A Dynamical Systems Approach to a Climate-Driven Aquatic Ecosystem with Fisheries Management

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Abstract

The accumulation of greenhouse gases and subsequent environmental warming impose severe physiological stress on marine organisms and disrupt the structural balance of aquatic ecosystems, altering plankton and fish population dynamics [1, 2, 3]. To investigate these interacting stressors alongside human intervention, we formulate an autonomous ordinary differential equation model coupling greenhouse gas concentration, environmental temperature, and plankton and fish dynamics with an explicit fisheries management component. We analytically establish the well-posedness, positivity, and uniform boundedness of the system. We determine the algebraic conditions governing the local stability of the boundary equilibria, while evaluating the coexistence state numerically. Treating the atmospheric depletion rate of greenhouse gases, the management-targeted fish capacity, and the environmental cooling rate as primary bifurcation parameters, numerical continuation reveals that the stable coexistence equilibrium loses stability via supercritical Hopf bifurcations in all three cases. While variations in the depletion rate and management targets drive the system into sustained oscillatory regimes, a reduction in the environmental cooling rate forces the ecosystem through a period-doubling cascade. Positive maximal Lyapunov exponents and one-dimensional return maps are consistently indicative of a transition to chaotic dynamics driven by restricted thermal dissipation. Ultimately, these findings demonstrate that parameters influencing fish population dynamics play a critical role in ecosystem stability, highlighting the significance of properly calibrated fisheries management in maintaining ecological balance.

Keywords: Dynamical systems, stability analysis, numerical continuation, global warming, greenhouse gases.

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