Supporting Information

Smith et al. 10.1073/pnas.0907365107

SI Appendix

SI Appendix A1 illustrates fishermen's discrete, time-dependent decisions about whether to go fishing and, if so, where. *SI Appendix A2* contains 10 propositions and proofs that analytically demonstrate the short-run results reported in Table 1. The directions of effects are based on signing comparative statics. That is, we take partial derivatives of expected willingness-to-pay with respect to each factor and determine whether the effect is positive or negative. *SI Appendix A3* contains the baseline parameter values used to generate Figs. 1 and 2 and Figs. S2–S4. *SI Appendix A4* contains additional modeling details as well as analysis of dynamic simulations that explore the effects of fuel costs and a relative density dispersal matrix on the results in Fig. 2, the impacts of fishing skill heterogeneity over time, and the importance of other sources of ecological heterogeneity. *SI Appendix A5* discusses how broader social issues surrounding marine reserve creation can be incorporated into our modeling framework.

A1. Decision Tree of Commercial Fishermen.

A2. Proofs.

1. Expected willingness to pay to avoid forming a reserve decreases as the nonfishery opportunity increases. **Proof.** Taking the derivative of the willingness-to-pay (WTP) function with respect to the nonfishery opportunity gives the following:

$$\frac{\partial E(WTP)}{\partial \alpha} = \left(\frac{e^{\alpha}}{e^{\alpha} + \sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \varphi z_j\right)}\right) - \left(\frac{e^{\alpha}}{e^{\alpha} + \sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \varphi z_k)}\right).$$

Because the denominator of the second term is smaller, the difference is negative.

Q.E.D.

2. Expected willingness to pay to avoid forming a reserve decreases as the nonfuel cost of taking a trip increases. **Proof.** Taking a derivative with respect to the quasi-fixed cost gives the following.

$$\begin{aligned}
\frac{\partial E(WTP)}{\partial c} &= \left(\frac{-\sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)}{e^{\alpha} + \sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)}\right) - \left(\frac{-\sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \phi z_k)}{e^{\alpha} + \sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \phi z_k)}\right) \\
&= \left(\frac{\sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \phi z_k)}{e^{\alpha} + \sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \phi z_k)}\right) - \left(\frac{\sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)}{e^{\alpha} + \sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)}\right) \\
&= \left(1 - \frac{e^{\alpha}}{e^{\alpha} + \sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \phi z_k)}\right) - \left(1 - \frac{e^{\alpha}}{e^{\alpha} + \sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)}\right) \\
&= \left(\frac{e^{\alpha}}{e^{\alpha} + \sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)}\right) - \left(\frac{e^{\alpha}}{e^{\alpha} + \sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \phi z_k)}\right).
\end{aligned}$$

Because the denominator of the second term is smaller, the difference is negative.

Q.E.D.

3. Expected willingness to pay to avoid forming a reserve decreases as the stock of any of the remaining fishing sites increases. **Proof.** Consider stock m, where $m < J$. Taking a derivative with respect to the stock at site m cost gives the following.

$$\frac{\partial E(WTP)}{\partial X_{mt}} = \left(\frac{\exp(p_t q_m X_{mt} - c - \phi z_k) p_t q_m}{e^{\alpha} + \sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)}\right) - \left(\frac{\exp(p_t q_m X_{mt} - c - \phi z_k) p_t q_m}{e^{\alpha} + \sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \phi z_k)}\right).$$

Because the numerators are the same and the denominator of the first term is larger, the difference is negative.

Q.E.D.

4. Expected willingness to pay to avoid forming a reserve decreases as the catchability at any of the remaining fishing sites increases. **Proof.** Consider site m, where $m < J$. Taking the derivative of the WTP function with respect to the catchability at site m gives the following.

$$\frac{\partial E(WTP)}{\partial q_m} = \left(\frac{\exp(p_t q_m X_{mt} - c - \phi z_k) p_t X_{mt}}{e^{\alpha} + \sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)}\right) - \left(\frac{\exp(p_t q_m X_{mt} - c - \phi z_k) p_t X_{mt}}{e^{\alpha} + \sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \phi z_k)}\right).$$

Because the numerators are the same and the denominator of the first term is larger, the difference is negative.

Q.E.D.

5. Expected willingness to pay to avoid forming a reserve increases as the distance from port to a nonreserve site increases. **Proof.** Taking the derivative of the WTP function with respect to the distance from port to the nonreserve site gives the following.

$$\frac{\partial E(WTP)}{\partial z_m} = \left(\frac{-\exp(p_t q_m X_{mt} - c - \phi z_m)\phi}{e^{\alpha} + \sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)}\right) - \left(\frac{-\exp(p_t q_m X_{mt} - c - \phi z_m)\phi}{e^{\alpha} + \sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \phi z_k)}\right).$$

Because the numerators are the same, both terms are negative, and the denominator of the first term is larger, the difference is positive.

Q.E.D.

6. Expected willingness to pay to avoid forming a reserve increases as the stock at the reserve site increases. **Proof.** Now consider the reserve site itself, namely site J.

$$\frac{\partial E(WTP)}{\partial X_{Jt}} = \left(\frac{\exp(p_t q_J X_{Jt} - c - \phi z_J) p_t q_J}{e^{\alpha} + \sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)} \right) - (0) > 0.$$

Q.E.D.

7. Expected willingness to pay to avoid forming a reserve increases as the catchability at the reserve site increases. **Proof.** Consider the reserve site itself, namely site J. Taking the derivative of the WTP function with respect to the catchability at site J gives the following.

$$\frac{\partial E(WTP)}{\partial q_J} = \left(\frac{\exp(p_t q_J X_{Jt} - c - \phi z_J) p_t X_{Jt}}{e^{\alpha} + \sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)} \right) - (0) > 0.$$

Q.E.D.

8. Expected willingness to pay to avoid forming a reserve decreases as the distance from port to the reserve site increases. **Proof.** Taking the derivative of the WTP function with respect to the distance from port to the reserve site gives the following.

$$\frac{\partial E(WTP)}{\partial z_J} = \left(\frac{-\exp(p_t q_J X_{Jt} - c - \phi z_J) \phi}{e^{\alpha} + \sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)} \right) - (0) < 0.$$

Q.E.D.

9. The effect of fish price on expected willingness to pay to avoid forming a reserve is ambiguous. A higher price tends to increase expected willingness to pay if the stock in the reserve is high, the catchability at the reserve site is high, or the nonfishery opportunity is high. A higher price tends to decrease expected willingness to pay if the stocks outside the reserve are high or catchabilities at nonreserve sites are high.

Proof. Taking the derivative of the WTP function with respect to price gives the following.

$$\frac{\partial E(\mathrm{WTP})}{\partial p_t} = \left(\frac{\sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right) q_j X_{jt}}{e^{\alpha} + \sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)} \right) - \left(\frac{\sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \phi z_k) q_k X_{kt}}{e^{\alpha} + \sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \phi z_k)} \right).$$

Because each term in the numerator is weighted by catchability and stock, the sign of the comparative static is ambiguous. Using the v notation from Eq. **1** and cross-multiplying for a common denominator, we have:

$$\begin{aligned}\frac{\partial E(WTP)}{\partial p_t} &= \left(\frac{\left(\sum_{k=0}^{J-1} e^{v_k}\right) \sum_{j=1}^{J} e^{v_j} q_j X_{jt}}{\left(\sum_{j=0}^{J} e^{v_j}\right)\left(\sum_{k=0}^{J-1} e^{v_k}\right)} \right) - \left(\frac{\left(\sum_{j=0}^{J} e^{v_j}\right) \sum_{k=1}^{J-1} e^{v_k} q_k X_{kt}}{\left(\sum_{j=0}^{J} e^{v_j}\right)\left(\sum_{k=0}^{J-1} e^{v_k}\right)} \right) \\ &= \left(\frac{e^{v_J} q_J X_{Jt} \left(\sum_{k=0}^{J-1} e^{v_k}\right)}{\left(\sum_{j=0}^{J} e^{v_j}\right)\left(\sum_{k=0}^{J-1} e^{v_k}\right)} \right) - \left(\frac{e^{v_J} \left(\sum_{k=1}^{J-1} e^{v_k} q_k X_{kt}\right)}{\left(\sum_{j=0}^{J} e^{v_j}\right)\left(\sum_{k=0}^{J-1} e^{v_k}\right)} \right) \\ &= \left(\frac{e^{v_J} \left[e^{\alpha} q_J X_{Jt} + \left(\sum_{k=1}^{J-1} e^{v_k} (q_J X_{Jt} - q_k X_{kt}) \right) \right]}{\left(\sum_{j=0}^{J} e^{v_j}\right)\left(\sum_{k=0}^{J-1} e^{v_k}\right)} \right).\end{aligned}$$

The sign of this expression depends on whether the term in square brackets is positive. From arranging the terms in this way, we can see that it will tend to be positive if α is big, q_J is big, or X_{Jt} is big and negative if the q_k's and X_{kt}'s are big.

Q.E.D.

10. The effect of fuel price (ϕ) on expected willingness to pay to avoid forming a reserve is ambiguous. A higher fuel price tends to decrease expected willingness to pay if the reserve site is far away or if the nonfishery opportunity is high. A higher fuel price tends to increase expected willingness to pay if the remaining open fishing sites are far away.

Proof. Taking the derivative of the WTP function with respect to fuel price gives the following.

$$\frac{\partial E(WTP)}{\partial \phi} = \left(\frac{-\sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right) z_j}{e^{\alpha} + \sum_{j=1}^{J} \exp\left(p_t q_j X_{jt} - c - \phi z_j\right)} \right) - \left(\frac{-\sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \phi z_k) z_k}{e^{\alpha} + \sum_{k=1}^{J-1} \exp(p_t q_k X_{kt} - c - \phi z_k)} \right).$$

Because each term in the numerator is weighted by z (the distance to each site), the sign of the comparative static is ambiguous. Using the v notation and cross-multiplying for a common denominator, we have:

$$\begin{aligned}\frac{\partial E(WTP)}{\partial \phi} &= \left(\frac{-\left(\sum_{k=0}^{J-1} e^{v_k}\right) \sum_{j=1}^{J} e^{v_j} z_j}{\left(\sum_{j=0}^{J} e^{v_j}\right)\left(\sum_{k=0}^{J-1} e^{v_k}\right)} \right) - \left(\frac{-\left(\sum_{j=0}^{J} e^{v_j}\right) \sum_{k=1}^{J-1} e^{v_k} z_k}{\left(\sum_{j=0}^{J} e^{v_j}\right)\left(\sum_{k=0}^{J-1} e^{v_k}\right)} \right) \\ &= \left(\frac{e^{v_J} \left(\sum_{k=0}^{J-1} e^{v_k} z_k\right)}{\left(\sum_{j=0}^{J} e^{v_j}\right)\left(\sum_{k=0}^{J-1} e^{v_k}\right)} \right) - \left(\frac{e^{v_J} z_J \left(\sum_{k=1}^{J-1} e^{v_k}\right)}{\left(\sum_{j=0}^{J} e^{v_j}\right)\left(\sum_{k=0}^{J-1} e^{v_k}\right)} \right) \\ &= \left(\frac{e^{v_J} \left[\left(\sum_{k=1}^{J-1} e^{v_k} (z_k - z_J) \right) - e^{\alpha} z_J \right]}{\left(\sum_{j=0}^{J} e^{v_j}\right)\left(\sum_{k=0}^{J-1} e^{v_k}\right)} \right).\end{aligned}$$

The derivative will be positive when the following condition holds:

$$\left(\frac{\sum_{k=1}^{J-1} e^{v_k} z_k}{e^{\alpha} + \sum_{k=1}^{J-1} e^{v_k}} \right) > z_J,$$

and negative when z_J is larger than this value.

Q.E.D.

A4. Additional Details and Analysis of Dynamic Simulations. In our analysis, we assume there is a cap on the number of vessels or, in other words, we are considering a limited-entry fishery. We vary that cap (2, 3), levels of travel cost, and alternative earning opportunities. In each analysis, the simulations begin at the relevant bioeconomic equilibrium, which is defined by fishermen making choices that make them as well off as possible, including the possibility that they not fish. The changes in behavior (switching from not fishing to fishing as well as switching across sites) and the changes in stocks are zero in the equilibrium. Depending on the vessel cap and other parameters, there may or may not be positive profits in the prereserve equilibrium. Each simulation is run for 50 years after a reserve is formed in one of the three sites.

Fig. S2 repeats the analysis in Fig. 2 with the addition of another dispersal system (relative density, which is depicted in Fig.

S2 *Bottom*) and simulations to explore variation in fuel costs (Fig. S2 *Left*). The relative density dispersal system leads to outcomes in between the independent and source-sink systems. Like the source-sink case, opposition initially rises and then declines toward a steady state during the transition. However, for most cases the long-run opposition is still higher than the short-run opposition, as in the independent system. The exception is when the fishery is severely overexploited (a large number of boats) at the time the reserve is created (1).

Lower fuel costs have similar effects to nonfishery earnings in that they exacerbate the differences between short- and long-run opposition. If travel costs are low when the reserve is formed, it is easier for fishermen to reallocate their effort to other fishing areas. The implication is that lower fuel costs increase the fishing pressure on nonreserve areas relative to instances with higher travel costs. For the closed system, opposition increases over time because effort displaced from the reserve reduces stocks outside the reserve. For the source-sink dispersal system, lower travel costs tend to increase the peak of opposition during the transition but also decrease opposition in the long run. The logic follows from the closed system. With low travel costs, it is easy to reallocate fishing effort from the reserve to other fishing areas, decreasing stocks in the transition. However, in the long run, lower travel costs make traveling to nonreserve areas cheaper, and the spillover benefits of the reserve are thus greater.

Fig. S3 depicts how fishing skill heterogeneity influences dynamic opposition to forming a reserve. Results are described in the main text.

Fig. S4 shows that ecological spatial heterogeneity can intensify or dampen short- and long-run opposition to reserves. We use patch-specific parameters for intrinsic growth (r) to represent heterogeneity in reproductive output, whereas patch-specific carrying capacity (K) represents habitat quality that varies over space, i.e., two locations with the same fixed amount of space can sustain different population levels. In the short run, r and K effects are qualitatively the same. A higher r or K leads to a higher initial stock before the formation of the reserve. Thus, if the reserve is sited in the more productive patch, opposition is higher compared to the baseline with no spatial heterogeneity. In contrast, if the reserve is sited in the less productive patch, i.e., the more productive patch remains open to fishing, opposition is lower compared to the baseline.

In the long run, the qualitative impact of ecological heterogeneity depends on the type of dispersal. In closed and relative density systems, heterogeneity in r and K both maintain the short-run pattern. When the more (less) productive patch becomes the reserve, opposition is higher (lower) relative to the baseline. The opposite is true for the source-sink system. Ecological heterogeneity reinforces the dispersal dynamics such that opposition is lower in the long run relative to the baseline if the reserve is sited in the more productive patch. For intrinsic growth (Fig. S4 *Left*), more reproductive output leads to more spillover benefits to the remaining areas open to fishing. For carrying capacity, a higher long-run unfished population in the reserve leads to more spillover benefits to the remaining areas open to fishing.

Although the long-run qualitative consequences are similar, the transition dynamics unfold differently for systems with heterogeneous intrinsic growth rates and carrying capacities. Consider the source-sink case as an example (Fig. S4 *Middle Left*). When r is higher in the reserve site, the system adjusts more quickly. This adjustment leads to a higher peak of opposition in the short run because effort reallocates outside the reserve and these populations regenerate more slowly compared to the base case. However, opposition declines rapidly because the reserve site begins to produce spillovers quickly as a result of the high r in the reserve. The processes are slower when we consider differences in carrying capacity. Considering again the source-sink example (Fig. S4 *Middle Right*), opposition levels with and without ecological heterogeneity follow similar paths for 10 years. Only as the population in the reserve has time to rebuild do the cases begin to separate. These results demonstrate that the tradeoff between the short- and long-run consequences of forming a reserve can depend on the type of spatial ecological heterogeneity and not just on the type of dispersal.

A5. Incorporating Social Dimensions into the Opportunity Cost of a Marine Reserve. Many, if not most, fishermen have a strong attachment to the fishing profession, and decisions to move out of fishing are not based solely on comparing income in fishing to income in other potential professions. Implicitly, this feature is embedded in the parameter α in our framework. Just as the opportunity cost of fishing is a wage that can be earned in alternative employment, the opportunity cost of not fishing is the financial return to fishing and the nonfinancial value that the fisherman attaches to fishing (e.g., enjoyment of the work, the independence, the lifestyle, etc.). Suppose that the financial value of the nonfishing alternative is α_1, and the nonfinancial value of fishing is α_2. The nonfinancial value of fishing as a profession would apply to all fishing locations, whereas the financial value of the nonfishing alternative applies only to the nonfishing choice. Substituting Eq. **2** into Eq. **1** and adding this interpretation yields

$$U_{ijt} = \begin{cases} \alpha_1 + \varepsilon_{ijt}, \text{for } j = 0 \\ p\, h_{ijt} - c - \phi z_j + \alpha_2 + \varepsilon_{ijt}, \text{for } j = 1, 2, \ldots, J. \end{cases} \quad \textbf{[S1]}$$

The fact that fishermen make discrete choices makes this model identical to the one used in the main analysis. Recall that the fisherman chooses the alternative with the highest utility. So, to choose the nonfishery alternative in a fishery with three fishing grounds would imply:

$$\begin{aligned} \alpha_1 + \varepsilon_{i0t} &> p\, h_{i1t} - c - \phi z_1 + \alpha_2 + \varepsilon_{i1t} \\ \alpha_1 + \varepsilon_{i0t} &> p\, h_{i2t} - c - \phi z_2 + \alpha_2 + \varepsilon_{i2t} \\ \alpha_1 + \varepsilon_{i0t} &> p\, h_{i3t} - c - \phi z_3 + \alpha_2 + \varepsilon_{i3t.} \end{aligned}$$

But these inequalities can be rewritten as:

$$\begin{aligned} \alpha_1 - \alpha_2 + \varepsilon_{i0t} &> p\, h_{i1t} - c - \varphi z_1 + \varepsilon_{i1t} \\ \alpha_1 - \alpha_2 + \varepsilon_{i0t} &> p\, h_{i2t} - c - \varphi z_2 + \varepsilon_{i2t} \\ \alpha_1 - \alpha_2 + \varepsilon_{i0t} &> p\, h_{i3t} - c - \varphi z_3 + \varepsilon_{i3t.} \end{aligned}$$

Based on Eq. **S1**, we can interpret α_2 as capturing the income differential between fishing and nonfishing employment that is required to induce switching. If we define $\alpha = \alpha_1 - \alpha_2$, where α is the outside opportunity cost net of a fishermen's nonfinancial value of fishing, then nothing changes analytically. When nonfinancial value of fishing is higher, the net outside opportunity cost is lower. When the financial value of the nonfishery alternative is higher, the net outside opportunity cost is higher. Thus, all of the short- and long-run results of the model hold with this social interpretation added. An interesting direction for future research would be to explore how opposition responds to heterogeneity in α, which could indicate some fishermen having higher wages outside of fishing or simply that some fishermen are less attached to fishing as a profession. This could be achieved by indexing α by i in Eq. **2**:

$$v_{ijt} = \begin{cases} \alpha_i, \text{for } j = 0 \\ p_t h_{ijt} - c - \phi z_j, \text{for } j = 1, 2, \ldots, J. \end{cases}$$

Another interesting extension for future work is to embed fishermen spatially into the social-ecological landscape. When fishermen are associated with particular home ports, the long-run effects of a reserve can change (4). The simplest modification of our model along these lines would be to index travel distances (z_j) by each individual (i) (5), the deterministic portion of utility in Eq. **2** into:

$$v_{ijt} = \begin{cases} \alpha, \text{for } j = 0 \\ p_t h_{ijt} - c - \phi z_{ij}, \text{for } j = 1, 2, \ldots, J. \end{cases}$$

This formulation situates each fishermen in a particular place ashore relative to each fishing ground. The effects on behavior and opposition to the reserve are mediated by differences in travel distances across fishermen. One might also introduce embedding of fishermen through a separate parameter (b_{ij}) that is not necessarily scaled by travel cost and can be modeled empirically as a random effect (6):

$$v_{ijt} = \begin{cases} \alpha, \text{for } j = 0 \\ p_t h_{ijt} - c - \phi z_j + \beta_{ij}, \text{for } j = 1, 2, \ldots, J. \end{cases}$$

Here, each individual has a unique attachment to each fishing ground that will influence spatial and temporal behavior and the resulting opposition to marine reserves.

1. Sanchirico JN, Wilen JE (2001) A bioeconomic model of marine reserve creation. *J Environ Econ Manage* 42:257–276.
2. Sanchirico JN (2004) Designing a cost-effective marine reserve network: A bioeconomic metapopulation analysis. *Mar Resour Econ* 19:46–63.
3. Sanchirico JN, Wilen JE (2002) The impacts of marine reserves on limited-entry fisheries. *Nat Resour Model* 15:380–400.
4. Smith MD, Wilen JE (2004) Marine reserves with endogenous ports: Empirical bioeconomics of the California sea urchin fishery. *Mar Resour Econ* 19:85–112.
5. Smith MD (2002) Two econometric approaches for predicting the spatial behavior of renewable resource harvesters. *Land Econ* 78:522–538.
6. Smith MD (2005) State dependence and heterogeneity in fishing location choice. *J Environ Econ Manage* 50:319–340.

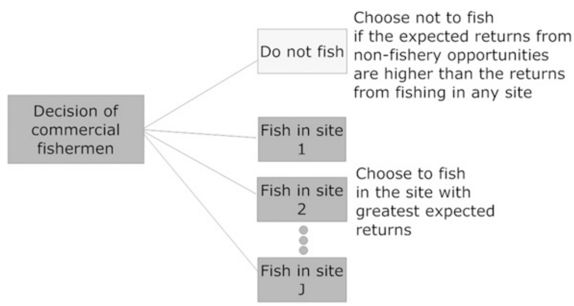

Fig. S1. Decision tree of commercial fishermen.

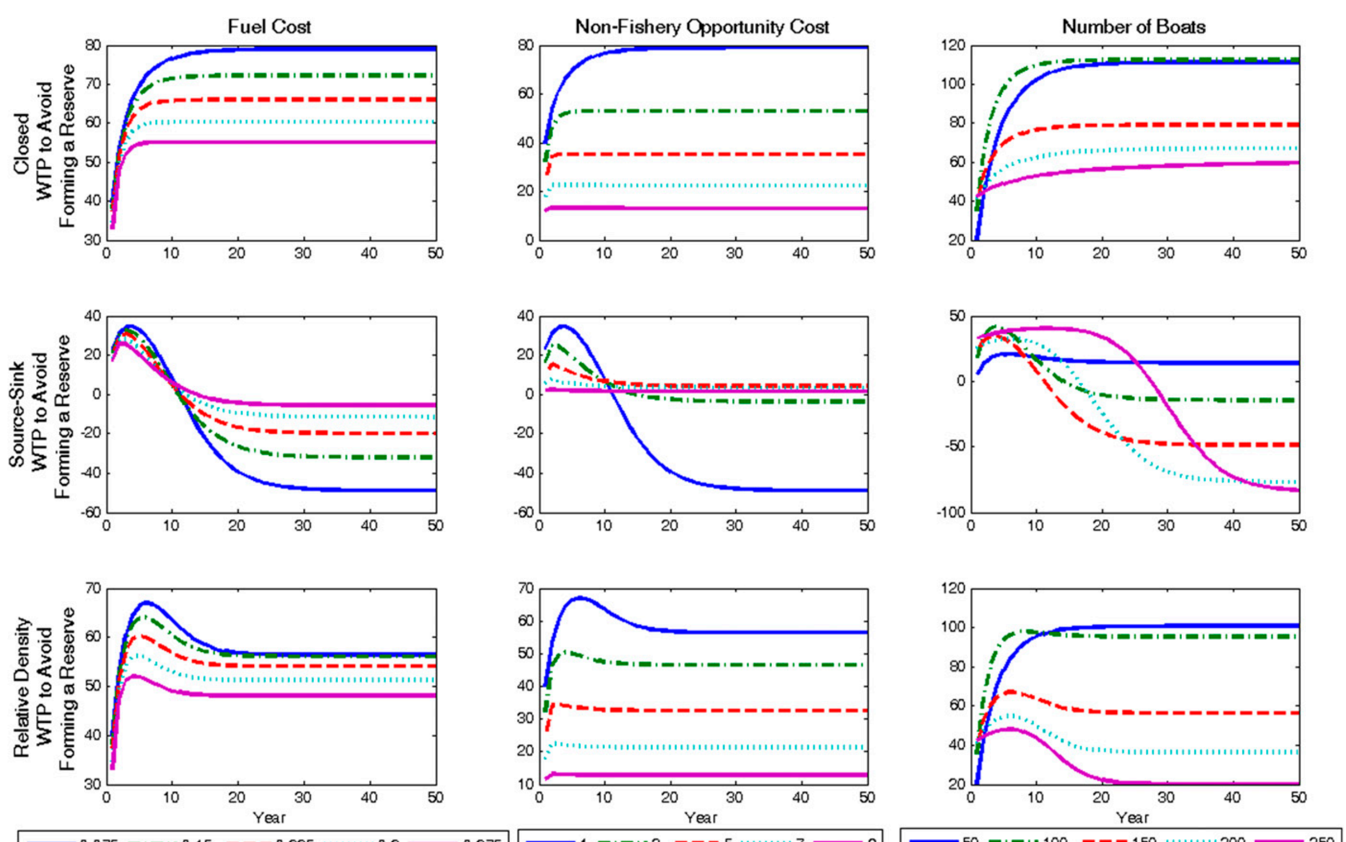

Fig. S2. Sensitivity of dynamic opposition to forming marine reserves. Rows report three dispersal scenarios (closed, source-sink, and relative density). Columns report sensitivity to the five levels each of fuel cost, nonfishery earning opportunities, and number of participants (boats) in the fishery. Other parameters are fixed at baseline levels (*SI Appendix A3*).

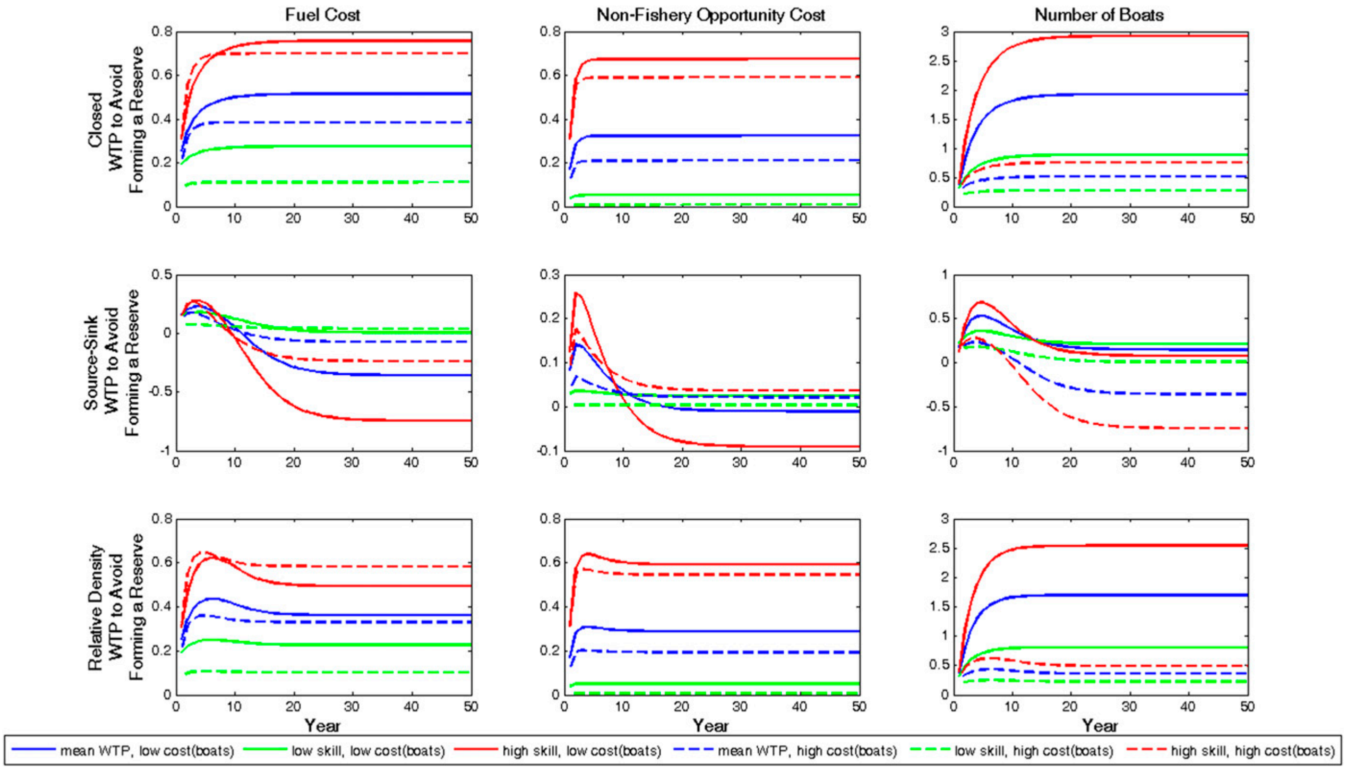

Fig. S3. Sensitivity of the effects of skill heterogeneity on dynamic opposition to marine reserves. Rows report three dispersal scenarios (closed, source-sink, and relative density). Low-skill and high-skill are 10th and 90th percentile of the skill distribution. Solid and dashed lines reflect low and high parameter values: fuel cost of 0.075 (low) or 0.375 (high), nonfishery earning opportunities of 4 (low) or 7 (high), and boats of 75 (low) or 150 (high). Other parameters are fixed at baseline levels (*SI Appendix A3*).

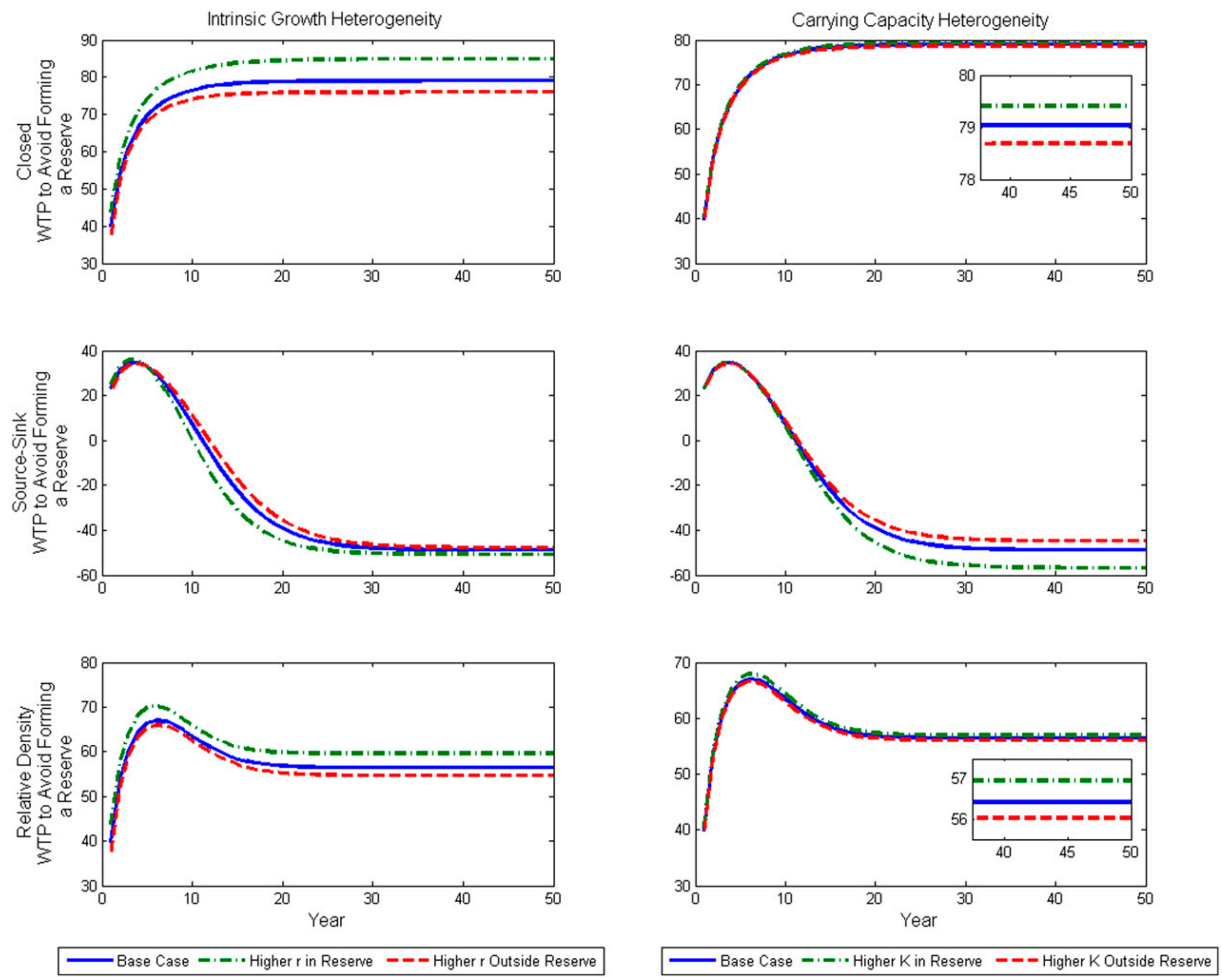

Fig. S4. Dynamic opposition to forming marine reserves with ecological heterogeneity. Rows report three dispersal scenarios (closed, source-sink, and relative density). Columns report sensitivity to varying different ecological parameters over space: intrinsic growth (*Left*) and the carrying capacity (*Right*). The base cases (blue) assume ecological parameters are equal over space and are depicted in Fig. S2 (blue lines in *Middle*). Comparison cases increase the parameter 10% at the reserve site and decreases it 5% at each of the other sites (green) and increase the parameter 10% at a nonreserve site and decrease it 5% at the reserve site and the other nonreserve site (red). Other parameters are fixed at baseline levels (*SI Appendix A3*). Insets zoom in on the end of the time horizon.

Table S1. Baseline parameter values

Parameter	Value
$r_1 = r_2 = r_3$	0.4
$K_1 = K_2 = K_3$	10
N	150
α	1
$p_1 = p_2 = \ldots = p_T$	100
$q_1 = q_2 = q_3$	0.01
c	0.05
ϕ	0.075
$z_1 = z_2 = z_3$	6

For the dispersal function, $d(X_{1t}, X_{2t}, X_{3t})$, we adopt a standard linear dispersal matrix and impose adding up restrictions that imply no mortality or straying during dispersal (1). The matrices for the three different scenarios we evaluate are as follows (where the element d_{ij} represents the fraction of the population in site j that disperses to patch i):

Table S2. Dispersal matrices

Closed system	Source-sink system	Relative density system
$d = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	$d = \begin{bmatrix} -0.4r_1 & 0 & 0 \\ 0.2r_1 & 0 & 0 \\ 0.2r_1 & 0 & 0 \end{bmatrix}$	$d = \begin{bmatrix} -0.4r_1/k_1 & 0.2r_1/k_2 & 0.2r_1/k_3 \\ 0.2r_1/k_1 & -0.4r_1/k_2 & 0.2r_1/k_3 \\ 0.2r_1/k_1 & 0.2r_1/k_2 & -0.4r_1/k_3 \end{bmatrix}$