Application of an MSVPA to evaluate the effect of predation mortality on forage species in the Northwest Atlantic ecosystem

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MSVPA in a nutshell

MSVPA is an age structured modeling technique that consists of a series of single species virtual population analysis (SSVPA) models linked by a feeding model. The feeding model uses predator-prey interactions to calculate predation mortality rates for prey. The SSVPA's are iteratively run until the predation mortality rates converge.

Key MSVPA equations

$$Z = F + M_1 + M_2$$

Total mortality, *Z*, is the sum of fishing mortality, *F*, natural mortality due to disease and senescence, M_1, and predation mortality, M_2.

$$M_{2\,jb}^{\;ia} = \frac{P_{jb}^{ia}}{w_{jb} N_{jb}}$$

Predation mortality due to predator *i*, age class *a*, on prey *j*, in age class *b*, is the ratio of the biomass removed by the predator, *P*, to the product of the average abundance of prey during the time interval, *N*, and the weight, *w*, of the prey.

MSVPA-X modifications- a temperature dependent feeding rate

$$C_{ys}^{ia} = 24 E_s^{ia} \cdot \overline{SC_s^{ia}} \cdot D_s \cdot w_{ys}^{ia} \cdot \overline{N_{ys}^{ia}}$$

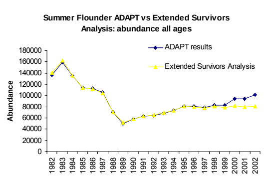
Consumption rate, *C*, is calculated for predator *i*, age class *a*, in year *y*, for season *s*. *E* is the hourly evacuation rate (defined below), *SC* is weight of stomach contents relative to predator body weight, *D* is the number of days in a season, *w* is the average weight, and *N* is the predator abundance.

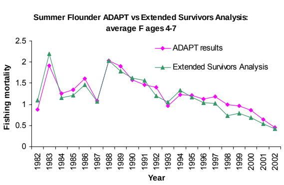
$$E = \alpha e^{\beta T}$$

The evacuation rate, *E*, is calculated using fitted parameters α and β, which are derived from laboratory and field studies (Elliot and Persson 1978; Durbin *et al.* 1983). *T* is the average seasonal temperature in °C. We used 0.004 and 0.115 respectively for α and β; these values are considered conservative for teleost fish (Durbin *et al.* 1983). For elasmobranchs, we used 0.0165 for α.

MSVPA-X innovations- choice of SSVPA's

Four types of SSVPA's are available in MSVPA-X, including Extended Survivors Analysis which utilizes tuning indices and is conceptually similar to the widely used ADAPT VPA. Estimates of fishing mortality and abundance are very similar between the two VPA methods.

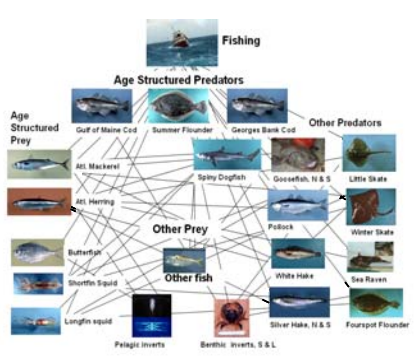


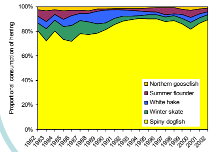


Abstract

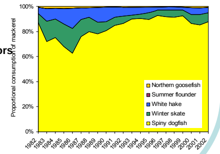
Ecosystem-based fisheries management calls for consideration of ecological interactions in fisheries stock assessments. For some species, predation mortality may equal or exceed fishing mortality and a failure to account for this predation may lead to a misrepresentative understanding of stock dynamics. Multispecies virtual population analysis (MSVPA) is an age structured population dynamics modeling approach that accounts for predator-prey interactions for a subset of the commercially targeted species in an ecosystem. Expanded MSVPA (MSVPA-X) modifies the consumption model of the traditional MSVPA to incorporate the effects of temperature dependent metabolism on predator consumption rates. MSVPA-X also includes a provision for "biomass predators" whose predation affects the mortality of explicitly modeled prey species but whose population dynamics are not modeled. We evaluated the sensitivity of MSVPA-X to its innovations by applying it to the Northeast US continental shelf ecosystem. Sensitivity analyses focused on predation mortalities of the two age structured prey species, Atlantic herring and Atlantic mackerel. We examined the effect of including or ignoring predation by biomass predators, the effect of assuming static versus annual variation in water temperatures, and the effect of varying two input parameters that affect prey consumption rates. Results indicated that MSVPA-X is a robust approach and some of its innovations, particularly the provision for non-age structured predators, strongly affect predation mortality for herring and mackerel. Accounting for temporal and ontogenetic variations in predation mortality is prudent for species such as herring and mackerel whose populations are strongly influenced by both fishing and predators.

The MSVPA Food Web



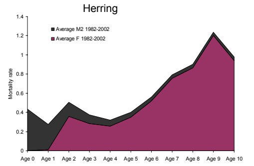


Most important predators
1 Spiny Dogfish
2 Winter Skate
3 White Hake
4 Summer Flounder
5 Northern Goosefish

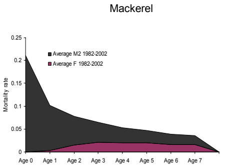


Relative influence of predation and fishing mortality for different ages

Herring



Mackerel



Predation mortality declines steadily and rapidly with increasing age.

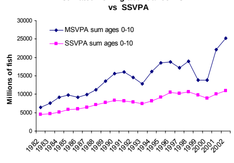
For herring ≥ 6 years old, predation mortality is relatively constant and very low; while fishing is an increasingly important source of mortality for herring ages 4-9.

For mackerel, predation mortality stabilizes at low levels after age 4 and fishing mortality is relatively constant for fish ≥ 3 years old. For ages 0-5, mackerel have lower predation mortalities than herring.

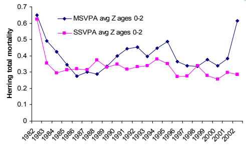
MSVPA-X for the Northeast US Continental Shelf Ecosystem:
Extended Survivors Analysis (SSVPA) vs MSVPA-X results

Abundance
MSVPA abundance estimates for herring and mackerel are consistently higher than those from SSVPA.

MSVPA produces higher abundance estimates for the youngest age classes which are the sizes most susceptible to predators.

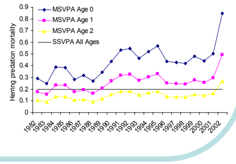


Total mortality
When averaged across the three youngest age classes, MSVPA-X total mortality estimates were higher than SSVPA estimates, except for three years in the 1980's when herring's predation mortality was relatively low.



Predation mortality (M_2)
SSVPA's assume a constant, low value for M_2, but MSVPA-X shows that M_2 is variable through time.

MSVPA–X shows the youngest (smallest) size classes experience the highest predation mortality.



Conclusions

Predation mortality is not constant through time and is strongly affected by predator abundance.

Predation mortalities are highest for the youngest ages of fish, while fishing becomes a more important source of mortality with age. For the majority of age classes, herring generally has higher predation and fishing mortality than mackerel.

Compared to the conventional estimate of 0.2, average predation mortality estimated by MSVPA-X for the 0-2 age classes was 40% higher for herring and 38% lower for mackerel.

Of the top 5 most important predators, four were "biomass predators" indicating even though age structured data isn't available for these species, their predatory impacts on forage species are substantial. Removing biomass predators from the model resulted in enormous reductions in herring and mackerel's predation mortalities.

Spiny dogfish were the most important predators for herring and mackerel.

Sensitivity analyses indicated variations in the weight of stomach contents resulted in larger changes in predation mortalities than changing the evacuation rate alpha.

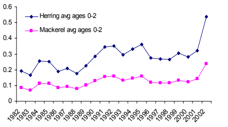
Incorporating these variable predation mortalities for species that are subject to both heavy predation and fishing pressure is an important consideration for implementation of ecosystem-based fisheries management.

Sensitivity Analyses

A series of analyses were conducted to examine how variations to the MSVPA-X configuration and input parameters affected herring and mackerel's predation mortalities. We examined the effect of:
1) ignoring predation due to "biomass predators", whose population dynamics are not explicitly modeled because of a lack of age-structured data for these species,
2) removing annual temperature variation,
3) 25% variations in the evacuation rate parameters α of the top five predators and,
4) 25% variations in stomach content weights for the top five predator species.

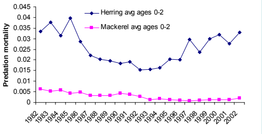
Predation mortality from base run

From 1982-2002, the average predation mortality for ages 0-2 herring was 0.28 and for mackerel it was 0.12.



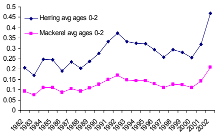
Predation mortality without biomass predators

•Excluding biomass predators dramatically decreased the average herring M_2 by 92%,
•and mackerel by 98% compared to the base run.



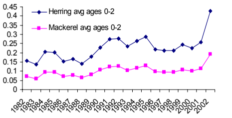
Predation mortality without annual temperature variation

•Compared to the base run, steady temperatures resulted in an average 4% decrease in herring M_2,
•and a 3% decrease in average mackerel M_2.



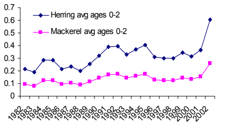
Predation mortality with a 25% decrease in evacuation alpha

•Compared to the base run, reducing the evacuation rate alpha by 25% resulted in a 20% decline for herring M_2,
•and a 19% decrease in mackerel M_2



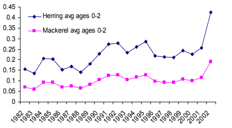
Predation mortality with a 25% increase in evacuation alpha

•M_2's are higher with a 25% increase in evacuation alpha;
•average herring M_2 was 13% higher and,
•average mackerel M_2 was 10% higher compared to the base run.



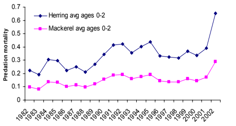
Predation mortality with a 25% decrease in stomach contents of top 5 predators

•Compared to the base run, a 25% decrease in stomach contents caused herring M_2 to decline by 24%,
•while mackerel's average M_2 decreased by 22%.



Predation mortality with a 25% increase in stomach contents of top 5 predators

•A 25% increase in stomach contents resulted in a 20% increase in both herring and mackerel M_2 compared to the base run.



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Durbin, E.G., Durbin, A.G., Langton, R.W. and Bowman, R.E. 1983. Stomach contents of silver hake, *Merluccius bilinearis*, and Atlantic cod, *Gadus morhua*, and estimation of their daily rations. Fisheries Bulletin 81:437:454.

Acknowledgements

Funding for this project was provided by the Lenfest Foundation. Special thanks to Brian Smith and to past members of the Food Web Dynamics Program for managing the food habits database.