Supplementary Figures: Eco-evolutionary dynamics and collective migration: implications for salmon metapopulation robustness

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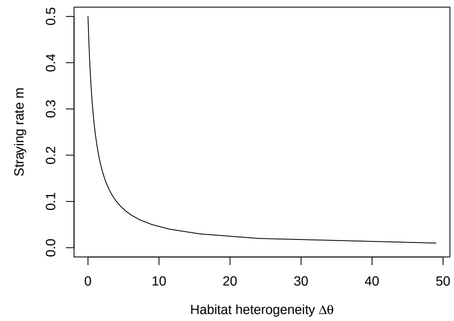

Figure S1: In some cases, habitat heterogeneity may be assumed to determine the rate of straying, if for example: 1) sites may be distributed over greater spatial distances, where habitat differences are assumed to be greater between more distant sites, or 2) individuals have behaviors promoting dispersal between habitats that are more similar. To examine such cases, we use the relationship $m = 0.5(1 + \Delta\theta)^{-1}$ where maximum straying is assumed to occur at $m = 0.5$ (perfect mixing).

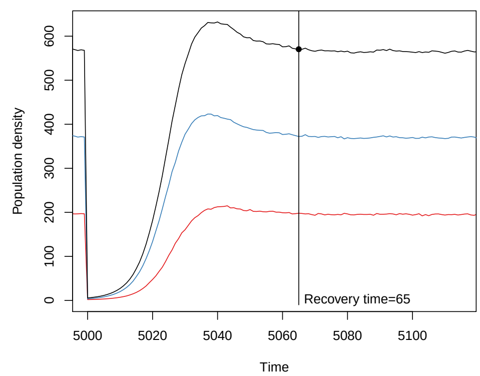

Figure S2: Example of the numerical procedure used to estimate recovery time. After a disturbance is introduced, the recovery time is calculated by measuring the point in time where N_T (in black), which is the aggregate of both populations (blue, red) settles to within one standard deviation of the new equilibrium N_T^*.

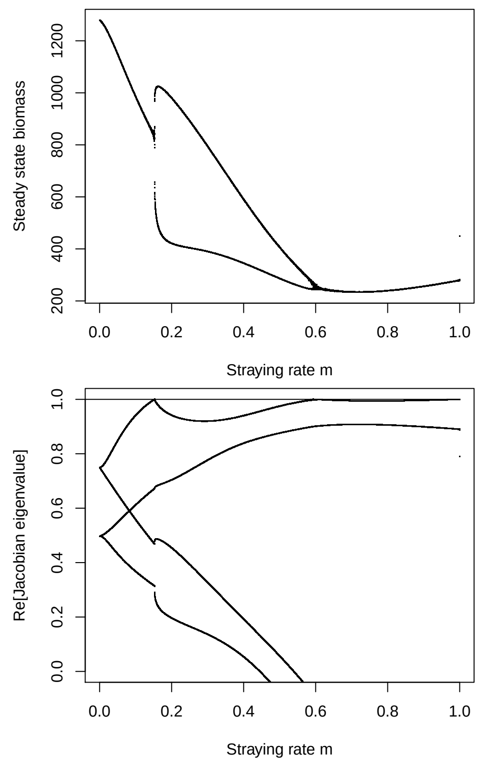

Figure S3: The real parts of the four eigenvalues for the Jacobian matrix of the 4-dimensional system. The pitchfork bifurcation occurs when the dominant eigenvalue crosses the unit circle at +1.

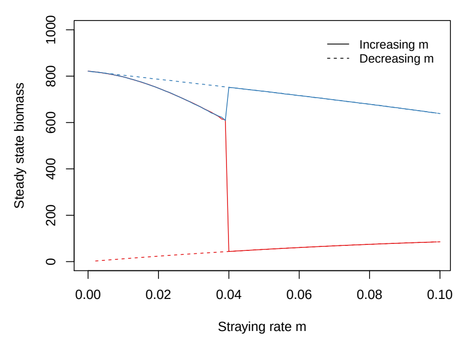

Figure S4: Increasing the straying rate results in the transition from a single steady state for both populations to a dominant and subordinate states. If the straying rate is subsequently lowered, the single steady state is not easily obtained, which is the hallmark of hysteresis.

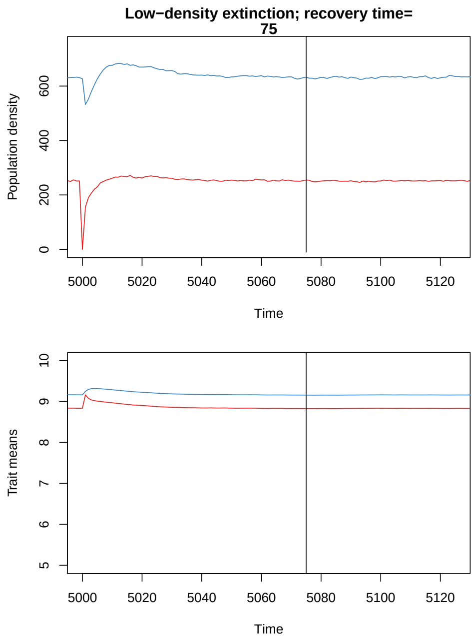

Figure S5: Extinction of low-density population with a high constant straying rate $m = 0.4$ and low trait heritability $h^2 = 0.2$ (see figure 4a). Black line marks the calculated point of recovery post-perturbation. Trait optima are $\theta_1 = 10$ (blue population trajectory) and $\theta_2 = 5$ (red population).

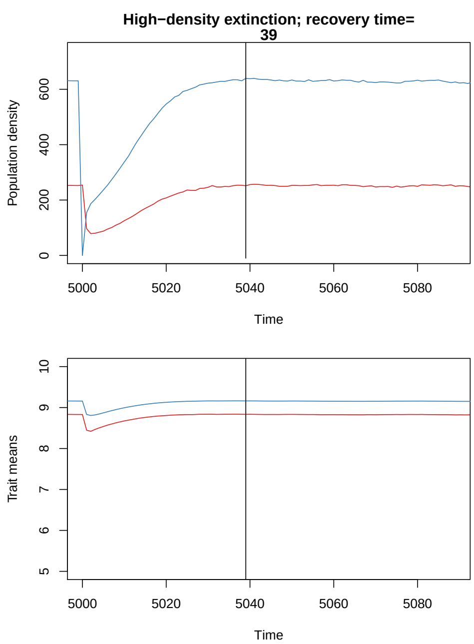

Figure S6: Extinction of high-density population with a high straying rate $m = 0.4$ and low trait heritability $h^2 = 0.2$ (see figure 4a). Black line marks the calculated point of recovery post-perturbation. Trait optima are $\theta_1 = 10$ (blue population trajectory) and $\theta_2 = 5$ (red population).

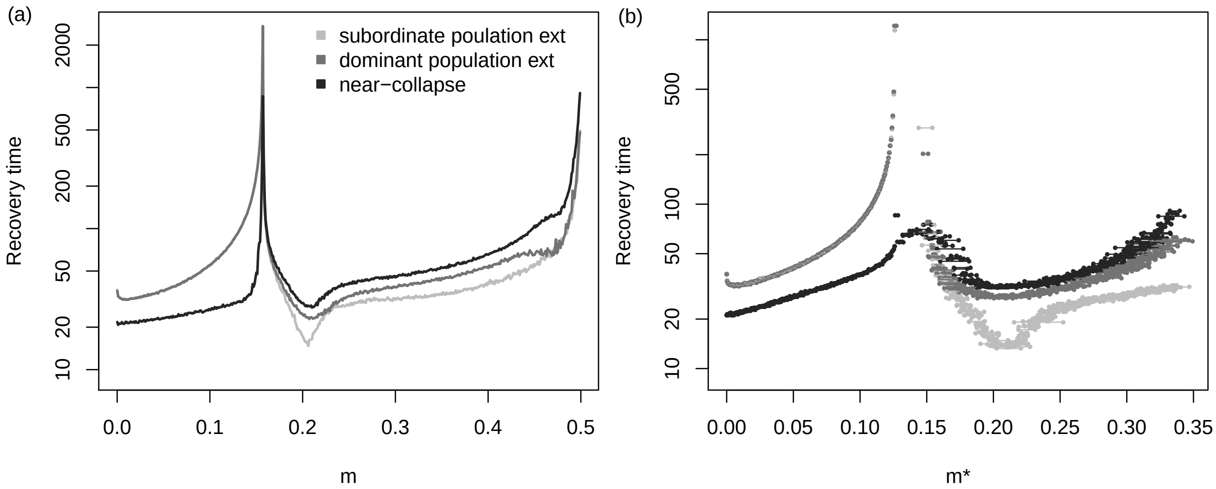

Figure S7: Recovery time of N_T following the extinction of either the low-density (light gray) or high-density (gray) population, or the near-collapse of both (dark gray) assuming (a) constant straying rates m and (b) density-dependent straying rates (evaluated at the steady state m^*) with trait heritability $h^2 = 0.8$. If m is density-dependent, in the alternative stable state regime there are two straying rates observed: one each for the low- and high-density populations, respectively, which are linked by a horizontal line.

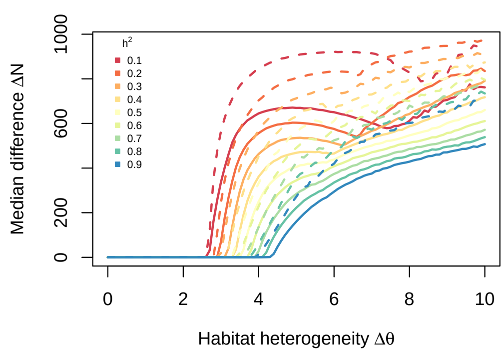

Figure S8: Median difference in population densities taken over the straying rate as a function of habitat heterogeneity $\Delta\theta$. Solid lines are for constant m; dashed lines are for density-dependent m

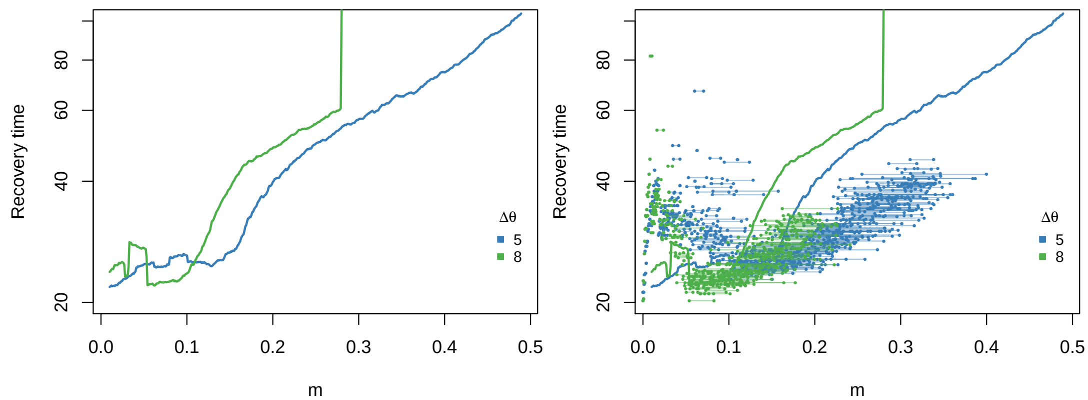

Figure S9: (a) Recovery time after near collapse of both populations as a function of straying rate m and habitat heterogeneity $\Delta\theta$. (b) The same as (a) but including recovery times when straying is density-dependent, shown by linked pairs of points. Recovery times for systems with density-dependent straying are longer at low straying rates and shorter at higher straying rates, mirroring the change in portfolio effects shown in figure 3.

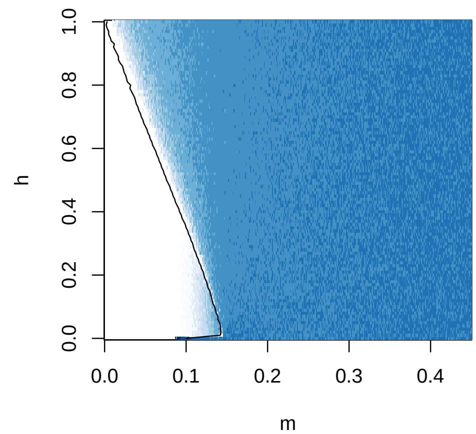

Figure S10: Distance dependent portfolio effects as a function of straying rate m and trait heritability h^2. When straying is distance dependent, m increases as $\Delta\theta$ decreases.

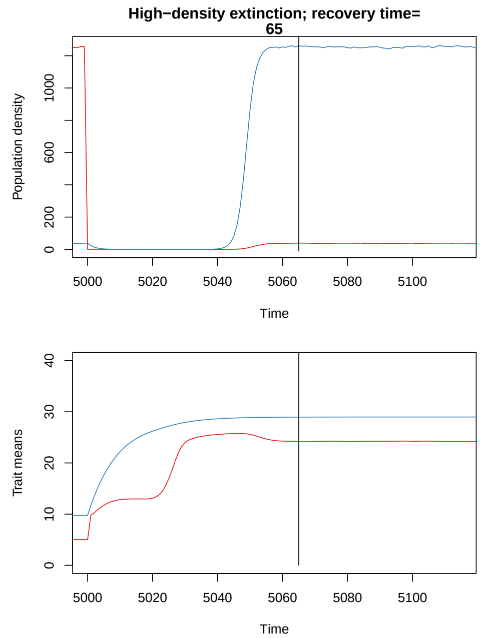

Figure S11: Distance dependent straying, where increased differences in trait optima between sites $\Delta\theta$ corresponds to lower rates of straying m. At low rates of straying $m = 0.02$ ($\Delta\theta = 24$), extinction of the dominant population leads to slower-than-expected recovery times because the subordinate population is isolated enough to evolve towards its own trait optimum. In this case, m is less than $m = 0.034$ (denoted by the asterisk in figure 6), such that isolation allows the subdominant population to 'run away' from the influence of the dominant population, leading to a switch in states. If m is low but greater than 0.034, isolation permits the subdominant population to 'run away' from the influence of the dominant population, until it is overwhelmed by the recovering dominant population, and reverts back to its previous trait mean prior to the disturbance.

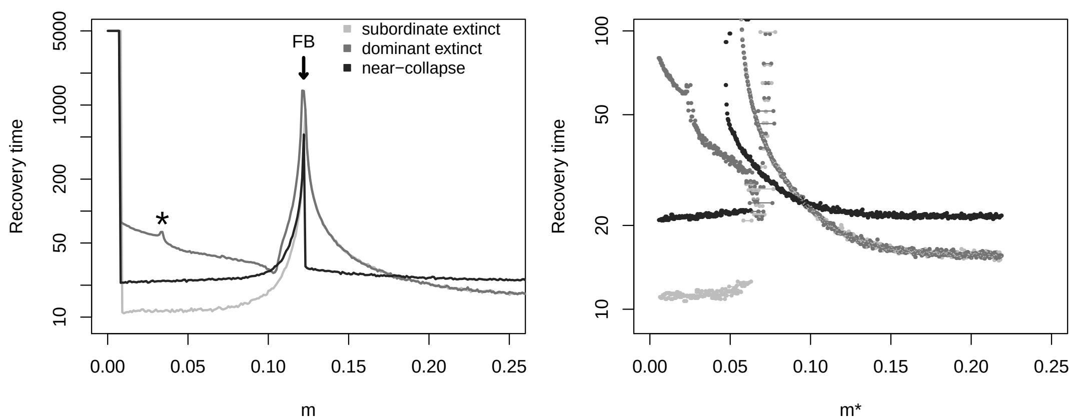

Figure S12: Distance dependent recovery times for three disturbance types. When straying is distance dependent, m increases as $\Delta\theta$ decreases for constant (a) and density-dependent (b) staying rates. The pitchfork bifurcation is not as clear in (b) because $\Delta\theta$ is a function of the individual straying rate m_0, whereas the x-axis in (b) is the straying rate at the steady state m^*. Despite this difference, the general trends shown in (a) are also present in (b).

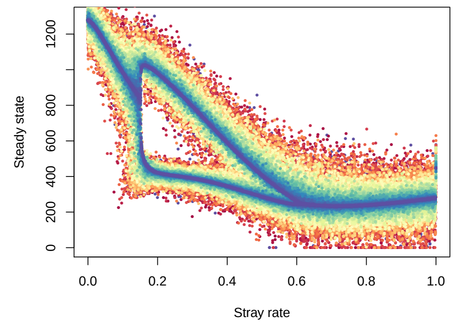

Figure S13: Steady state densities of both populations as a function of m, where a pitchfork bifurcation indicates the emergence of alternative steady states: one in a dominant state and one in a subordinate state. Steady states for populations with symmetrical values ($\alpha = 0$) in the vital rates $r_{\max}$ and β are shown with cool tones. As the asymmetry among populations between sites increases ($\alpha > 0$), their vital rates diverge, such that the maximal growth at sites 1 and 2 is now $r_{\max,1} = r_{\max}(1 + r\tilde{v}_1)$ and $r_{\max,2} = r_{\max}(1 + r\tilde{v}_2)$ where $rv_{1,2}$ are independently drawn from $\mathrm{Normal}(0, \alpha)$ and $r_{\max} = 2$. Similarly the strength of density dependence is calculated at sites 1 and 2 as $\beta_1 = \beta(1 + r\tilde{v}_1)$ and $\beta_2 = \beta(1 + r\tilde{v}_2)$ where $r\tilde{v}_{1,2}$ are independently drawn from $\mathrm{Normal}(0, \alpha)$ and $\beta = 0.001$. Steady states for populations with increasingly asymmetric values ($\alpha \to 0.1$) for vital rates $r_{\max}$ and β are shown in warmer tones.

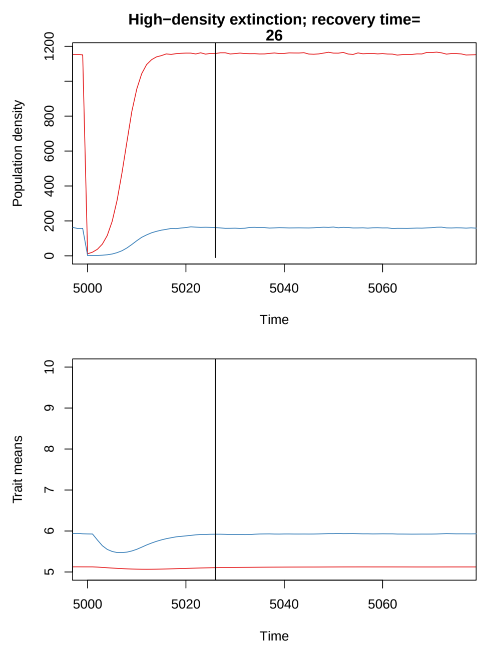

Figure S14: Near collapse of both populations with a low straying rate $m = 0.1$ and low trait heritability $h^2 = 0.2$ (see figure 4a). Black line marks the calculated point of recovery post-perturbation. Trait optima are $\theta_1 = 10$ (blue population trajectory) and $\theta_2 = 5$ (red population).