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A simple predation pressure index for modeling changes in natural mortality: Application to Gulf of Maine northern shrimp stock assessment

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ABSTRACT

This paper describes a method for incorporating varying predation pressure in stock assessment that does not require estimation of consumption rates or absolute consumption by predators. The method is applied to assessment of northern shrimp *Pandalus borealis*, an important forage species in the North Atlantic Ocean and the target of major fisheries. A predation pressure index (PPI) was developed using data collected during resource surveys in Gulf of Maine northern shrimp habitat areas during 1968–2013. Predators were identified based on the percent frequency of occurrence (PFO) of Pandalid shrimp in their diets. The PPI for each year was the weighted sum of the biomass indices of 21 identified predators, where the weights were the time-series average PFO for each predator. The PPI thus reflected the effects of both the biomass of each predator and its importance as a predator of shrimp. The PPI time series was used to scale an assumed average natural mortality rate (M) that replaced a constant M assumption in the stock assessment model. Use of the PPI-scaled M improved the overall fit of the model and reduced a retrospective pattern in the constant M model by nearly 60%. The PPI approach allows time-varying predation to be accounted for in an assessment model without requiring estimates of absolute abundance of predators and their total consumption, quantities which may be unavailable or difficult to estimate accurately.

1. Introduction

The importance of accounting for species interactions in fishery management has been recognized for decades (e.g., McHugh, 1959, 1988; Mercer, 1982; Tyler et al., 1982; Fogarty, 2014), yet most fisheries continue to be managed based on information about the target species only. The foundations for more holistic approaches to fishery management have been accumulating with increasingly sophisticated observation systems, ecological understanding and modeling capabilities (Murawski, 2007). However, parameterizing complex multi-species and ecosystem models can be a substantial challenge (Fulton et al., 2003) and simpler approaches are also needed (Murawski, 2007; Fogarty, 2014). This paper describes a simple approach to including species interactions in stock assessment by accounting for predation on an important forage species in the North Atlantic Ocean.

The northern shrimp *Pandalus borealis* is distributed across a wide latitudinal range (~42°N –70°N; Shumway et al., 1985; Bergström, 2000) in the North Atlantic Ocean and is the target of important fisheries. It is also a key component of food webs that support demersal fish, including Atlantic cod *Gadus morhua* (Parsons, 2005a). A meta-analysis of nine northern shrimp populations found that cod predation was a structuring force in most regions. However, in the Gulf of Maine (GOM), cod did not appear to exert a controlling influence (Worm and Myers, 2003). The GOM has a complex food web (Overholtz and Link, 2009) and a broader suite of predators than the more northern systems. Thus, the overall impact of predation is probably not well represented by only a single predator. A subsequent study identified ten fish species that consistently prey on Pandalid shrimp in the GOM (Link and Idoine, 2009).

Management of the GOM northern shrimp fishery is guided by annual stock assessments that have used Collie-Sissenwine catch-survey analysis (CSA; Collie and Sissenwine, 1983; Cadrin et al., 1999) for almost two decades. However in recent years the CSA developed a retrospective pattern (Mohn, 1999; Legault, 2009) that suggested biomass was overestimated and fishing mortality

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Table 1
Sources of data for estimating PPI and inputs to the CSA models. PFO is percent frequency of occurrence of Pandalids in predator stomachs; CSA is Collie–Sissenwine Analysis (Collie and Sissenwine, 1983).

Data type	Estimated quantity	Source	Years	Comments
Food habits	PFO for each predator	NEFSC spring, fall surveys	1973–2011	Aggregated over season and years
Survey indices	Predator biomass index	NEFSC fall surveys	1963–2012	Used to estimate PPI
Survey indices	Shrimp abundance index	ASMFC shrimp surveys	1984–2012	Recruit and post-recruit indices for CSA
Survey indices	Shrimp abundance index	NEFSC fall surveys	1984–2012	Aggregate abundance index for CSA

Table 2
Species of Pandalid predators included in the PPI, number of stomachs examined, average PFO of Pandalids in each predator's diet (1973–2011), and proportion of the total PPI accounted for by each species on average. CV is inter-annual coefficient of variation of PFO for each species during 1977–2012.

Predator scientific name	Predator common name	Number stomachs sampled	Average PFO	CV (PFO)	Average percent of PPI
Sebastes fasciatus	Acadian redfish	2375	6.6	117%	20.6%
Urophycis tenuis	White hake*	6924	15.5	61%	17.3%
Squalus acanthias	Spiny dogfish	6825	3.5	106%	15.2%
Gadus morhua	Atlantic cod*	5311	12.9	55%	15.1%
Merluccius bilinearis	Silver hake*	14,157	7.5	64%	7.5%
Amyblyraja radiata	Thorny skate*	1888	8.6	80%	6.4%
Urophycis chuss	Red hake*	5111	13.1	59%	5.1%
Pollachius virens	Pollock*	1905	6.4	76%	3.8%
Melanogrammus aeglefinus	Haddock	1985	2.8	110%	3.0%
Clupea harengus	Atlantic herring	4527	1.9	119%	1.5%
Hippoglossoides platessoides	American plaice	5284	1.2	134%	0.8%
Lophius americanus	Goosefish	2414	2.9	80%	0.8%
Malacoraja senta	Smooth skate	751	20.8	56%	0.7%
Myxocephalus octodecemspinosus	Longhorn sculpin*	1782	9.6	70%	0.6%
Dipturus laevis	Barndoor skate	28	35.7	26%	0.6%
Leucoraja ocellata	Winter skate	344	4.4	249%	0.3%
Hippogrossus hippoglossus	Atlantic halibut	192	12.5	60%	0.3%
Hemipterus americanus	Sea raven*	1487	4.3	100%	0.2%
Leucoraja erinacea	Little skate	493	11.0	100%	0.1%
Paralichthys oblongus	Fourspot flounder*	337	5.0	80%	0.0%
Scophthalmus aquosus	Windowpane*	213	1.4	264%	0.0%
*included in Link and Idoine (2009)	Total	64,333			

underestimated, clearly a concern for fishery management. Further eroding confidence in the CSA, consumption of Pandalid shrimp by fish in the GOM was estimated to equal or exceed the population size of northern shrimp estimated by the CSA (Link and Idoine, 2009). CSA continued to be used for the assessment, assuming higher rates of natural mortality to account for the apparent underestimation of population size. However, in a 2014 benchmark assessment review (NEFSC, 2014), all models put forth for the northern shrimp assessment were rejected for use in management because of poor performance on diagnostic measures, including retrospective patterns. The modeling approaches were considered appropriate for the assessment, but required further development to resolve diagnostic issues.

To explore a potential cause for the retrospective patterns in the CSA, we devised a simple index-based method for incorporating time-varying natural mortality due to predation. The approach uses diet data and predator trend data from research surveys, but avoids the need for estimates of absolute numbers of northern shrimp consumed. In this paper we describe the method and its application to assessment of GOM northern shrimp.

2. Methods

The general approach was to first identify predators and quantify their relative importance to shrimp using food habits data. Trends in biomass of each predator were then estimated and a weighted sum calculated where the weights were each predator's importance as a source of shrimp predation. The weighted sum was taken as an annual index of predation pressure on northern shrimp and was used to track interannual trends in assumed natural mortality (M) in the CSA. CSA model estimates and diagnostics were compared for runs with constant and variable M to evaluate whether incorporating predation pressure improved model performance. Table 1 summarizes the data that were used in the study.

2.1. Sampling methods for predators

Food habits and predator biomass data used to calculate the predation pressure index (PPI) were collected during spring and autumn bottom trawl surveys conducted annually since the 1960s by the Northeast Fisheries Science Center (NEFSC). Sampling is conducted according to a stratified random sampling design, with strata defined by depth and latitude, and sampling effort (number of stations) proportional to stratum size. Details of survey design, operations and gear specifications can be found in Grosslein (1969), Azarovitz (1981) and Miller et al. (2010). Operating procedures have followed a standard protocol since the inception of the survey. However, a major change occurred in 2009 that included replacement of the research vessel and modernization of the net design (Miller, 2013). Calibration coefficients estimated from experimental tows (Miller et al., 2010) were applied to adjust survey catch data for predators for these changes (see Section 2.2). Approximately 40 stations in GOM northern shrimp habitat were visited during each survey (Fig. 1).

Food habits data collected during 1973–2011 NEFSC spring and autumn surveys in northern shrimp habitat areas were used to identify fish predators and estimate the prevalence of Pandalids in their diets. Typically, stomach contents were identified for a subsample of individuals of predator species at each station up to a maximum number per species per stratum. Food habits sampling was distributed across geographic regions, and the number of samples per station was limited to ensure that sampling was distributed across strata. After 1980, sampling was also stratified by length class within predator species. Data collected included prey species identification, volume or weight of each prey species, prey number,