elakhaalliance.org | info@elakhaalliance.org

@ElakhaAlliance | facebook.com/elakhaalliance
@ElakhaAlliance | instagram.com/elakhaalliance
@ElakhaA | twitter.com/ElakhaA
@ElakhaAlliance | youtube.com/c/ElakhaAlliance

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