Using the Atlantic Zone Monitoring Program (AZMP) to develop indices of bio-physical environmental variability in the context of pelagic fish stock assessments in the Gulf of St. Lawrence, Canada

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Summary

We present an approach integrating environmental monitoring data and fish stock assessment parameters with the goal of measuring the impacts of environmental variability on pelagic fish stock dynamics in the Gulf of St. Lawrence (GSL), Canada. Environmental data were collected by the Department of Fisheries and Oceans through the Atlantic Zone Monitoring Program (AZMP) during spatial surveys with high-frequency sampling sites. Forty variables were selected to describe long-term changes in physical environmental conditions (1971-2012), zooplankton abundance/composition and phenology (1992-2012). Principal Component Analysis (PCA) was performed to reduce the data set into composite variables describing the dominant patterns of environmental variability. PCAs revealed different modes of variability with evidence for a strong link between physical forcing and zooplankton dynamics. Generalized Additive Models (GAM) revealed strong effects of environmental variability on the recruitment strength and condition of pelagic fish stocks in the GSL. Our results highlight the importance of considering environmentally-driven variations of pelagic fish stock productivity in the stock assessment process.

Introduction

The GSL is the southernmost region in the northwest Atlantic with seasonal ice cover. Considering the significant warming trend and the diminishing sea ice cover observed over the last two decades (Galbraith et al. 2013), one must expect profound changes in zooplankton dynamics in the region given the relationship between physical environmental conditions and zooplankton dynamics. However, a comprehensive description of the temporal variability of zooplankton community dynamics, their dependence to physical environmental forcing and their influence on the productivity of pelagic fish stocks in the region is still lacking. Using long-term monitoring data collected by AZMP in the GSL (Therriault et al. 1998), the first goal of this study was first to describe the variability of physical and biological oceanographic conditions in the GSL using PCA. Second, we developed a set of GAMs models to identify and quantify the role that variations in bottom-up processes could play in controlling Atlantic herring (*Clupea harengus*) and Atlantic mackerel (*Scomber scombrus*) individual condition (K) and recruitment success (R_s).

Materials and Methods

A set of 40 variables collected by AZMP was assembled to describe the long-term changes in oceanographic conditions in the GSL. Abiotic environmental variables included large-scale climate indices (3) and several physical parameters (11) measured at discrete sampling stations over the period considered (1971-2012). Variables characterizing zooplankton dynamics were comprised of indices describing variations in abundance/composition (14) and phenology (10) extracted from the Rimouski station data series (1992-2012). PCAs were run separately for each set of physical and zooplankton indices in order to extract the dominant modes of variability and correlation coefficients were computed to describe potential links between physical forcing and plankton dynamics. GAMs were used to explore the role of intrinsic stock dynamics, the physical environment and the zooplankton dynamics affecting variations of K and R_s of NAFO's 4R herring spring and fall spawning stocks and 4T Atlantic mackerel (see Cardinale et al. 2009). GAMs were first built using only variables considered in the Atlantic herring and Atlantic mackerel stock assessment (R_s, K, and SSB) (Grégoire et al. 2012, Grégoire et al. 2013). We then applied a forward selection approach to test the effect of different PCA axes describing environmental variability. The best models were selected on the basis of the gain in deviance explained relative to the basic model while minimizing the Generalized Cross Validation criterion (GCV).

Results and Discussion

The PCA1s explained 42-57% of the variability and mainly described a long-term (15-20 years) warming of upper and deep water layers and an earlier melt of a diminishing sea-ice cover, a decrease in the abundance of arctic copepods and an earlier peak in the zooplankton production seasonal cycle. PCA2s (16-20%) and PCA3 (9-17%) also explained a significant proportion of the variability by describing oscillations between cold and warmer environmental regimes and in the zooplankton dynamics (abundance, composition, and phenology of dominant copepod species) occurring at higher frequency (5-10 years).

A highly-significant positive correlation was obtained between PCA1s describing long-term variations in physical conditions and those of zooplankton abundance or phenology. Moreover, zooplankton PCA2 was negatively correlated with PCA2 of physical conditions, suggesting a relationship between high abundance of *C. finmarchicus* and *C. hyperboreus* and cold surface water, sea-ice index above normal, and lower freshwater runoff from the St. Lawrence River. Therefore, our analyses revealed that variations in physical forcing strongly influence zooplankton abundance, composition and phenology in the GSL at different temporal scales.

GAMs revealed highly significant effects of environmental variability on K and R_s of 4R Atlantic herring spring and fall spawning stocks and 4T Atlantic mackerel in the GSL. Optimal GAMs typically explained more than 70% of deviance of the independent variables. Optimal GAMs always included variations in zooplankton dynamics, which improved model performance by 40-50% relative to those considering only intrinsic stock dynamics and/or physical environmental conditions. Most notably, optimal GAMs for R_s included both zooplankton abundance and phenology PCAs supporting in a general way the match-mismatch hypothesis proposing that adequate prey must be abundant enough at the right time to favor feeding success, and consequently individual condition and recruitment success (Cushing 1990). The high percentage of deviance in observations explained by our optimal GAMs indicates that the three principal PCAs derived from AZMP data did capture elements of bottom-up processes fundamental to pelagic fish stock dynamics.

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