How effective are marine protected areas for managing stocks with maternal effects in larval survival?

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Introduction

Recent studies have indicated that the viability of larvae for some species, including Pacific rockfish (genus *Sebastes*) and Atlantic cod (*Gadus morhua*), may depend upon spawner age. These maternal effects imply that the age structure of the spawning population is a management consideration, as older fish would be expected to contribute disproportionately to the viable offspring. Closed areas have been proposed as a management tool that would allow old spawners to accumulate. The purpose of this study is to consider the effects of closed areas on the population dynamics and potential yield for populations with maternal effects in larval survival.

Methods

Equilibrium properties and stochastic simulations were evaluated for a population model that incorporates a Beverton-Holt stock-recruitment function, maternal effects in larval survival, multiple options for spatial density-dependence, and movement of adults. The model was parameterized for Bering Sea/Aleutian Islands Pacific ocean perch (*Sebastes alutus*), a common north Pacific rockfish species. The model is similar to that developed by Ralston and O'Farrell (2008), and was modified by inclusion of a maternal effect in the production of "viable larvae" (defined here as larvae at 14 days). The spatial areas are oriented in a linear pattern of three cells, with the middle cell forming the marine reserve.

Maternal effect in larval survival

The survival of larvae to two weeks as a function of spawner age is shown in Figure 1, where the slope and spawner age of 50% larval survival were obtained by adjusting the results of Berkeley et al. (2004) on black rockfish for the increased longevity for Pacific ocean perch.

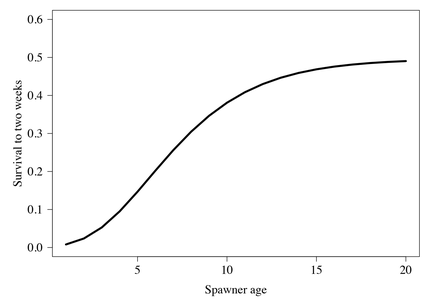

Figure 1. Survival to viable larvae as a function of spawner age, obtained from modifying the results for black rockfish from Berkeley et al (2004) to account for the increased longevity of Pacific ocean perch.

Spatial Stock-Recruitment Models

Density-dependence can result from various spatial mechanisms, two of which are considered here (Figure 2; modified from Ralston and O'Farrell (2008):

1) **Intracohort density-dependence** – Density-dependent mortality is a function of the total number of pooled larvae from the subareas. A potential mechanism is competition between the pooled larvae.

2) **Postdispersal intercohort density-dependence** – Density-dependent mortality is applied after pooling the viable larvae from the subareas and redistributing the 'settlers' equally back to the subareas. However, the density-dependent mortality is based on the number of viable larvae produced from the subarea (not the number of settlers). Potential mechanisms include competition for space between newly settled individuals and existing local adults.

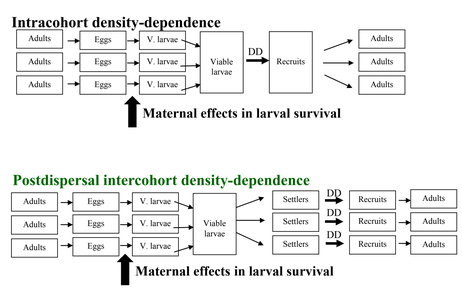

Figure 2. Spatial stock-recruitment models with the incorporation of maternal effects in the production of viable larvae.

Movement of adults

The movement of adults between spatial areas was modeled as a function of spawner age, the distance between spatial areas, and the asymptotic probability of movement (X_{max}) (Figure 3).

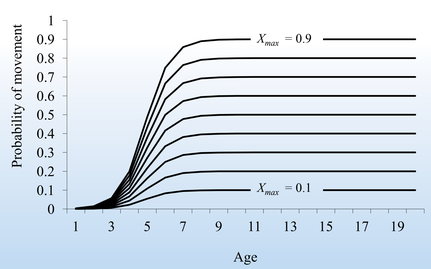

Figure 3. The probability of movement between spatial cells by age for various levels of X_{max} (the asymptotic probability of movement).

Results

Improvement in equilibrium yield with a marine reserve is dependent on the form of density-dependence and amount of adult movement (Figure 4). With intracohort density-dependence, the equilibrium yield at a given level of adult movement with a marine reserve is less than the maximum equilibrium yield (across F) without a marine reserve. In contrast, with postdispersal density-dependence, equilibrium yields with a marine reserve at moderate fishing levels and/or low movement rates can exceed the maximum equilibrium yield obtained without a marine reserve. For each form of density-dependence, the equilibrium yields obtained from fishing near F_{msy} (approximately 0.1) either with or without a marine reserve become more similar to each other. Equilibrium yields with a marine reserve decrease sharply with fishing rate when adult movement and fishing rates are not low, particularly when maternal effects occur.

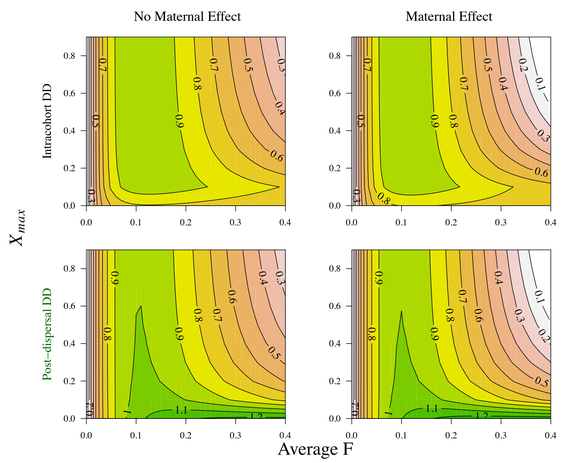

Figure 4. Equilibrium yield with a marine reserve scaled to the maximum equilibrium yield (across F) without a marine reserve, as a function of X_{max}, fishing rate, maternal effect, and spatial density-dependence.

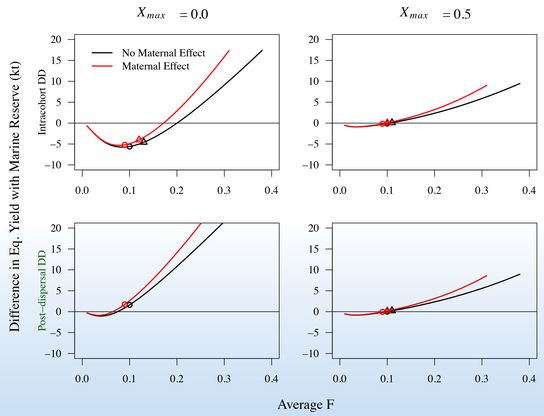

Figure 5. The difference in equilibrium yield with a marine reserve from an otherwise equal population without a marine reserve as a function of fishing rate. The triangles and circles denote F_{msy} with and without a marine reserve, respectively.

The difference in equilibrium yield obtained with a marine reserve from an otherwise equal population without a reserve is shown in Figure 5. At fishing rates close to F_{msy}, the benefit in equilibrium yield from a marine reserve is small. For a stock with no adult movement and intracohort density-dependence fished at F_{msy}, a marine reserve would reduce equilibrium yield. Marine reserves can increase equilibrium yields at high fishing mortality rates, with the lower bound of F rates where these increases occur being lower with maternal effects.

Stochastic simulations were used to illustrate the effect of marine results on yield and population biomass. Simulated stocks with maternal effects and no adult movement (consistent with the life-history of Pacific ocean perch) and intracohort density-dependence were fished either at $F = 0.09$ (the F_{msy} with no marine reserve) or 3 times F_{msy} (Figure 6) for 100 years. When fishing at F_{msy}, time series of simulated yield and biomass indicate a reduction of yield with the marine reserve. In contrast, when fishing at the higher F level the marine reserve resulted in increased yields and biomass (relative to fishing at this level with no reserve), but the yields were lower than those obtained from fishing at F_{msy} with no marine reserve.

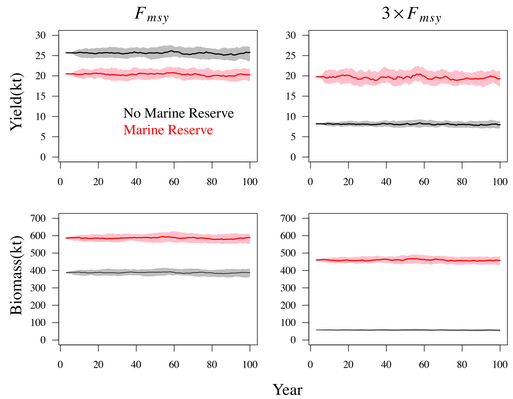

Figure 6. Median and inner quartile range of simulated yields and biomass with and without a marine reserve at two fishing mortality rates for Pacific ocean perch with maternal effects and intracohort density-dependence.

Conclusions

Marine reserves can increase the equilibrium yield at high fishing rates for stocks with maternal effects, although their performance is sensitive to the form of spatial density-dependence and the level of adult movement. A superior way to achieve high yields may be to fish at F_{msy}, where the loss of equilibrium yield associated with maternal effects is reduced.

References

Berkeley, S.A., C. Chapman, and S.M. Sogard. 2004. Maternal age as a determinant of larval growth and survival in a marine fish, *Sebastes melanops*. Ecology 85:1258-1264.

Ralston, S. and M.R. O'Farrell. 2008. Spatial variation in fishing intensity and its effects on yield. Canadian Journal of Fisheries and Aquatic Sciences 65:588-599.

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