Fish 505
Assignment 2
Due January 23 2009

Spatial effort and stock responses to MPAs

One approach to evaluation of Marine Protected Area (MPA) performance is to predict equilibrium spatial distributions of abundance and fishing effort over a set of spatial grid cells, as in Walters et al (2007 CJFAS 64:1009-1018). Develop a spreadsheet model to represent the following assumptions for a grid of i=1…50 cells along a coastline.

First, assume that adult abundance in each cell varies as $dN_i/dt=r(L_i)-MN_i-2mN_i+m(N_{i+1}+N_{i-1})-F_iN_i$, implying equilibrium abundance

$$N_i=[r(L_i)+ m(N_{i+1}+N_{i-1})]/[M+2m+F_i] \quad (1)$$

Here, $r(L_i)$ is recruitment as a function of larval settlement L_i to cell i; assume it is Beverton-Holt in form: $r(L)=aL/(1+bL)$; assume a=5, b=4 (can you explain why these are reasonable choices, if L is scaled so as to average 1.0 for cells near the center of the coastline?). M is natural mortality rate (use 0.2), m is instantaneous dispersal rate between adjacent cells, and F_i is fishing mortality rate. Assume that larval transport is a random walk process along the coast, implying normal distribution of larvae from each cell to other cells, so that L_i is a sum of larval contributions L_{ij} from all of the cells ($L_i=\sum_j L_{ij}$), with contribution of cell j to cell i given by

$$L_{ij}=\exp(-.5*(i-j)^2/sd)/(6.28*sd) \quad (2)$$

where sd is standard deviation of larval dispersal distance in units of cell width.

Note in equation (1) that the equilibrium N_i are interdependent through the numerator term and through L_i, and hence must be calculated iteratively (set N_i to some initial values, solve for new values of L_i and N_i using equation (1)-(2), repeat until the N_i stop changing; use relaxation steps (new N)=R x (last N)+(1-R)(N from eq 1) with "relaxation parameter" R=.5 if necessary).

Test the iterative procedure initially by setting $F_i=F_o$ for all cells that are open to fishing, and to 0 for cells designated to be MPAs ($F_i=open_iF_o$, where $open_i$=0 or 1 for each i). Predict total catch as $C=\sum_i F_iN_i$. Show that for high F_o, C is maximized by having $open_i$=0 for at least some i, and that protection policies fail if m is large.

Next, include prediction of F_i in the iterative solution scheme, by assuming

$$F_i=F_{tot}W_i/\sum_j W_j \quad (3)$$

Where F_{tot} is total F (effort) over all cells, and W_i is a logit choice weight for cell i, given by

$$W_i=open_i e^{d\ \ln N_i} =open_i N_i^d \quad (4)$$

Here d is an effort concentration factor representing variation among fishers in perception of the quality of fishing in cell i (assume d=1 initially, test d over the range 0.5-2.0). eq (4) assumes that the relative utility of a cell for fishing is proportional to the log of abundance in the cell. What happens to effort in cells near MPA boundaries as the concentration parameter d is increased (NB, high d values cause numerical instability in the iterative calculation of equilibrium N_i,L_i, and F_i, forcing use of smaller relaxation weights R).

If F_{tot} is high, e.g. 25-50 implying severe overfishing, is it possible to achieve near natural abundances N_i=5 in MPA cells, if larvae disperse widely (sd>5), even if adult movement rate is low (m=0.05 or less)? What does this say about the "SLOSS" debate (single large vs several small MPAs)? If m is large enough to produce significant "spillover" of fish into open areas from MPAs (in addition to larval seeding from MPAs), does this change your conclusion about the SLOSS debate?