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

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

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# Contents

# 1    Introduction/Context

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

# 2    Methods

## 2.1   Overview

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

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

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

## 2.2 Demographic processes

As with previous sea otter models (Tinker 2015), the core of ORSO is a stage-structured projection matrix describing demographic transitions and thus population growth over time (Caswell 2001). The projection matrix is used to model transitions among four age/sex classes ($c$ = 1:4): 1) juvenile females (weaning-3 y), 2) adult females (3-20 y), 3) juvenile males (weaning-3 y) and 4) adult males (3-20 y).  Transition probabilities are described by 3 parameters: stage-specific annual survival ($S$), adult female reproductive output ($R$, defined as the probability an adult female gives birth to and successfully weans a male or female pup into the juvenile age class), and the growth transition parameter ($G$, the probability that juveniles advance to the adult age class, conditional upon survival). These demographic transitions can be visualized as a loop diagram (Figure 1). Survival rates are age- and sex-dependent and are assumed to vary stochastically and as a function of population density (Siniff and Ralls 1991, Eberhardt and Schneider 1994, Monson et al. 2000b, Tinker et al. 2006).
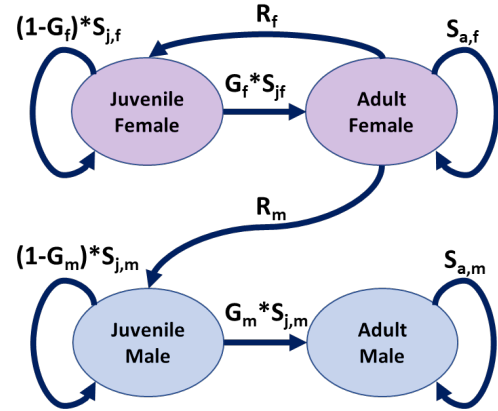
### Demographic Transitions: Loop Diagram



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

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

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

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

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

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

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

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

2

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

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

(4)

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

## 2.3 Spatial Processes

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

efficiency, continuous diffusion dynamics can be approximated within a discretized matrix model by incorporating key features and predictions (e.g. the asymptotic invasion speed of the frontal edge of a population). Discretization can be especially effective if the population is divided into relatively small sub-sections such that demographic processes vary between sub-sections but can be assumed to be approximately homogeneous within sections.

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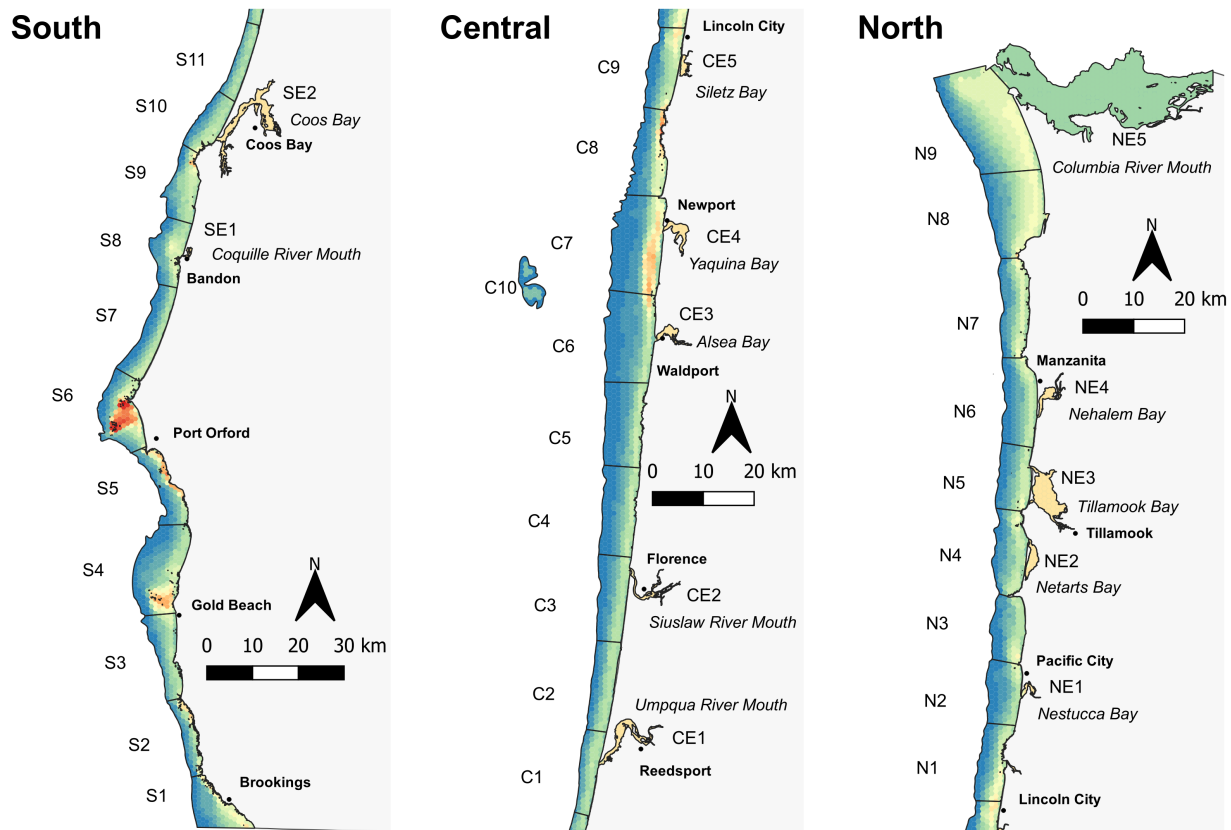


*Figure 2. Spatial configuration of coastal habitat in Oregon used for population model. Coastal habitat sections (labeled polygons) show the basic geographic unit for modeling demographic processes, while the colored spatial grid within these olygons show the relative expected density at carryign capcity,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

Dispersal of sea otters between coastal sections is modeled and tracked separately for each age/sex class in ORSO, reflecting the different mobility and dispersal capability of sea otters of different ages and sex (Jameson 1989, Tarjan and Tinker 2016, Breed et al. 2017). We used previously collected data from radio-tagged sea otters to estimate probabilities that otters of each age/sex class emigrate from coastal section $i$ to coastal section $j$ in
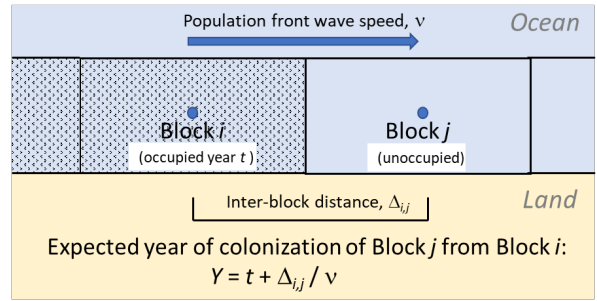
## Range Expansion Dynamics



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

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

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

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

## 2.4  Estimating K and Habitat Effects

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

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

## 2.5  Establishment Phase

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

sections, only emerge after this establishment phase, which may extend for 5-20 years after the initial translocation (Jameson et al. 1982, Bodkin et al. 1999, Carswell 2008, Bodkin 2015).

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

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

In equation (6), the annual excess mortality rate ($m_t$) is drawn from a *Beta* distribution with parameters $\alpha$ and $\beta$, which are set so as to create a $0 - 1$ bounded distribution with mean of $M$ and coefficient of variance (CV) of 0.25, a level of variation consistent with previously published demographic schedules (Gerber et al. 2004, Tinker et al. 2019b). The modified stochastic survival rates ($S'_{c,t}$) are used to parameterize the population projection matrix **P** (equations 1-3 above) for each year during the establishment phase. Thus, if we define the initial population vector of introduced animals as $n_{c,0}$ (where $N_0 = \Sigma \, n_{c,0}$), then the survivors in year 1 are calculated via matrix multiplication as $n_{c,1} = $ **P$_0$** * $n_{c,0}$.

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

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

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

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

7

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

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

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

## 2.6   Model Simulations

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

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

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

b.  If establishment phase complete ($t > E$), determine any new sections that have become occupied since the previous time step: a section is eligible to be colonized depending on its distance to a neighboring occupied section, the number of years the neighboring section has been occupied, and the value of $\nu$, as illustrated in Figure 3.

c.  For all sections occupied at time $t$, calculate intrinsic population growth rates (equation 4). Draw random sets of vital rates corresponding to $\lambda_{i,t}$ and use these to parameterize projection matrix $\mathbf{P}_{i,t}$ following equation 3. If establishment phase ($t \leq E$), adjust rates accordingly based on parameter $M$ (equation 6). To account for spatial autocorrelation in environmental stochasticity, values of $\varepsilon_{i,t}$ are drawn from a multivariate normal distribution with mean of 0 and co-variance matrix adjusted (using standard auto-regressive methods) to produce standard deviation $\sigma$ and correlation across neighboring sections of 0.8 (Gelfand and Vounatsou 2003).

d.  If establishment phase complete ($t > E$), draw randomly from Poisson distribution (with rate parameters $n_{c,i,t} \cdot \delta_{c,i}$) to determine how many (if any) otters of each age/sex class disperse from section $i$ ($d_{c,i,t}$).

e.  Draw randomly from multinomial distribution (with probability vector PDF$_{i,j}$) to determine which occupied sections will receive the dispersers from section $i$.

f.  Calculate the stage-specific change in abundance for section $i$ in year $t$ as:

$$n_{c,i,t} = \mathbf{P}_{i,t} \cdot n_{c,i,t-1} - d_{c,i,t} + \sum_j a_{c,j,i,t} + o_{c,i,t} \qquad (9)$$

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

5.  Tabulate the abundance of otters in each section for each year of each model simulation.

6.  Down-scale estimated densities to the scale of 1-km$^2$ habitat cells by spatial-interpolation between section centroids, weighted by the habitat suitability index of each cell (equation 5).

7.  Summarize results graphically and in tables.

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

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

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

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

# 3   Simulation Results: Sample Scenario

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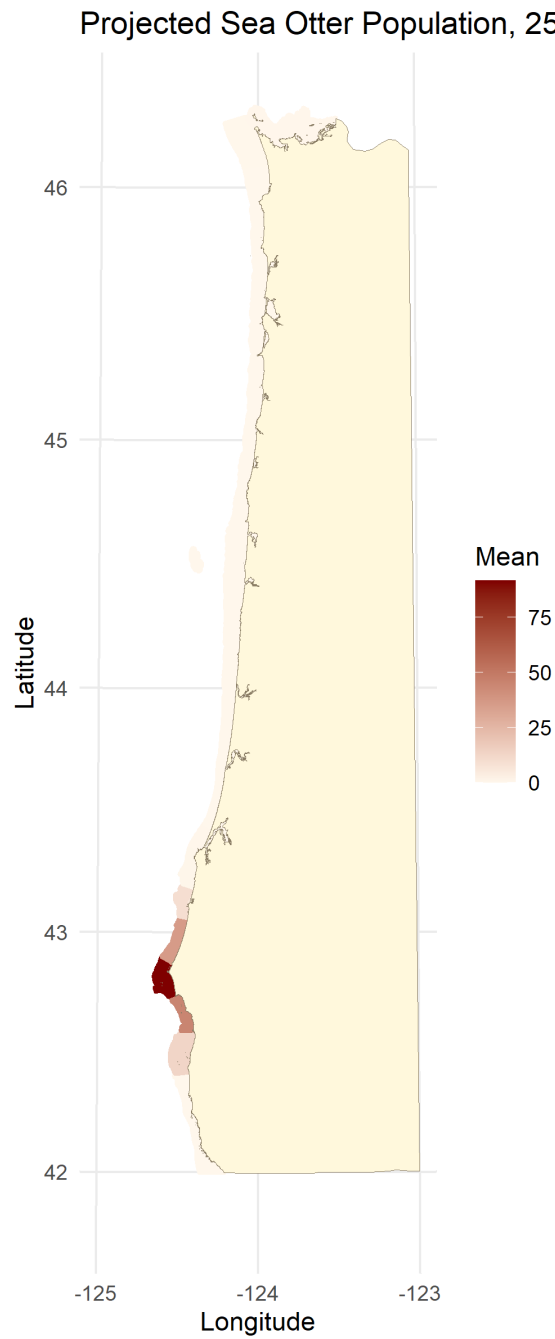
# Projected Sea Otter Population, 25 Years



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

Projected Sea Otter Population, 25 Years
Average expected abundance (line) with 95% CI for the mean (dark shaded band) and 95% CI for projection uncertainty (light shaded band)
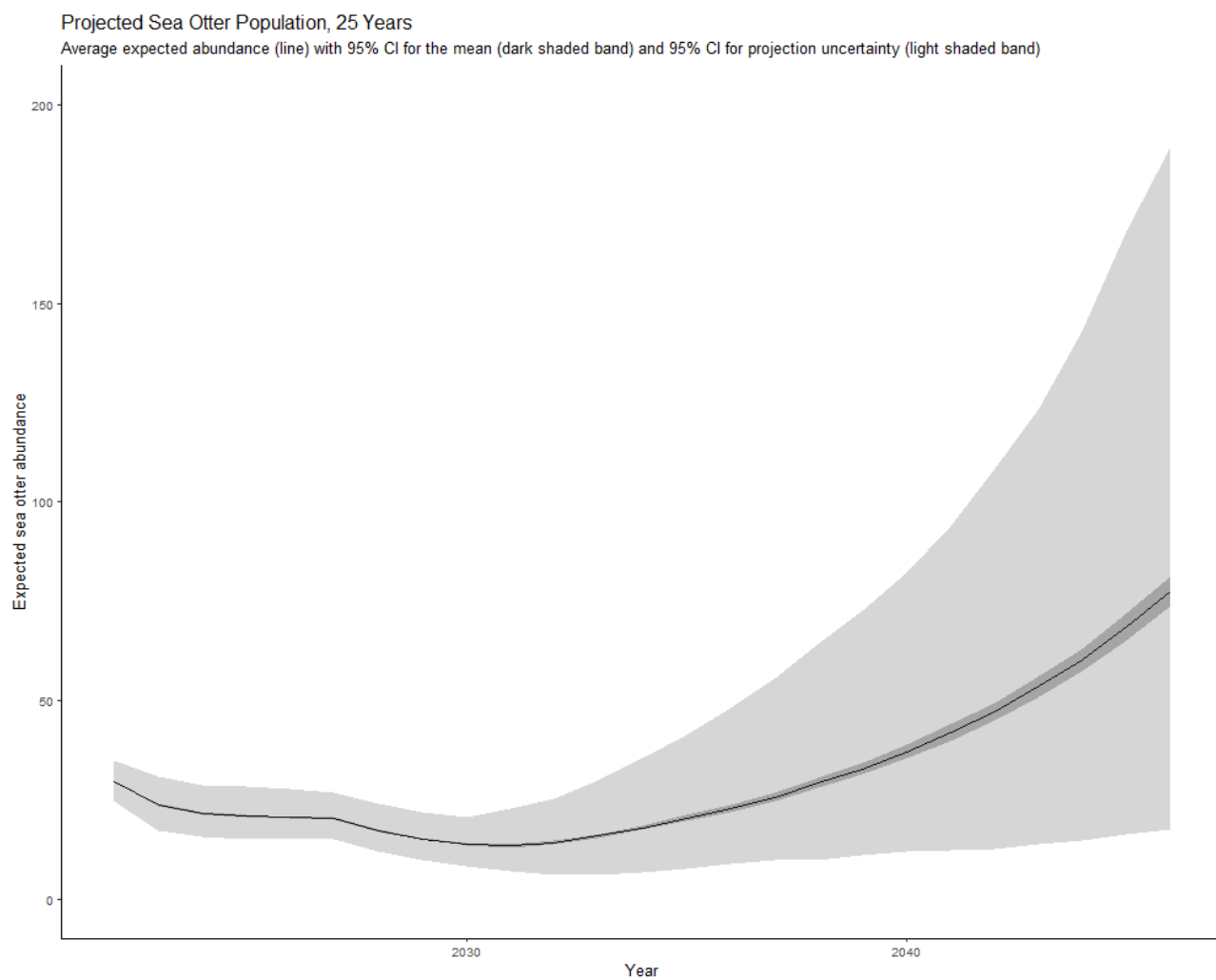
*Figure 5. Results from model simulations of sea otter population dynamics over 25 years in coastal Oregon, showing projected population trends. Light gray band shows 95% CI for simulations; dark gray band shows 95% CI for mean.*
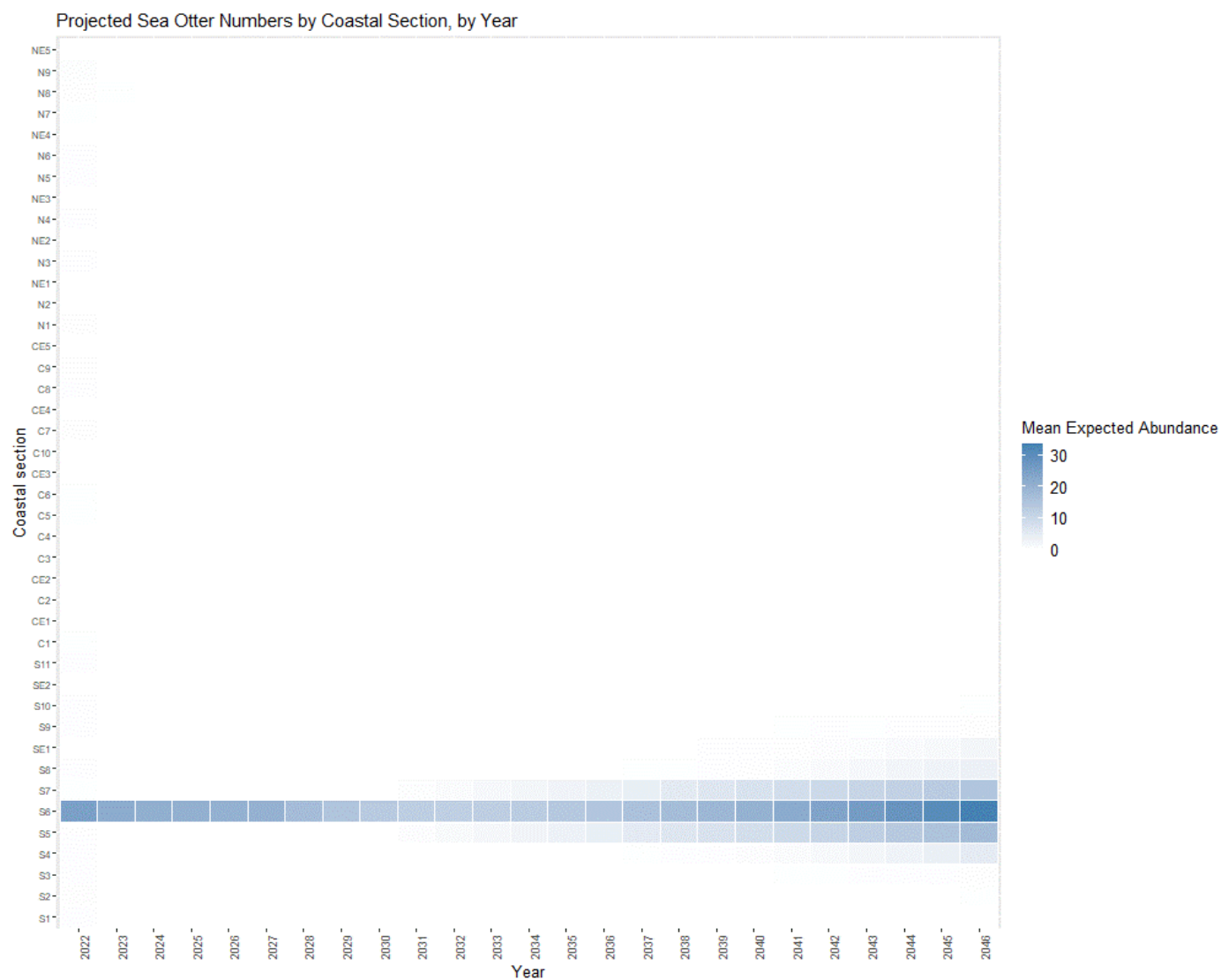
*Figure 6. Results from model simulations of sea otter population dynamics in coastal Oregon, showing a heatmap of mean expected abundance by Coastal Section over a 25-year period. Refer to figure 2 for locations and boundaries of each coastal section.*

# Oregon Sea Otter Population Model (ORSO), User Interface

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

## Overview

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

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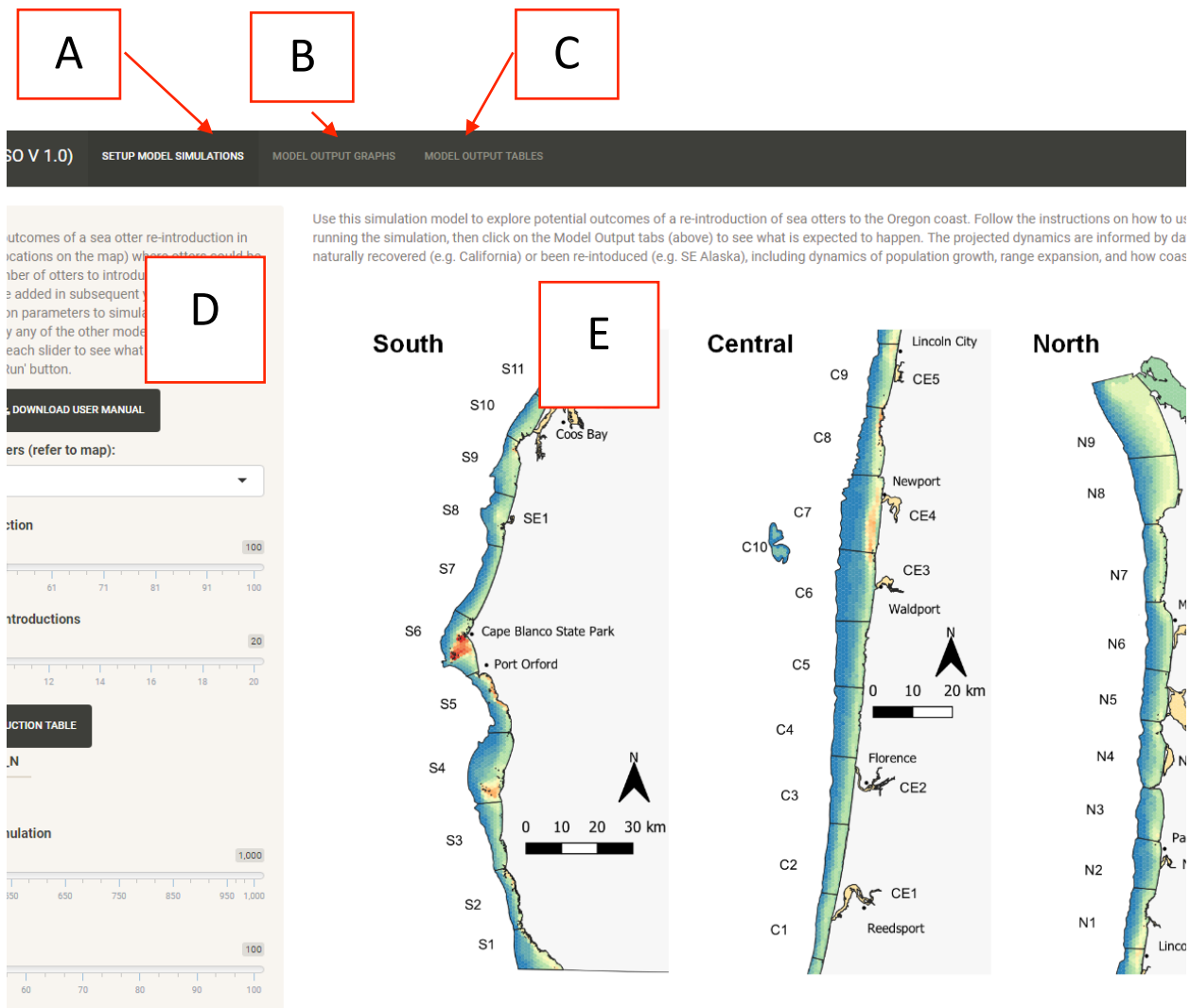
## Components of ORSO App
### Setup Model Simulations Panel

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

HOW TO USE THIS APP: To explore potential outcomes of a sea otter re-introduction in Oregon: (1) Select a coastal section (refer to locations on the map) where otters could be re-introduced; (2) Use sliders to adjust the number of otters to introduce to this coastal section, as well as any additional animals to be added in subsequent years; 3) Click 'Update table' button to add these reintroduction parameters to simulation, and repeat if desired for addition coastal sections; 4) Modify any of the other model parameters below to explore their effects (hover the mouse over each slider to see what each term means); and (3) Run the simulation by clicking on the 'Run' button.

**RUN SIMULATIONS NOW**    **⬇ DOWNLOAD USER MANUAL**

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

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

Select a coastal section for re-introducing otters (refer to map):

| S6 | ▼ |
|---|---|

Number of otters initially added to coastal section

1 —————————————————[50]————————————————— 100

| 1 | 11 | 21 | 31 | 41 | 51 | 61 | 71 | 81 | 91 | 100 |

Number of otters (per year) in supplemental introductions

0 ——[3]————————————————————————————— 20

| 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |

**UPDATE INTRODUCTION TABLE**    **CLEAR INTRODUCTION TABLE**

| Intro_Section | Initial_N | Supplemental_N |
|---|---|---|
| S6 | 50 | 3 |

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

15

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

### *Adjust number of iterations*

**Number of times to iterate this population simulation**

| 50 | 500 | 1,000 |

50  150  250  350  450  550  650  750  850  950  1,000
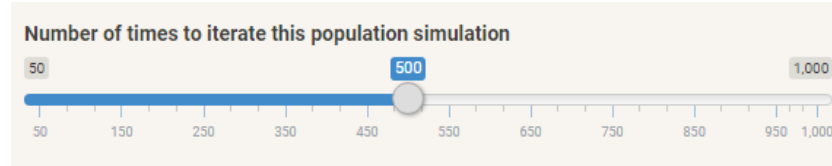
This slider control is used to increase or decrease the number of simulation iterations: that is, the number of times a population simulation is replicated with random draws of all appropriate stochastic parameters. Increasing the number of replications of a simulation improves the precision of model predictions but will take longer to run. At least 100 iterations are suggested.

### *Adjust number of years*

**Number of years for each simulation**

| 10 | 25 | 100 |

10  20  30  40  50  60  70  80  90  100
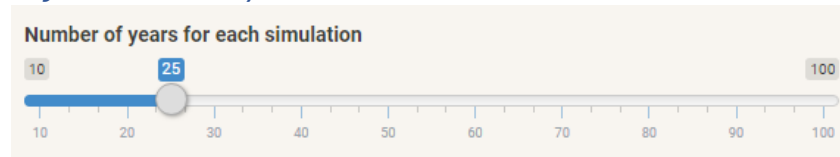
This slider control is used to increase or decrease the number of years into the future the simulation is run. Increasing the number of years ('N') can provide insights into conditions farther in the future, but results become less reliable the farther ahead in time the model is projected.

### *Adjust number of years that supplemental introductions occur*

**Number of years of supplementary introductions**

| 0 | 5 | 25 |

0  3  6  9  12  15  18  21  24  25
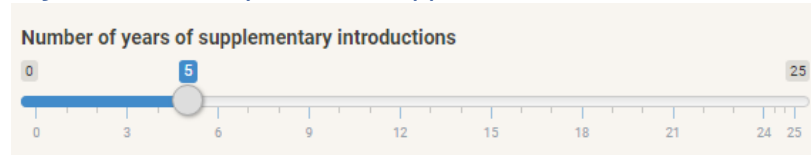
This slider control is used to increase or decrease the number of years after the initial translocation event in which additional otters may be added to the initial reintroduction site (supplemental reintroductions). Adding more otters could potentially improve success of the reintroduction by stabilizing the population during the establishment phase. These additional otters could be wild otters or juvenile re-habilitated otters from captivity.

### *Adjust sex ratio of reintroduced otters*
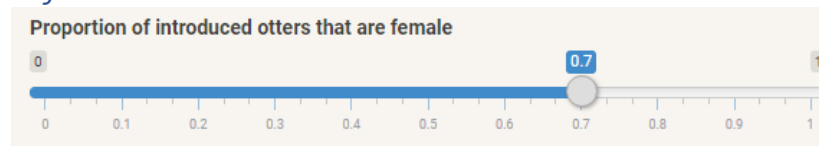
**Proportion of introduced otters that are female**

| 0 | 0.7 | 1 |

0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1

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

## Adjust age composition of reintroduced otters
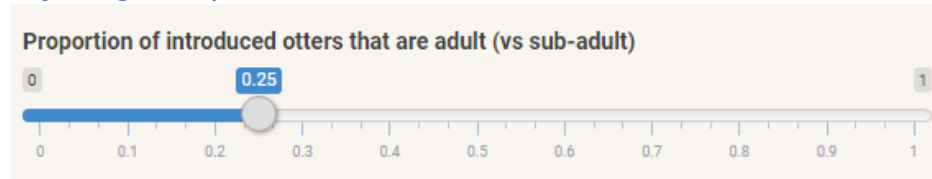
**Proportion of introduced otters that are adult (vs sub-adult)**

0    |0.25|    1

0    0.1    0.2    0.3    0.4    0.5    0.6    0.7    0.8    0.9    1

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

## Adjust duration of "population establishment" phase

**Number of years expected population establishment phase**

1    |15|    20

1    3    5    7    9    11    13    15    17    19  20
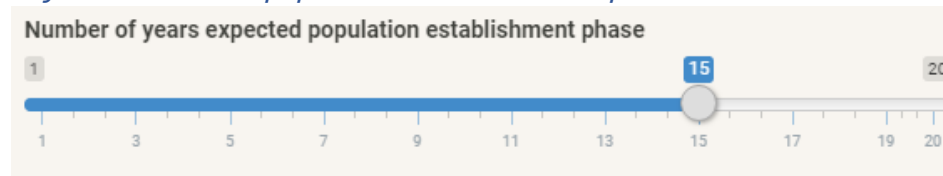
Newly established sea otter populations often experience an initial period of reduced growth and limited range expansion, as the population becomes established. This establishment period has varied from 5-15 years in previous re-introductions and natural return events. This slider control allows the user to set the expected duration of this phase. In addition to reduced survival rates and range expansion during the establishment period, the user can specify the probability of post-introduction dispersal away from the release site.

## Adjust excess mortality during establishment

**Excess annual mortality during establishment phase**

0    |0.12|    0.5

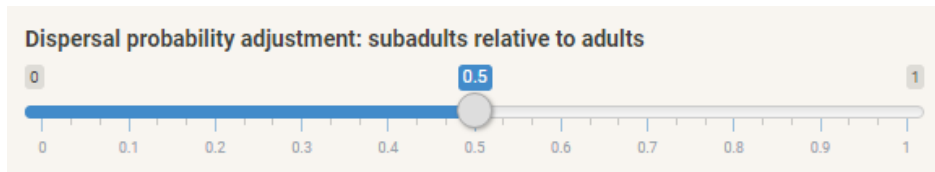0    0.05    0.1    0.15    0.2    0.25    0.3    0.35    0.4    0.45    0.5

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

## Adjust probability of dispersal during establishment phase (adults)

**Probability of dispersal during establishment phase (adults)**

0    |0.7|    0.95

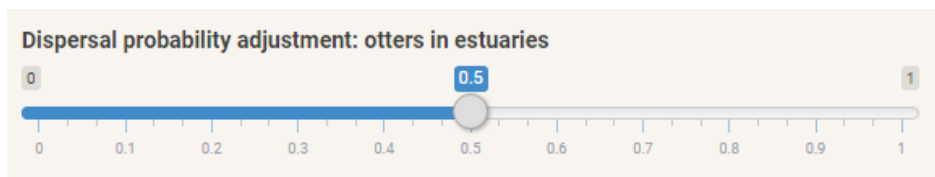0    0.1    0.2    0.3    0.4    0.5    0.6    0.7    0.8    0.9  0.95

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

## Adjust probability of dispersal during establishment phase for subadults

**Dispersal probability adjustment: subadults relative to adults**

| 0 | 0.5 | 1 |

0    0.1    0.2    0.3    0.4    0.5    0.6    0.7    0.8    0.9    1
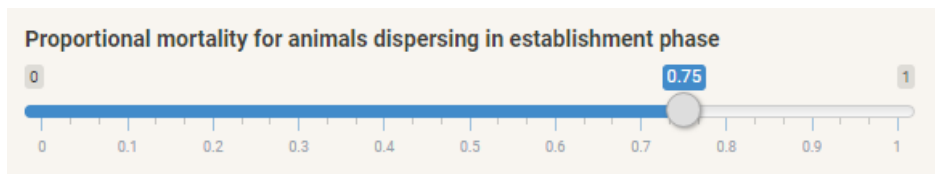
In previous sea otter translocations, it has been observed that subadult animals may be less likely to disperse than adults (i.e. more likely to remain near the introduction site). This parameter adjusts the likelihood of dispersal for subadults as compared to adults: a value of 0.25 would mean that subadults are 1/4 as likely to disperse as adults.

## Adjust probability of dispersal during establishment phase for otters in estuaries

**Dispersal probability adjustment: otters in estuaries**

| 0 | 0.5 | 1 |

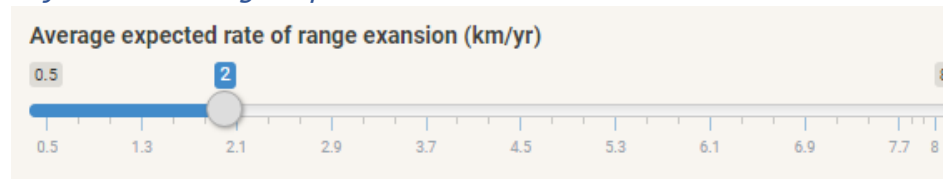0    0.1    0.2    0.3    0.4    0.5    0.6    0.7    0.8    0.9    1

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

## Adjust mortality rate of otters that disperse during establishment phase

**Proportional mortality for animals dispersing in establishment phase**

| 0 | 0.75 | 1 |

0    0.1    0.2    0.3    0.4    0.5    0.6    0.7    0.8    0.9    1

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

## Adjust rate of range expansion

**Average expected rate of range exansion (km/yr)**

| 0.5 | **2** | | | | | | | | | 8 |

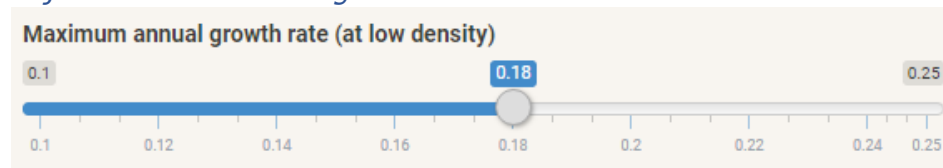| 0.5 | 1.3 | 2.1 | 2.9 | 3.7 | 4.5 | 5.3 | 6.1 | 6.9 | 7.7 | 8 |

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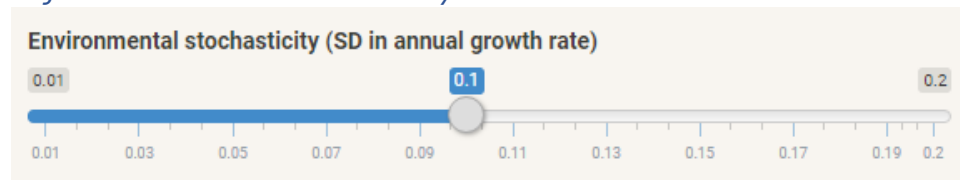
### Range Expansion Dynamics
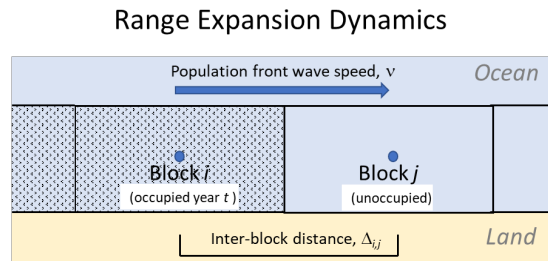


*Schematic drawing illustrating how the model incorporates range expansion of sea otter population from occupied habitat into adjacent unoccupied habitat*

## Adjust maximum rate of growth

**Maximum annual growth rate (at low density)**

| 0.1 | | | | **0.18** | | | | 0.25 |

| 0.1 | 0.12 | 0.14 | 0.16 | 0.18 | 0.2 | 0.22 | 0.24 | 0.25 |

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

## Adjust environmental stochasticity

**Environmental stochasticity (SD in annual growth rate)**

| 0.01 | | | | **0.1** | | | | | 0.2 |

| 0.01 | 0.03 | 0.05 | 0.07 | 0.09 | 0.11 | 0.13 | 0.15 | 0.17 | 0.19 | 0.2 |

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

## Adjust 'theta' parameter, for theta-logistic growth

**Value of 'theta' (for theta-logistic growth)**

| 0.5 | 0.9 | 2 |
|---|---|---|

0.5    0.7    0.9    1.1    1.3    1.5    1.7    1.9    2

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

## *MODEL OUTPUT GRAPHS Panel*

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

## *Population Trend Graph*
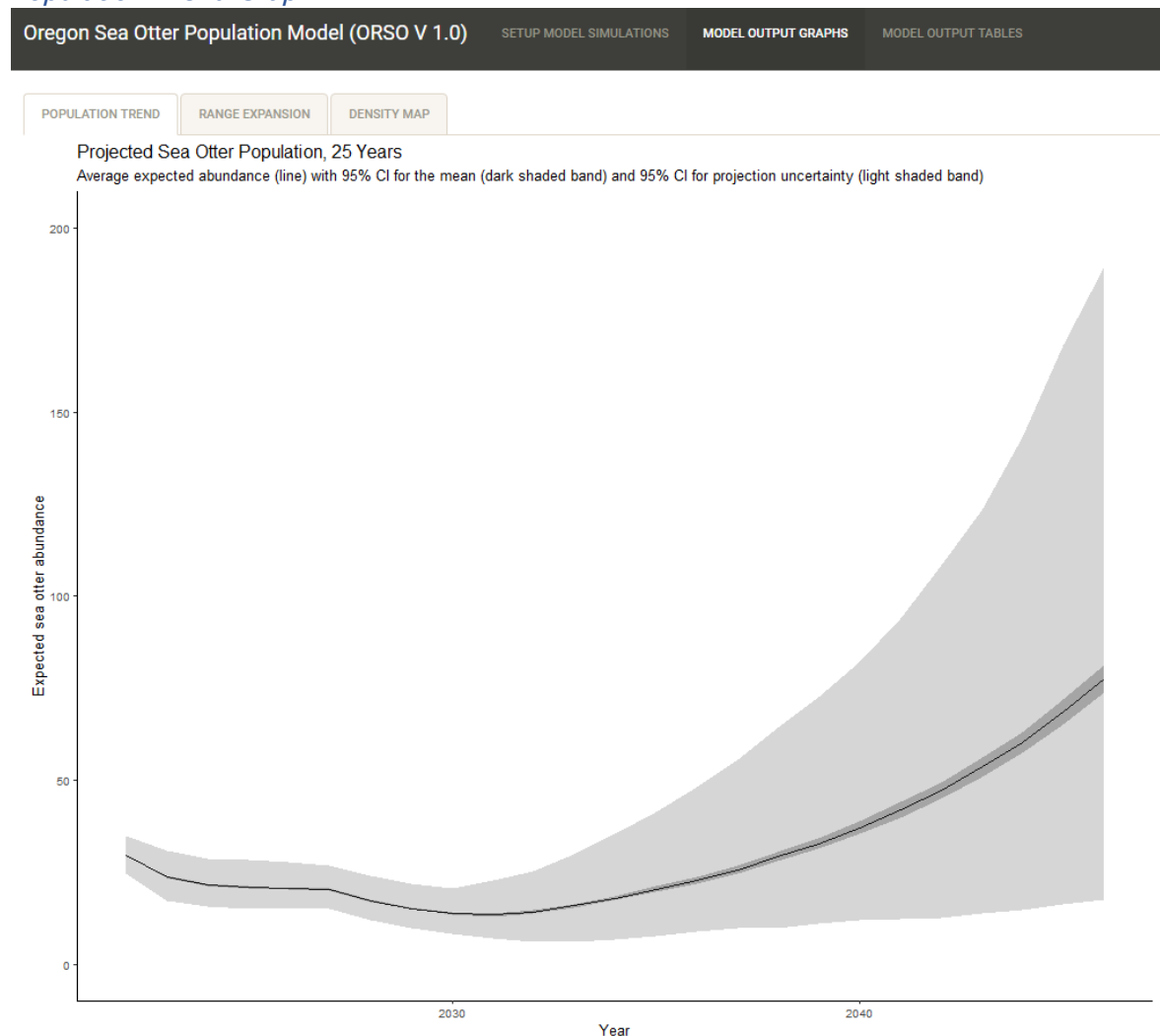


This plot shows the projected abundance over time of sea otters in Oregon, based on results from the simulation model (EXAMPLE SHOWN IS FOR ILLUSTRATIVE PURPOSES ONLY). The horizontal axis represents years into the future, while the vertical axis represents the expected total number of sea otters in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

*Range Expansion Graph*



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

## Density Map
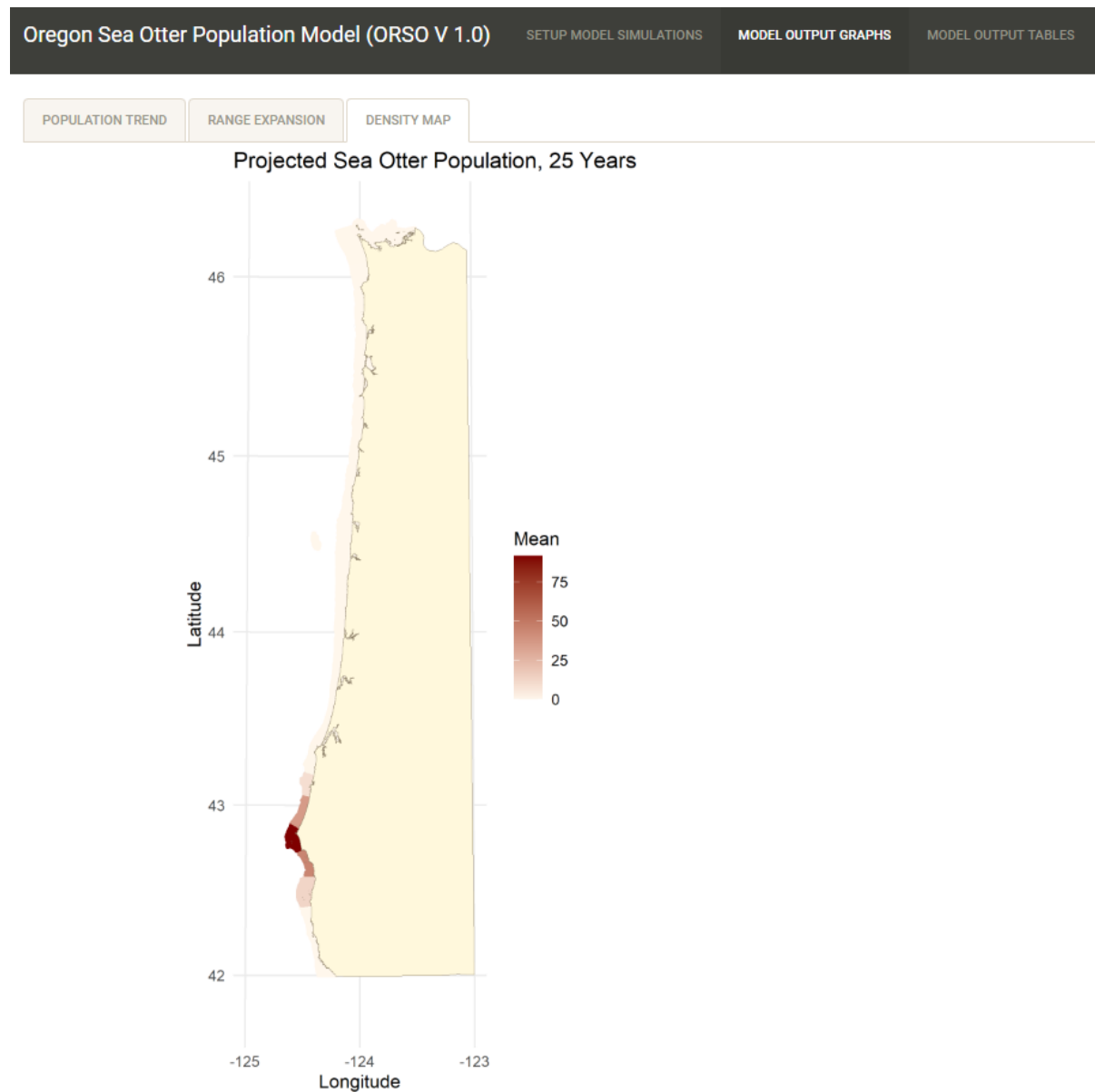


This map figure of coastal Oregon shows the average projected abundance and distribution of sea otters at the end of the simulation period (EXAMPLE SHOWN IS FOR ILLUSTRATIVE PURPOSES ONLY). The mean expected number of sea otters in each coastal section (for the specified reintroduction scenario) is illustrated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

## MODEL OUTPUT TABLES Panel

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

  "Table 1: Projected Sea Otter Abundance by Year"

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

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

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

⬇ DOWNLOAD TABLE 1

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

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

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

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

⬇ DOWNLOAD TABLE 2

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

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

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

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# 4 Appendix A

**R Code for Oregon Sea Otter Model (ORSO)**

(following pages)