Appendix E

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

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INTRODUCTION

The issue

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

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

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

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

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

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

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

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

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

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

Study objectives

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

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

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

STUDY AREA

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

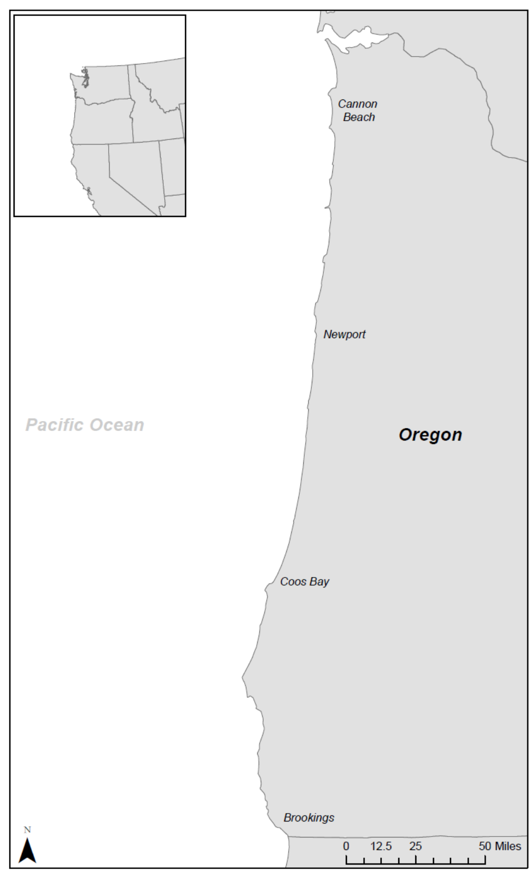


Figure 1: Our study area - The Oregon coast.

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

THE COLLABORATIVE PROCESS

In-person meetings

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

Expertise identification

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

Question identification

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

Analyses

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

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

METHODS

The rationale for reintroduction

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

The precontact Oregon sea otter

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

Genetics

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

Archaeology

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

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

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

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

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

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

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

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

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

Modelling sea otter population growth

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

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

Preferences and Perceptions

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

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

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

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

Table 1: Stakeholder Affiliations of Respondents

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

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

Measures

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

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

Integration

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

RESULTS

Reintroduction rationale and historical justification

Why translocate

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

Conservation translocations

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

Ecological restorations

Ecological restorations, by contrast, have an underlying motivation of *genetic adaptation* (Broadhurst et al. 2008). Even when a small recipient population persists in an environment, its genetic variability may be limited, and the attempt to recruit from it exclusively may further depress its viability. Rather, the focus is on bringing in high-quality stock that will generate genetic diversity, some of which will prove adaptive to the local environment. This approach is well-suited for keystone species that have the potential to dramatically enhance local ecosystems. Timeframes are necessarily greater in scope with this strategy, with long-term persistence the goal. The 25-year window that Alaskan sea otter recovery plans (USFWS 2013) employ in determining listing status are appropriate.

The Oregon sea otter

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

<u>Taxonomy by morphometrics</u>

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

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

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

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

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

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

RFLP: first use of DNA

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

Taxonomy matters

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

Microsatellites as genetic markers

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

Genetics and the Oregon sea otter

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

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

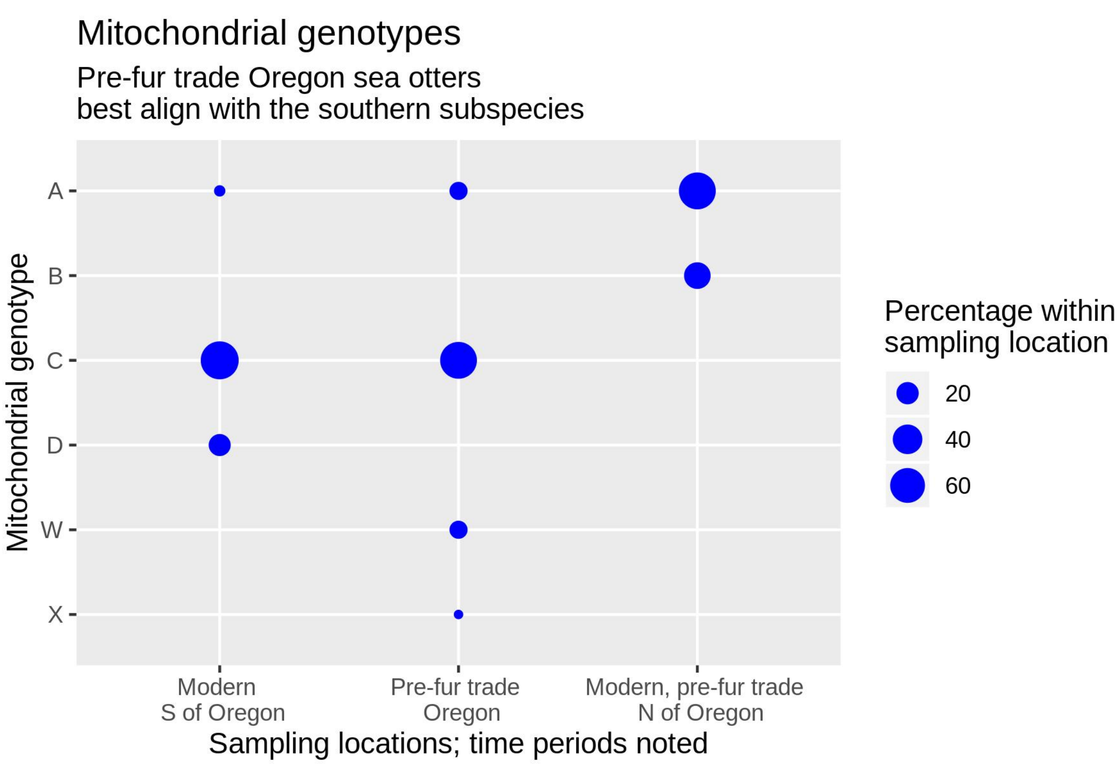


Figure 2: Genotypes from mitochondrial DNA were compared across three groups of sea otters. Modern Californian samples represent the southern ssp. Washington and Alaskan samples ancient and modern are pooled to compare to ancient Oregon.

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

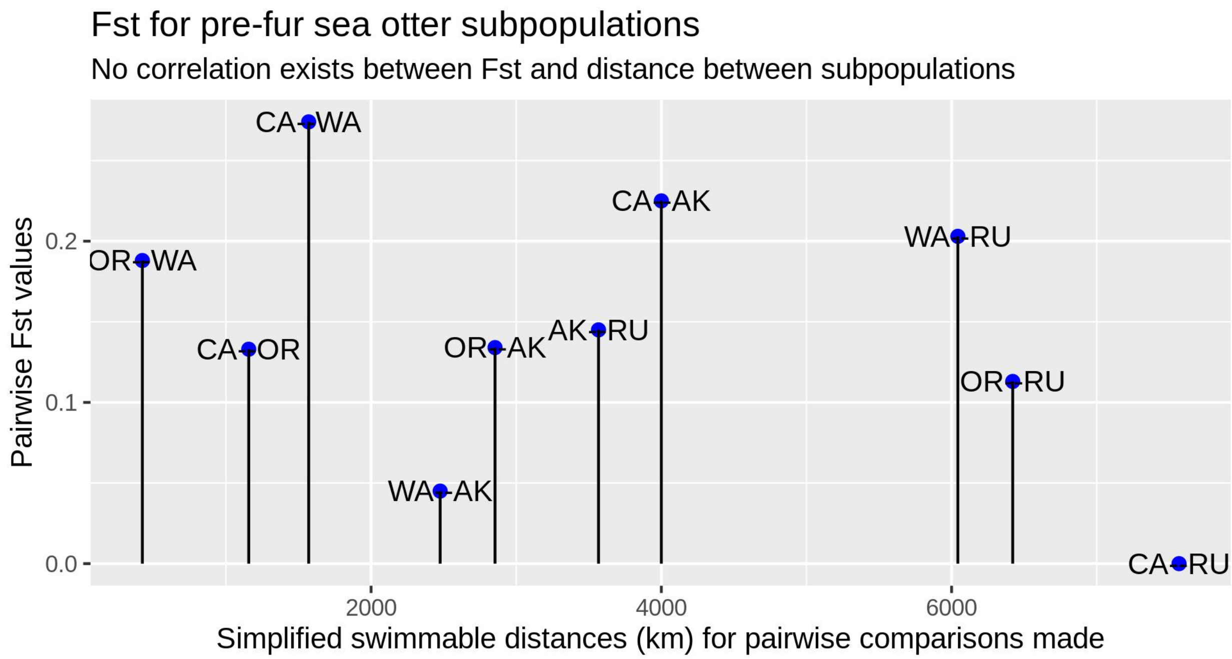
In a study more generally concerned with genetic diversity and population parameters for the species as a whole before the fur trade, Larson et al. (2012) employed 5 microsatellite loci in a study that drew on samples of 5 pre-fur trade populations and 5 contemporary populations. From Oregon, 40 samples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

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

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

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

A)



B)

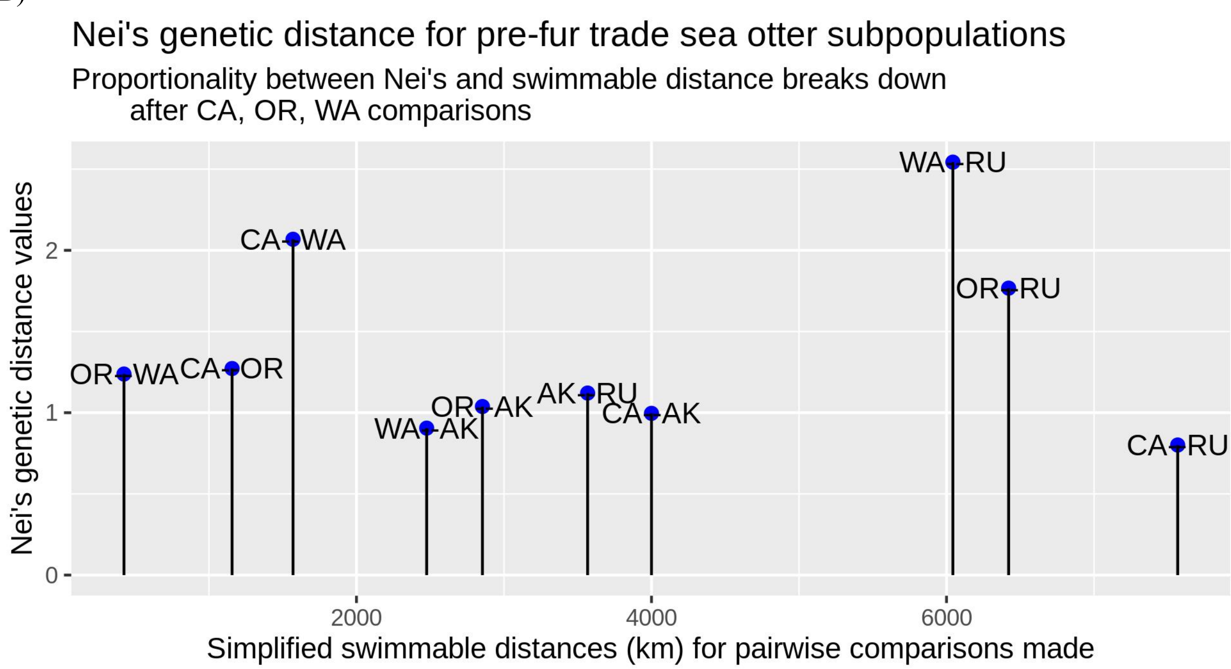


Figure 3: A) the values of pairwise Fst comparisons made among pre-fur trade sea otter populations are plotted against the swimmable distances between each population's geographic location. Swimmable distance refers to the less direct path that sea otters, largely limited to nearshore waters, might take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

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

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

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

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

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

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

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

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

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

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

Zooarchaeological arguments, resources for sea otter reintroduction strategies

Shell middens

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

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

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

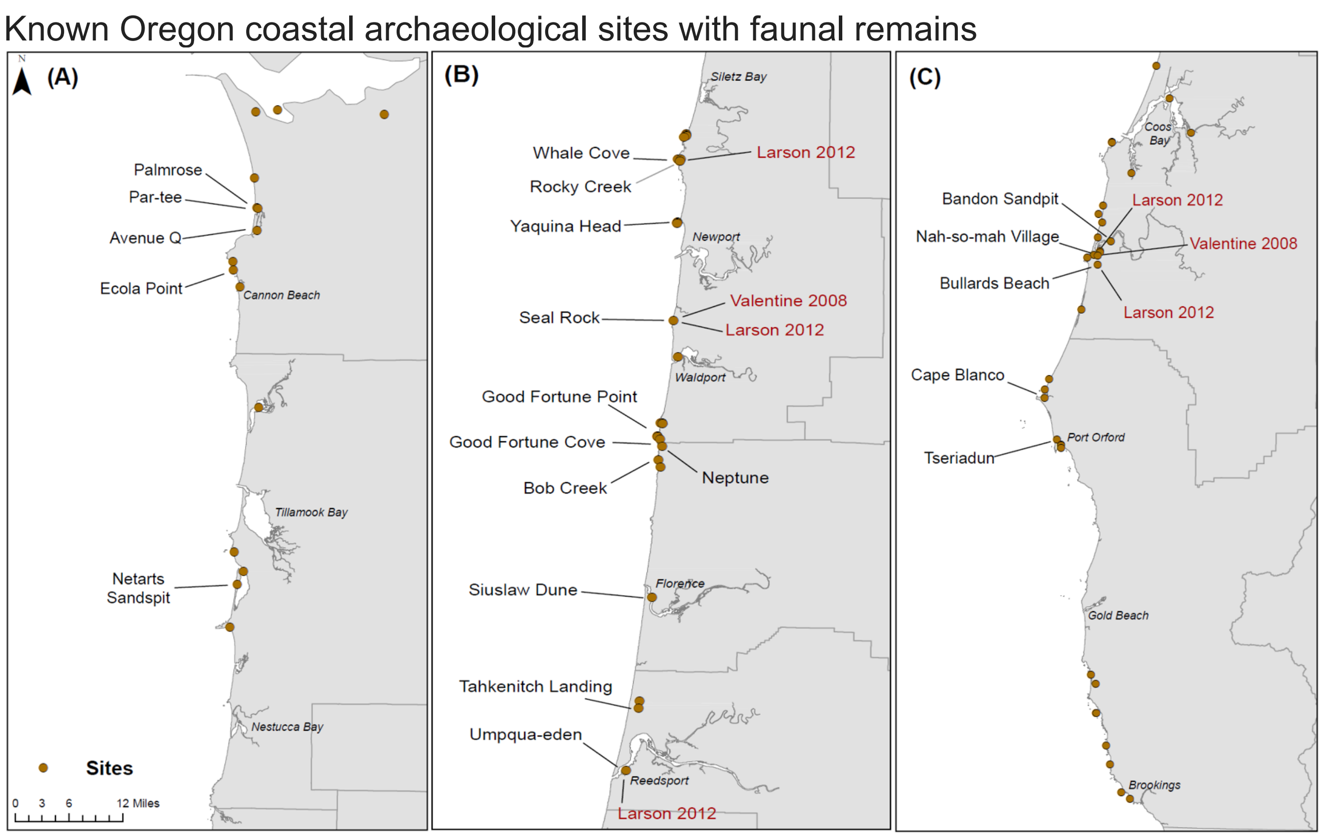


Figure 4: Coastal Oregon archaeological sites with known vertebrate faunal remains plotted across the North (A), Central (B), and South (C) regions. Labelled sites are known to have held sea otter remains. Sites that past genetic studies have sampled are labelled in red.

North Oregon coastal sites

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

Central Oregon coastal sites

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

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

South Oregon coastal sites

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

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

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

Carrying capacity & suitable habitat

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

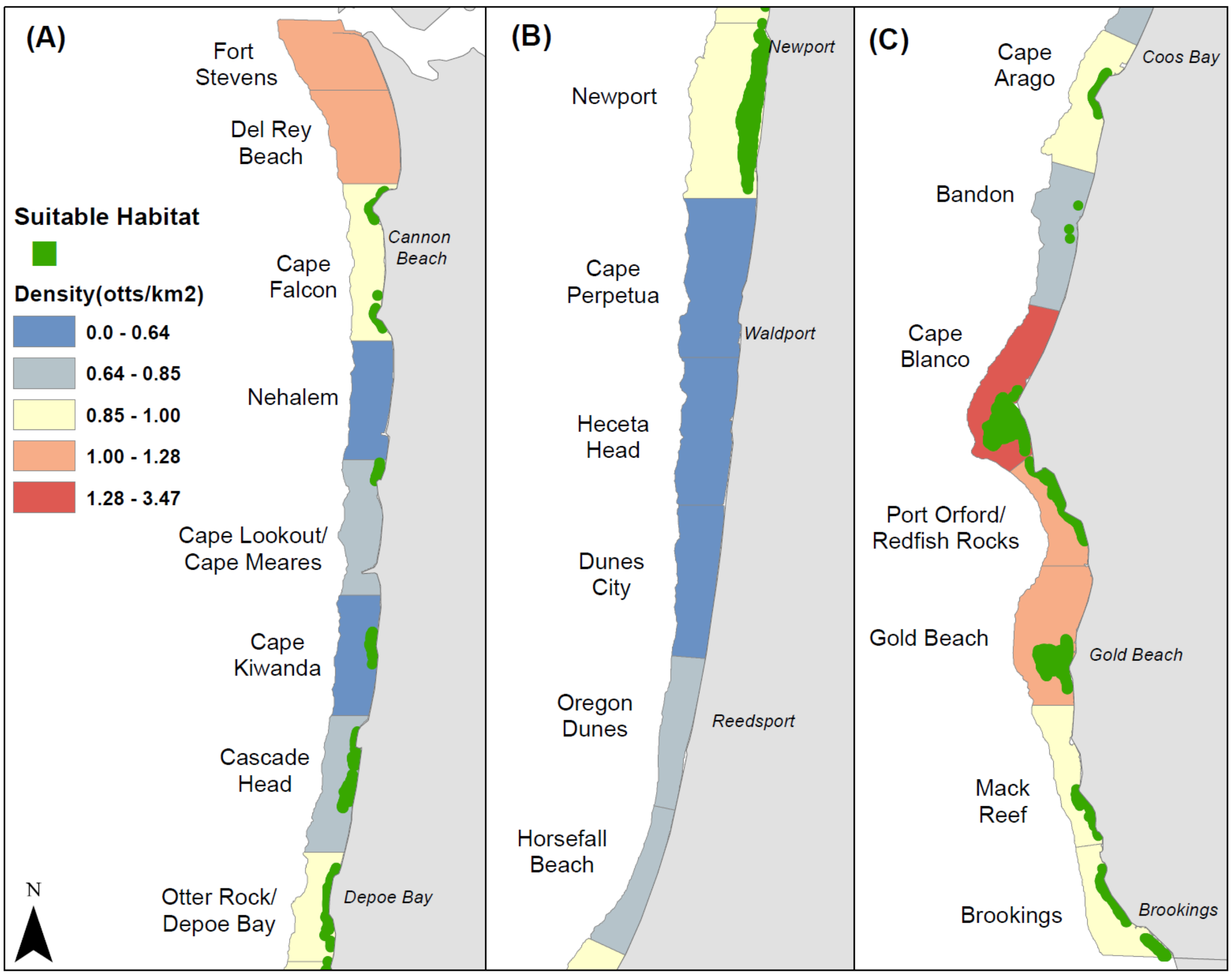


Figure 7. Identified suitable sea otter habitat areas, and outer coastal zones created around suitable habitat with predicted otter densities. Areas are presented by region for visualization (A = north, B = central, C = south).

Predicted otter densities

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

Human Activities

Protected Areas

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

Accessibility

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

Fisheries Overlap

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

Sea otter population growth

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

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

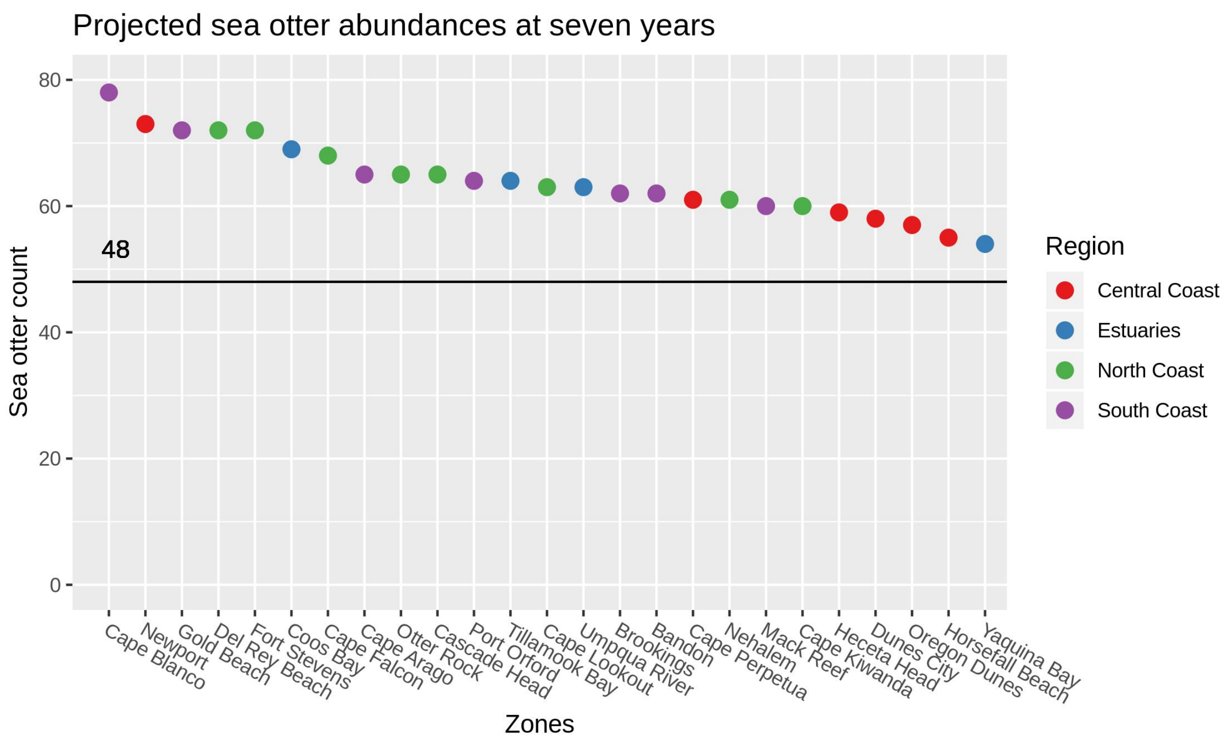


Figure 8: For each zone, population growth over 7 years was projected using a density-dependent model with stochasticity. The horizontal line reflects the 20 of the initial reintroduction and the 7 years x 4 individuals with which the initial population was augmented.

Preferences towards potential sea otter reintroduction locations

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

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

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

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

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

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

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

Anticipated outcomes of sea otter reintroduction

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

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

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

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

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

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

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

Sea otter reintroduction policy support

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

Table 5: Sea Otter Reintroduction Policy Opposition or Support

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

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

Table 6: Sea Otter Reintroduction Policy Support by Stakeholder Group

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

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

Sea otter reintroduction stock considerations

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

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

A region-level comparison

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

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

High Levels of Support

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

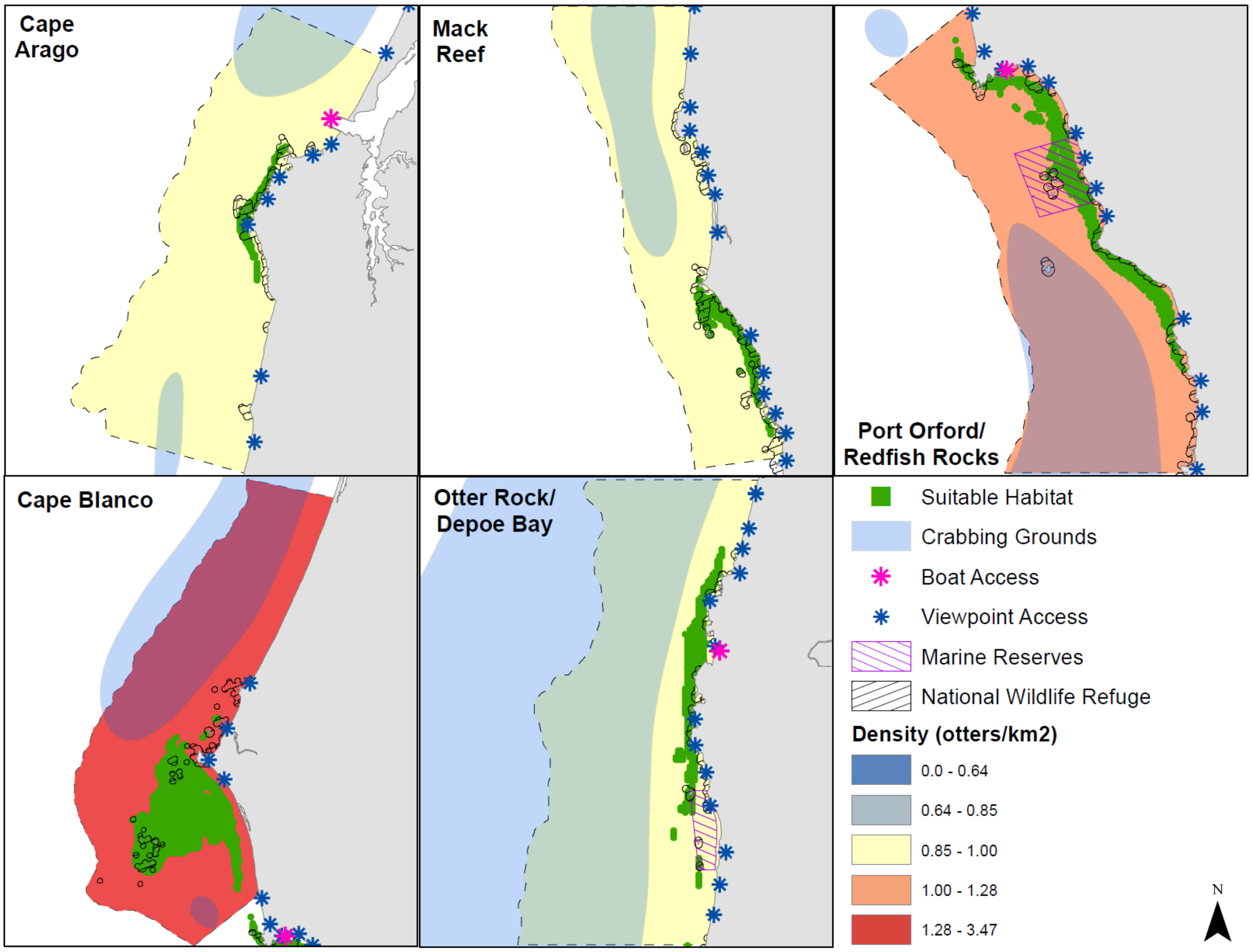


Figure 12: 5 sites across all three regions given high levels of support in survey results with additional ecological and management metrics.

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

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

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

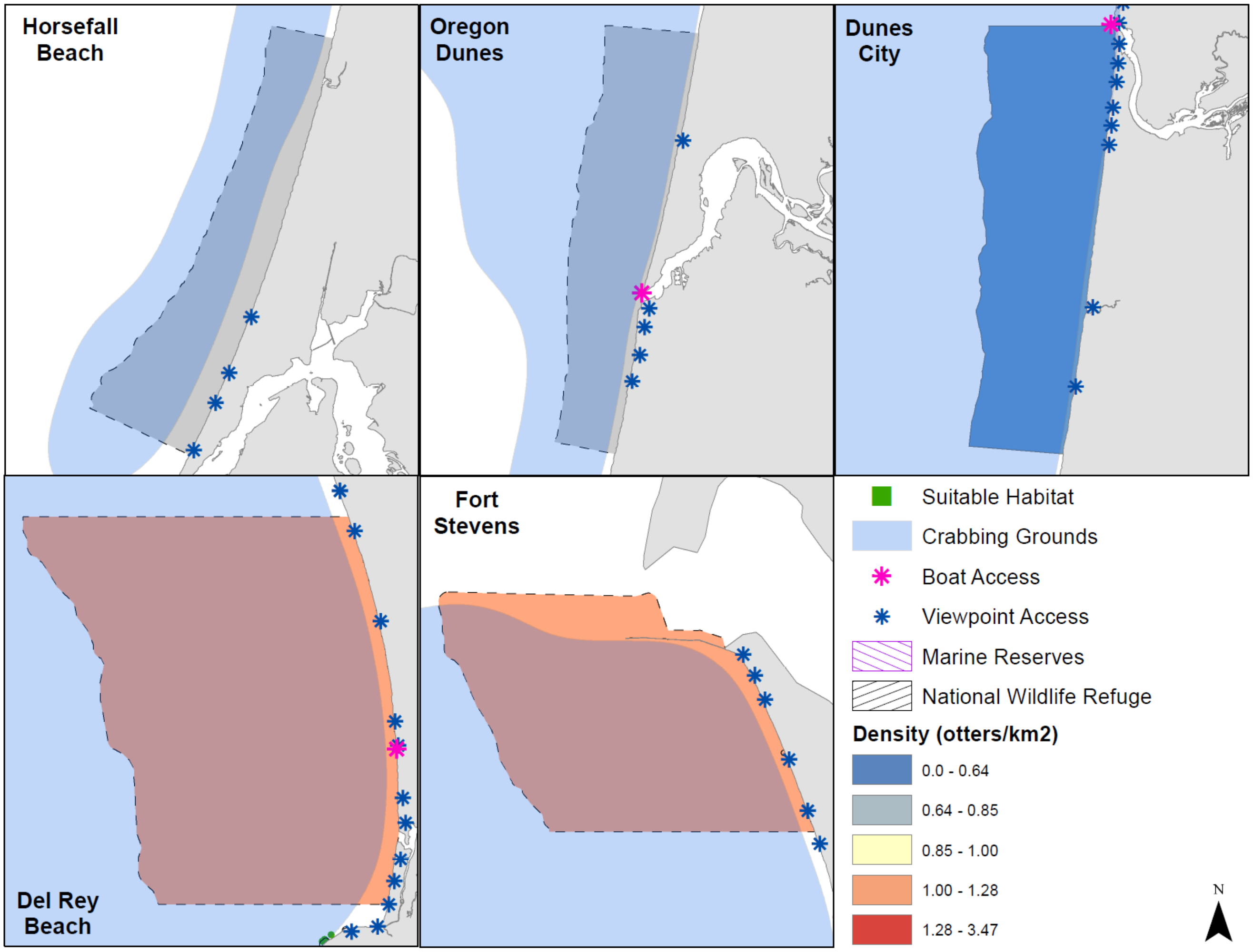


Figure 13: 5 sites that received low levels of support in survey responses with additional ecological and management metrics

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

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

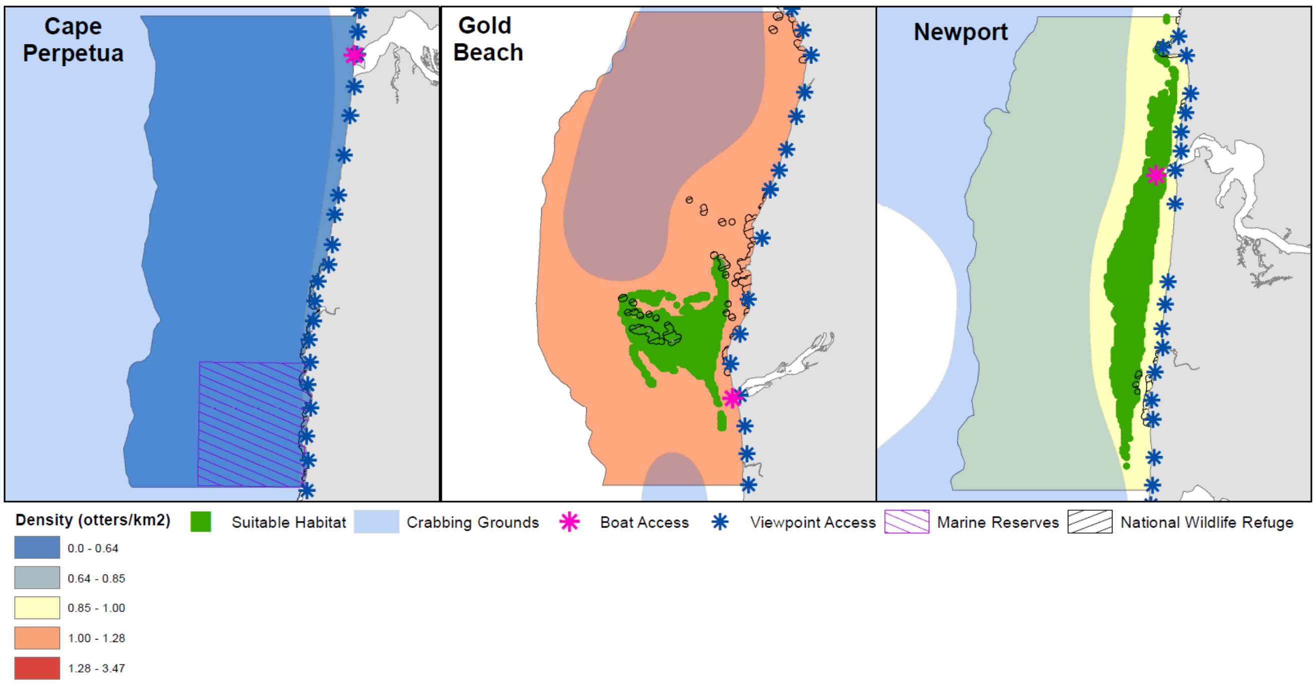


Figure 14: Selected sites that warrant additional discussion.

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

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

zones based on emotional or intrinsic values. However, Gold Beach does not contain any landmarks that make it distinguishable or unique, such as Otter Rock/Depoe Bay or Cape Perpetua. It is otherwise unclear why respondents did not support Gold Beach as much as other zones when in fact it contains several ecological and demographic factors that may facilitate a successful reintroduction.

Newport

Newport had some of the greatest disagreements between factors. Survey respondents were not as supportive of this zone as a potential reintroduction site. They rated Newport a 4.42 in support, not significantly different from the top score, but a difference of 1.11 could still suggest slightly less support. In terms of ecological factors, Newport has a large suitable habitat area. Still, we estimate a modest predicted density of 0.94 otters/km^2 (8th overall). Newport had the 2nd highest population growth potential, at 25 otters over 7 years. In terms of protection, Newport ranked very much in the middle of all zones. Yet, these estimates were quite small with only 3.23 otters occurring within protected areas, and only 0.71 otters within suitable habitat. For accessibility, Newport presents some potentially positive and negative results, with the highest level of vessel accessibility (distance = 0.10 km) and 5th highest level of viewer accessibility (0.59 points/km), which could facilitate effective research and management, but also disturbance. Given the disparate rankings of these factors, it's difficult to determine how Newport's suitability compares with other zones. We suggest that Newport does have some potential as a reintroduction site, based on ecological and demographic factors. Yet, there appears to be some unknown reasons as to why survey respondents were not as supportive of Newport, relative to other zones.

DISCUSSION

We asked survey respondents to list any potential positive or negative outcomes of a sea otter reintroduction to Oregon. These responses allow us to better understand the respondents' mental models, as well as what they value and are most concerned with in this effort. We hand select a few of these responses as key points to drive the discussion of our study, and identify which of these responses (i.e., perceptions of risk and benefits) our analyses are able to address - even if partially - and the sources of uncertainty that remain. These responses also help to potentially explain or provide hypotheses behind some of the identified disagreements among our ecological, demographic, and social factors.

Positive outcomes

Increased ecosystem health & ecosystem services

When sea otters reclaim historical habitat, they can increase overall species diversity via trophic cascades triggered by top-down forcing (Estes and Duggins 1995). Increased species diversity has been linked to improved ecosystem resilience and health. More resilient and healthy ecosystems can provide a suite of ecosystem services. While our analyses did not investigate these potential ecosystem changes, by identifying where sea otters are likely to reside (i.e., suitable habitat) we can make some speculations as to where these ecosystem changes and associated benefits may occur. Yet, we must recognize there are several human activities along the Oregon coast that could influence where a sea otter reintroduction should take place occur. Our analyses attempted to investigate some of those factors (i.e. protected areas, accessibility, and fisheries) that could influence sea otter distribution. Some of these factors could increase sea otter reestablishment, facilitate ecosystem service provisioning, or impede sea otter reestablishment. Factors such as accessibility are more complex. While they could serve as a potential source of disturbance to sea otters, they can also facilitate recreational activities (i.e., wildlife viewing, fishing) and the benefits derived from those activities. Ultimately, our analysis did not determine what these ecosystem changes will be, their magnitude, and if and whom they will serve. Regardless, several survey respondents noted these ecosystem benefits as positive outcomes of a reintroduction. It is possible that respondents supported specific zones based on these perceived benefits, which would make some zones appear more suitable as potential reintroduction sites. This raises the question as to whether stakeholders' general knowledge and awareness of these potential benefits influence their level of support for such an effort. As stakeholders become better informed, their attitudes toward reintroduction sites and the prospect of sea otter translocation as a whole may well shift.

Species recovery & conservation

Survey responses suggested that respondents could appreciate both the historical context of a sea otter reintroduction and how the founding would impact on source populations. Over two-thirds of respondents favored a reintroduction source that reflected the genetic heritage of the now-absent Oregon sea otter. Conservation biology concerns were strongly expressed in their support for considering species-level viability concerns. Intriguingly, half of respondents found a balance of rescues from stranding programs and wild-caught otters to be appropriate. This may reflect a sense that no single strategy is best. While half of respondents were not unduly concerned at the prospect of mortality in the founding population, the 7% extremely concerned should be respected. Those fully engaged in sea otter conservation know that excessive mortality is a concern in even established populations. But the charismatic appeal of otters can be expected to elicit deep concerns over animal suffering. If responses among a larger sample size followed the same trend, Oregonians could be said to both deeply value the uniqueness of the Oregon sea otter and also share concern for their global well-being.

We see two favorable outcomes from the preliminary population viability analysis. Despite the clearly optimistic parameters set for the model, prospects for the success of a sea otter reintroduction appear to be promising. All zone outcomes were at least nominally positive. While an actual reintroduction effort will not be afforded a chance to have 1000 replicates, adaptive management strategies can institute precautionary measures and help offset the cost of adverse events to the translocated population for a positive outcome. Secondly, the modest increase in the number of individuals in the medium-term future gives the human side of the coupled human-natural system time in which to adapt. We would hope that the ecological restoration evident in other translocations will take effect in Oregon's nearshore environment as well. However, managers may want to prioritize the uncertainties associated with species reintroductions and trophic cascades to facilitate accurate understanding among stakeholders. Oregon residents may well be able to take advantage of the return to a more balanced nearshore ecosystem dynamic that sea otters may initiate. The projected gradual expansion of an Oregon sea otter population should give managers the ability to monitor and manage sea otter impacts and benefits.

Restored cultural connections

Beyond definitively establishing the sea otter presence in Oregon, the prevalence of sea otter remains in shell middens speaks to their place in Native American culture for thousands of years. Accounts speak of the value placed on their pelts and their importance in trade (Ruby and Brown 1993). In both research (e.g., Hall et al. 2012) and conversations with tribal representatives, we can attest to the importance that Oregon tribes place on the return of the sea otter. Were the decision made to proceed with a sea otter reintroduction, not only would a missing ecological component be remade but the cultural connection between native tribes and the sea otter would be restored as well. Sea otters as a cultural resource, both for tribes and for Oregonians generally, was a positive outcome mentioned by multiple survey respondents. Whether Oregon's general public views sea otters as a cultural resource is unclear from our results, though, and sea otters' absence during the past century may constrain their status as a cultural resource for the public. However, a number of respondents also mentioned as a positive outcome, sea otters serving as a flagship species to promote conservation and education. If reintroduction does occur and sea otters assume a flagship species role, then that could foster cultural connections over the medium to long term.

Negative outcomes

Fisheries conflict

Competition between sea otters and fisheries is a common concern wherever sea otters and people co-occur. Sea otters can sufficiently reduce local prey populations (Estes and Duggins 1995), but reductions will depend on where sea otters are located. Understanding where sea otters are likely to distribute can help us assess whether interactions with fisheries is possible. We found little overlap between suitable habitat and important crabbing grounds. Based on these results, alone, it's possible sea otters will have limited interaction with this fishery. This finding does not mean sea otters will never interact with this fishery, or even other fisheries (i.e. sea urchins, bay clams, mussels) at that. Sea otters can travel dozens of kilometers in search of food and may travel beyond suitable habitat, if necessary. If crabbing grounds are within their dispersal capability, there could be an interaction. However, our study did not assess proximity to fishing grounds. It is also important to note that these important crabbing grounds are (1) stated, and therefore, may not reflect where relatively high catches occur (i.e. grounds may be important for other reasons beyond catch), and (2) were identified approximately 6+ years ago. In that time, crab populations could have shifted, spatially, or the fishery may have experienced some changes that may warrant these grounds no longer important. Ultimately, these assessments of fishery overlap may not hold today.

In terms of reintroduction suitability, it is possible survey respondents are less supportive of certain zones if they perceive or anticipate conflicts between sea otters and fisheries. Respondents could perceive these types of interactions as a risk for sea otters (i.e. disturbance from fishing activity) or fishermen (i.e. competition for resources), which could reduce their overall support for a reintroduction within any zone, thereby reducing the zone's reintroduction suitability. Interestingly, some respondents were already aware of these perceptions, and noted that potential misconceptions of these interactions with fisheries would be a negative outcome. Further research could focus on gaining a better understanding of the likelihood of otter-fishery interactions, while communication and outreach efforts could focus on aligning these perceptions with relatively accurate predictions or case studies from other regions. Here, we attempted to align some of these perceived risks, but the methods used and date of important crabbing grounds introduces uncertainty in our assessments.

Community polarization

Predator reintroductions are typically controversial in nature (Serfass et al 2014). Because our survey sample underrepresents commercial fishing interests and is not random in nature, the overall support exhibited could belie reality to a degree. However, even if a majority of stakeholders' support sea otter reintroduction, there is still the possibility that it could be politically scuttled. One respondent questioned the legitimacy of a sea otter reintroduction because they believed it was an interest group effort, as opposed to an effort being undertaken by the government. Others may also share this perception and it could potentially wrought into a political narrative to oppose reintroduction, which occurred in the case of Bitteroot Ecosystem grizzly reintroduction (Smith 2003).

Most of the sample indicated positive benefits from potential sea otter reintroduction, including some of the select respondents who expressed opposition to reintroduction, and only one respondent expressed strong opposition to reintroduction in any of the zones. Thus, there may be opportunities to identify compromises with potentially opposed stakeholders. One of the negative outcomes respondents expressed was restricted access to the marine environment. Considering what areas are already protected in evaluating potential reintroduction locations could help minimize new potential restrictions. In considering compromises, it is notable that the MMPA does not have as much flexibility as the ESA to temper its restrictions, and thus the MMPA may be a limiting factor in what compromises may be struck. Additionally, opposition may not be entirely based on perceived costs or negative outcomes, but could also relate to social identity and ideology, potentially making compromise less likely. Attempting to engender trust between stakeholder groups and facilitate empathic understanding may be necessary to reach compromise if this is the case (Opotow & Brook 2003). It is notable that less than half of respondents associated potential negative outcomes with sea otter reintroduction, as negative outcomes are certainly possible, and recognition of the effects of reintroduction on affected stakeholder groups could be important for achieving compromise.

Unanticipated outcomes or consequences
Species reintroductions are inherently risky and typically involve some uncertainty. Despite our vast knowledge on the natural science underpinning reintroductions, they don't always go as planned and can lead to unanticipated consequences (e.g. reintroduction failure, con-specific competition, etc.). Outcomes are even more difficult to anticipate when we consider the human system, and all of the complexities of human behavior and psychology. We attempted to address some of these uncertainties so managers can better understand the potential for a successful sea otter reintroduction and anticipate potential outcomes. Our analyses do not and cannot address all uncertainties, but by identifying the limitations and caveats in our analyses, we've provided some key information on what unanticipated outcomes could occur. We must also recognize that our factor assessments and interpretations are temporally-static and only capture contemporary characteristics and trends. If managers decide to proceed with a reintroduction, these factors may change overtime. For example, human populations could continue to increase, increasing disturbance potential; species and habitats could shift under a changing climate, potentially reducing or moving suitable habitat and fishing grounds; or changes in management and research practices, while adapting to rapid environmental change or sustainability needs, could make people change their opinions on their support for a reintroduction. Future analyses may want to consider how these factors may change, as well as other factors and processes outside the scope of this study. Such assessments could help further identify potential outcomes and consequences.

Identified research needs
Phylogenetic investigations into the pre-fur trade sea otter are due for renewed research effort. A more conclusive answer than past mtDNA and microsatellites tools gave us can come from what Toews et al. (2016) discuss and we will call the "problem of riches" with contemporary high throughput sequencing. Thousands of loci along the genome can provide more statistical power to discern population structure. More information comes at a cost--the expense per sample increases. Still, these methods afford more power for the analysis to detect fainter signs of introgression between genotypes. Sequencing is problematic with the degree of degradation found in aDNA, but markers associated with ultra-conserved regions can be more reproducible across samples (Faircloth, 2012). Answering this intrinsically interesting scientific question will also indicate what contemporary ssp. would be the most appropriate source population a given reintroduction effort might utilize.

Experimental methods of selective removal of sea otter prey now can model the effects of sea otter predation. Replicates in the different zones we identified may show that sea otter impacts are spatially variable and guide reintroduction site selection. Work to establish ecological baselines now will prove valuable to managers when they gauge sea otter effects on the nearshore. Social research into stakeholder attitudes toward sea otter reintroduction can indirectly lead to a better-informed community and guide managers in their deliberations on the issue.

CONCLUSIONS & COLLABORATIVE PROCESS REFLECTIONS

This report is the product of National Science Foundation fellowships awarded to graduate students at Oregon State University (1545188 NRT-DESE). Our team within the 2018-19 cohort employed our respective disciplinary expertise in molecular ecology, community ecology, and public policy to develop this narrative by which we hope to have communicated the issues surrounding a potential sea otter reintroduction in Oregon and their potential resolutions.

Teaching us how to integrate our disciplines was a prime goal of the program. Transdisciplinary projects require developing a common scientific understanding among participants and creating the tools of analysis and communication suited to addressing a complex societal issue. Much like our first steps were in developing a transdisciplinary approach, the discussion of a possible sea otter introduction is in its preliminary stages. The difficulty we faced in quantifying concerns and benefits of reintroduction will extend as well to the public deliberation process. Weighting the individual factors requires knowledge of each. Still, the importance of factors will change from person to person. In addressing the perceptions of risks and the levels of uncertainty regarding the effects of a sea otter reintroduction, we hope that this report and future dialogue will contribute to a comprehensive assessment of how the reintroduction of sea otters to Oregon would change the state of our coupled human-natural system.

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APPENDICES

Appendix 1: Coastal Oregon archaeological sites (provisional as of August 31, 2019)
We submit a reference list of coastal archaeological sites known to have held vertebrate faunal remains for the use of science educators, sea otter and pinniped researchers, as well as terrestrial vertebrate researchers. Holocene ages given at this time are not inclusive of all site dates. Sources are given in full in the above References.

Index	Site	Holocene	Sources
35CU37	Lone Ranch Creek Mound	-	Hall-2009 Minor-1986 NPS 2017
35CU160	NA	-	Hall-2009
35CU68	NA	-	Minor-1986
35CU67	Indian Sands	early	Aikens-2011 Hall-2009
35CU35	Whale Head	-	Hall-2009 NPS 2017
35CU157	Khustenete-Hustenete-Xusteneten	-	Minor-1986 NPS 2017
35CU61	Pistol River Site-Chetlessentan-Chetleshin	-	Hall-2009
35CU62	Raymond Dune	mid	Hall-2009
35CU59	Tlegetlinten	-	Hall-2009
35CU12	NA	-	Minor-1986
35CU9	Port Orford	-	Hall-2009 Minor-1986
35CU7	Tseriadun	mid	Hall-2009
35CU2	Cape Blanco	-	Hall-2009

35CU106	Blundon	-	Hall-2009
35CU75	Blacklock Point	early	Hall-2009
35CU47	Strain Site (newman)	-	Hall-2009
35CS3	Bullards Beach	late	Aikens-2011 Hall-2009 Minor-1986 NPS 2017
35CS136	NA	-	Hall-2009
35CS69	NA	-	Minor-1986
35CS43	Nah-so-mah Village	late	Hall-2009 Hall-1995
35CS158	Busman	mid	
35CS61	Blue Barn	mid	
35CS5	Bandon Sandspit	late	Aikens-2011 Hall-2009 Tveskov-1999
35CS1	Philpott	-	Hall-2009
35CS120	Twin Dunes	mid	
35CS2	NA	-	Hall-2009
35CS62	NA	-	Hall-2009
35CS30	NA	-	Hall-2009
35CS17	NA	-	Hall-2009
35CS173	NA	-	Hall-2009
35CS142	NA	-	Hall-2009

35CS24	NA	-	Hall-2009 Minor-1986 NPS 2017
35CS114	Hauser	mid	Aikens-2011
35DO83	Umpqua-eden	mid	Aikens-2011 Hall-2009
35DO130	Tahkenitch Landing	early	Aikens-2011 Hall-2009 NPS 2017
35DO175	NA	-	Hall-2009
35LA25	Siuslaw Dune	late	Hall-2009 Minor-1999
35LA3	Devils Elbow	-	Hall-2009 NPS 2017
35LA16	NA	-	Hall-2009 NPS 2017
35LA10	Bob Creek	late	Aikens-2011 Hall-2009 NPS 2017
35LNC56	Good Fortune Cove	late	Aikens-2011 Hall-2009
35LNC57	Cape Creek Shell Midden	late	Aikens-2011 Hall-2009
35LNC54	Cape Perpetua	late	Aikens-2011 Hall-2009
35LNC55	Good Fortune Point	late	Aikens-2011 Hall-2009 Minor-1995
35LNC63	NA	-	Hall-2009 NPS 2017
35LNC48	NA	-	Hall-2009 NPS 2017
35LNC29	NA	-	Minor-1986
35LNC15	NA	-	Minor-1986
35LNC14	Seal Rock	late	Aikens-2011 Hall-2009 Lyman-1988

35LNC50	NA	-	Hall-2009
35LNC49	NA	-	Hall-2009
35LNC62	Yaquina Head	mid	Aikens-2011 Hall-2009
35LNC43	Rocky Creek	-	Hall-2009 NPS 2017
35LNC68	Rocky Creek Wayside	late	Aikens-2011 Hall-2009 NPS 2017
35LNC92	NA	-	Hall-2009
35LNC60	Whale Cove	late	Aikens-2011 Hall-2009 Lyman-1988
35LNC44	Government Point	mid	NPS 2017
35LNC101	NA	-	Hall-2009
35LNC100	NA	-	Hall-2009
35LNC45	Boiler Bay	mid	Hall-2009 NPS 2017
35TI35	Cove Creek Midden	-	Minor-1986 NPS 2017
35TI1	Netarts Sandspit	late	Aikens-2011 Hall-2009 Minor-1986 NPS 2017
35TI36	NA	-	Minor-1986 NPS 2017
35TI47	Oceanside	-	Hall-2009 Minor-1986 NPS 2017
35TI4	NA	-	Minor-1986
35CLT12	Indian Creek Village	-	Hall-2009 NPS 2017

35CLT21	Ecola Point	late	Aikens-2011 Hall-2009 Minor-1986 Minor-1991 NPS 2017
35CLT34	Indian Point?/Ivy Station	late	Aikens-2011
35CLT13	Avenue Q	late	Aikens-2011 Hall-2009
35CLT20	Par-tee	late	Aikens-2011 Hall-2009
35CLT47	Palmrose	mid	Hall-2009
35CLT66	Earl Dune	late	Aikens-2011 Hall-2009
35CLT33	Eddy Point	late	Aikens-2011 Hall-2009
35CLT22	Young’s Bay 2	-	Hall-2009
35CLT16	Young’s Bay	-	Hall-2009

Appendix 2. Carrying capacity model & parameters.

Parameters – for which there may be multiple for a single habitat variable – were estimated and confirmed by fitting the model to time-series survey data of sea otters along the central California coast. Annual counts (from 1983 – 2017, except 2011) and geographic location of sea otters were collected using shore-based and aerial surveys. Using a 100m spatial grid, total otter counts across all surveys were summed and key habitat variables recorded for each grid cell. Using Bayesian methods, a process model was fit to the observed survey data, and individual parameters were estimated to represent the functional relationship between otter densities at equilibrium and each of the habitat variables (Table 1).

Table 1. Parameters estimates from the CA model. A description of parameter is provided in text, as well as the mean, standard deviation (SD), and 95% confidence interval (CI) of the fitted posterior distribution. All parameters are associated with habitat features and environmental variables on the outer coast, except where indicated for estuaries. Table was adapted from Tinker et al. 2019 (in prep).

Parameter	Description	Mean	SD	Lower CI (95%)	Upper CI (95%)
k_s	Intercept; mean log-density in soft sediment habitats	0.5613	0.3025	-0.0297	1.1749
k_e	Alternative intercept; mean log-density in estuaries	1.2238	0.7384	-0.2421	2.6498
$D*$	modal depth (at which mean densities are highest)	5.7711	0.6978	4.4123	7.1518
b_1	effect of decreasing depth from $D*$ on log-K	3.4262	1.2871	1.3157	5.9135
b_2	effect of increasing depth from $D*$ on log-K	0.1266	0.0072	0.1124	0.1409
a_{PR}	effect of increasing proportion of rocky substrate on log-K	1.7268	0.1346	1.4499	1.9786

a_{PK}	effect of increasing proportion of kelp cover on log-K	2.6727	0.1497	2.3820	2.9681
a_{DSR}	effect of deviations from mean slope on log-K, linear response	0.1816	0.0917	0.0006	0.3592
a_{DSR2}	effect of deviations from mean slope on log-K, quadratic response	0.2051	0.0637	0.0787	0.3283
a_{OFSH}	effect of increasing distance from shore beyond 1km (i.e. "far offshore effect") on log-K	-0.6058	0.1713	-0.9334	-0.2618
a_{NPP}	effect of increasing net primary production on log-K	0.5537	0.1305	0.3002	0.8117

Appendix 3. Oregon habitat variable datasets.

Bathymetry data – originally obtained from hydrographic surveys, multibeam surveys, and marine trackline data – were collected from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information U.S. Coastal Relief Model (CRM). We convert this layer into a 100m grid using bi-linear interpolation, and clip from 0m to 60m depths, and from the Columbia River in the north to the Oregon-California border in the south. Kelp canopy cover was collected from the Marine Resources Program at the Oregon Department of Fish & Wildlife. Kelp canopy was derived from multiple aerial kelp biomass surveys conducted in 1990, 1969-1999, and 2010. This data layer is a composite of all survey years. Using maximum area, we converted this kelp layer to our 100m grid, with each grid cell assigned a value for presence or absence of kelp canopy. We obtained benthic substrate data from the Active Tectonics & Seafloor Mapping Laboratory at Oregon State University. Substrate data was collected using several seafloor mapping surveys (e.g. multibeam sonar, side scan sonar, sediment grad samples, etc.). Substrate was classified as hard, soft, or mixed, following the classification scheme used to describe seafloor induration in Greene et al. 1999 (Greene et al. 1999). After comparing with our kelp layer, we reclassified any mixed substrate to hard as these areas could also provide important habitat for other rock-dependent species, such as sea urchins or abalone. Benthic substrate was converted to the 100m grid, with each grid cell assigned a value corresponding to the proportion of rock substrate within each grid. Net primary productivity (NPP) data was previously estimated for the California and Oregon continental shelves by Dr. Tom Bell from the University of Santa Barbara. Data was converted to our 100m grid using bi-linear interpolation, and we filled in the missing nearshore areas using k-d tree to assign cells with missing NPP values with an average of the 5 nearest cells. We incorporate an estuary layer, from Oregon State University, that represents Oregon's coastal tidal wetlands, based on interpreted historic and present remote sensing data. Sea otters regularly use estuarine environments – as evidenced by Elkhorn Slough – as these features provide access to additional prey resources and protection from outer coastal conditions (Hughes et al. 2013). Given the sea otter's high prey requirements, we only include estuaries with seagrass beds, identified from an Oregon shoreline study (Oregon Shorezone 2013), as seagrass could provide habitat for otter prey, such as crabs. Additionally, we only include estuaries with permanently open access to the outer coast. Access was assessed using Google Maps and online sources, such as The Oregon Conservation Strategy and the Oregon Coastal Atlas. While searching for an Oregon land polygon, we found many publicly-available data layers disagreed on the shoreline structure and position. After comparing several datasets, we merged a rocky and sandy shorelines layer from ODFW – used in Oregon's Territorial Sea Plan – and created our own Oregon land polygon. We visually compared this new land polygon with satellite imagery included in several ESRI base maps, provided in the ArcGIS 10.6 program package, to ensure this accurately represented the shoreline.

Appendix 4. Effect of depth, distance-to-shore, and slope

Seafloor slope dictates how dense or spread out a sea otter population is in space. Several areas along the California coast have shallow slopes, where relatively low depths exist further offshore, creating accessible habitat for sea otters. Other locations have steeper slopes, where the bathymetry increases – beyond sea otter diving capacity – relatively closer to shore. This difference in seafloor slope could produce more spread out and denser, respectively, sea otter populations. We incorporate this effect by calculating seafloor slope, using the Euclidean distance-to-shore and depth at each grid cell. In California, researchers observed a strong, non-linear relationship between the log of distance-to-shore and depth (D_g). To detrend distance-to-shore (DS_g) from depth and gain a better understanding of how slope effects otter densities, we apply the following equation:

$$\log(DS_g + 1) \sim 1.669 \cdot D_g^{\,0.289} + 3.123$$

The numeric values in the least-squares equations were estimated using maximum likelihood methods and fit to grid cells along the California coast (Tinker et al. 2019, in prep). The residuals (DSR_g) of this equation are independent of depth and provide a straightforward index of slope, where positive values represent areas that are shallower than expected (i.e. average slope) and negative values represent areas that are steeper than expected.

Appendix 5. Carrying capacity terms

Adult female sea otters can disperse up to, on average, 4 - 5km in one day (Ralls et al 1995, Tinker et al. 2017). This presents potential measurement uncertainty and sampling error during population surveys. Before calculating our expected sea otter densities, we account for this dispersal capability by applying a 4km smoothing window to select habitat variables (kelp, benthic substrate, and the residuals of the distance-to-shore) along predetermined depth bins. We first divide our habitat into 3 large classes of depth: 0m to 20m, 20m to 30m, and 30m to 60m. We then further subdivide these depth classes into individual bands by dividing our 0m to 20m depth class into equal-size bands every 1m in depth, our 20m to 30m depth classes every 10m in depth, and out 30m to 60m depth classes every 5m in depth. A 4km smoothing window was then applied to each of these contiguous depth bands, individually, to average our habitat variables.

There is a non-linear and asymmetrical functional relationship between otter density and depth (Tinker et al. 2017). To account for this depth effect within the carrying capacity equation, we include the following function:

$$f(D_g \mid \beta_i, D^*) = -0.01 \cdot \left[\beta_1 \cdot \max\left(0, D^* - D_g\right)^2 + \beta_2 \cdot \max\left(0, D_g - D^*\right)^2 \right]$$

D* is the model depth at which otter densities peak, while B_1 and B_2 are the rates of otter density decrease as one moves away from the model, either inshore or offshore, respectively.

Appendix 6. Human activity data layer sources & analyses

Accessibility

We assess access to the shoreline and suitable habitats as accessibility could facilitate (1) effective management and research, which could increase reestablishment potential, and/or (2) increase recreation and coastal visitation, which could serve as a source of human disturbance and potentially decrease reestablishment potential. Coastal viewing points were collected from two sources - an Oregon beach access and state parks layer created by the Oregon Parks & Recreation Department, Department of Land Conservation and Development, and the Oregon State Marine Board, and a public access site metric data layer for the Oregon Coastal Zone from NOAA. We found a high degree of overlap between viewing points identified in both layers. However, they did not fully agree. To account for all potential viewing points, we combine these two layers and excluded any duplicate points occurring in the same geographic location. The beach access data layer included access points for a variety of activities and uses, including boating, pedestrian, vehicles, view points, and not developed. For viewing points, we were only interested in locations where sea otters could be observed from the shoreline by foot. Therefore, we exclude any activity, except for pedestrian and view point, before combining with the NOAA data layer. We defined boat access points as any large port collected from a 2011 Ecotrust study that identified large ports that supported shoreline infrastructure and businesses, as well as dock large vessels.

We use two metrics to determine accessibility: (1) mean number of viewing points per kilometer of coastline and (2) distance (km) (for vessel travel) to suitable habitats. We define viewing points as any point within 1km of either the shoreline or an estuary. Boat access points were defined as any coastal port that provides facilities for large ships and commercial fishing vessels (Hesselgrave et al. 2011). We also included smaller ports and ramps where small research vessels could be deployed (e.g. Salmon River, Cannon Beach, Depoe Bay). For the outer coast, we measured the distance from ports to the nearest suitable habitat. For estuaries, no suitable habitat was identified. Therefore, we took the centroid of each estuary and measured the distance from the closest port or ramp. Viewing and boat access points were extremely clustered. To remove unnecessary clustering and avoid overestimating accessibility, we omitted any point within 1km of another.

Fisheries

Sea otters can sufficiently reduce local prey densities (Estes et al. 1995). Oregon has several commercial and recreational fisheries that target typical sea otter prey, including Dungeness crab, Oregon's most lucrative fishery (Davis et al. 2017). Fishermen responses were only collected for the outer coast. To attempt to compare with estuaries, we obtained publicly available commercial landings data (ODFW Landing Statistics) and averaged the annual pounds landed across all ports for bay and outer coast Dungeness crabs, from 2004-2010. We estimated that approximately 99% of all commercial Dungeness crab catch was landed from the outer coast, during that period. Based on this finding, we assume that if stated importance was collected for estuaries, estuaries would not be identified in the top 75% most important crabbing grounds. Therefore, we did not assess the overlap between estuaries and crabbing grounds.

Protected areas

We assessed protected areas because, while various human activities and fisheries activity could disturb sea otters, protected areas could prevent these types of interactions by providing a “safe haven” for otters where they are spatially separated from people. We define protected areas as any marine reserve or national wildlife refuge with no-take restrictions. Oregon has 5 no-take marine reserves (Redfish Rocks, Cape Perpetua, Cape Falcon, Cascade Head, and Otter Rock) within our study area. The Oregon Coast National Wildlife Refuge Complex is composed of 6 individual national wildlife refuges (Oregon Islands, Three Arch Rocks, Cape Meares, Bandon Marsh, Nestucca Bay, and Siletz Bay) spanning both the coastal and nearshore environments. Of these refuges, we only include the Oregon Islands National Wildlife Refuge as it is the only refuge that affords protection to the water (500 feet around any rocks, islands, or cliffs) (Fish and Wildlife Service 2009). We create a 500ft buffer around each island and cliff to serve as protected areas. We quantify both the total predicted abundance of sea otters occurring within and outside suitable habitats, within protected areas. We include the South Slough National Estuarine Research Reserve in Coos Bay. Data on important commercial crabbing grounds were also collected from the 2011 Ecotrust study that spatially-identified crabbing grounds using interviews (Ecotrust 2011). Marine reserve spatial data was collected from ODFW’s Marine Reserve Program and the national wildlife refuge data was obtained from the U.S. Fish & Wildlife Service’s National Cadastral Data. South Slough National Estuarine Research Reserve was also obtained from the National Estuarine Research Reserve System.

Appendix 7. Predicted sea otter densities (otters/km²) from carrying capacity model.

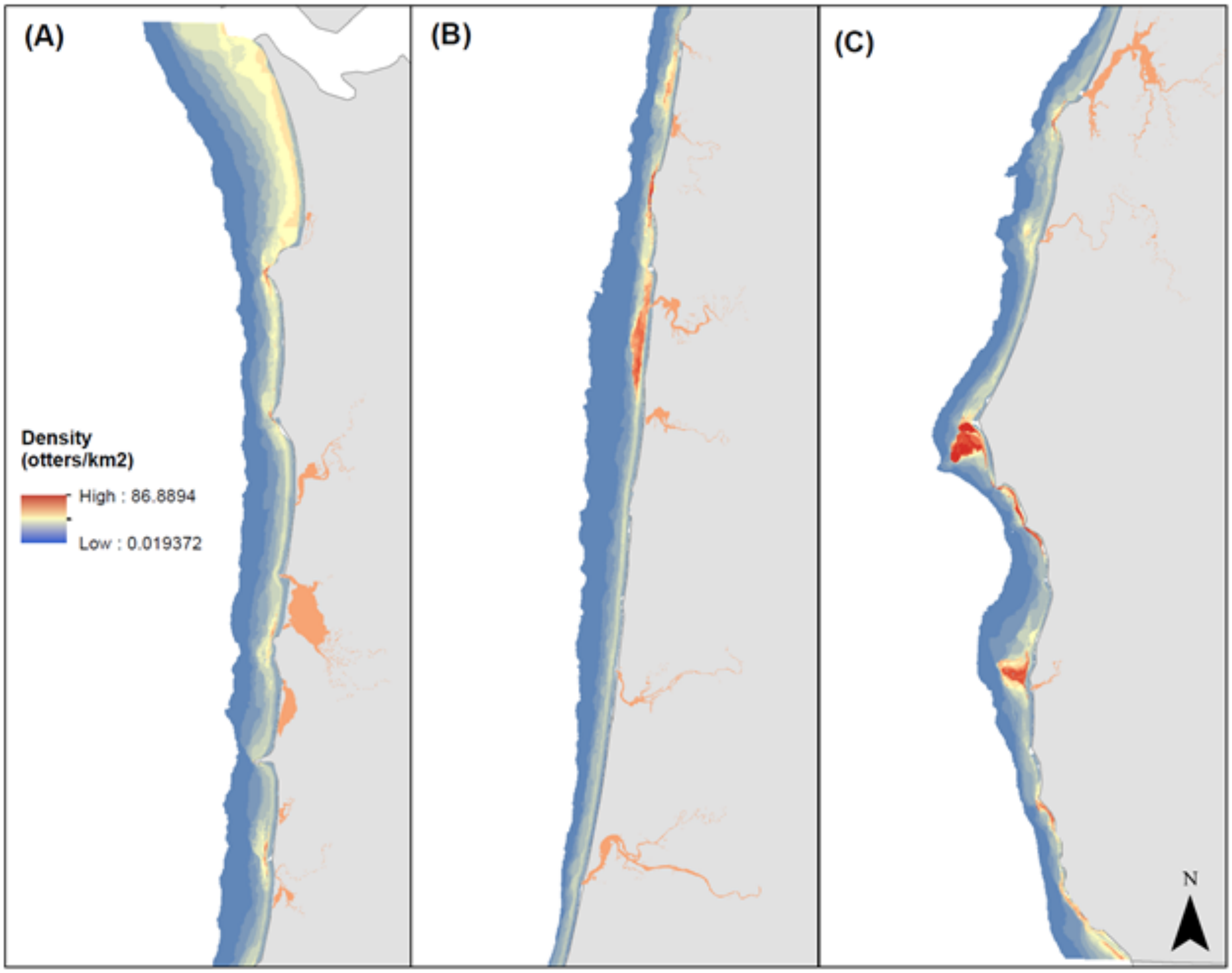
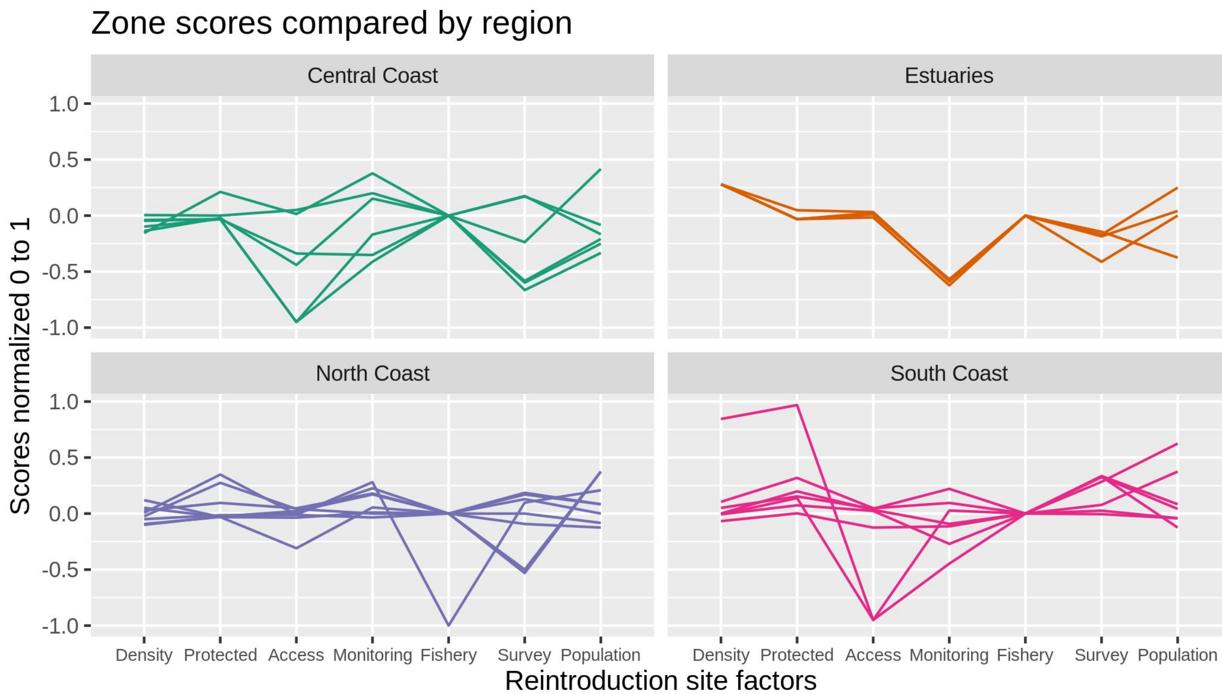
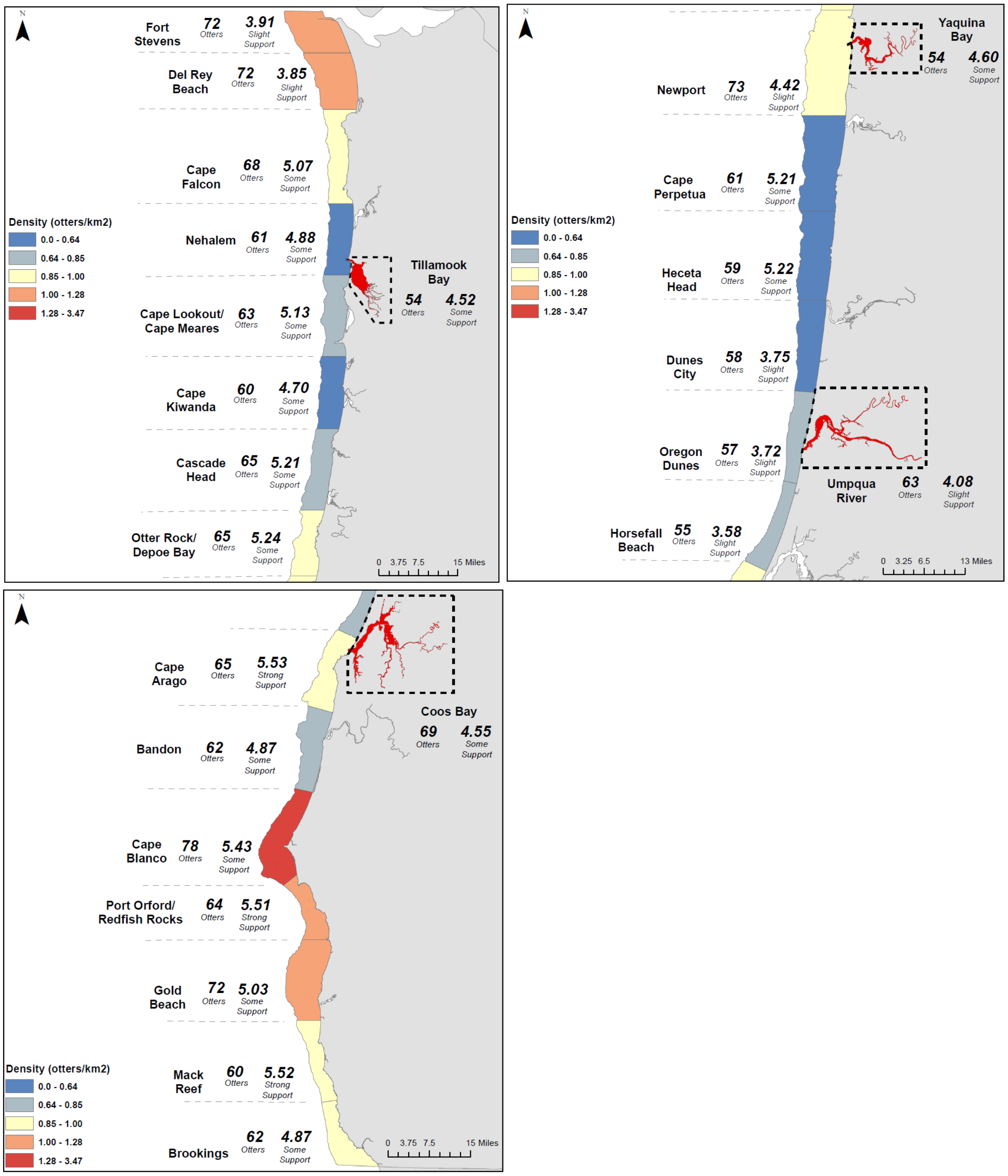


Figure 2. Predicted sea otter densities from the carrying capacity model. Results are presented in regions for visualization (A = north, B = central, C = south).

Appendix 8: Regional comparisons



Diverse metrics were used to rate potential sea otter reintroduction zones. Here, scores are univariately set to a min:mix scale with the center at the median. Density is carrying capacity/km^2, Protected is projected abundance within marine protected areas, Access is boat travel time (negative factor), Monitoring is viewpoints/km coastline, Fishery is known conflict with crabbing, Survey is the level of support by survey respondents, and Population is projected abundance after 7 years of reintroduction effort.



North Coast, Central Coast, and South Coast zones are presented with several key metrics of social/ecological support for their potential as sea otter reintroduction sites. Potential density of sea otters is based on habitat evaluation. Numbers of otters are those projected after 7 years of population growth following an initial introduction of (net) 20 individuals, followed by 7 years x 4 individuals of augmentation. Support are mean levels of favorable support in the survey (1: strongly oppose - 6: strongly support).