Data-driven Mathematical Modeling of Climate Change Effects on Chesapeake Bay Fishes

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Our project develops an innovative bio-mathematical framework that combines mathematical theory with empirical data to comprehensively explore the impact of climate change on fish populations in Chesapeake Bay. Most fish population studies utilize single-species models and statistical methods to examine populations sustainability and to propose harvesting policies for fishes. Our approach is novel because it integrates numerical simulations with data science and multi-species dynamical systems methodologies to create a predictive model that captures the underlying ecological interactions between several species and uses those outputs to forecast the long-term effects of changing environmental conditions on fish populations. This project brings a new perspective to fishery studies by applying modern mathematical techniques rarely used in fisheries science. We seek to apply stability theory, optimal control theory, parameter sensitivity, and multi-scale analysis to assess native fish resilience to climate change, derive sustainable harvesting strategies, and investigate climate-change impacts across multiple timeframes. The broader impact of our proposed modeling approach is that it will provide a framework to improve our understanding of interactions among fish populations and under changing environmental conditions.

Research Objective 1: Develop a data-driven, ecosystem-based multi-species model that captures ecological interactions among species and incorporates climate change through environmental drivers of reproduction, recruitment, mortality, predation, and competition.

Research Objective 2: Use the model to assess the long-term impacts of climate change on fish populations and study population resilience under various climate scenarios.

The novelty of the proposed approach lies in the unique integration of numerical simulations and data science methodologies with dynamical systems to forecast the effects of disturbances associated with climate change on the long-term sustainability of fish populations. By integrating climate-change factors as parameters into the dynamical system, we can study different climate-change scenarios to gain a comprehensive understanding of their effects on fish populations. Climate-change scenarios will be derived based on the results obtained from the data analysis.

Dr. Fabrizio from VIMS will contribute a time series of relative abundance data from the VIMS Juvenile Striped Bass Seine Survey, the VIMS Juvenile Fish Trawl Survey, and the VIMS Adult Striped Bass Gill Net Survey. These datasets, spanning back to 1994 and encompassing the Virginia waters of Chesapeake Bay, include estimated relative abundances of striped bass, bay anchovy, blue catfish, and Atlantic menhaden, key species that include both predators and prey. The availability of these data will support the development and verification of the model. These datasets also contain records of temperature, dissolved oxygen, and salinity, which will support the inclusion of climate-related dependencies in the model. In the case of limited data, we will explore alternative sources as well as use data interpolation and extrapolation techniques that leverage statistical methodologies.

Employing statistical methods and data analysis techniques, including data-fitting methodologies, we will extract valuable insights from the available datasets considering climate-change impacts by identifying trends, relationships, patterns, and correlations that emerge from the data. The ultimate objective is to estimate the recruitment, predation, competition, and mortality parameters as functions of the climate-change drivers (temperature, salinity, oxygen concentration) so they can be implemented in our ecosystem-based model. The resulting model will provide a realistic representation of the complex ecological dynamics among multiple species and will assist with informed resource management strategies that promote climate resilience of native fishes. Alternatives to our modeling approach are primarily based on single-species models and statistical methods. Such approaches generally do not account for predator-prey interactions. In contrast, our modeling framework offers a superior, cost-effective approach to assess climate-change effects across multiple fish populations.