ABSTRACT

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Title of the Thesis: Mathematical Study of Socio-Ecological-Economic Interaction: Sustainability Perspective

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In this thesis, we study social-ecological-economic interaction and management of some commercial fish species in the presence or absence of an infectious disease. The basis of this thesis is to know how the dynamics of a renewable species are affected by human intervention and the demand-supply theory of the open market. **Chapter 1** contains a brief history of fisheries and fish exploitation. It also includes a literature review and the motivation behind the study.

In **Chapter 2**, we analyzed a basic two-dimensional bioeconomic model representing the time evolutions of fish population in the presence of harvesting and market price that depends on supply and demand. We explored the dynamic behaviours of the system with four different harvesting functions and eight demand functions. Different analytical results were presented for a pair of saturated demand and saturated harvesting functions, but simulation results were given for all the thirty-two pairs. It is shown for all thirty-two combinations that the system may shift from a harvesting state to a non-harvesting state through a transcritical bifurcation for some values of harvesting effort and demand. However, a disastrous regime shift with unbounded prices may be observed only in some combinations. For example, there will be no regime shift for quadratic demand, whatever be the harvesting rate. However, regime shift may be observed in all four harvesting rates if the demand function is of saturated type. A trade-off between the harvesting effort and net revenue always occurs for the quadratic and exponential demand functions but never occurs for saturated and mixed demand functions.

Intense harvesting and emerging infectious diseases are potential threats to the global fishery. A proper management policy with a scientific understanding of species interaction is a footstep in a long-term sustainable fishery. Considering those factors in **Chapter 3**, we performed a qualitative study of the bioeconomic management of a fishery in the presence of infection and dynamic harvesting. The harvested fish biomass is shown to be higher at the infection-free equilibrium state than at the infected equilibrium state under an increasing infection rate. However, the outcome is the opposite under increasing environmental carrying capacity. The total revenue is highest in the infection-free state when demand is high. An unintuitive result is that the infection persists higher if demand decreases.

Taxation policy for fishing received global consent to protect fisheries from drastic harvesting. In **Chapter 4**, we proposed a nonlinear bioeconomic harvesting model of a single-species fishery with infection, variable market price, and nonlinear demand to explore taxation's ecological and economic effects. We provided the analytical conditions for the existence of transcritical bifurcation. Taxation might control intensive harvesting but augment disease spreading and price hiking. Higher regulatory tax may even cause a regime

shift, where the system enters into a non-harvesting regime from the harvesting one, causing an ecological and economic imbalance.

In **Chapter 5**, a four-dimensional bioeconomic fishery model is considered and analyzed to explore the system's dynamic behaviour. The objective is deciphering how increasing demand may cause a regime shift in the fish and fishery. We show that demand can make the system stable from its unstable state. It also plays a role in removing the infection from the system. Increasing demand corresponds to increased harvesting effort, which helps eliminate the disease. On the contrary, the negative side of high demand could be severe. There may be a drastic change in the system's qualitative behaviour. A regime shift from a harvested state to a non-harvested state may occur, causing an imbalance between demand and supply and the socioeconomic condition of the people associated with the fishery. The two-parameter bifurcation results were presented to demonstrate the more extensive dynamical behaviour of the system. It shows that the non-harvesting regime, where the price is unbounded, is not observed in any bifurcation results where demand is not one of the bifurcation parameters.

In **Chapter 6**, we have proposed and analyzed a harvesting model that integrates the ecological interaction of predator and prey fish with ecotourism and the open market economy theory. In the ecological interaction, the prey fish is harvested commercially, whose market price is determined by the demand-supply relationship. The regulatory authority imposes a fishing tax on landed fish as a controlling measure to restrict overfishing. The predatory fish (dolphin) is banned from commercial harvesting but used for recreation purposes for visitors as a part of ecotourism. The mentioned social-ecological-economic interaction may match various commercial and fishery-based ecotourism sites, including the Chilika lagoon of Odisha state, India. We analyzed the proposed model from the dynamic and economic points of view and provided the local and global stability conditions of the ecological and economic equilibrium points. The broader dynamics of the system are unveiled through one-and two-parameter bifurcation analysis. Using Pontryagin's maximum principle, we mathematically show that an optimal tax exists, maximizing overall revenue generation and societal benefit. The thesis ends with the conclusion and future direction in **Chapter 7**.

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