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Chapter 3

POPULATION AND DEMOGRAPHIC CONSIDERATIONS

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While there are multiple reasons that resource managers may decide to reintroduce a wildlife species to a habitat from which it has been extirpated, the success of such an action will ultimately be determined, in part, by the population's performance after the reintroduction. The key metrics of performance are thus evaluated at the population level rather than the individual level. According to the guidelines of the International Union for Conservation of Nature (IUCN) Species Survival Commission:

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

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

IMPACTS OF REINTRODUCTION TO SOURCE POPULATIONS

For any wildlife reintroduction program, individuals must be taken from some source population for translocation to the new habitat. Because removing individuals will necessarily cause a reduction in population size, the question is not whether a source population will be negatively affected but rather if these negative effects will be statistically or biologically significant. In the case of an Oregon reintroduction, there are several possible source populations (see Chapter 9), and the impacts are likely to vary among these potential sources. We consider three potential source populations here: Southeast (SE) Alaska, California, and aquarium-rehabilitated stranded juvenile sea otters (*Enhydra lutris*) from California. We selected these three populations because of the availability of recently completed population analyses that allow us to make a quantitative assessment of the impacts of removing animals from each of these sources. We do not explicitly consider Washington as a fourth possible source population because a comparable population model is not available at this time; however, given the similarity in population sizes, we believe the results from the California analysis will be relevant and provide guidance for the potential use of the Washington population as a source. We note that a population model for Washington was published in the past year (Hale et al. 2022) and is available for use in a similar assessment.

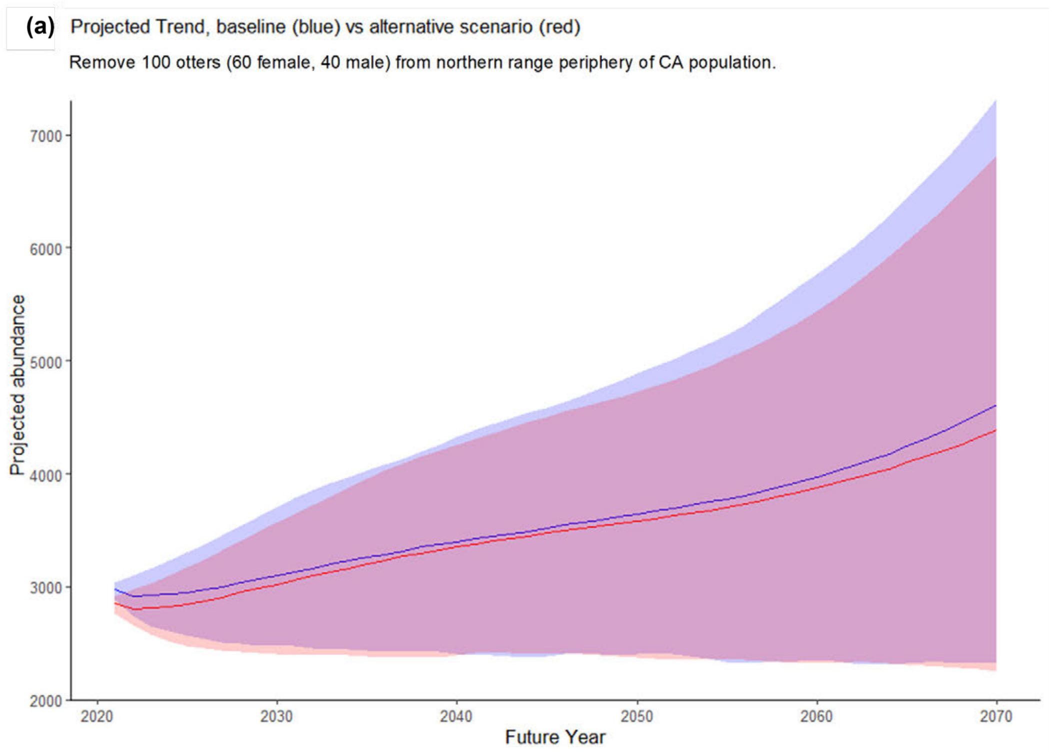
In SE Alaska, translocations of sea otters to multiple locations in the 1960s and 70s successfully established a growing meta-population that has now increased to over 25,000 animals (Esslinger and Bodkin 2009, Tinker et al. 2019). A spatially structured population model was recently developed for sea otters in this region (Tinker et al. 2019), and this model was then adapted to evaluate the population impacts of the Native Alaska subsistence harvest on sea otters (Raymond et al. 2019). Demographically speaking, removing sea otters to translocate them to a different region (Oregon) is identical to the lethal removal of animals during a harvest. Therefore, we can use the results of these analyses to evaluate the demographic consequences of using SE Alaska as a source population for an Oregon reintroduction.

The harvest impact study's key results were that the demographic consequences of harvest were negligible when annual removals were less than 10% of the local population size (Raymond et al. 2019). For example, in the Maurelle Islands, over 100 otters were frequently harvested in a single year, but because of the high number of otters in the Maurelle Islands, this harvest rate represented less than 5% of the population, and the effects on population trends were negligible. In Sitka Sound, harvest levels before 2005 were less than 10% in most years, and this level had only minor effects on population growth. However, after 2005, the annual harvest rate increased, and levels frequently exceeded 10% of the local population (and sometimes > 25%), resulting in substantial population impacts, with a decline in abundance greater than 50%. These results highlight two important points: (1) The consequences to a source population of removing animals for translocation should be assessed at a local scale (i.e., within 20-60 km of the capture site) rather than at a regional scale. (2) Removals of animals that approach or exceed 10% of the local population are likely to have population-level consequences, but removals of less than this level may be sustainable. If we assume that 100 animals were to be captured for translocation to Oregon, there are several subregional population segments in SE Alaska identified by Tinker et al. (2019) that could sustain this level of removal with minimal impacts (i.e., 100 animals would represent < 10% of local abundance), including Icy Straits and Glacier Bay in northern SE Alaska or the Maurelle Islands, northwest Prince of Wales Island, and Kuiu Island in southern SE Alaska.

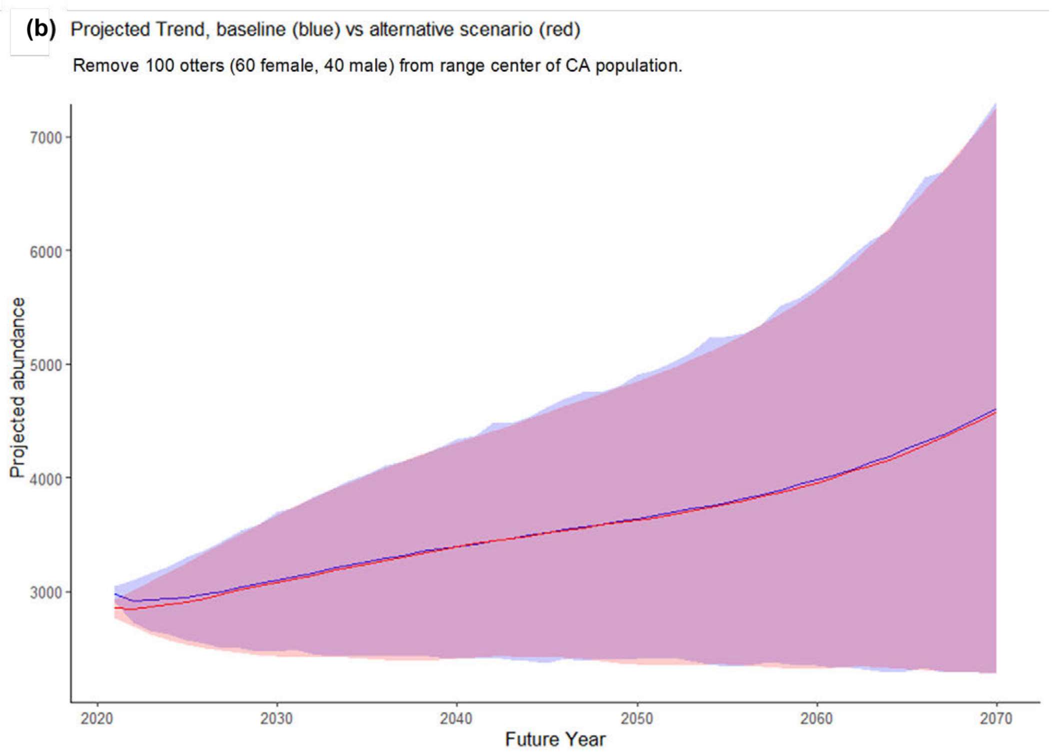
In California, a recent habitat-based estimate of sea otter carrying capacity (*K*; Tinker et al. 2021b), combined with a comprehensive analysis of sea otter mortality patterns (Miller et al. 2020), has allowed for the development of a spatially structured integrated population model (IPM) for southern sea otters (Tinker et al. 2021a). The IPM can be used to assess the population-level impacts of variation in cause-specific mortality, as well as reintroductions or removals of animals from specific locations within the range of sea otters in California. Therefore, we used this model to evaluate the impacts of a hypothetical removal of animals for translocation to Oregon. As with the SE Alaska model, we evaluated spatially explicit scenarios of removing up to 100 individuals. Specifically, we ran 50-year simulations of population dynamics in California, with 100 animals removed from one or more coastal segments in Year 1 of the simulation, and we then assessed how much this removal would reduce population growth over the next 50 years as compared to an identical simulation without the removal.

We found that a removal from the northern range periphery (the coastal area between Santa Cruz and Pigeon Point) would result in a 4.9% reduction in projected abundance after 50 years (Figure 3.1a). In contrast, a similar removal of 100 sea otters from the range center (between Monterey and San Simeon), where local abundance is high and approximately at *K*, resulted in only a 0.8% reduction in projected abundance after 50 years (Figure 3.1b). The first scenario resulted in greater impacts on the source population for two reasons: (1) The northern periphery is well below *K* and, thus, the removals would delay local recovery far more than removals from an area already near *K*. (2) A removal of animals near the range edge would tend to reduce or delay the potential for future range expansion into new habitats, while removal of animals from the range center would have no such effect.

Figure 3.1. Population simulation results for an IPM evaluated with and without the removal of animals for translocation to Oregon.


(a) Projected Trend, baseline (blue) vs alternative scenario (red)

Remove 100 otters (60 female, 40 male) from northern range periphery of CA population.


(b) Projected Trend, baseline (blue) vs alternative scenario (red)

Remove 100 otters (60 female, 40 male) from range center of CA population.

Note. The blue line shows the baseline projected trend, while the red line shows the projected trend under the "alternative scenario," with 100 sea otters removed in Year 1 of the simulation from (a) the northern range periphery and (b) the range center.

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

A third potential source of animals for reintroduction to Oregon are juvenile animals in California that strand as pups and are then rescued, rehabilitated, and reared by "surrogate" mother sea otters in captivity (Nicholson et al. 2007). Researchers have already demonstrated that these rehabilitated juvenile animals could enhance population recovery in areas of low abundance (Estes and Tinker 2017, Mayer et al. 2019). It has also been suggested that similar methods might allow these animals to be used to establish a new population in California or Oregon (Mayer et al. 2019, Becker et al. 2020). A key advantage of this approach would be that the wild population in California would not be impacted at all since the stranded animals are already effectively disconnected (demographically) from the wild population. Thus, at first glance, this potential source population would seem ideal for avoiding negative impacts on a wild population. However, it is also true that the rehabilitated captive juvenile population is a highly limited resource: Currently, only a small number of animals are successfully rescued, rehabilitated, and made available for release to a new area each year. Using these animals as a source population for Oregon reintroduction would prohibit their use to establish new population centers within unoccupied habitats in California (or at least would reduce the number of animals available for reintroductions within California).

Population simulations using the IPM have shown that the reestablishment of new population centers in unoccupied areas of California using rehabilitated animals could substantially impact future population growth. Projected increases are estimated to be up to 50% (compared to simulations without reintroductions) for a population established in the Channel Islands. Projected increases reach up to 100% for a population successfully established in San Francisco Bay (Tinker et al. 2021a). These projections are based on a great many assumptions—most importantly, that the establishment of new populations using rehabilitated animals would be successful. Thus, they should be interpreted cautiously. Nonetheless, these results demonstrate that using rehabilitated sea otters for reintroduction in Oregon would come with a hidden opportunity cost: Because they represent a limited resource, their use for reintroduction in one area will preclude their use in other areas. Therefore, this strategy's potential benefits (and costs) should really be considered regionally, in both Oregon and California.

IMPACTS OF REINTRODUCTION TO RECIPIENT POPULATION

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

To help in our assessment of the likely viability of reintroduced sea otters in Oregon, we have developed an Oregon Sea Otter Population Model (ORSO). This model features a user-friendly interface to help community members, stakeholders, and managers explore possible sea otter recovery patterns after introduction. Full details of the rationale, analytical methods, and results of this model are provided in Appendix A. ORSO is intended to contribute to responsible stewardship of sea otters and other nearshore marine resources by helping to anticipate the approximate magnitude of expected population growth and range spread of sea otters in coastal Oregon in the foreseeable future, considering different scenarios of translocation and reintroduction. This information can help evaluate management options and anticipate ecological and socioeconomic impacts in a spatially and temporally explicit way. We caution, however, that experience from prior reintroductions demonstrates the difficulty in predicting where translocated animals will settle, how many will remain following the release, and how soon population growth will commence. ORSO is thus not intended to predict specific outcomes but rather to explore a range of outcomes that may be most likely, given an extensive scope of model inputs and assumptions.

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

Previous sea otter translocations and reintroductions have shown that the years immediately after reintroduction can be a period of great uncertainty (Jameson et al. 1982, Bodkin et al. 1999, Carswell 2008, Bodkin 2015). During the population establishment phase, there is generally limited population growth and often a significant decline in abundance associated with elevated mortality and dispersal of a substantial proportion of animals away from the release site. The likelihood of post-release dispersal is thought to be high but might be less for younger sea otters that have not yet formed strong attachments to a specific home range (Carswell 2008). Also, releasing sea otters in estuaries may allow for better retention of animals near the release site (Mayer et al. 2019, Becker et al. 2020). Otters that do disperse from the introduction site may settle in other areas of suitable habitat within the region (as occurred in SE Alaska), return to their former home ranges if possible (as occurred at San Nicolas Island), or move entirely out of the region (as was suspected of occurring for some animals in the Oregon translocation, where the otters were believed to have moved north to join the Washington or British Columbia populations). Elevated mortality is also likely for both dispersing and non-dispersing animals during the establishment phase. Thus, the "typical" patterns of density-dependent population growth, dispersal, and range expansion only emerge after this establishment phase, which may extend for five to 20 years after the initial translocation (Jameson et al. 1982, Bodkin et al. 1999, Carswell 2008, Bodkin 2015). ORSO accounts for these establishment-phase dynamics and allows the user to adjust the relevant parameters, specifically,

- the expected duration of the establishment phase,
- the degree of elevated mortality during the establishment phase,
- the probability of dispersal away from the release site, and
- how this dispersal probability varies as a function of both the sea otter age class and whether the release site is in an estuary.

While the "true" values of these parameters are impossible to determine at present, given available data, we provide appropriate ranges based on the results of past translocations. Varying the parameters to explore their effects on population viability is perhaps the most appropriate way to move forward at this stage. Conducting small-scale experimental reintroductions may be the only means of improving the accuracy and precision of these parameters.

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

A second insight is that all reintroduction scenarios are likely to involve a period of population establishment, during which population growth will be sluggish and very possibly negative (Figure 3.2a). This pattern is consistent with the post-release declines (and/or slow growth) observed after previous reintroductions, even when those reintroduced populations grew rapidly after the establishment phase (as with SE Alaska; see Chapter 2). To ensure a high probability that a reintroduced population does not go extinct, we suggest the following guidelines based on ORSO results:

1. A sufficiently large number of individuals should be included in the initial reintroduction.
2. The release site should be carefully chosen (and post-release management conducted) to maximize the chance that animals remain near the release site.
3. Supplementary introductions could be used (if possible) to enhance the probability of success (see Chapter 9).

Supplementary introductions could consist of small numbers of rehabilitated juvenile animals added annually to the initial establishing population: This approach has been tested in Elkhorn Slough, California (Mayer et al. 2019), and appears to be an effective means of improving population viability during the establishment phase (Figure 3.2b). In the absence of supplementary additions to enhance viability, ORSO results suggest that at least 100 animals would have to be included in an initial reintroduction to have a 90% probability of maintaining a population of at least 25 otters after 25 years (Figure 3.3).

A third important insight gained from ORSO simulations is that spatial considerations and the selection of a release site can have substantial implications for the outcomes of a reintroduction project. Spatial differences in the likelihood of population establishment and future growth are partially a reflection of the release site's suitability but also reflect the spatial granularity of sea otter populations and density-dependent population regulation. Sea otters have relatively small lifetime home ranges (Breed et al. 2013, Tarjan and Tinker 2016) and thus tend to be limited by habitat quality and resource abundance at local rather than regional scales (Bodkin 2015, Tinker 2015, Tinker et al. 2019). Population growth potential depends on *K*, which can vary at local scales based on the recruitment dynamics and productivity of invertebrate prey (Tinker et al. 2021b). Furthermore, the small home ranges and limited movements of adult sea otters mean that the spatial extent of the population distribution tends to change slowly (compared to the invasion potential for more mobile mammals): the long-term rate of range spread along linear coastlines has been documented at 2–5 km/year (Lubina and Levin 1988, Tinker et al. 2008). Together, these fundamental properties suggest that the population performance of a reintroduced population will depend on the quality of habitat and productivity of prey resources in the neighborhood around a reintroduction site, and the ORSO results are consistent with this prediction.

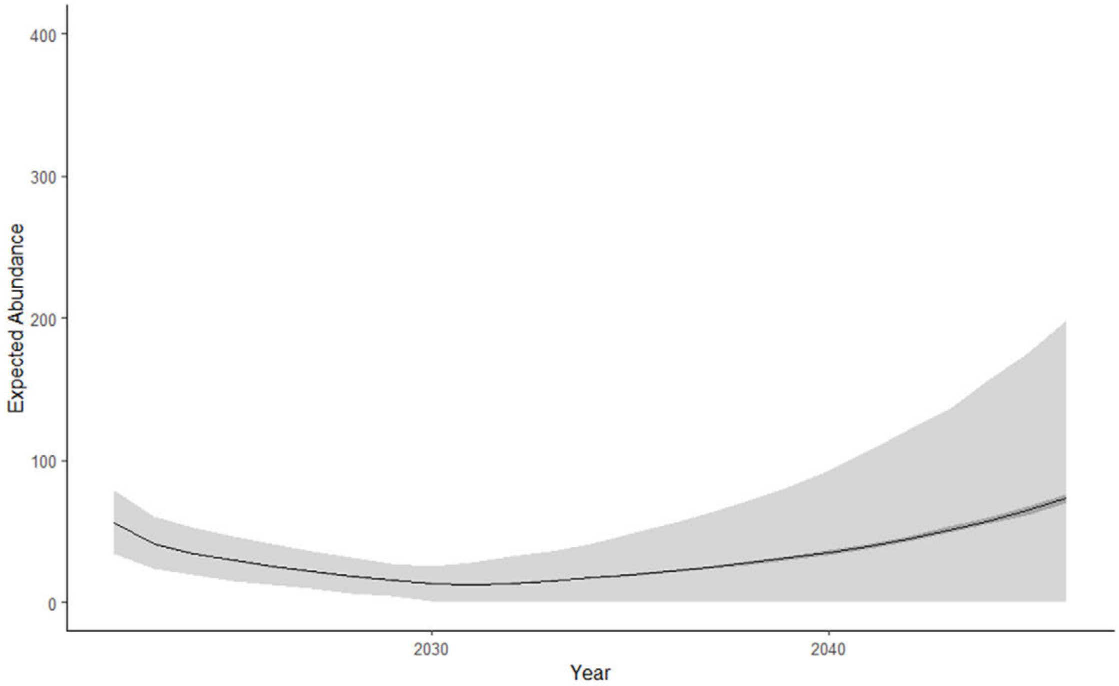
A previous application of a habitat-based model of sea otter *K* to the Oregon coast (Kone et al. 2021) indicated substantial variation in habitat quality along the coastline (Figure 3.4), as measured by the expected density of sea otters at *K*. Based on ORSO simulations, spatial differences in the expected success of reintroductions (the number of otters remaining after 25 years) were consistent with these habitat differences: the highest growth potential occurred in coastal segments that encompass areas of high-quality habitat, such as S6, SE2, or NE3 (Figure 3.5). In these high-quality habitat areas, a reintroduction of 70 sea otters (supplemented by 30 more over the next decade) would be expected to result in a successfully established population of more than 150 otters after 25 years, as compared to less than 50 otters for low-quality areas.

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

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

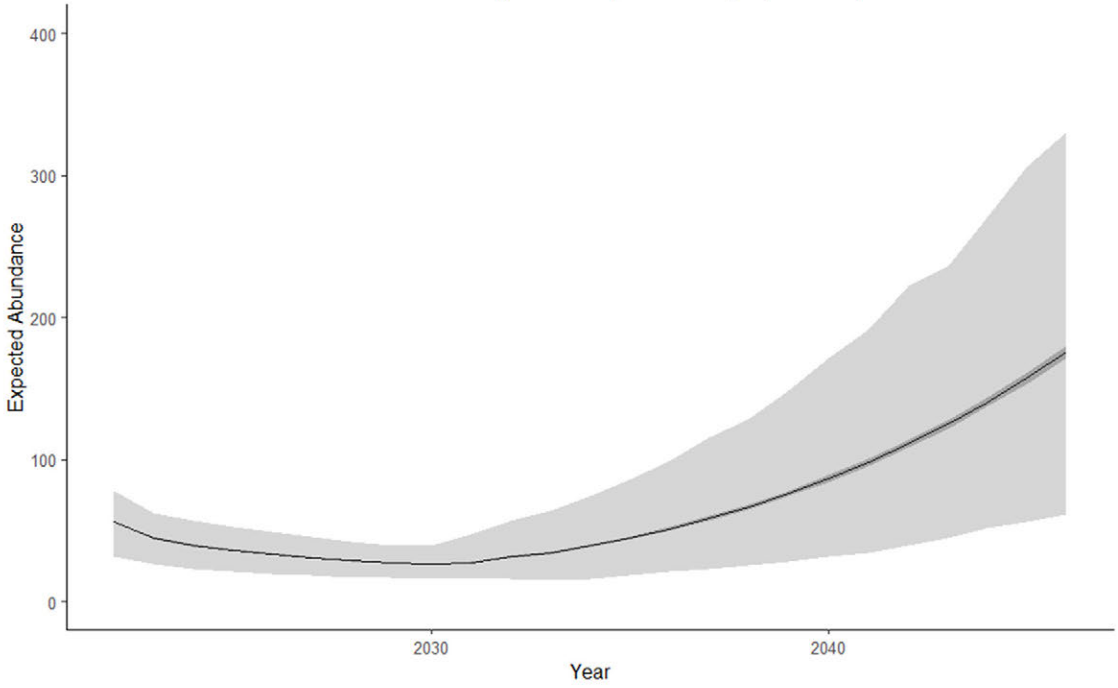
(a) Projected Sea Otter Population, 25 Years: mean = 73(95% CI 70 - 77)

Initial translocation of 100 located in section S6



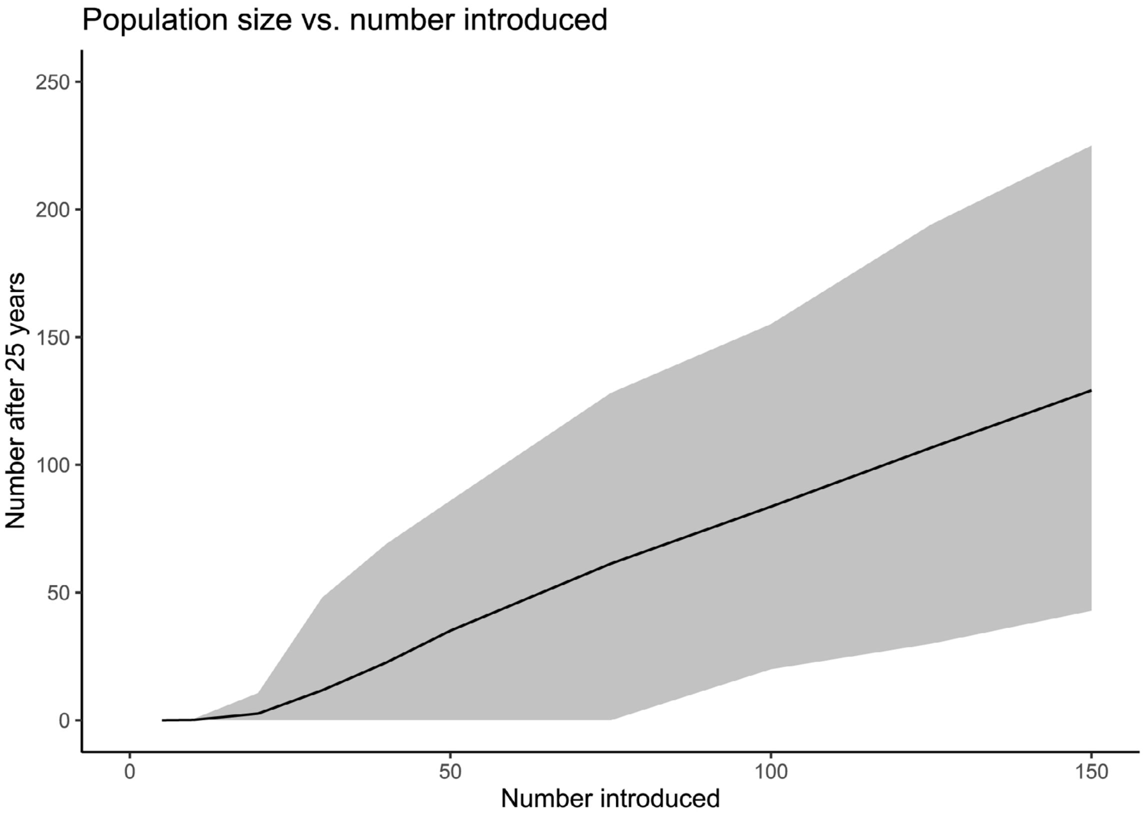
(b) Projected Sea Otter Population, 25 Years: mean = 176(95% CI 172 - 181)

Initial translocation of 100 located in section S6 supplemented by 3 subadults per year for 10yrs



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

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



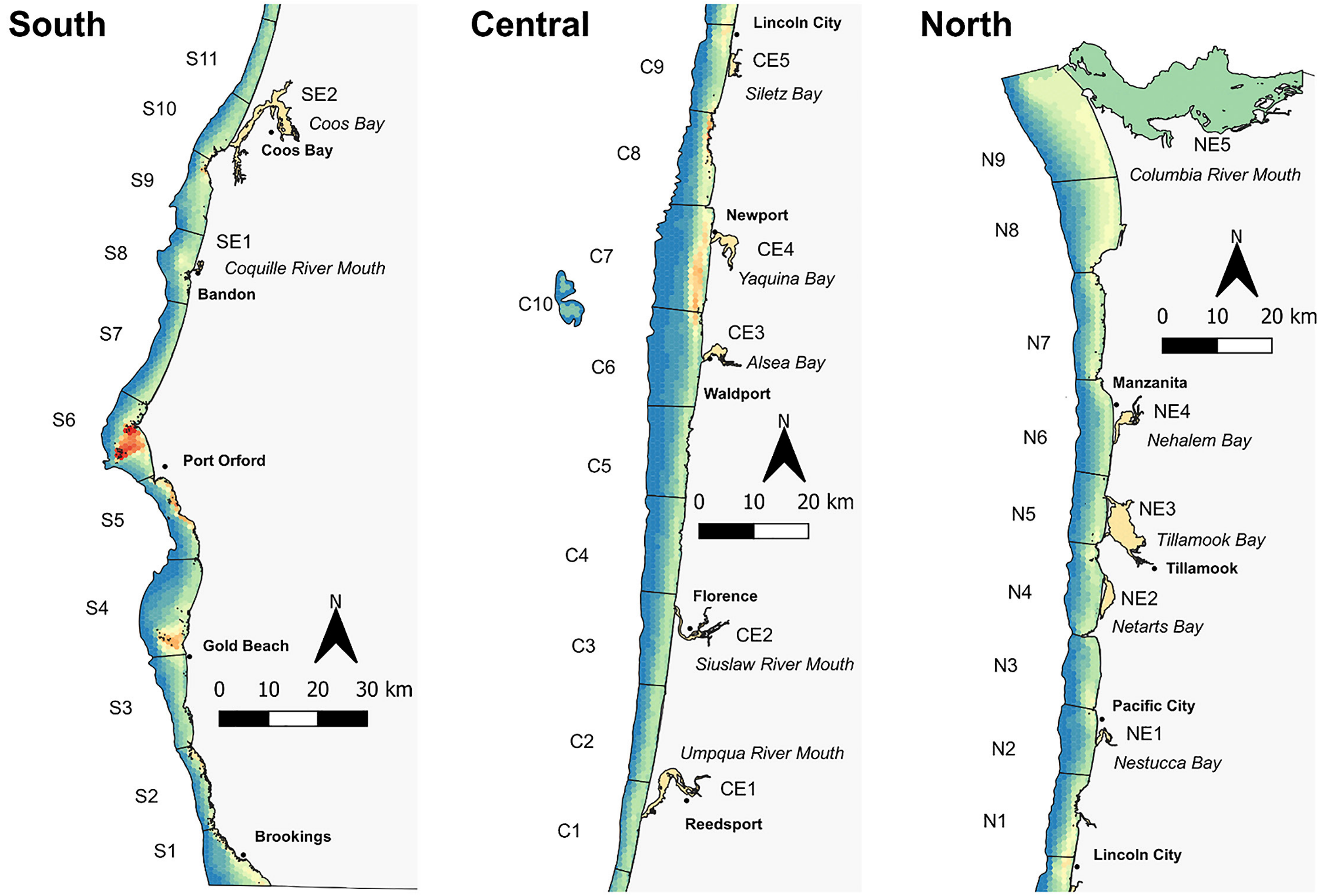
Note. The coastal area in this analysis is Section S6, as shown in Figure 3.4. The reintroduction's success is measured by the mean number of otters remaining after 25 years. The solid line indicates the mean expected value of all simulations, while the gray band represents the 80% CI.

constraints of diffusion along a linear coastline. Because each population center is limited both by local density dependence and the rate of range spread to the north and south, the same number of animals divided between two centers will result in greater net growth than if they were combined into a single center (all else being equal and assuming that both populations are successfully established).

The SE Alaska translocation provided a concrete example of this principle. One reason that sea otter numbers in SE Alaska are so high today is that the original 450 animals were divided among six release sites (see Chapter 2 for details). Spatially distributed release sites in SE Alaska led to many separate population nodes, each growing exponentially and expanding outwards. The same number of animals introduced at a single release site would have resulted in a much smaller population with a more limited distribution (Tinker et al. 2019). Using ORSO to compare a reintroduction scenario of 100 animals introduced to a single site (S6; Figure 3.6a) versus a scenario of the same number of animals divided between two spatially distant sites (SE2 and CE4; Figure 3.6b) resulted in almost two times more animals after 25 years under the latter scenario. Comparing maps of the projected populations under the two scenarios reveals the reason for the difference: the two release sites resulted in two distinct population centers (Figure 3.7).

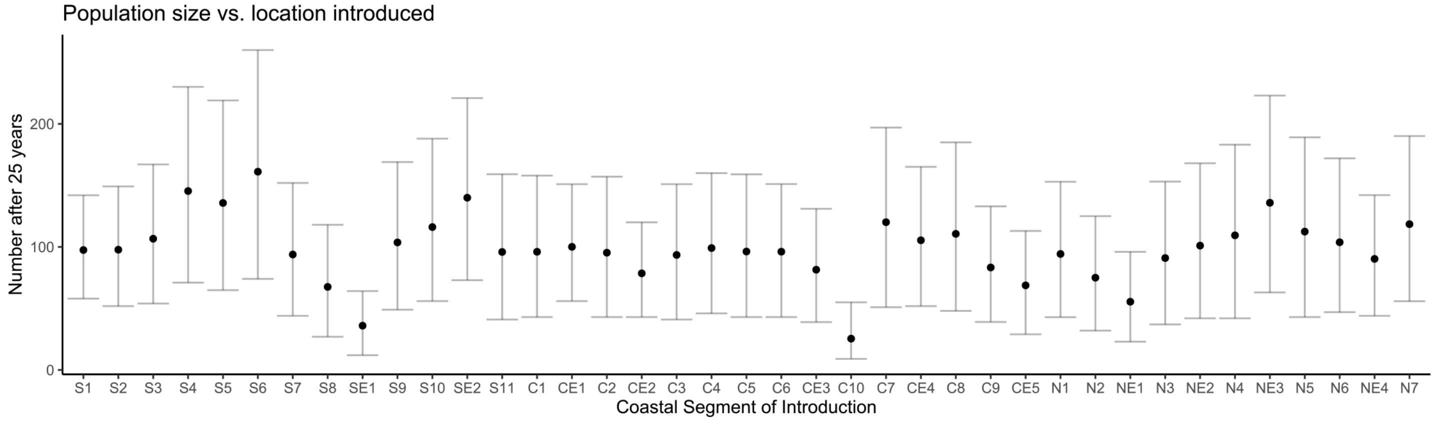
In summary, the ORSO population model provides an easy-to-use tool for exploring the factors that may affect the future viability of reintroduced sea otter populations in Oregon. Broadly speaking, the take-home message is that a reintroduced population (or populations) of sea otters in Oregon could indeed be viable, but there is an unavoidable and high degree of uncertainty associated with the outcome of any one reintroduction scenario. A prudent approach would therefore be to use the model to consider a wide range of options with the goal of identifying an appropriate

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



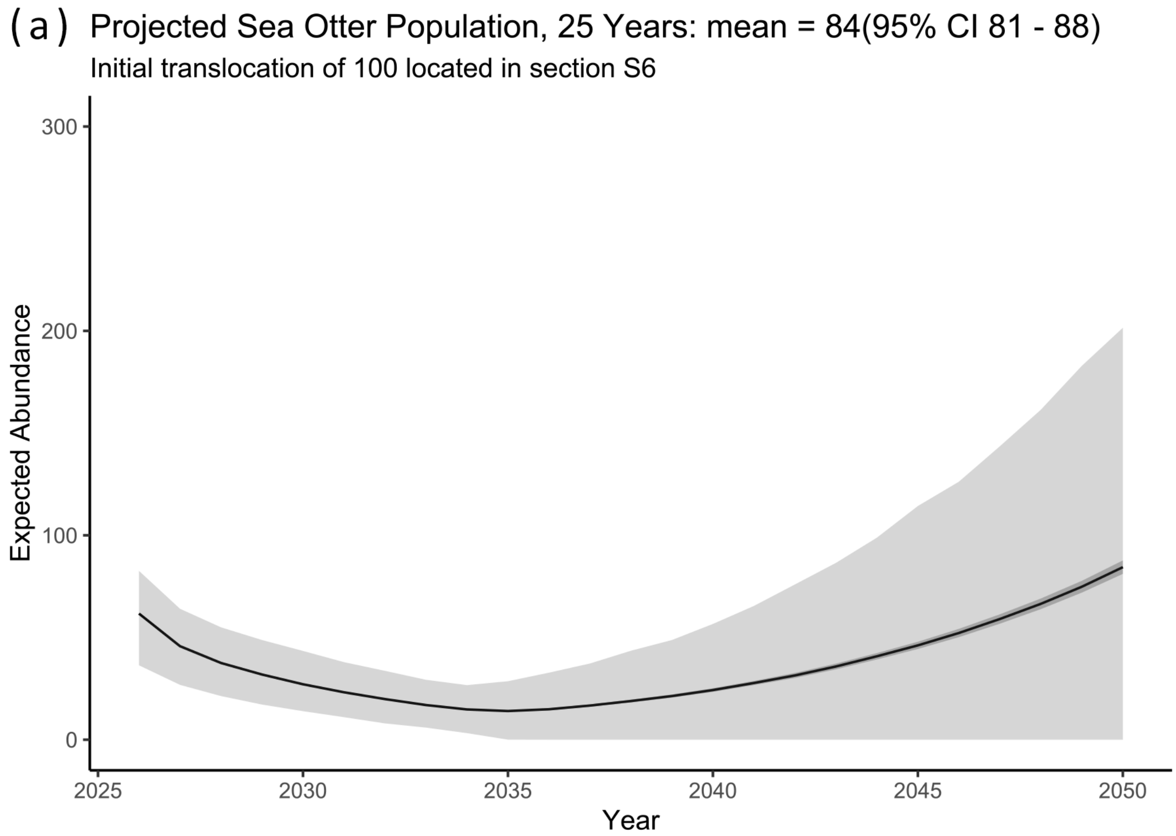
Note. These results show variation in the expected density of sea otters at *K* resulting from differences in habitat suitability.

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



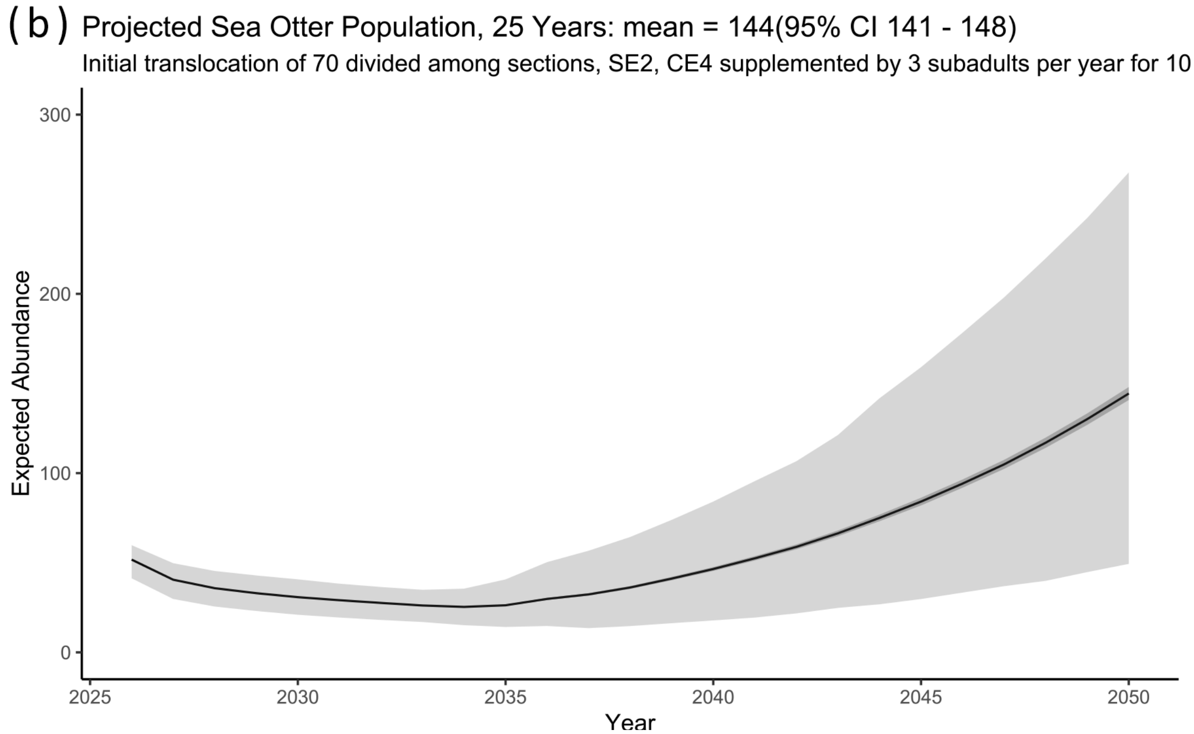
Note. See the map in Figure 3.4 for an explanation of the coastal segments, such as Segments S1, SE1, C1, CE1, N1, and NE1. Each scenario consisted of an initial reintroduction of 70 animals followed by supplementary additions of three otters per year for 10 years. The establishment phase was assumed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

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



(a) Projected Sea Otter Population, 25 Years: mean = 84(95% CI 81 - 88)

Initial translocation of 100 located in section S6



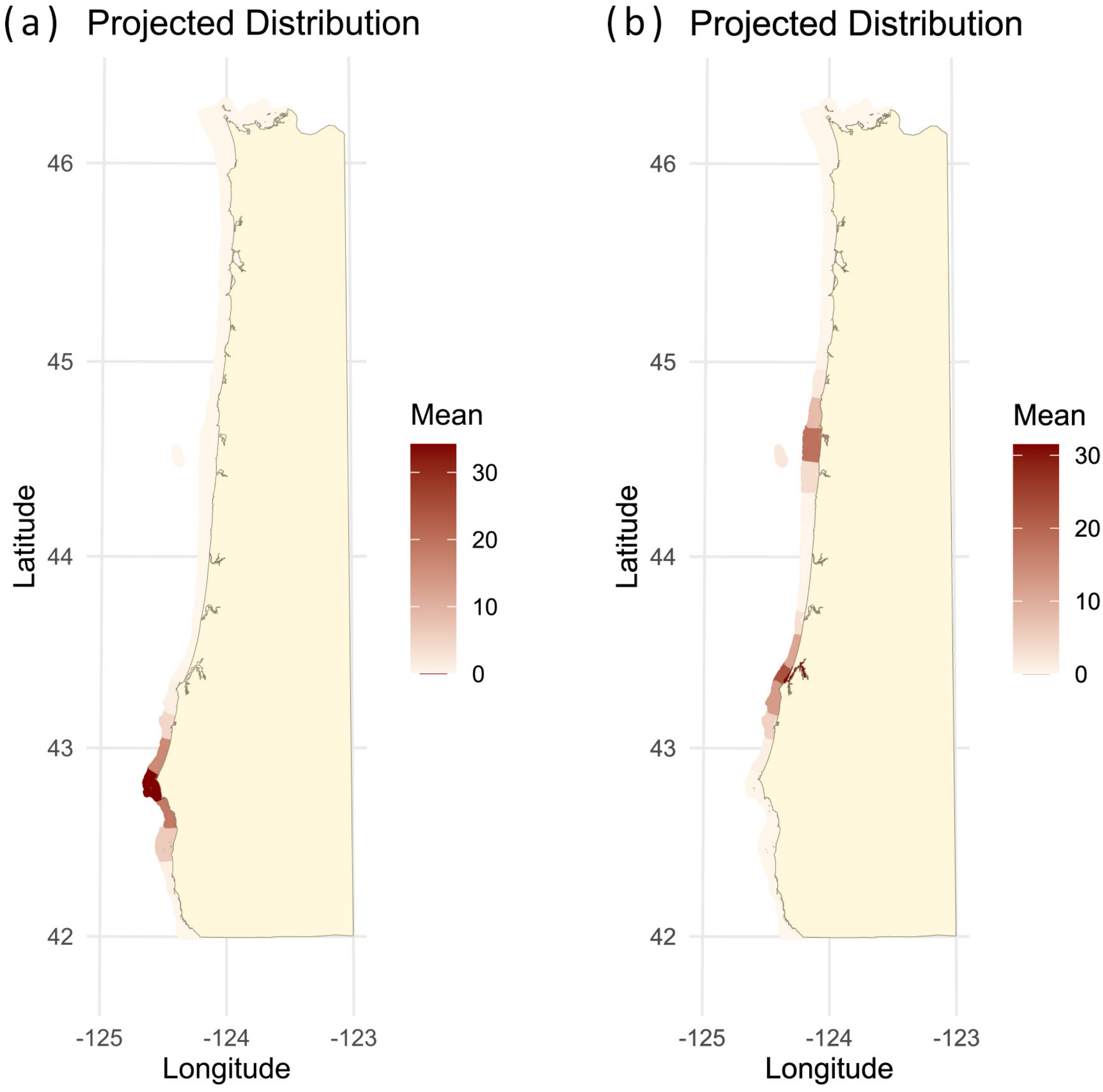
(b) Projected Sea Otter Population, 25 Years: mean = 144(95% CI 141 - 148)

Initial translocation of 70 divided among sections, SE2, CE4 supplemented by 3 subadults per year for 10

Note. The two reintroduction scenarios are (a) an initial translocation of 100 animals to a single coastal area (Section S6 per the map in Figure 3.4) and (b) an initial translocation of 70 animals divided equally among two sections (SE2 and CE4), with supplemental additions of three subadults per year for 10 years (also divided equally between the two areas). Despite the fact that both scenarios involved reintroducing 100 animals, the second scenario resulted in an expected abundance after 25 years that was twice that of the first scenario. The difference reflects the benefits of using multiple centers and supplementary additions of animals to improve the population viability at a given release site.

set of candidate scenarios for which the level of uncertainty (risk of failure) is "acceptable" to all stakeholders. Each of these candidate scenarios should also be evaluated through the lens of potential ecological effects on local ecosystems (see Chapter 5), local habitat suitability (see Chapter 6), possible socioeconomic impacts (see Chapter 7), logistical constraints and considerations (see Chapter 9), and other potential risk factors (see Chapter 10). While this process may be time-consuming and labor-intensive, it will almost certainly result in a greater chance of success and a lower likelihood of unintended and undesirable outcomes.

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



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

Sample Scenarios Evaluated with ORSO

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

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

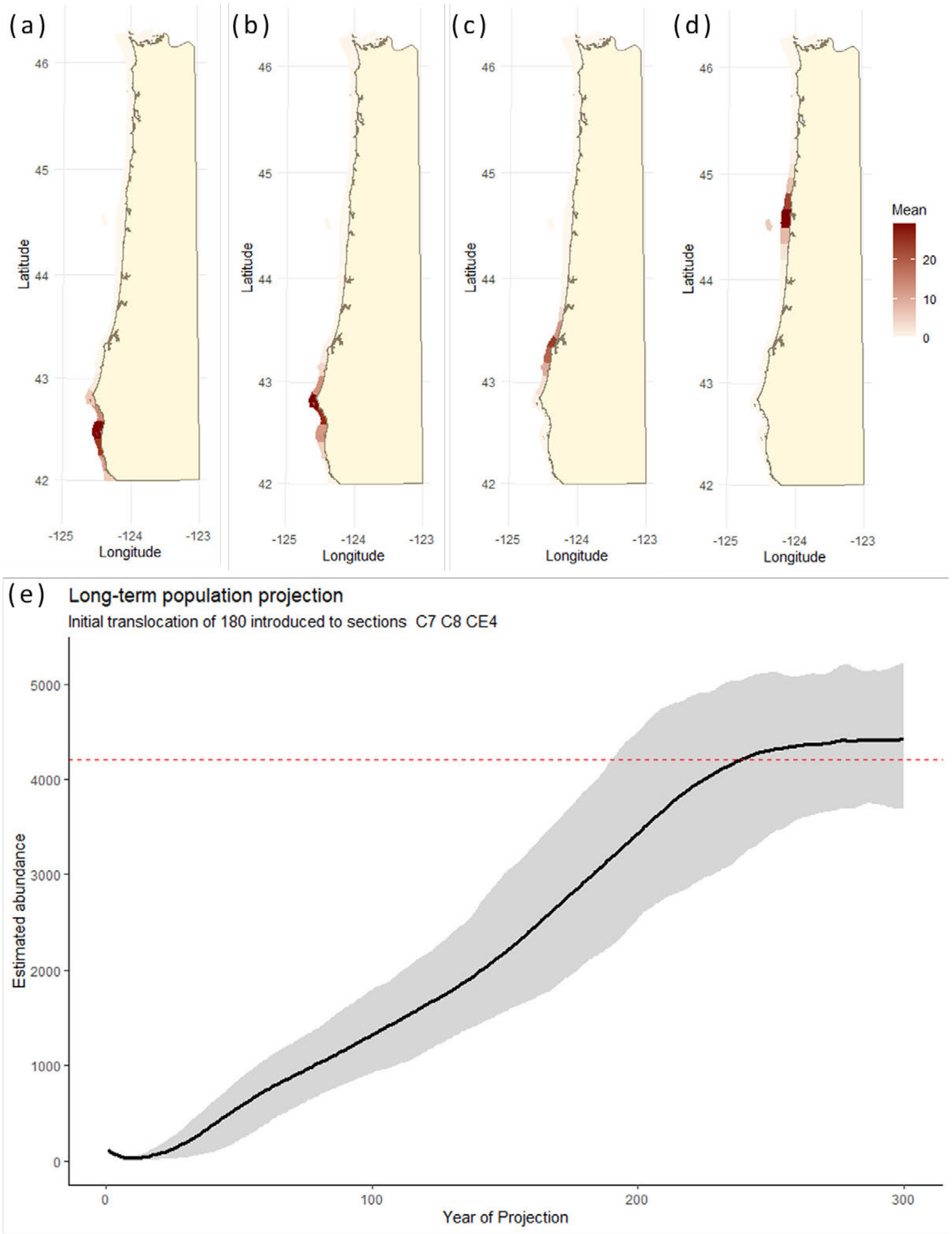
In the case of Scenarios 1–4, for which the initial number of otters introduced was 180, the average number of otters expected to persist after 25 years was greater than 100, although mean estimates varied from 117 to 144 depending on where the reintroduction occurred (Table 3.1), and the spatial distribution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

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

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

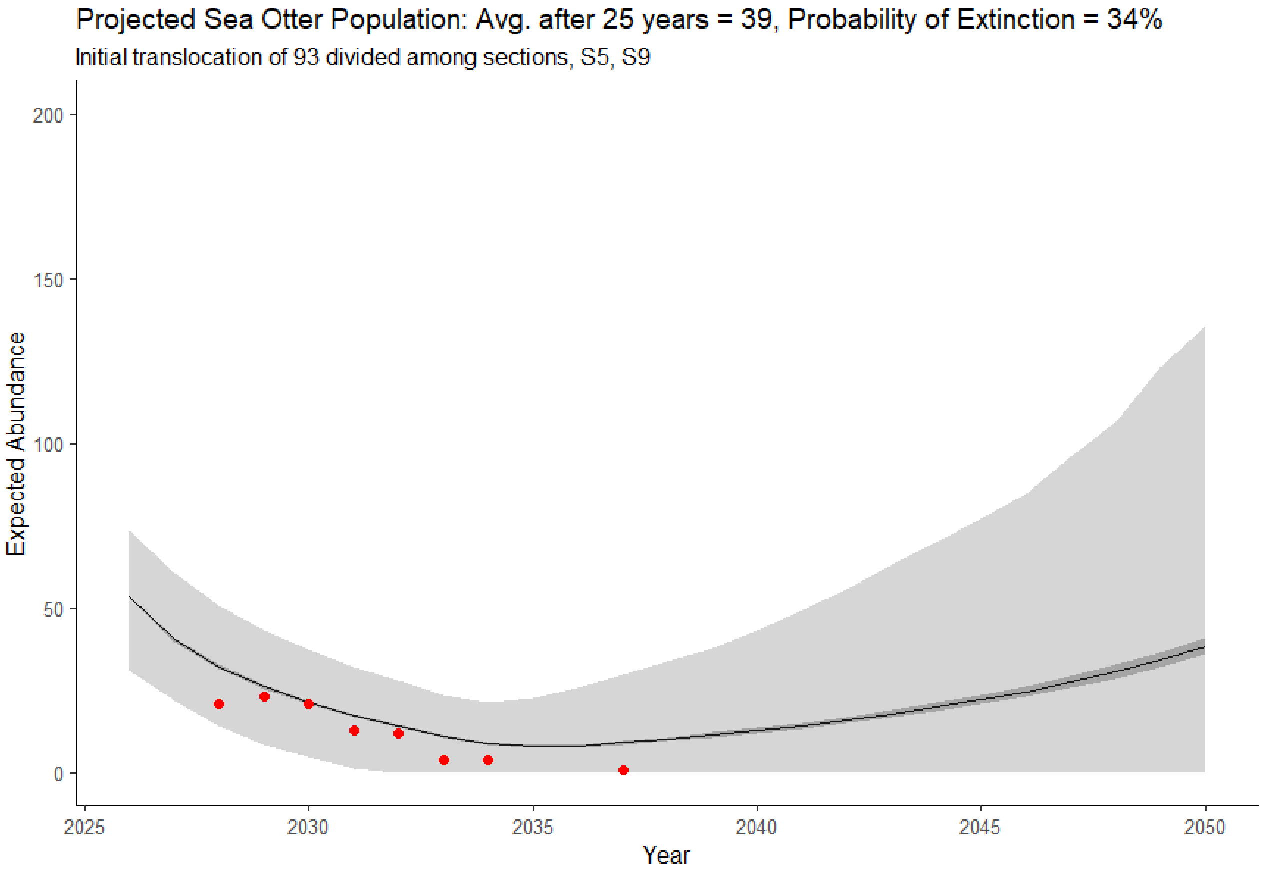
Note. Shown are the initial coastal sections (per Figure 3.4), number of otters introduced, sex composition (% Fm = the percentage female), age composition (% Ad = the percentage adult), expected abundance after 25 years (mean and 95% quantiles), percentage of simulations going to extinction within 25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

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



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

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



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

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

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

IMPLICATIONS OF REINTRODUCTION FOR THE SPECIES

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

The North Pacific fur trade of the 18th and 19th centuries dealt a severe blow to sea otters, completely extirpating them from a vast stretch of their historical range in North America (Kenyon 1969). This event greatly increased the susceptibility of the species to total extinction due to the demographic risks of a small population size, as well as the genetic consequences of population reduction and fragmentation (see Chapter 4). Just as importantly, it eliminated their functional role as a keystone apex predator in nearshore ecosystems from Mexico to Alaska (Estes and Duggins 1995, Estes et al. 2004).

One of the primary challenges managers face in facilitating the recovery of sea otters and the restoration of their functional roles in coastal ecosystems is that natural range expansion is extremely slow in this species. As discussed above, this slow expansion is due to inherent traits in sea otters: the limited mobility and high site fidelity of reproductive adults. Because of these traits, sea otters' natural recolonization of all their former habitats in western North America from the remnant colonies in Alaska and California could have taken centuries. Instead, this process was greatly accelerated by translocations from southwestern Alaska to SE Alaska, British Columbia, and Washington (Jameson et al. 1982). However, there remains a sizable stretch of unoccupied coastline between the Washington population and California population, and given the relatively slow rate of range spread for both these populations, the point at which they converge naturally could be many decades away.

From a species-level perspective, the significance of a managed reintroduction to Oregon would be the acceleration of sea otters' return to the entirety of its former range, restoration of its functional role in those habitats, and reestablishment of a near-continuous (albeit patchy) distribution along the west coast of North America. Restoring a near-continuous distribution is a requirement for allowing pre-fur trade levels of gene flow (Larson et al. 2002, Wellman et al. 2020) and would greatly enhance the potential for demographic rescue effects (the process by which natural dispersal from one area can "rescue" a neighboring subpopulation that has experienced a decline from disease, predation, or anthropogenic impacts like oil spills). When considering the species-level implications of an Oregon reintroduction, this biogeographic perspective is more relevant than a simple tabulation of sea otter numbers.

CONCLUSIONS

An assessment of the population impacts of a species reintroduction must form a core part of any feasibility study because restoring a viable population within the former range is a fundamental objective of conservation-based reintroductions (Seddon et al. 2007, IUCN 2013). Population viability should be considered from the perspective of the source population, the proposed recipient location, and the species overall. Here, we have used quantitative approaches to assess the population-level impacts of removing animals from putative source populations and the likely viability of an established Oregon population under various reintroduction scenarios. Managers and a wide range of stakeholders can easily use the model framework developed for this assessment (the ORSO web app) to explore the potential outcomes of alternative reintroduction scenarios, assess the relative risks and implications for coastal ecosystems and socioeconomic activities, and evaluate the factors likely to determine a reintroduction's success or failure.

We emphasize that biological considerations (i.e., population viability and ecological impacts) represent just one set of variables to be factored into decisions about reintroduction. They must be placed in a broader context of social and economic, legal and administrative, and logistical considerations (Reading et al. 2002). We believe ORSO can help in evaluating all these subject areas, as it provides a spatially and temporally explicit tool for visualizing the outcomes of a sea otter reintroduction under different scenarios and assumptions. Finally, in thinking about the species-level implications of reintroduction, we encourage a broad perspective that considers the history and biogeography of past and current sea otter populations.

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