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Joint effects of physical processes and multiple invasive species on Great Lakes zooplankton production, with implications for fish recruitment

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ABSTRACT:

Invasive species have dramatically altered the Great Lakes food web, and physical factors such as light and temperature may mediate these effects, with likely implications for fisheries recruitment. Rich time series data from long-term surveys offer the opportunity to evaluate such effects and improve predictions for future changes in the lakes. However, ecological complexity (e.g., nonlinearities, process stochasticity) and methodological challenges (e.g., measurement error) have previously limited the information that can be extracted from available data. In this project, we applied a suite of modern modeling approaches (state space models, generalized additive models, and an individual-based bioenergetics model) that help to overcome these barriers. We coupled these approaches to long-term time series data for the offshore zooplankton community in Lake Michigan to explore effects of physical factors and invasive species, with a focus on effects of the invader, *Bythotrephes longimanus*. Application of state-space models to the zooplankton time series data revealed that *Bythotrephes* has affected population growth rates and densities of the dominant herbivorous cladocerans, *Daphnia mendotae* and *Bosmina longirostris*, including through nonconsumptive effects (costs to fitness due to migration by prey species to avoid predation) on *Daphnia* and both consumptive and nonconsumptive effects on *Bosmina*. The state space models also revealed the influence of other environmental factors (e.g., seasonality, density dependence) on these zooplankton and provided estimates for key parameters (e.g., birth rates, mortality rates, measurement error). Additional analyses using generalized additive models suggested effects of *Bythotrephes*, temperature, and seasonality occur across several major zooplankton groups in Lake Michigan. Finally, use of an individual-based model of first-year alewife growth and survival suggest that effects of *Bythotrephes* on *Daphnia* may lead to reduced alewife growth and survival in years with high *Bythotrephes* densities. Overall, our project findings demonstrate how employing a suite of modeling approaches can advance mechanistic understanding for invasive species effects across multiple trophic levels in the lake. Our findings suggest that *Bythotrephes* continues to have disruptive effects that will have consequences for ongoing management of Lake Michigan and other lakes (e.g., Huron and Ontario) experiencing similar effects.