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Appendix 1

Appendix 1: Comparison of the Beverton-Holt and theta-logistic models of density dependence.

The Beverton-Holt model is a classic discrete-time model of density dependent dynamics, which projects the expected number of individuals in time step $t + 1$ as a function of the number of individuals at time step t . In the fisheries stock recruitment literature, Beverton-Holt curves are usually expressed in terms of the number of recruits to a population as a function of the number of spawners, or in biomass terms. Stage-specific Beverton-Holt functions (BHF) can also be formulated for transitions between any two life stages (Mousalli and Hilborn 1986). In our simulation model, we used a BHF to specify the expected number of recruits in year $t + 1$ as a function of the number of offspring reared to independence in year t (eq. 3 in the paper). The α and β parameters together determine the shape of the function, while the mean recruitment probability S at very low density is given by α/β (see eq. 4 in paper). Fig. A1 shows the effects of varying both parameters on S , emergent \hat{N} (the equilibrium number of adults) and emergent r_1 (the intrinsic population growth rate when $N=1$).

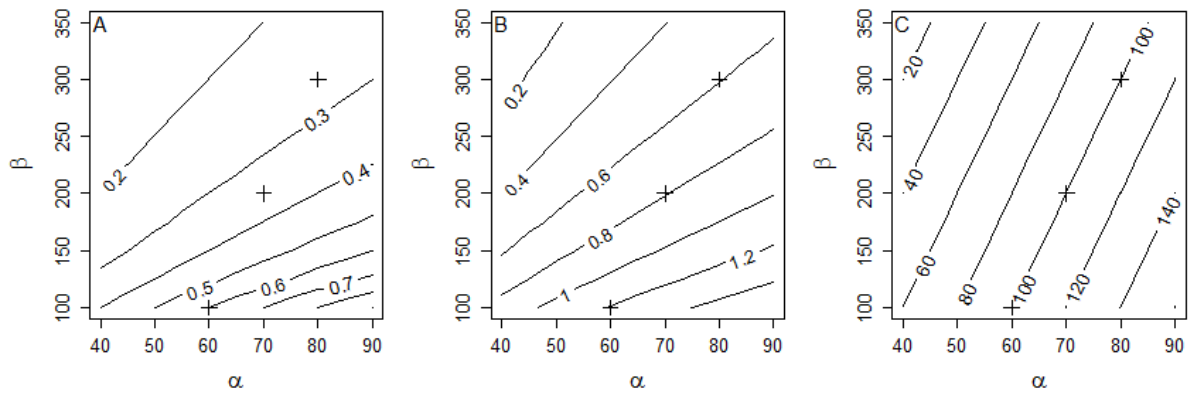


Fig. A1 (A) S as a function of α and β . (B) r_1 as a function of α and β . (C) \hat{N} as a function of α and β . The crosses in each panel indicate the actual parameter values chosen in the main text to illustrate different strengths of DD: Strong DD: $\beta = 100, \alpha = 60$. Moderate DD: $\beta = 200, \alpha = 70$. Weak DD: $\beta = 300, \alpha = 80$.

The theta-logistic model can be written as follows:

$$E(\Delta N|N) = r_1 N \left(1 - \frac{N^\theta - 1}{K^\theta - 1} \right)$$

where N = population size, r_1 = the specific growth rate when $N=1$, K = the carrying capacity and θ = the shape parameter. θ determines the form of density regulation; for example as $\theta \rightarrow 0$, you have the Gompertz model, when $\theta = 1$, the familiar logistic model, and when $\theta = \infty$ the ceiling model. The strength of density regulation is $\gamma = r_1 \theta / (1 - K^{-\theta})$ and the ‘characteristic return time to equilibrium’ $T = 1/\gamma$ (Lande et al. 2003, Sæther and Engen 2010).

Fig. A2 shows the effects of varying θ , K , and r_I (each time holding the other two parameters constant). In each case, the dashed curves corresponds to high γ , the solid curves correspond to moderate γ , and the dotted curves correspond to low γ . Chevin and Lande (2010) compared scenarios with DD against a density independent baseline by fixing r_I at the maximum value in the density independent case. The dash-dot line in Fig. A2, panel A, represents this ‘no DD’ case. Here we have used arbitrary parameter values that do not correspond with those used in Chevin and Lande 2010 (who used a slightly different model formulation), but the qualitative patterns are the same. When they compared DD cases against the ‘no DD’ baseline, they naturally found that DD reduces persistence probability following environmental change, given that r is always lower in the DD cases for all $N > 1$, as can be seen in Fig. A2.

However, when Chevin and Lande (2010) compared different strengths of DD by varying θ , they found that the rate of population recovery was faster when θ was higher. The reason is evident in Fig. A2, panel A: when θ is larger, (small) reductions in N below K are associated with larger compensatory responses in r . Thus our model and their model both found that stronger density regulation dampens the effect of maladaptation on population dynamics, but using quite different assumptions and underlying DD functions. Note that reductions in K in the theta-logistic model would also result in stronger density regulation (i.e. steeper r - N curves: Fig. A2 panel B) and N would be expected to gradually decrease towards the new K . For example, Sæther & Engen (2010) simulated a gradual decline in K and showed that it takes quite some time for N to respond. Note that increasing r_I in the theta-logistic model also has the effect of increasing the strength of density regulation, for a given K , particularly at low N (Fig. A2 panel C). This latter pattern is similar to the pattern that emerged in the deterministic version of our model when we varied the β parameter of the BHF, while simultaneously tuning α such that a constant \hat{N} always resulted (see Fig. 1D in

the main paper). The key difference, however, is that the r - N curves in our case are always concave up, whereas with the theta-logistic they can be either concave up or down, depending on θ .

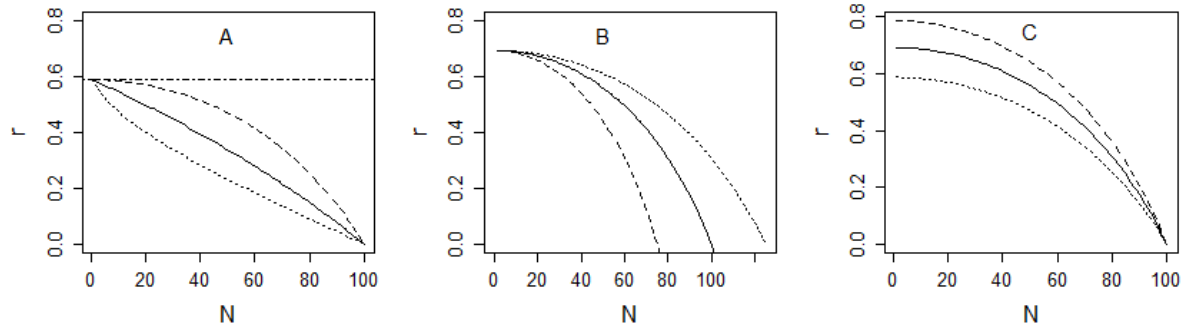


Fig. A2 r - N curves for the theta-logistic model. (A) The effect of varying θ (dashed: $\theta = 2$; solid: $\theta = 1$; dotted: $\theta = 0.5$), while $K = 100$ and $r_I = 1$. Dash-dot line shows the ‘no DD’ case. (B) The effects of varying K (dashed: $K = 75$; solid: $K = 100$; dotted: $K = 125$), while $\theta = 2$ and $r_I = 1$. (C) The effects of varying r_I (dashed: $r_I = 1.2$; solid: $r_I = 1$; dotted: $r_I = 0.8$), while $\theta = 2$ and $K = 100$.

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