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Supplementary Material: Catastrophes, connectivity, and Allee effects in the design of marine reserve networks

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Data and code for all the figures and tables can be found at (https://github.com/eastonwhite/MPA-disturbances).

Appendix S1 n-patch model description

To extend the two-patch model described in the main manuscript to an n-patch scenario, we have to use a slightly different model formulation. We use the same Beverton-Holt structure within each patch for production described in the main manuscript. However, we model spatially-explicit dispersal (i.e. resulting connectivity between patches) and disturbances. We focus on a coastline system (a simple one-dimensional landscape) where d_{ij} is the distance between patches i and j (also see Figure 1d in main text). Thus, the patches are in a contiguous line and where discrete patches next to each other would have a distance of $d_{ij} = 1$ between them.

We use geometric decay for the dispersal kernel, with a dispersal shape parameter δ, where increasing δ decreases dispersal amount and distance. The probability of dispersal from patch i to j is

$$P(\text{dispersal from patch i to patch j}) = \text{Geometric}(\delta, d_{ij}). \tag{S1}$$

For disturbances, we model the probability of disturbance, M_i, in each patch as a binomial process with probability p_i:

$$M_i(t) \sim \text{Binomial}(1, p_i). \tag{S2}$$

The spatial extent of the disturbance is a stochastic process giving the disturbance size (x), which affects patches near the disturbance. If a disturbance in patch i is larger than the distance between patches i and j, d_{ij}, then patch j will also be affected by the disturbance:

$$P(\text{disturbance in patch j} \mid \text{disturbance in patch i}) = \begin{cases} 1 & \text{if } d_{ij} < x \\ 0 & \text{if otherwise.} \end{cases} \tag{S3}$$

A disturbance causes density-independent mortality, μ, for the entire patch and all patches with distance x.

With this n-patch model, we can relax the assumption of a "scorched earth" between patches by setting the fraction of biomass fished in non-reserves to be $F < 1$. This allows us to study the effect of fishing pressure outside reserves on the effectiveness of the marine reserve network.

Notation	Description	Default value(s)
$r_i(t)$	growth factor of patch i at time t described as a normal distribution	
μ_r	mean of growth factor normal distribution	3
σ_r^2	variance of growth factor normal distribution	0.5
K_i	carrying capacity for patch i	1
ω	Allee effect parameter	1 for no Allee effect or >1 for Allee effect
δ	dispersal kernel shape parameter (larger δ indicates less dispersal)	0.7
p_i	probability of disturbance	0.02
x	size of disturbance (number of patches adjacent to disturbed patch that will also be disturbed)	1
μ	density-independent mortality from disturbance	0.9
F	fraction of biomass fished in non-reserves	for scorched earth assumption of all biomass caught or <1 for moderate levels of fishing

Table S1: Parameter notation, description, and default values for the n-patch model. As a sensitivity analysis, several parameters are varied in the Figs. 5,6, S4.

Appendix S2 Additional figures

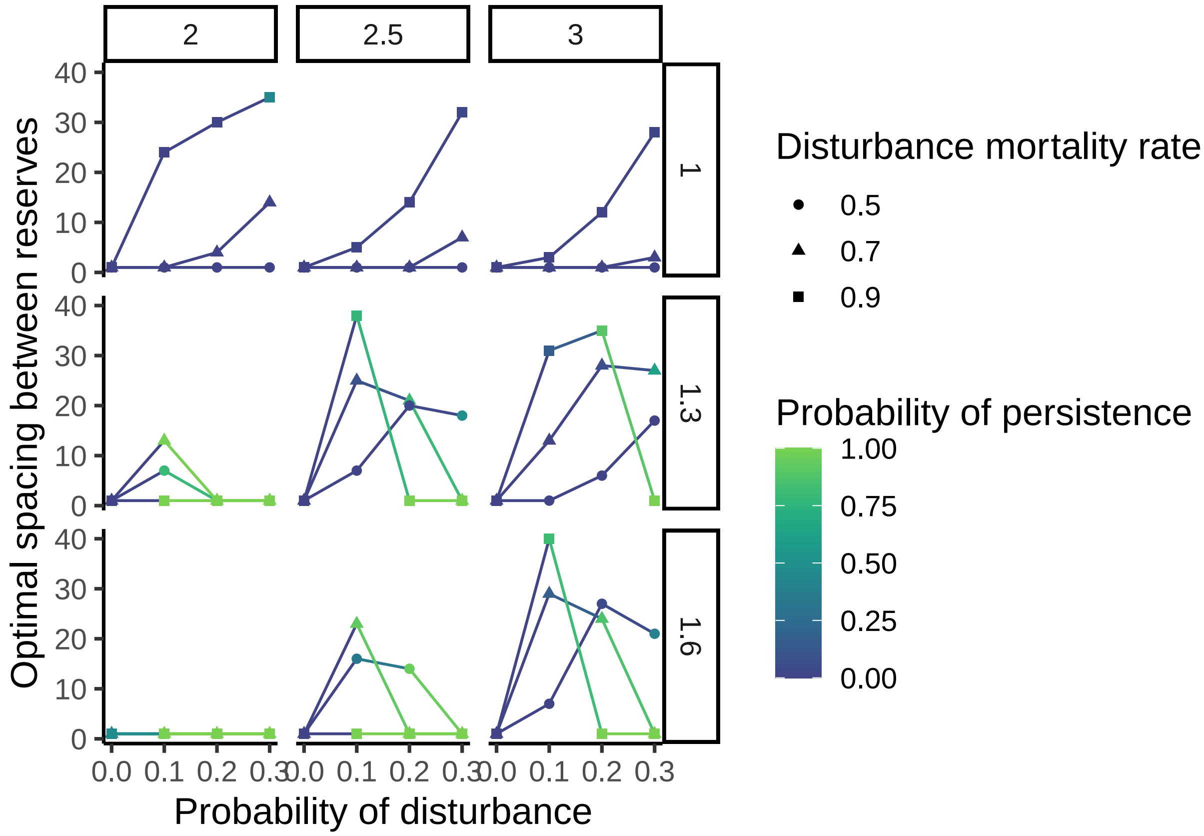

Figure S1: Optimal spacing for varying Allee and r values along with different disturbance parameters.

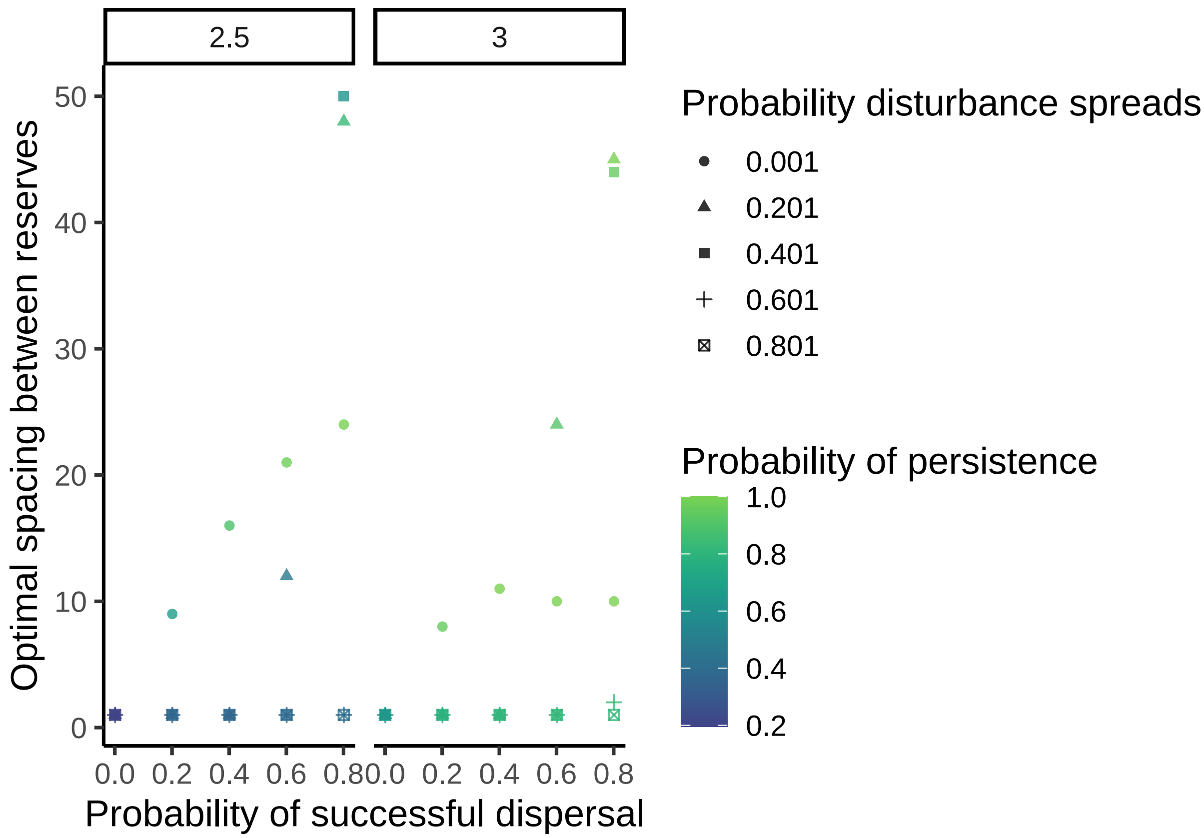

Figure S2: Optimal spacing for different γ, δ, r, and probability of disturbance.

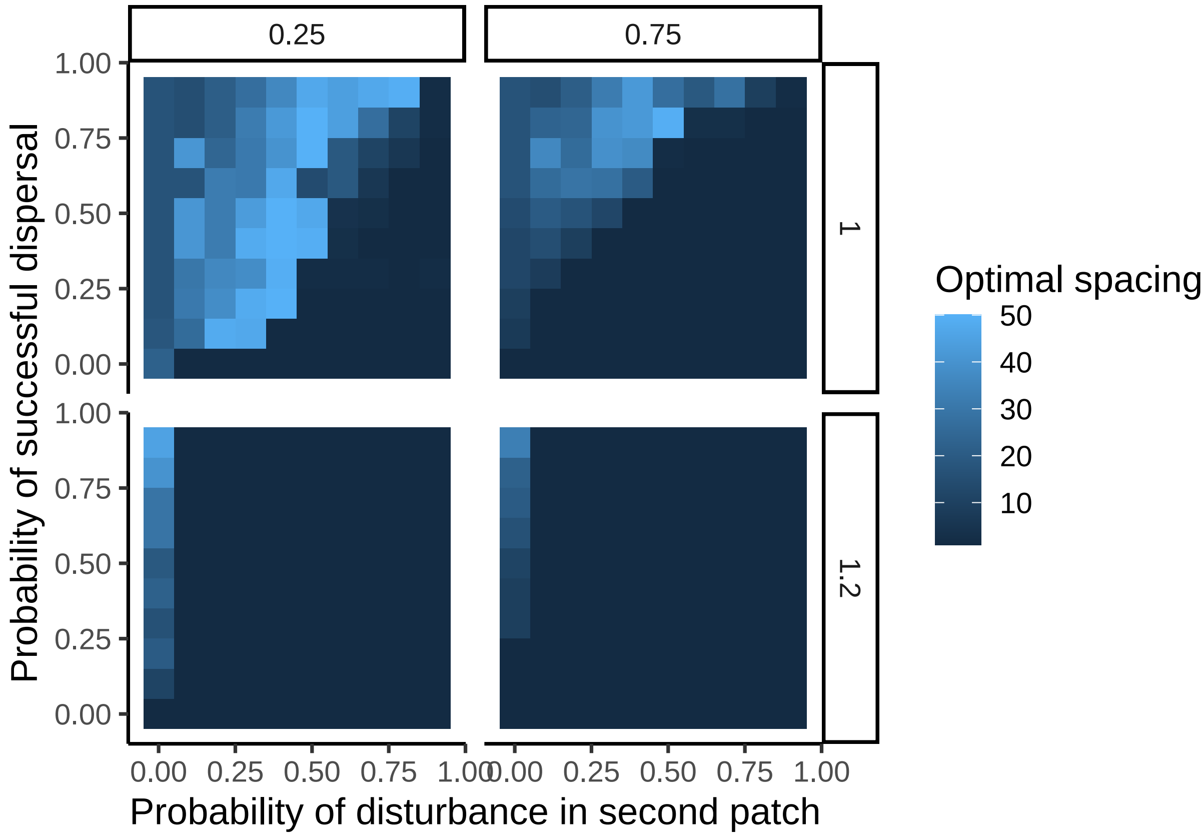

Figure S3: Optimal spacing for all the dispersal parameters and the probability of disturbance.

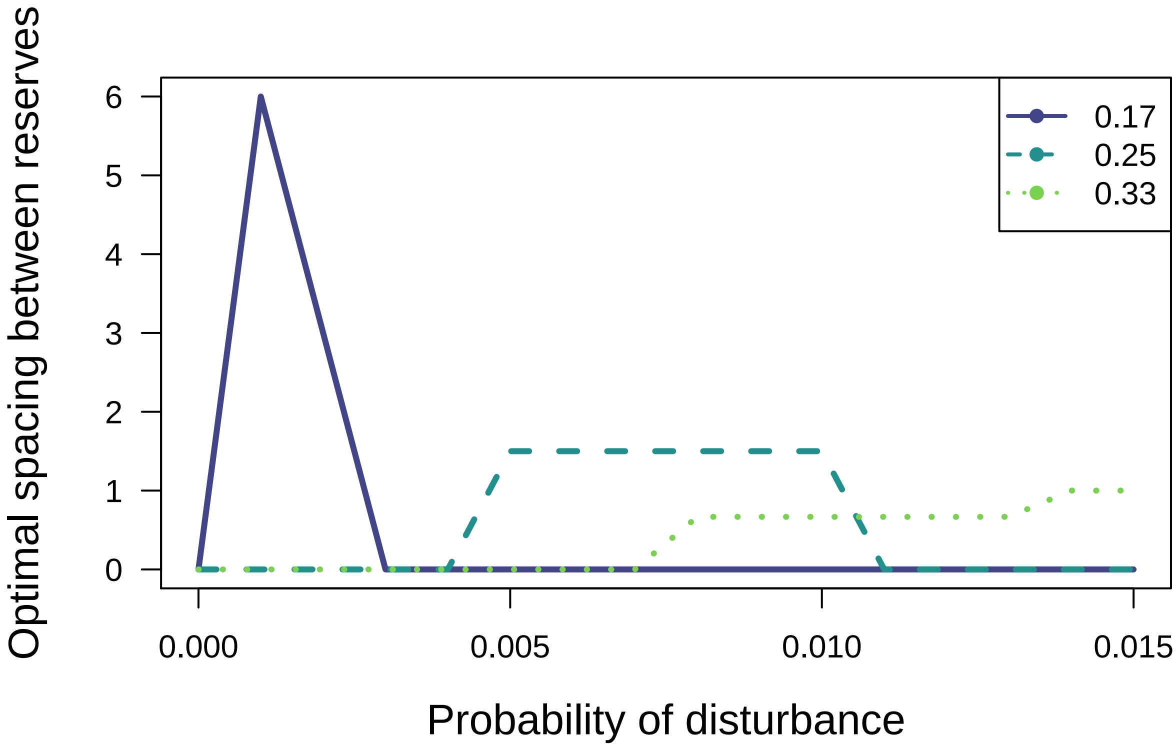

Figure S4: Optimal mean spacing between reserves for different probabilities of disturbance and fraction of coasline in reserves. The specific parameters used here include: $\delta = 0.7$, $\omega = 1.2$, r = 3, and $\mu = 0.9$.