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The Influence of Maternal Age on Fishery Harvest Reference Points

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Maternal effects, defined here as the reduction of larval viability with reduced spawner age, have been proposed as a feature of marine populations that motivate the conservation of age and size structure, and have been observed in both Atlantic cod (*Gadus morhua*) and Pacific rockfish (*Sebastes* spp.) stocks. The combination of maternal effects and populations composed of younger and smaller fish as a result of fishing pressure would be expected to produce eggs/larvae of reduced viability, thus reducing stock productivity. For fisheries stock assessment and management, a critical question is how the existence of maternal effects would influence the estimation of stock productivity and fishery management reference points.

The purpose of this work is to use simulation modeling to gain a more generalized understanding of how maternal effects can influence the estimated productivity of marine fish populations. A two-stage recruitment model was used to relate age-dependent larval survival to stock productivity, and was applied to Bering Sea/Aleutian Islands (BSAI) Pacific ocean perch (*Sebastes alutus*) and BSAI Pacific cod (*Gadus macrocephalus*), a species taxonomically similar to Atlantic cod and with substantially different life-history parameters than Pacific ocean perch. The "viable larvae" stage represents the period from fertilized eggs (cod) or released larvae (Pacific ocean perch) to 14-day larvae and includes larval survival dependent on spawner age, and is followed by a "pre-recruit" phase representing the period from 14 days to age of recruitment. An operational model that incorporates autocorrelated recruitment variability and level of harvesting was used to simulate recruitment, and F_{msy} (the F level associated with maximum sustainable yield) and F_{crash} (the F level where equilibrium yield is reduced to zero) were estimated for each of two indices of reproductive potential: total larvae (the estimated amount of larvae at 14 days in the absence of maternal effects, which is proportional to fertilized eggs or released larvae), and viable larvae.

Deterministic simulations reveal the importance of distinguishing the influence of maternal effects on stock productivity from the influence on *estimated* productivity arising from spawner-recruit analyses. Maternal effects add additional larval mortality, and recruitment and stock productivity are reduced. Stock-recruitment analyses, however, are generally applied to a given time series of recruitment that reflects pre-recruit mortality; if maternal effects occur they would, in theory, be reflected in a time series of reduced observed recruitments if age structure is affected. Thus, differences in estimated equilibrium yield obtained from indices of reproductive potential that either include or do not include the maternal effect can be relatively small, particularly at intermediate and low fishing rates where the age structure has not been substantially affected. Over a range of harvest rates and levels of recruitment autocorrelation for the cod and Pacific ocean perch life-history type, estimates of F_{msy} obtained when using total larvae ($F_{msy(TL)}$) were similar but slightly larger than estimates obtained when using viable larvae ($F_{msy(VL)}$). However, estimates of F_{crash} from total larvae ($F_{crash(TL)}$) showed larger increases relative to estimates of F_{crash} from viable larvae ($F_{crash(VL)}$).

Differences between $F_{crash(TL)}$ and $F_{crash(VL)}$ are reduced at high fishing rates, which allow observation of recruitment at low stock sizes and thus should improve estimates of F_{crash}. However, even at relatively high fishing levels estimates of $F_{crash(TL)}$ are on average higher than estimates of $F_{crash(VL)}$ for both Pacific cod and Pacific ocean perch. Because F_{crash} reflects productivity at the slope of the origin of the stock-recruitment curve, maternal effects could influence estimation of the rate of rebuilding for overfished stocks. Future work will use management strategy evaluations to further explore the influence of maternal effects on rebuilding rates, and the general implications of maternal effects on stock assessment and management.

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