Appendix B

Effects of density-dependent maturation rates on population size and persistence under compensatory recruitment

We examine the applicability of our findings to populations which do not exhibit an overcompensatory recruitment. One of the most commonly used alternatives is the Beverton-Holt recruitment function,

$$\gamma_t = \frac{\alpha}{1+\beta A_t\left(1-h_A\right)}, \qquad \text{(B.1)}$$

in which maximum recruitment of juveniles occurs at high (relative to carrying capacity) rather than at intermediate levels of adult abundance as seen in the Ricker (1954) model. As mentioned above, for a given value of α in a deterministic environment, different shapes of the recruitment function will not affect the harvest level at which the population collapses because $\gamma_t \approx \alpha$ at $A_t \approx 0$. Rather, here we examine the implications of compensatory recruitment for adult abundance at intermediate levels of harvest (specifically h_{half}), and whether it interacts with the density-dependent changes in maturation.

As in the text, we set the strength of density dependence $\beta=1$ for all trials, and derive a new equation for adult abundance at zero harvest for use in the Type I, II, and III maturation functional norms (eqns. A.1, A.2, A.3). Solving for A_t with $h_J=h_A=0$, we obtain:

$$K = \beta^{-1}\frac{m_{min}\alpha}{m_{min}-1+\left(1-s_A\right)s_J^{-1}}+1. \qquad \text{(B.2)}$$

Because compensatory recruitment levels decline with decreasing adult abundance and increasing harvest levels, the buildup of juveniles at high levels of juvenile survival observed under overcompesatory recruitment (leading to an increase in population size, Fig. B1) is absent.

Because there are fewer juveniles (compared to overcompesatory recruitment) when juvenile survival is high, adults lost to mortality are replaced more slowly, and equilibrium adult abundance (i.e., h_{half}) is reduced. Thus, the main effect of whether recruitment is overcompensatory is on adult abundance in populations with high juvenile survival rates (Fig. B1), and is independent of the rate of maturation and whether it is density-dependent (Fig. B2).

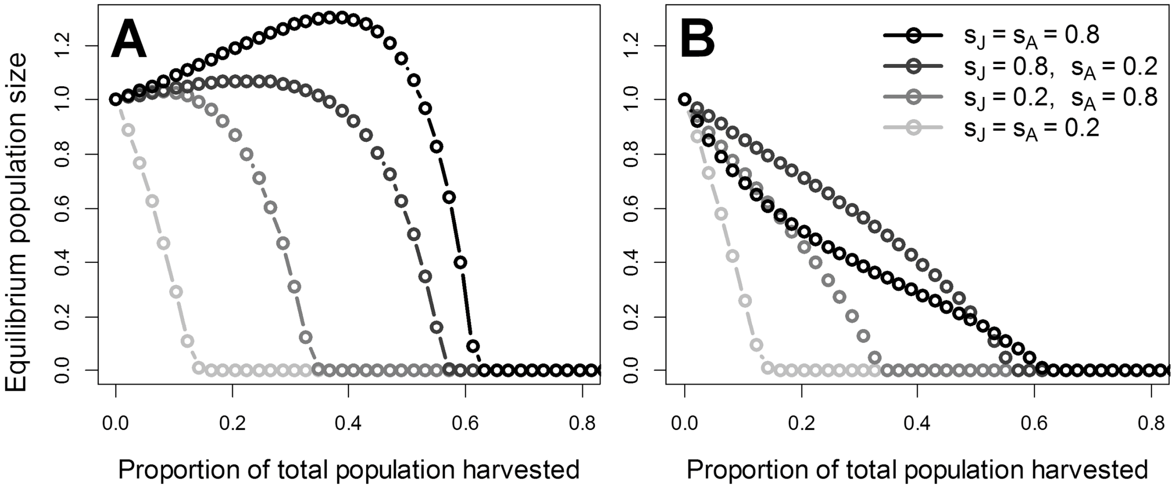

FIG. B1. Effect of harvest intensity on population abundance under overcompensatory (A) and compensatory (B) recruitment across four survival regimes. Populations with compensatory recruitment collapse at identical harvest levels, but decline in abundance more strongly at lower harvest intensities when juvenile survival rates are high (darker curves). In all cases, both stages are harvested, α=10, and maturation rates are fixed at m_t=0.5.

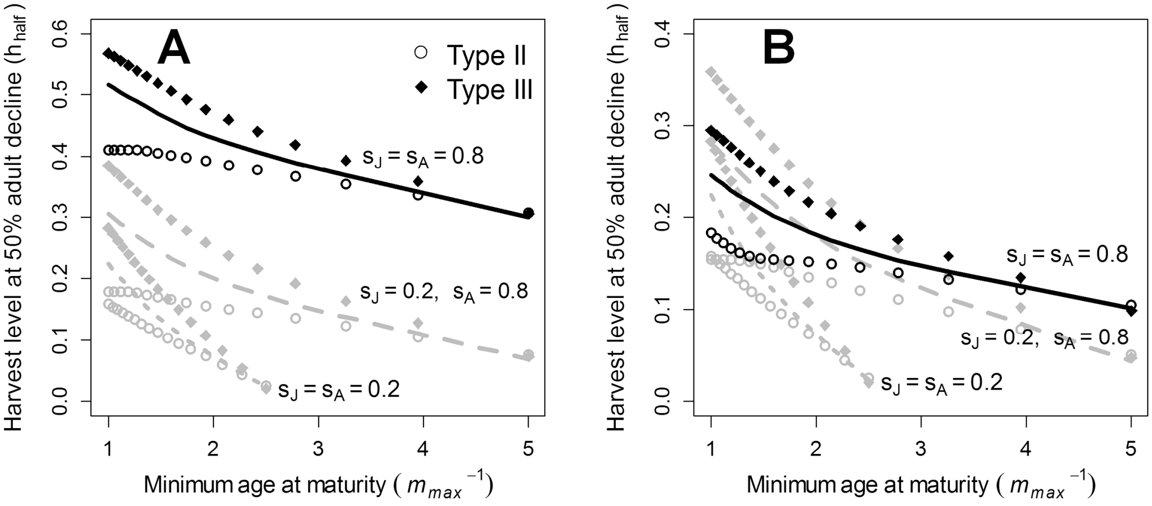

FIG. B2. Effects of overcompensatory (A) *vs.* compensatory (B) recruitment, the functional form of maturation rate, and minimum age at maturity (maximum maturation rate m_{max}^{-1}) on the harvest level at which adult abundance declines by 50% compared to zero harvest (h_{half}). Compared to overcompensation, compensatory recruitment reduces adult abundance (h_{half}) most strongly when juvenile survival is high (s_J=0.8, black curves *vs.* s_J=0.2, gray curves), and the maturation functional form has no qualitative impact on this effect. For each value of m_{max}, the values of h_{half} are given under the Type I (lines), Type II (open dots), and Type III (diamonds) functional forms of maturation rates. All parameters are as in Fig. 3.

LITERATURE CITED

Ricker, W. E. 1954. Stock and recruitment. Journal of the Fisheries Research Board of Canada 11:559–623.