

Chapter 6. Habitat Suitability

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

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

Critical Resources for Sea Otters

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

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

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

The relative abundance and proximity to these two resources – concentrations of preferred prey and suitable sheltered habitats (although the former resource appears to be more limiting than the later) – will help determine the relative degree of habitat suitability for sea otters within their coastal habitats. Unfortunately, measuring these resources directly (especially prey availability) at spatial scales that are relevant for sea otters poses an enormous logistical challenge. In some regions the diets of sea otters are dominated by a single prey type, such as green urchins in the Aleutian Islands, and it has been possible to use scuba-based sub-tidal sampling methods to measure the relative availability of this prey species directly (Estes et al. 2010). In other regions, however, the diet is far more diverse, and often includes a high proportion of cryptic prey (such as crabs) that cannot be effectively measured by scuba-based methods at the appropriate scales. In such cases it may be possible to measure some proportion of prey taxa (e.g. Tinker et al. 2008), but an alternative approach is to utilize other indices of prey abundance (e.g. substrate characteristics) that can be more readily measured. A quantitative model of

habitat suitability for sea otters (defined as the potential population density at equilibrium) was recently developed for California: this model indirectly reflects the quality of key resources using readily available GIS layers of abiotic and biotic features (Tinker et al. 2021). Nearshore coastal habitats in Oregon are, broadly speaking, fairly similar to coastal habitats in much of California (especially northern California), and all the basic habitat features used as predictor variables in the California model are also applicable to coastal Oregon. The California model was thus applied to the Oregon coast using the same GIS habitat layers (Kone et al. 2021). The results of this model (Figure 6.1) provide a useful starting point for understanding habitat suitability in Oregon.

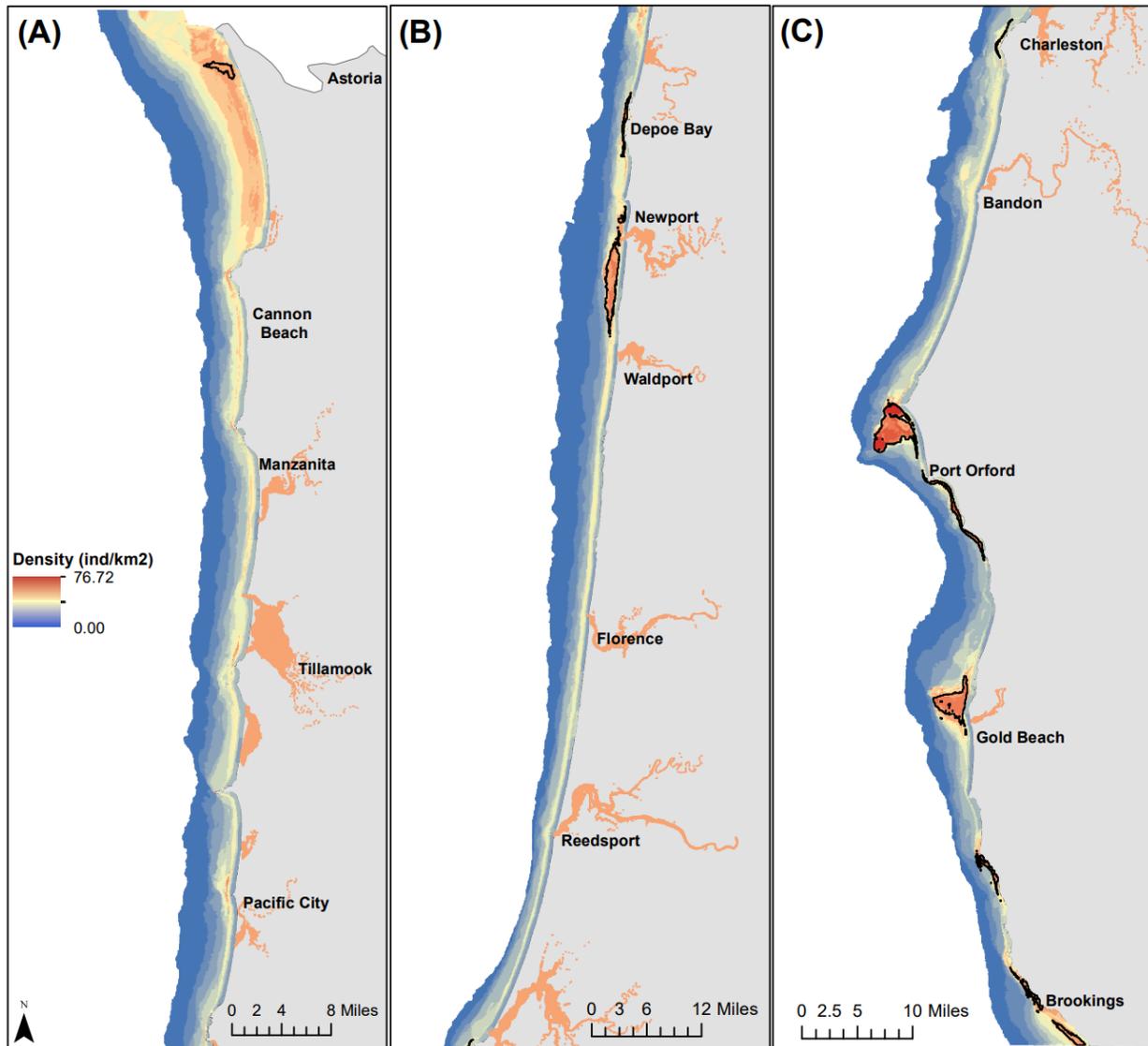


Figure 6.1. Estimated potential densities of sea otters at equilibrium (ie., assuming a population were to reach carrying capacity) along the outer coast and in estuaries of Oregon, for the north (A), central (B), and south (C) regions. Density values are visualized using natural breaks (Jenks) with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

Habitat Suitability in Oregon: Overview

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

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

Substrate

Oregon's nearshore subtidal consists of a mosaic of substrate ranging from rock reefs to mud plains. Oregon's Nearshore Strategy web site (<https://oregonconservationstrategy.org/oregon-nearshore-strategy/habitats/>) provides an overview of substrate for approximately 53% of Oregon's Territorial Sea¹ collected using high-resolution sonar technologies that outline this substrate mosaic. The maps (Figure 6.2) are based on the Coastal and Marine Ecological Classification Standard substrate classification and provide a starting point for assessing habitat suitable for supporting sea otter populations.

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

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

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

Another online resource for viewing physical habitat GIS layers in conjunction with mapping data on hydrographic, oceanographic, biological and human activities, is the “SeaSketch” online Oregon Ocean Planning tool:

<https://www.seasketch.org/#projecthomepage/5c1001699112e049f68fc839>

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

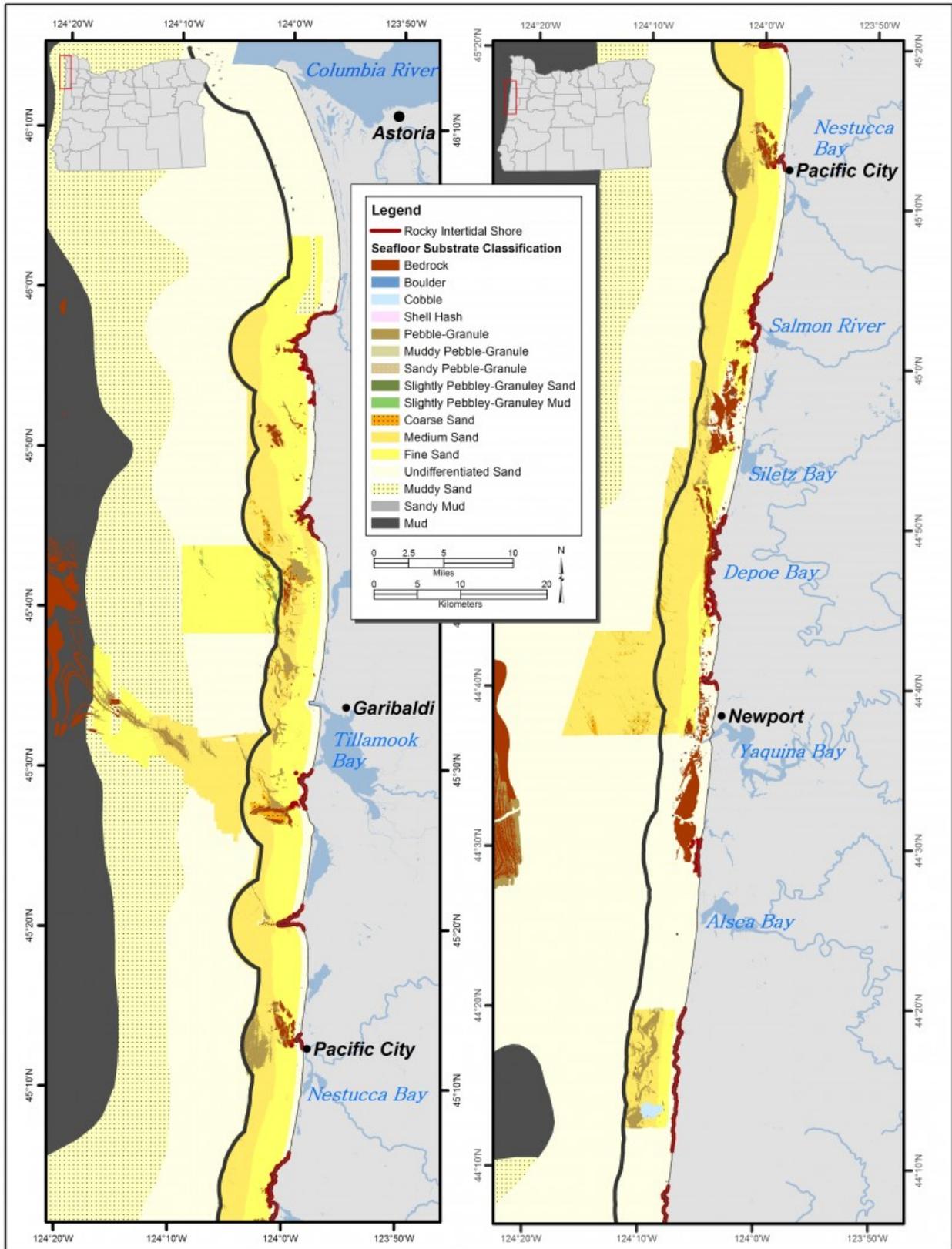


Figure 6.2a. Benthic substrate classification for the northern half of the Oregon coast

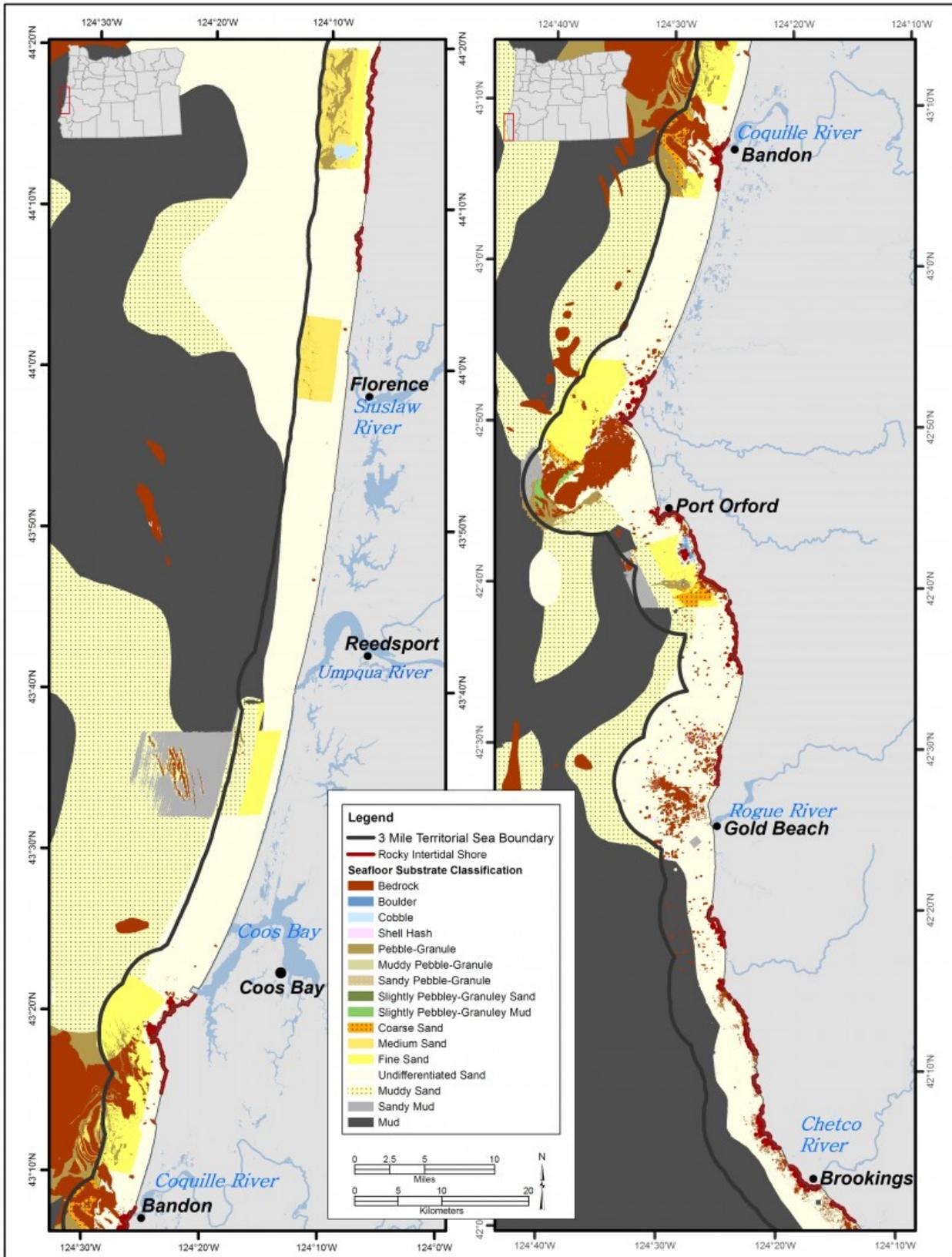


Figure 6.2b Benthic substrate classification for the southern half of the Oregon coast

Kelp Distribution

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

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

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

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

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

from 2011 aerial surveys of the southern coast of Oregon using a digital multi-spectral imaging system. Complete composite maps of kelp canopy extent from these surveys are provided in Appendix D.

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

AREA	CONCENTRATION (Acres)					HARVESTABILITY (Acres)		
	Not Con- firmed	Thin	Moderate	Dense	Total	Unknow n	Unhar- vest- able	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- Hum- bug Mountain .....	.....	167	23	11	201	.....	201	.....
Sisters Rocks .....	.....	14	1	4	19	.....	19	.....
Rogue River Reef	61	.....	.....	.....	61	61	.....	.....
Hunter Island .....	.....	3	.....	.....	3	.....	3	.....
Crook Point .....	.....	152	7	22	181	.....	.....	181
Yellow Rock	87	.....	.....	.....	87	87	.....	.....
Burnt Point-Thomas Point	77	.....	.....	.....	77	77	.....	.....
Whales Head	24	.....	.....	.....	24	24	.....	.....
House Rock .....	.....	16	.....	.....	16	.....	16	.....
Cape Ferello	124	.....	.....	.....	124	124	.....	.....
Twin Rocks-Goat Island	117	87	.....	.....	204	.....	204	.....
Brookings .....	.....	200	8	.....	208	.....	208	.....
Chetco River-Red Point .....	.....	300	.....	.....	300	.....	300	.....
Winchuck River .....	.....	102	88	.....	190	.....	190	.....
Total	490	1,071	257	891	2,709	373	1,141	1,195
Total for Lincoln, Coos, and Curry Counties	508	1,159	754	1,283	3,704	391	1,307	2,006

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

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

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

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

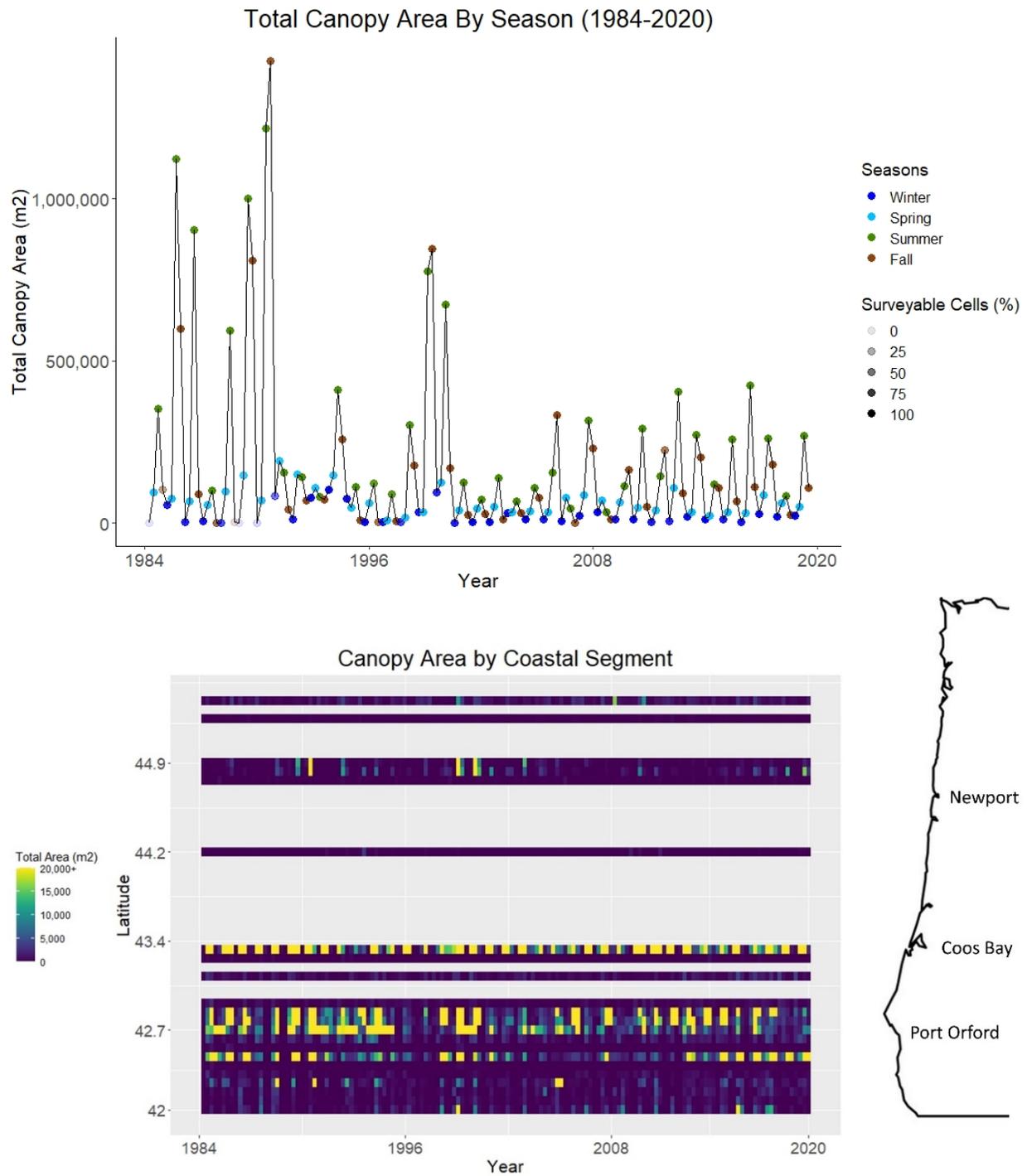


Figure 6.3. A) Total kelp canopy area across Oregon for every quarter from 1984 - 2020. Quarters are displayed as 'seasons' using colors and the transparency of the point indicates the percentages of all Oregon kelp pixels that were able to be surveyed during that quarter. B) Total kelp canopy area for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

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

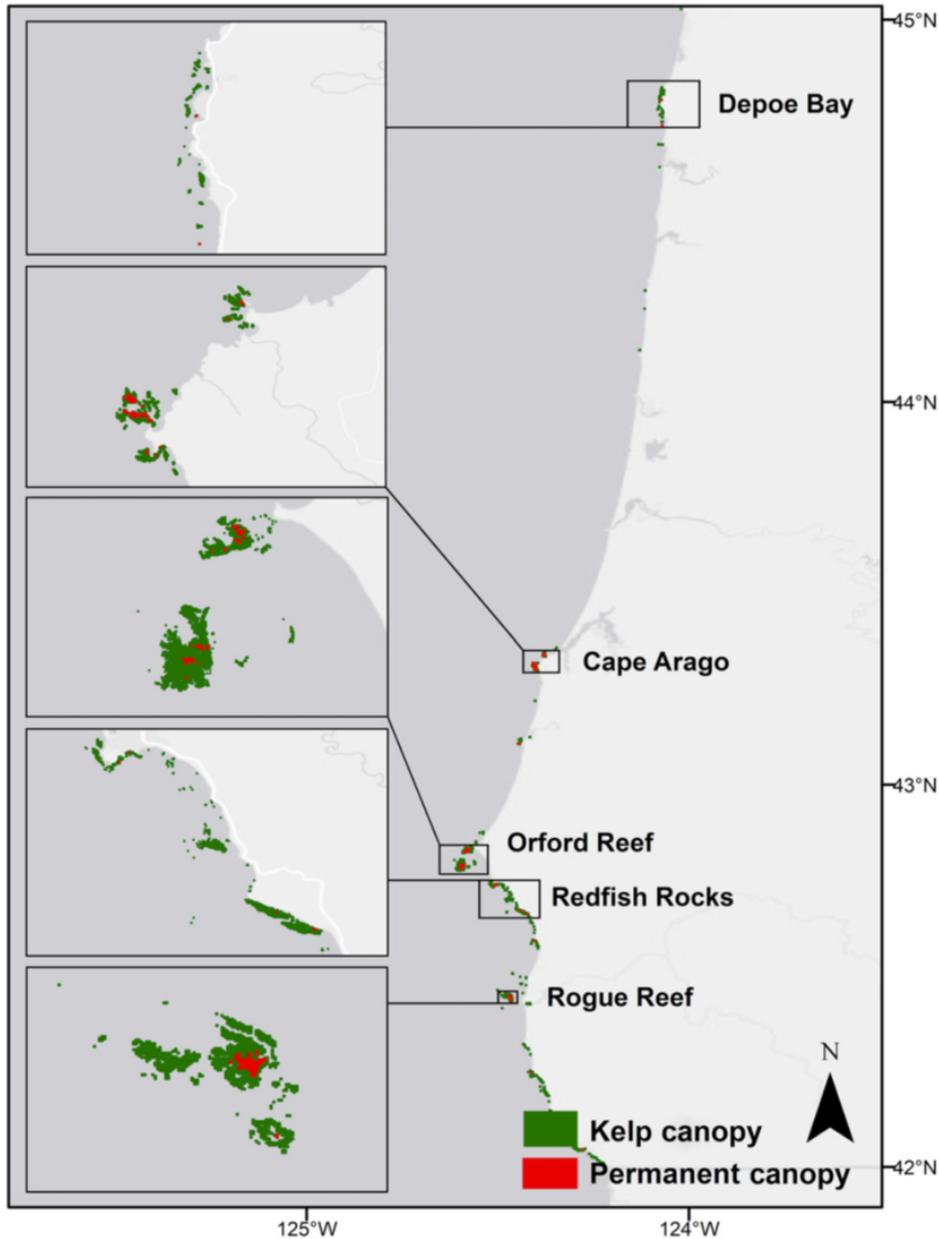


Figure 6.4. Map of all kelp detected in Oregon in at least 1% of the available Landsat images (green) and all “permanent” canopy (red), which is defined as being present in 80% of the summers for which a Landsat image was available. The five largest reefs in Oregon are labeled. From Hamilton et al. (2020).

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

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

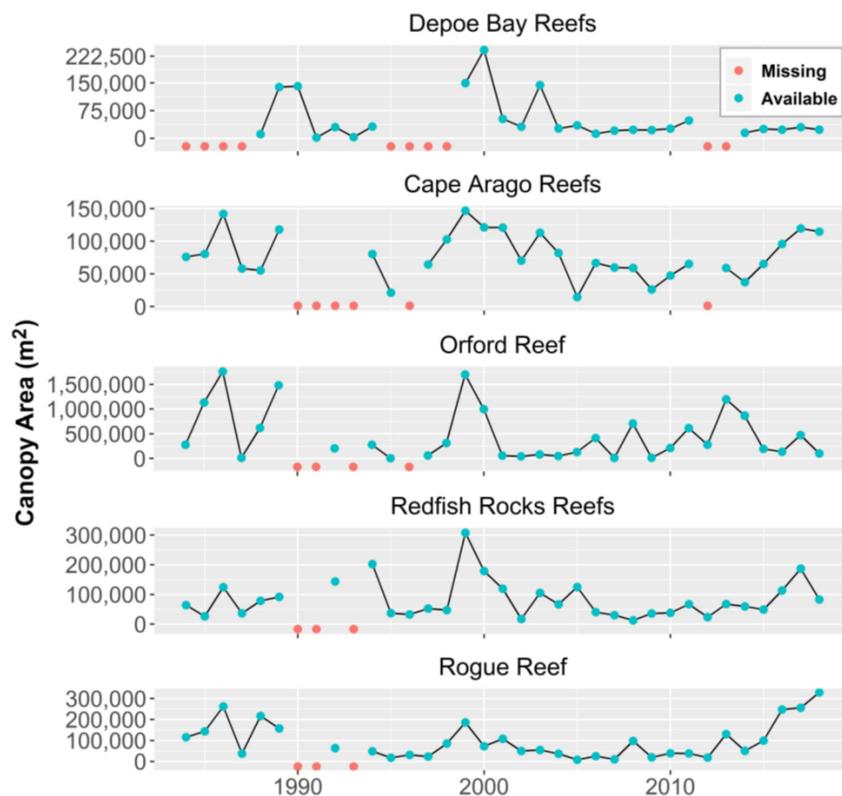


Figure 6.5. Time series of maximum detected summer kelp canopy area (m²) for the five largest reefs in Oregon from 1984 to 2018. Note that the y-axis scale varies between reefs. Blue (pink) points represent summers when canopy area could (could not) be estimated, usually because of lack of cloud-free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

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

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

Sea otter prey

Intertidal invertebrates

There are limited data for many of the potential sea otter prey items that are not commercially harvested in Oregon. Some intertidal sites have regular monitoring as part of groups such as the Partnership for Interdisciplinary Study of Coastal Oceans (<http://www.piscoweb.org/about-us-0>) or the Multi-Agency Rocky Intertidal Network (<https://marine.ucsc.edu/overview/index.html>), but for many species that could be potential sea otter prey items based on the sea otter's diet in California (Tinker et al. 2008, Tinker et al. 2012), such as black turban snails, *Tegula* sp., top shells, *Calliostoma* sp., mussels, and cancrivora crabs, there are few data other than short-term studies in localized areas. Some information, however, does exist for those species that are part of recreational harvests. In some of the south coast's rocky intertidal areas, native littleneck clams (*Leukoma staminea*) and butter clams (*Saxidomus giganteus*) are found under rocks and amongst gravel. ODFW conducts irregular surveys for these species at two sites south of Port Orford (Ainsworth et al. 2012). Few butter clams were found, but for littleneck clams there were an average of 3 – 5/m² in surveys conducted in 2010 and 2013.

Subtidal Invertebrates

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

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

Red sea urchins

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

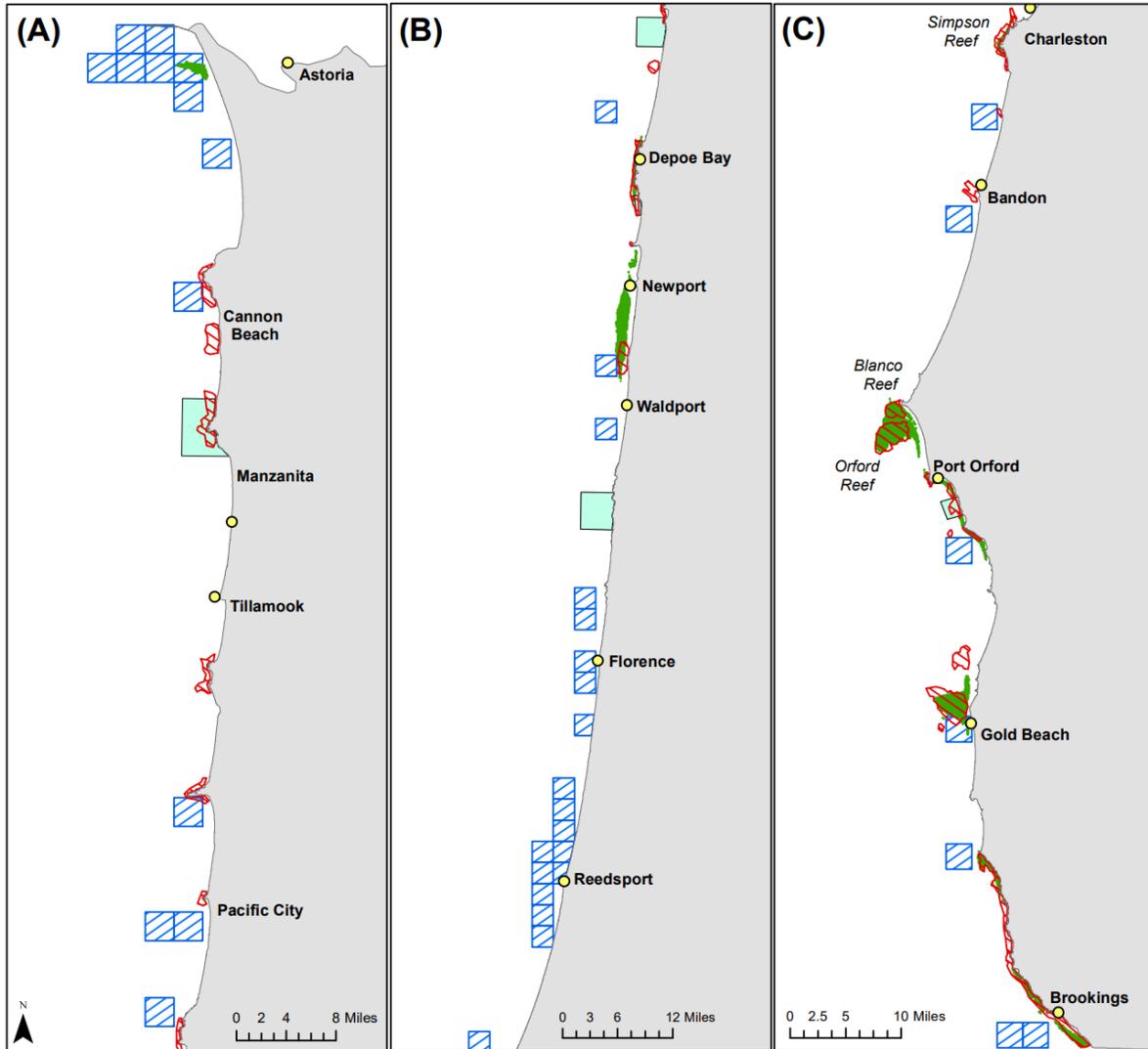


Figure 6.6. Spatial location of predicted high-density sea otter habitat (green polygons) along the outer coast and the potential overlap with and proximity of these areas to high-catch crabbing grounds (blue hatched grid cells; data from 2007 - 2017), sea urchin harvest areas (red hatched polygons;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

Dungeness crab

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

Abalone

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

1962 and a recreational fishery from 1953-2017. Both were closed because of the concerns for depletion and surveys for red abalone conducted by ODFW in 2015 showed that there were only 0.03 individuals/m² (ODFW report to the ODFW fish commission Sept 13, 2019). Flat abalone, *Haliotis walallensis*, are found in vegetated rock reefs throughout Oregon. They were commercially harvested from 2001-2008. There are no data on current population levels, but it is likely to be small as the closure was the result of conservation concerns about the population's status. Pinto abalone, *Haliotis kamtschatkana*, is a small species which ranges from Baja to Alaska, but this species is extremely rare in Oregon. There is no current commercial or recreational take of any abalone species in Oregon.

Rock Scallops

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

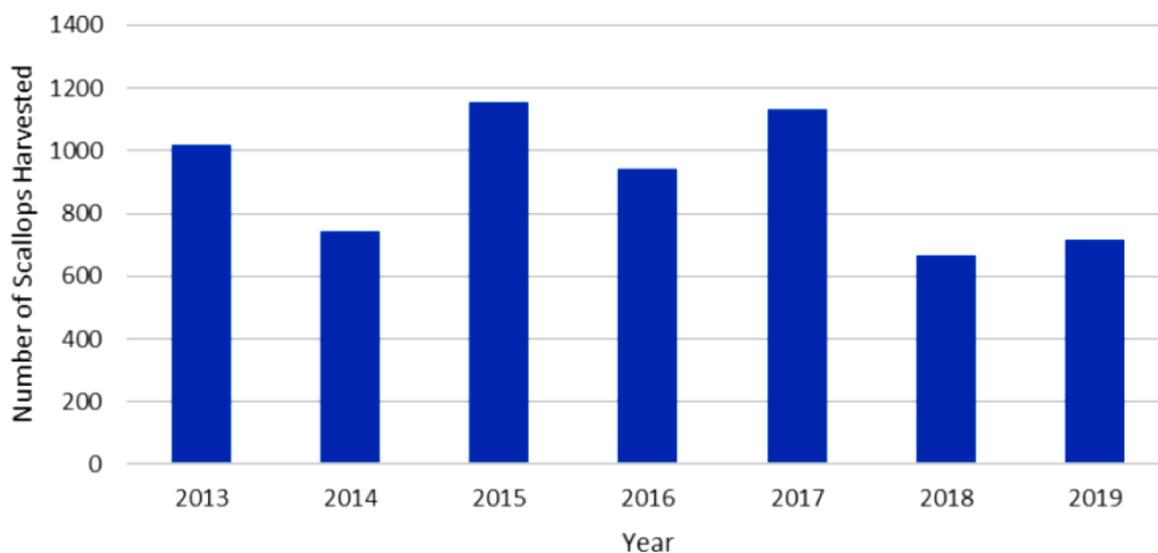


Figure 6.7. Number of rock scallops (*Crassadoma gigantean*) harvested recreationally by year in Oregon.

Coastal soft sediment areas

In addition to their use of rocky reef areas, sea otters are known to feed in soft sediment habitats in coastal areas (Kvitek and Oliver 1988, Dean et al. 2002, Hale et al. 2019). The habitat substrate maps from the Active Tectonics and Seafloor Mapping Lab at Oregon State University (Appendix B) provide details on where sand and mud substrates occur along the Oregon coast. Potential prey items in these substrates could include clams, cancrivore crabs, and sand or mole crabs (*Emerita analoga*). There is a paucity of information about subtidal invertebrate species in Oregon, particularly from nearshore soft sediment habitats. McCrae and Daniels (1998) indicate that both gaper calms (*Tresus capax*) and cockles (*Clinocardium nuttallii*) occur in soft sediment areas of the outer coast, though in smaller numbers than are found in estuaries. Razor clams, another common prey species for sea otters, are found in sandy

substrates both sub-tidally and in the low intertidal (McCrae and Daniels 1998) and are most common in northern Oregon from the mouth of the Columbia to Seaside, but also occur at lower densities throughout the coast. ODFW surveys the intertidal populations of razor clams along 18 miles of beaches in Clatsop County (Figure 6.8), but there are no comparable data on subtidal razor clam populations elsewhere in Oregon. Worth noting is that domoic acid levels toxic to humans commonly result in closures of commercial and recreational harvests of crabs and razor clams in Oregon: refer to Chapter 10 for a discussion of domoic acid effects on sea otter health.

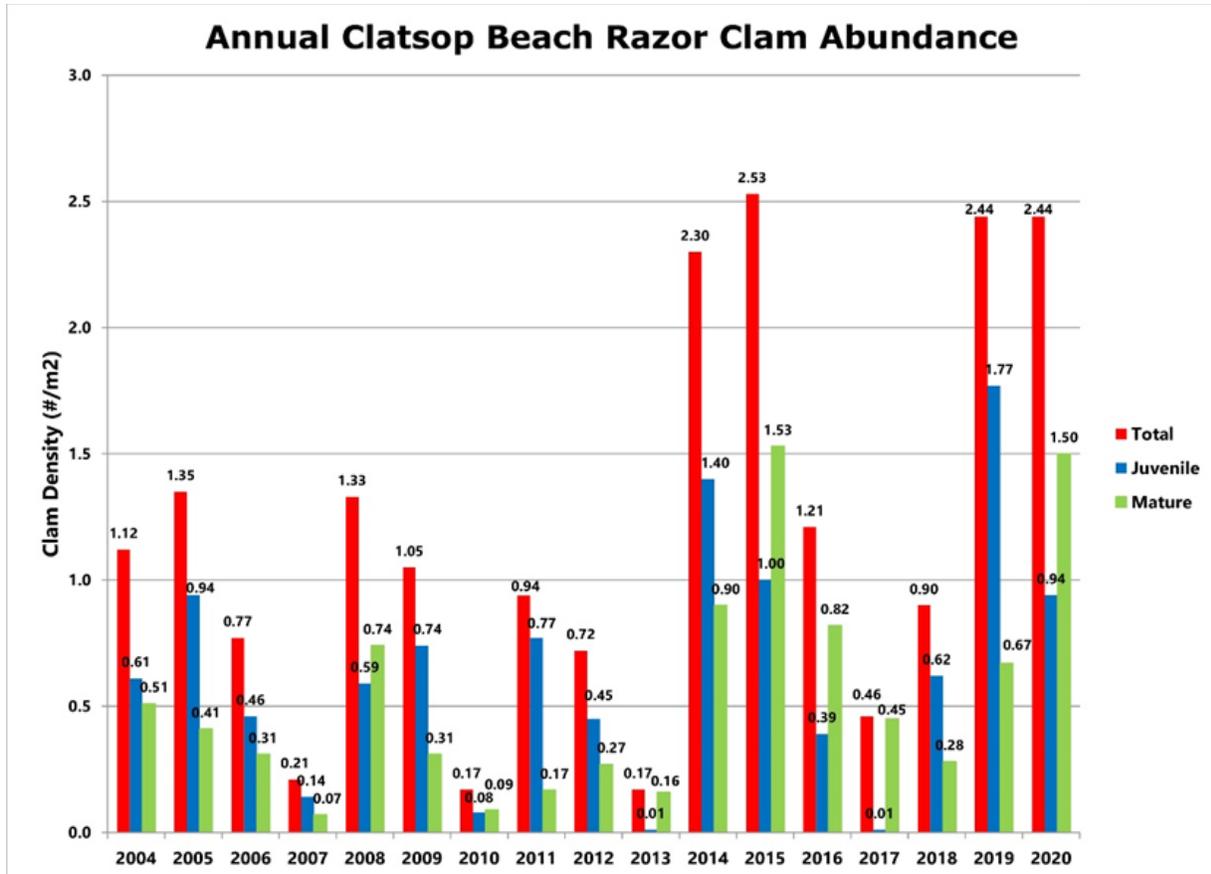


Figure 6.8. Data on annual abundance of intertidal razor clams in Clatsop County.

Estuaries

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

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

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

Eelgrass in Estuaries

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

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



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

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

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

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

- 1.) The West Coast Data Explorer of Estuaries, and
- 2.) the West Coast Eelgrass Maximum Observed Extent layer.

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

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

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

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

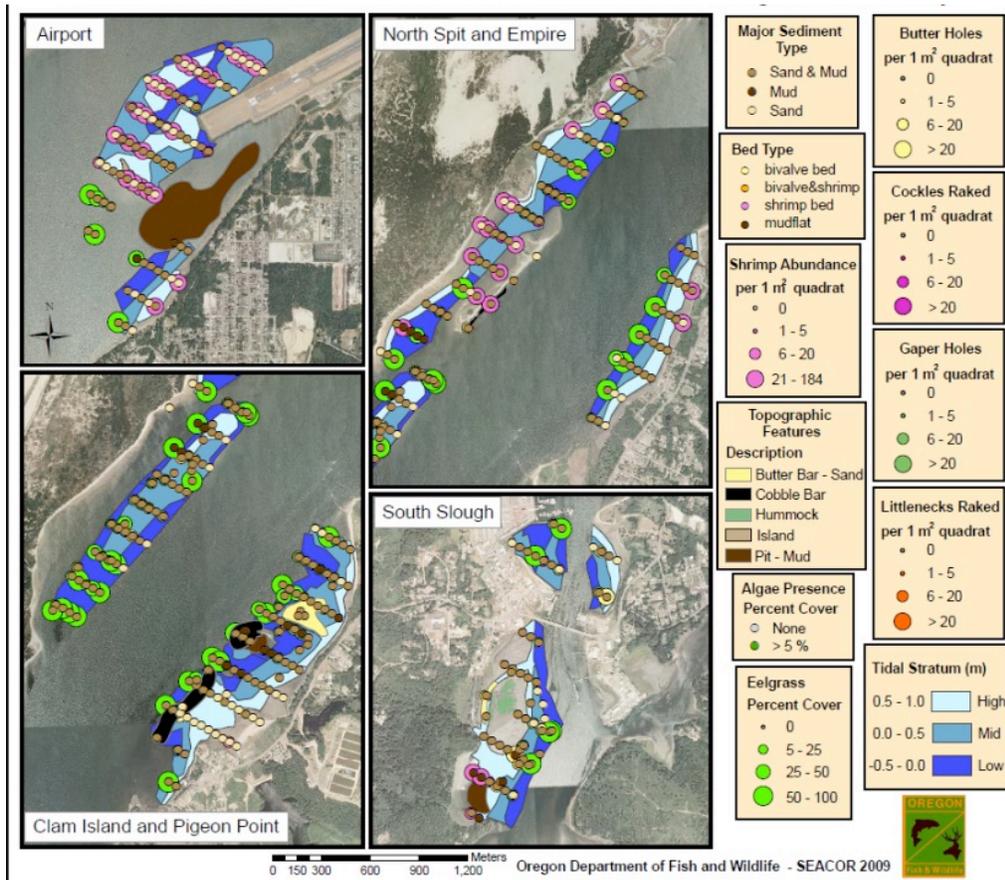


Figure 6.10 Substrate, clam abundance and eelgrass cover in Coos Bay

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



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

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

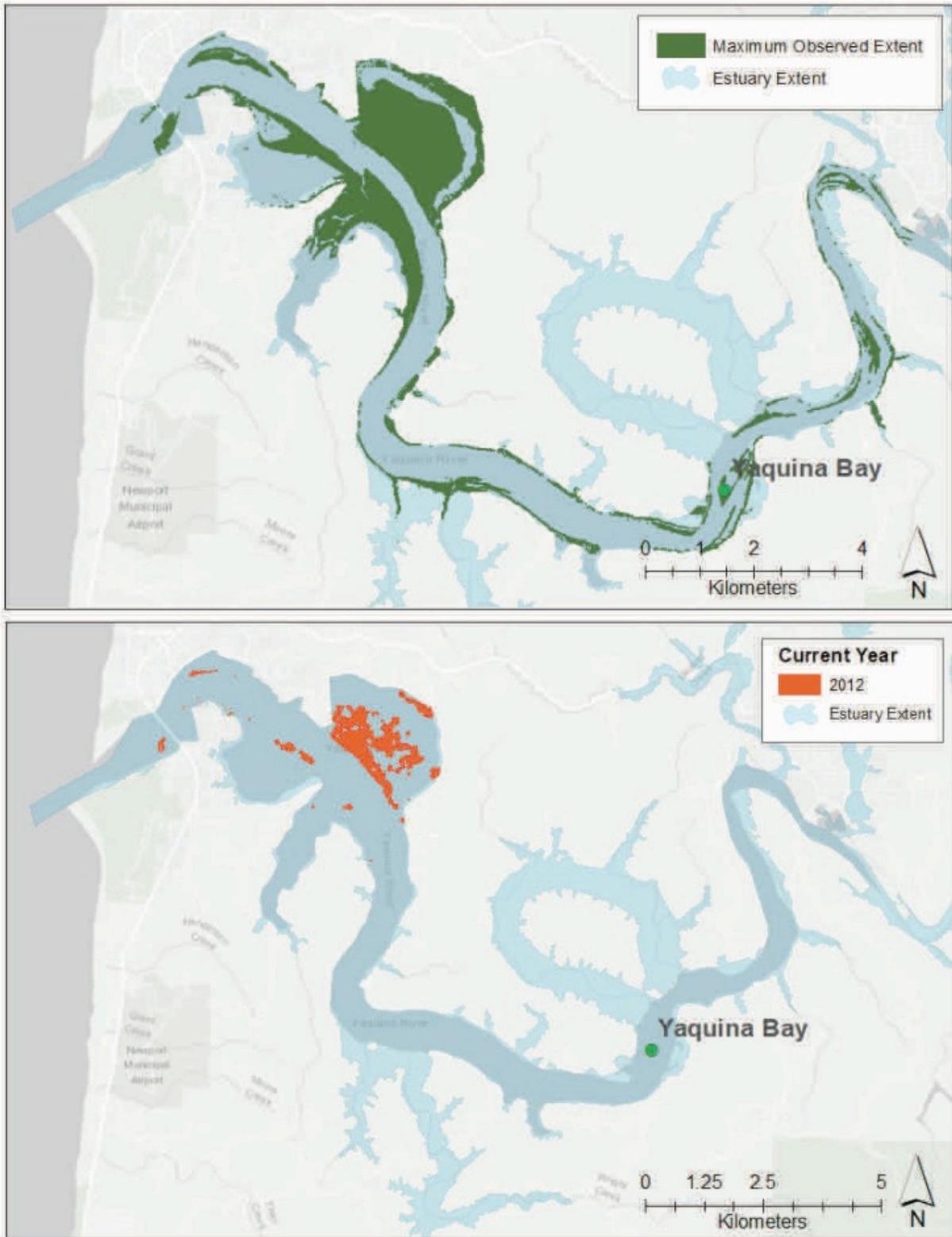


Figure 6.12. Comparison of current eelgrass extent to maximum extent for Yaquina Bay, OR. (Sherman and DeBruyckere 2018)

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

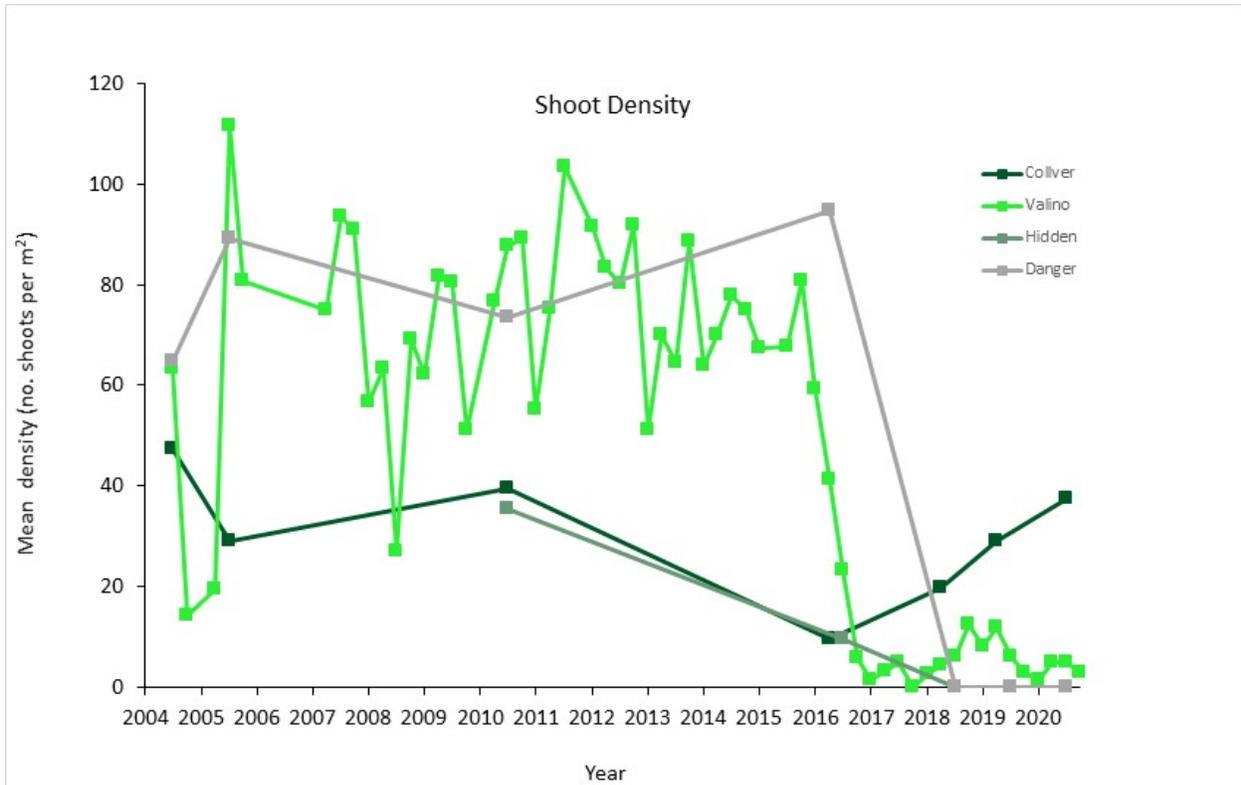


Figure 6.13. Shoot density of eelgrass from four sites in the South Slough National Estuarine Research Reserve (data provided via personal communication with Allie Helms, South Slough National Estuarine Research Reserve, Dec 2021)

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

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

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

* From (Lee II and Brown 2009).

** From Pacific Marine and Estuarine Fish Habitat Partnership: <https://estuaries.pacificfishhabitat.org/>

*** From (Phillips 1984)

Invertebrate Prey Resources in Estuaries

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

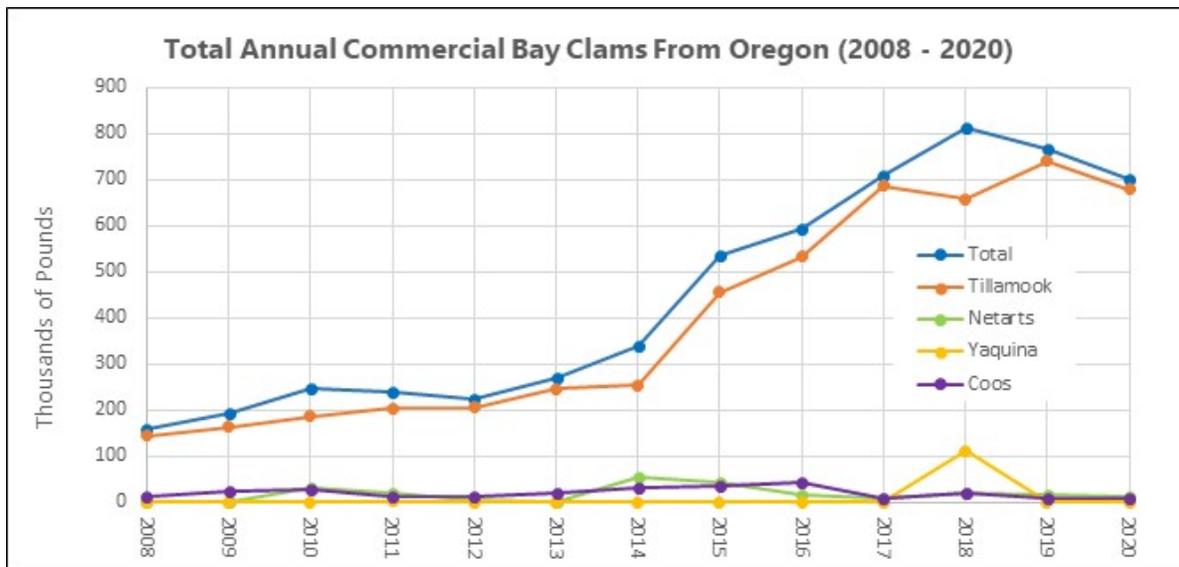


Figure 6.14. Commercial harvest of bay clams from four Oregon estuaries 2008-2020

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

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

Estuary Summary

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

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

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

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 habitats available for sea otters in Oregon.

Water quality monitoring in Oregon's marine waters is conducted by several entities and involves surveying for bacteria and biotoxins that are 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 meets, and in most cases exceeds, 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. Enterococcus is present in human and animal waste and can enter marine waters from a variety of sources such as streams and creeks, storm water 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 (OBMP) conducts regular evaluation of the enterococcus presence at beaches from Seaside to Brookings from mid-May to mid-September. In 2021 a total of 70 locations at eighteen 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. OBMP uses a testing method that estimates the number of colonies of bacteria in 100ml of water. When water samples indicate the number of colonies has reached a 130/100ml a health advisory is issued. For current health advisory results see:

<https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/RECREATION/BEACHWATERQUALITY/Pages/index.aspx>

In 2020, 8 (2.3%) samples exceeded the 130/100ml threshold. In total, since 2002, the OBMP has collected more than 17,061 samples, of which 1,203 (7.1%) exceeded the 130/100ml threshold. Overall, 68% of beach samples had no detectable fecal bacteria during the past 19 years (ODEQ 2021)

Oregon Surfriders' Blue Water Task Force Program also tests ocean water adjacent to several beaches in Oregon. Local Oregon Surfrider chapters partner with volunteers from schools, watershed councils and NGOs to operate seven labs which measure Enterococcus bacteria levels. The results of this sampling can be seen at: <https://bwtf.surfrider.org>. Data available for each site are variable: some have data from 2014 – 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 Oregon Department of Environmental Quality.

Fecal Coliform Monitoring in Estuaries

The Oregon Department of Agriculture (ODA) conducts monthly surveys for fecal coliform bacteria in estuaries that support commercial oyster farms or clam harvest. In Coos Bay, for example, there are

sixteen monitoring stations. The closure criteria occurs when samples indicate that an average of 14 bacteria colonies/100ml. ODA 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 ODA samples two other bacterial monitoring efforts take place in Coos Bay. The Confederated Tribes of the Coos, Lower Umpqua and Siuslaw Indians conducts water quality monitoring at two sites in mid Coos Bay. The Tribal Water Quality Assessment Report for October 2017 – September 2018 (<https://ctclusi.org/department-of-natural-resources-culture/>) indicates low levels of fecal coliform bacteria in the two samples from each site (Table 6.7).

Table 6.7. Fecal Coliform levels in mid Coos Bay November 2017 – September 2018

Coos - BLM 1 <i>E. coli</i>		Coos - BLM 2 <i>E. coli</i>		Coos - Empire Dock <i>E. coli</i>		Coos - Empire Dock <i>E. coli</i>	
Sample Date	MPN/100 ml	Sample Date	MPN/100 ml	Sample Date	MPN/100 ml	Sample Date	MPN/100 ml
11/7/2017	3.1	11/7/2017	2.0	11/7/2017	<1.0	11/7/2017	3.1
12/11/2017	<1	12/11/2017	<1	12/11/2017	2.0	12/11/2017	<1
1/16/2018	<1	1/16/2018	<1	1/16/2018	1.0	1/16/2018	<1
2/27/2018	<1	2/27/2018	2.0	2/27/2018	2.0	2/27/2018	<1
4/9/2018	8.5	4/9/2018	5.2	4/9/2018	7.3	4/9/2018	7.5
5/17/2018	<1	5/17/2018	<1	5/17/2018	<1	5/17/2018	1.0
6/20/2018	<1	6/20/2018	2.0	6/20/2018	<1	6/20/2018	<1
7/19/2018	<1	7/19/2018	1.0	7/19/2018	<1	7/19/2018	<1
8/23/2018	2.0	8/23/2018	<1	8/23/2018	<1	8/23/2018	<1
9/20/18	1.0	9/20/18	<1	9/20/18	<1	9/20/18	1.0

The South Slough National Estuarine Research Reserve (SSNERR) also takes water samples monthly to detect fecal coliforms, at both high and low tidal levels at multiple stations in Coos Bay, summarized at: <https://partnershipforcoastalwatersheds.org/lands-waterways-data-source> and these also consistently show low levels of fecal coliform bacteria (Ali Helms SSNERR pers comm. Jan 7, 2022).

Biotoxin Monitoring

Naturally-occurring bio-toxins can also affect sea otter health (see Chapter 10). The Oregon Department of Agriculture monitors mussels, clams and oysters for paralytic shellfish toxin and domoic acid, 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 ($\mu\text{g}/100\text{gm}$) or 20 ppm for domoic acid the recreational and/or commercial harvest is closed. Data for marine biotoxin levels and the status of closures are at:

<https://www.oregon.gov/oda/programs/foodsafety/shellfish/pages/shellfishclosures.aspx>

In summer 2021 the South Slough National Estuarine Research Reserve (SSNERR) initiated a sampling program for the presence of harmful algae in Coos Bay at seven sites in South Slough and one in mid bay. They also assessed whether the alga, mostly *Pseudo-nitzschia* spp., were producing toxins. Only in one sample from the mid bay site where toxin levels high enough that it was possible that shellfish were accumulating toxins (Ali Helms SSNERR pers comm. Jan 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 potentially suitable sea otter habitat. However, the preceding sections make clear that there is considerable variation in habitat features throughout the state – including benthic substrate (and associated invertebrate prey communities), kelp canopy cover along the outer coast, and eelgrass beds in estuaries – which would suggest that certain areas may provide higher quality habitat for sea otters (Figure 6.1). In terms of outer coast habitats, we suggest that areas in the southern half of the state appear to have a higher abundance of preferred habitat features and prey populations (especially urchins): in particular, the reef complexes near Port Orford (Blanco Reef, Orford Reef and Redfish Rocks) and Cape Arago (Simpson reef), and in the central part of the state Depoe Bay/Yaquina Head. In terms of estuarine habitats, there are three larger estuaries that appear to have an optimal combination of prey resources (clams, crabs) and resting habitats (eelgrass beds and tidal creeks) which suggest they could potentially support viable sea otter populations: Tillamook Bay, Yaquina Bay, and Coos Bay. Of these, the latter two have the additional advantage of proximity to outer coast reefs and kelp beds that could provide alternative habitats for establishing sea otter populations. 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.

Literature Cited

- Ainsworth, J., M. Vance, M. Hunter, and E. Schindler. 2012. The Oregon recreational dungeness crab fishery, 2007-2011. Oregon Department of Fish and Wildlife.
- Behrens Yamada, S., S. Schooler, R. Heller, L. Donaldson, G. T. Takacs, A. Randall, C. Buffington, and A. A. 2020. Status of the European Green Crab, *Carcinus maenas*, in Oregon and Washington coastal Estuaries in 2019. . Oregon State University, Corvallis, OR.
- Bodkin, J. L. 2015. Historic and Contemporary Status of Sea Otters in the North Pacific. Pages 43-61 *in* S. Larson, J. L. Bodkin, and G. R. Vanblaricom, editors. Sea Otter Conservation. Academic Press, Boston.
- Bodkin, J. L., B. E. Ballachey, and G. G. Esslinger. 2011. Trends in sea otter population abundance in western Prince William Sound, Alaska: Progress toward recovery following the 1989 Exxon Valdez oil spill. US Geological Survey Scientific Investigations Report **5213**:14.
- Burn, D. M., and A. M. Doroff. 2005. Decline in sea otter (*Enhydra lutris*) populations along the Alaska Peninsula, 1986–2001. Fishery Bulletin **103**:270-279.
- Cortright, R., J. Weber, and R. Bailey. 1987. Oregon estuary plan book. Oregon Department of Land Conservation and Development, Salem, OR.
- Davis, R., and J. Bodkin. in press. Sea otter foraging *in* R. Davis and A. Pagano, editors. Ethology of Sea and Marine Otters and the Polar Bear. Springer Verlag, New York, NY.
- Dayton, P. K., V. Currie, T. Gerrodette, B. D. Keller, R. Rosenthal, and D. V. Tresca. 1984. Patch dynamics and stability of some California kelp communities. Ecological Monographs **54**:253-289.
- Dean, T. A., J. L. Bodkin, A. K. Fukuyama, S. C. Jewett, D. H. Monson, C. E. O'Clair, and G. R. VanBlaricom. 2002. Food limitation and the recovery of sea otters following the 'Exxon Valdez' oil spill. Marine Ecology-Progress Series **241**:255-270.
- Eby, R., R. Scoles, B. B. Hughes, and K. Wasson. 2017. Serendipity in a salt marsh: detecting frequent sea otter haul outs in a marsh ecosystem. Ecology **98**.
- Ecoscan_Resource_Data. 1991. Oregon Kelp Resources Summer 1990. Revision 1.1. .
- Espinosa, S. M. 2018. Predictors of sea otter salt marsh use in Elkhorn Slough, California. Masters thesis. UC Santa Cruz, Santa Cruz, CA.
- Estes, J. A., J. Bodkin, and M. Tinker. 2010. Threatened southwest Alaska sea otter stock: delineating the causes and constraints to recovery of a keystone predator in the North Pacific Ocean. North Pacific Research Board final report **717**.
- Estes, J. A., and J. L. Bodkin. 2002. Otters. Pages 342-358 *in* W. F. Perrin, B. Würsig, and J. G. M. Thewissen, editors. Encyclopedia of marine mammals. Academic press, Orlando, FL.
- Feinholz, D. M. 1998. Abundance, distribution, and behavior of the southern sea otter (*Enhydra lutris nereis*) in a California estuary. Aquatic Mammals **24**:105-115.
- Fox, D., M. Amend, and A. Merems. 1999. Nearshore rocky reef assessment: Final Report for 1999 Grant Contract 99-072. Newport, OR: Oregon Department of Fish and Wildlife, Marine Program.
- Grimes, T. M., M. T. Tinker, B. B. Hughes, K. E. Boyer, L. Needles, K. Beheshti, and R. L. Lewison. 2020. Characterizing the impact of recovering sea otters on commercially important crabs in California estuaries. Marine Ecology Progress Series **655**:123-137.
- Hale, J. R., K. L. Laidre, M. T. Tinker, R. J. Jameson, S. J. Jeffries, S. E. Larson, and J. L. Bodkin. 2019. Influence of occupation history and habitat on Washington sea otter diet. Marine Mammal Science **35**:1369-1395.
- Hamilton, S. L., T. W. Bell, J. R. Watson, K. A. Grorud-Colvert, and B. A. Menge. 2020. Remote sensing: generation of long-term kelp bed data sets for evaluation of impacts of climatic variation. Ecology **101**:e03031.
- Harper, J. R., M. Morris, and S. Daley. 2011. ShoreZone Coastal Habitat Mapping Protocol for Oregon (v. 1). Oregon Department of Fish and Wildlife **CORI Project: 11-13**.

- Hatfield, B. B., J. L. Yee, M. C. Kenner, and J. A. Tomoleoni. 2019. California sea otter (*Enhydra lutris nereis*) census results, spring 2019. Report 1118, Reston, VA.
- Hessing-Lewis, M., E. U. Rechsteiner, B. B. Hughes, M. T. Tinker, Z. L. Monteith, A. M. Olson, M. M. Henderson, and J. C. Watson. 2018. Ecosystem features determine seagrass community response to sea otter foraging. *Marine Pollution Bulletin* **134**:134-144.
- Hughes, B. B., R. Eby, E. Van Dyke, M. T. Tinker, C. I. Marks, K. S. Johnson, and K. Wasson. 2013. Recovery of a top predator mediates negative eutrophic effects on seagrass. *Proceedings of the National Academy of Sciences of the United States of America* **110**:15313-15318.
- Hughes, B. B., K. Wasson, M. T. Tinker, S. L. Williams, L. P. Carswell, K. E. Boyer, M. W. Beck, R. Eby, R. Scoles, M. Staedler, S. Espinosa, M. Hessing-Lewis, E. U. Foster, K. M. Beheshti, T. M. Grimes, B. H. Becker, L. Needles, J. A. Tomoleoni, J. Rudebusch, E. Hines, and B. R. Silliman. 2019. Species recovery and recolonization of past habitats: lessons for science and conservation from sea otters in estuaries. *PeerJ* **7**:e8100.
- Huntington, B., J. Watson, K. Matteson, N. McIntosh, D. Wolfe Wagman, K. Pierson, C. Don, D. Fox, S. Marion, and S. Groth. 2015. Ecological monitoring report, 2012-2013. Oregon Department of Fish and Wildlife, Marine Resources Program, Newport, OR.
- Jameson, R. J. 1975. An evaluation of attempts to reestablish the sea otter, in Oregon. Oregon State University, Corvallis, OR.
- Jeffries, S., D. Lynch, S. Thomas, and S. Ament. 2017. Results of the 2017 survey of the reintroduced sea otter population in Washington state. Washington Department of Fish and Wildlife, Wildlife Science Program, Marine Mammal Investigations, Lakewood, Washington.
- Kone, D., M. T. Tinker, and L. Torres. 2021. Informing sea otter reintroduction through habitat and human interaction assessment. *Endangered Species Research* **44**:159-176.
- Kvitek, R. G., and J. S. Oliver. 1988. Sea Otter Foraging Habits and Effects on Prey Populations and Communities in Soft-Bottom Environments. *in* G. R. VanBlaricom and J. A. Estes, editors. *The Community Ecology of Sea Otters*. Springer Verlag Inc., New York.
- Laidre, K. L., R. J. Jameson, and D. P. DeMaster. 2001. An estimation of carrying capacity for sea otters along the California coast. *Marine Mammal Science* **17**:294-309.
- Laidre, K. L., R. J. Jameson, S. J. Jeffries, R. C. Hobbs, C. E. Bowlby, and G. R. VanBlaricom. 2002. Estimates of carrying capacity for sea otters in Washington state. *Wildlife Society Bulletin* **30**:1172-1181.
- Lee II, H., and C. A. Brown. 2009. Classification of regional patterns of environmental drivers and benthic habitats in Pacific Northwest Estuaries. National Health and Environmental Effects Research Laboratory.
- McCrae, J., and P. Daniels. 1998. Experimental clam dredge progress report. Oregon Department of Fish and Wildlife (ODFW) Technical Report https://ir.library.oregonstate.edu/concern/technical_reports/b8515p287.
- Newsome, S. D., M. T. Tinker, V. A. Gill, Z. N. Hoyt, A. Doroff, L. Nichol, and J. L. Bodkin. 2015. The interaction of intraspecific competition and habitat on individual diet specialization: a near range-wide examination of sea otters. *Oecologia* **178**:45-59.
- Nicholson, T. E., K. A. Mayer, M. M. Staedler, J. A. Fujii, M. J. Murray, A. B. Johnson, M. T. Tinker, and K. S. Van Houtan. 2018. Gaps in kelp cover may threaten the recovery of California sea otters. *Ecography* **41**:1751-1762.
- ODEQ. 2021. Oregon Beach Monitoring Program, 2021 Evaluation of Monitoring Sites. Oregon Department of Environmental Quality, DEQ21-LAB-0027-TR 5/26/2021.
- Ostfeld, R. S. 1982. Foraging strategies and prey switching in the California sea otter. *Oecologia* **53**:170-178.

- Phillips, R. C. 1984. The ecology of eelgrass meadows of the Pacific Northwest: a community profile. U.S. Fish and Wildlife Service, FWS/OBS - 84/24.
- Rathbun, G. B., B. B. Hatfield, and T. G. Murphey. 2000. Status of translocated sea otters at San Nicolas Island, California. *Southwestern Naturalist* **45**:322-328.
- Rechsteiner, E. U., J. C. Watson, M. T. Tinker, L. M. Nichol, M. J. Morgan Henderson, C. J. McMillan, M. DeRoos, M. C. Fournier, A. K. Salomon, L. D. Honka, and C. T. Darimont. 2019. Sex and occupation time influence niche space of a recovering keystone predator. *Ecology and Evolution* **9**:3321–3334.
- Riedman, M. L., and J. A. Estes. 1990. The sea otter, *Enhydra lutris*: behavior, ecology and natural history. U S Fish and Wildlife Service Biological Report **90**:1-126.
- Sanborn, E. I., and M. S. Doty. 1944. The marine algae of the Coos Bay-Cape Arago region of Oregon.
- Sherman, K., and L. A. DeBruyckere. 2018. Eelgrass habitats on the US West Coast. State of the Knowledge of Eelgrass Ecosystem Services and Eelgrass Extent. A publication prepared by the Pacific Marine and Estuarine Fish Habitat Partnership for The Nature Conservancy:67 pp.
- Silliman, B. R., B. B. Hughes, L. C. Gaskins, Q. He, M. T. Tinker, A. Read, J. Nifong, and R. Stepp. 2018. Are the ghosts of nature's past haunting ecology today? *Current Biology* **28**:R532-R537.
- Springer, Y. P., C. G. Hays, M. H. Carr, and M. R. Mackey. 2010. Toward ecosystem-based management of marine macroalgae—The bull kelp, *Nereocystis luetkeana*. *Oceanography and marine biology* **48**:1.
- Tinker, M. T., G. Bentall, and J. A. Estes. 2008. Food limitation leads to behavioral diversification and dietary specialization in sea otters. *Proceedings of the National Academy of Sciences of the United States of America* **105**:560-565.
- Tinker, M. T., J. L. Bodkin, M. Ben-David, and J. A. Estes. 2017. Otters. Pages 664-671 in B. Wursig, H. Thewissen, and K. M. Kovacs, editors. *Encyclopedia of Marine Mammals*, 3rd Edition. Elsevier Inc., New York, NY.
- Tinker, M. T., V. A. Gill, G. G. Esslinger, J. L. Bodkin, M. Monk, M. Mangel, D. H. Monson, W. E. Raymond, and M. Kissling. 2019a. Trends and Carrying Capacity of Sea Otters in Southeast Alaska. *Journal of Wildlife Management* **83**:1073-1089.
- Tinker, M. T., P. R. Guimarães, M. Novak, F. M. D. Marquitti, J. L. Bodkin, M. Staedler, G. Bentall, and J. A. Estes. 2012. Structure and mechanism of diet specialisation: testing models of individual variation in resource use with sea otters. *Ecology Letters* **15**:475--483.
- Tinker, M. T., J. A. Tomoleoni, B. P. Weitzman, M. Staedler, D. Jessup, M. J. Murray, M. Miller, T. Burgess, L. Bowen, A. K. Miles, N. Thometz, L. Tarjan, E. Golson, F. Batac, E. Dodd, E. Berberich, J. Kunz, G. Bentall, J. Fujii, T. Nicholson, S. Newsome, A. Melli, N. LaRoche, H. MacCormick, A. Johnson, L. Henkel, C. Kreuder-Johnson, and P. Conrad. 2019b. Southern sea otter (*Enhydra lutris nereis*) population biology at Big Sur and Monterey, California --Investigating the consequences of resource abundance and anthropogenic stressors for sea otter recovery. US Geological Survey Open-File Report No. 2019-1022. US Geological Survey Open-File Report, Reston, VA.
- Tinker, M. T., J. L. Yee, K. L. Laidre, B. B. Hatfield, M. D. Harris, J. A. Tomoleoni, T. W. Bell, E. Saarman, L. P. Carswell, and A. K. Miles. 2021. Habitat features predict carrying capacity of a recovering marine carnivore. *Journal of Wildlife Management* **85**:303-323.
- Waldron, K. D. 1955. A Survey of the Bull Kelp Resources in Oregon. Fish Commission of Oregon, Research Briefs **6**:15-20.
- Watt, J., D. B. Siniff, and J. A. Estes. 2000. Inter-decadal patterns of population and dietary change in sea otters at Amchitka Island, Alaska. *Oecologia* **124**:289-298.
- Wild, P. W., and J. A. Ames. 1974. A report on the sea otter, *Enhydra lutris* L., in California.