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Research paper

A Cost-Benefit Analysis of Marine Conservation Efforts

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Abstract

Overexploitation is a widespread issue in fisheries worldwide. The fishing industry in India is not an exception. The Indian Ocean's marine fisheries resources have drastically decreased. Biological overfishing occurs when the pace of harvesting exceeds the natural rate of renewal. Most Indian fishermen made their living under hazardous and vulnerable circumstances, according to literature on the country's fisheries. Numerous challenges are linked to deep-sea fishing, including the extensive use of vessels along the upper East coast, the overexploitation of specific species, capital-intensive operations, and the general limitation of fishing activities to areas within a depth of 40 fathoms. Additionally, the annual discarding of approximately 130,000 tonnes of unwanted fish and the considerable fishing pressure on shrimp resources further exacerbate these issues. Similarly, artisanal capture fisheries face their own set of problems, such as overfishing, the use of detrimental fishing techniques, damage to natural ecosystems, conflicts with other industries, fishing in unconventional areas, and the mismanagement and wastage of surplus catches. In essence, unsustainability and overcapacity are two aspects of the same issue. The absence of clearly defined property rights in fisheries is the primary cause of surplus capacity. Most commercially exploited stocks exhibit signs of overexploitation, putting the nation's fisheries resources under stress in various regions. The livelihoods of those who depend on these resources are affected by this.

Keywords: *Marine Fishery; Marine Conservation; Environment, Cost-benefit; Fishing Industry.*

1. Introduction

Since the demand for fish, which is mostly from relatively affluent customers in developing nations, is exceeded the supply, fish have gotten more expensive during the past 30 years in comparison to other food items (Alavi, 2014). As the population and per capita income of developing nations rise, as well as awareness of the health advantages of eating fish grows, so will the demand for fish (Das Gupta & Shaw, 2015). Global marine fish populations are under a lot of strain due to the growing demand for seafood in both industrialized and emerging nations (Arafeh-Dalmau et al., 2023). Market expansion leads to an increased demand for new products, resulting in a notable rise in the number of fish processing plants. This heightened need for raw materials in these facilities boosts their capacity and fosters the development of upstream connections to fishing operations (Galarza et al., 2024). A prominent example of this phenomenon is the proliferation of bottom trawling in Asian waters during the 1960s, which was driven by the burgeoning shrimp markets in the United States, Europe, and Japan (Shilpa Rani, 2021). Overfishing, the use of damaging fishing techniques, pollution, and commercial aquaculture are some of the ways that humans endanger marine life (Hoppit et al., 2022). Furthermore, marine habitats are already being impacted by climate change and the resulting ocean acidification. Fish migration from freshwater systems to the sea, population pressures that result in increasing coastal subsistence fishing, and environmental degradation of the nearby land all have a significant impact on coastal fisheries. Commercial fishing is one of the biggest threats to biodiversity in the ocean environment. When too many fish are taken out of an environment, populations of marine mammals, seabirds, turtles, sharks, and a variety of other predators in the marine food web have a worse chance of surviving (Zou & Ali, 2024). Each year, millions of creatures other than fish are killed or seriously injured because of fatal collisions with fishing gear (Maina et al., 2015). Both the habitat and residents are destroyed by fishing methods. For example, bottom trawling has led to the destruction of ancient deep-sea coral ecosystems. Since the onset of large-scale industrial fishing in the 1950s, 90% of large fish species, such as tuna, swordfish, marlin, cod, halibut, skate, and flounder, have been depleted (Al-Azawi, 2024). Additionally, the populations of apex predators, which are vital indicators of ecosystem health, are experiencing a concerning decline. When these top predator species become extinct, the entire ocean ecosystem may change, with smaller, plankton-eating fish replacing commercially valuable fish (Bryndum-Buchholz et al., 2022; Bryce & Hunter, 2024; Singhvi et al., 2018). As illustrated in Figure 1, the multidimensional goals of marine conservation include ecological, economic, and social objectives, which this study integrates through a cost-benefit analysis lens.

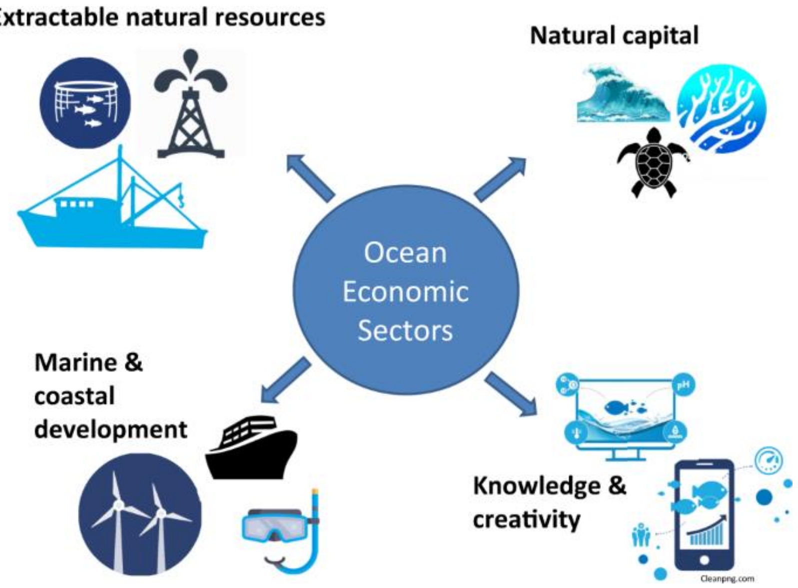

Fig. 1: Conceptual Overview of Marine Conservation Strategies

As a component of the complex food web, bycatch eliminates fish that would be better off remaining alive in the ocean. This includes juvenile, commercially valuable fish that, if given the chance to mature, may replenish the stocks. Non-commercial fish species that are crucial food for other fish that are targeted for commercial purposes, endangered fish species, and other marine animals like seabirds are examples of other bycatch. The entire maritime environment would be impacted by the enormous number of marine animals killed as bycatch. The depletion of marine life is another issue that gives cause for concern. Industrial fishermen kill or dump a vast amount of "unwanted" marine species, such as young fish, whales, dolphins, seabirds, old coral forests, and turtles, in addition to harvesting tons of fish from the ocean (Karani & Failler, 2020). Some of these unintended bycatch victims are already threatened species. Nearly 25% of all marine life captured in world fisheries is destroyed and thrown away, either too small or too huge, belong to the incorrect species, are of poor quality, or exceed the fishing operation's quotas. This diagram outlines the core components of marine conservation, including habitat protection, biodiversity maintenance, and sustainable fishing practices. It sets the contextual foundation for evaluating conservation costs and benefits.

2. Importance of Marine Conservation

In 2004, the globe received around 106 million tonnes of edible fish from aquaculture and capture fisheries. In 2004, the global fish and fisheries product trade hit a record high of $71.5 billion (McLeod et al., 2019). The global fishing fleet has grown twice as quickly as global catches since 1970. Consequently, there is now a concerning amount of excess fishing capacity. The lives of hundreds of millions of people who rely heavily on fishing for food and a living are currently in danger due to overfishing and wasteful, harmful fishing methods brought on by this startling growth. Around four million fishing boats are active in the world's waters, and they are all vying for the limited number of fish available. Due to the abundance of fishing vessels worldwide, enormous fleets are fleeing overfished regions and scouring the globe in a last-ditch effort to find less-fished fishing grounds. This poses a threat to global food security, particularly to the availability of animal protein, particularly in developing nations. There have already been some spectacular fishery collapses because of overexploitation and poor management (Eurich et al., 2024). A growing body of literature in environmental economics underscores the economic value of coastal and marine ecosystems (Hanley et al., 2015; Luisetti et al., 2011). Marine protected areas have been shown to generate long-term gains in biodiversity, fishery yields, and local income (Ferreira et al., 2023; Maina et al., 2015). Moreover, the integration of cost-benefit analyses, ecosystem service valuation, and policy evaluation frameworks is essential for marine conservation planning (Bateman et al., 2011; Das Gupta & Shaw, 2015). This study builds on these frameworks by incorporating valuation techniques into the socio-economic risk assessment of coastal communities.

The overexploitation of marine inshore resources leads to the loss of potential resource rents. In the long term, effective management aimed at capturing these resource rents can foster economic growth. Furthermore, the fishing community's population has grown significantly, and the adoption of newer technologies has led to biological and economic overfishing, lower per capita production, and a greater emphasis on the need for effective fisheries management that is fundamentally focused on sustainable development and distributive justice. As is common with free access resources that are more commercialized, drastically decreased. According to the economics of various craft-gear combinations and the per capita incomes of fishing labor, at least 60% of the population in the coastal rural sector lives below the poverty line. Therefore, a comprehensive fisheries management plan must be developed that takes into account the conservation elements of fisheries resources and safeguards the interests of many stakeholders, such as fishermen, traders, and consumers.

3. Methodology

The topic of sustainable fishing resource management has been the focus of our investigation. Since excessive resource usage cannot last for very long, the term "sustainable" was initially employed about human resource use. When defining equality in ecology for the World Conservation Strategy (IUCN, 1980), the International Union for the Conservation of Nature (IUCN) coined the term "sustainable development" (SD). Nonetheless, the Brundtland Commission report, which presented intergenerational and intragenerational justice, popularized the SD concept in 1987. According to WECD (1987), SD is development that satisfies current needs without jeopardizing the capacity of future generations to satisfy their own. Since then, SD has been a crucial factor in the formulation of policy. The sustainability paradigm is depicted in the following figure. Both ecological and economic sustainability must be guaranteed in order to manage fisheries resources sustainably. While economic sustainability may have varied motivations, ecological sustainability refers to the preservation of biodiversity via the appreciation of fisheries resources. When it comes to economic sustainability, a fair assessment of fisheries resources can empower the local population by discouraging overfishing. It can assist people in choosing different work options. The following is the study's conceptual framework (Burke et al., 2020). The study relies on primary data collected via structured surveys from 480 households across four fishing communities in the Gulf of Mannar. A stratified random sampling method was used to capture heterogeneity across income, occupational type, and geographical exposure. Sensitivity, adaptive capacity, and exposure variables were quantified using normalized indices derived from socio-economic indicators (e.g., income diversity, housing type, ecosystem dependence). Ordered logistic regression models were employed to assess predictors of risk perception, while multiple linear regression was applied to analyse determinants of adaptive capacity. All models were implemented in STATA 16, and variance inflation factors (VIF) were used to test for multicollinearity. Figure 2 highlights how sustainable fishing outcomes depend not just on biological parameters but also on economic tools such as valuation and rights-based access, which guide our model development.

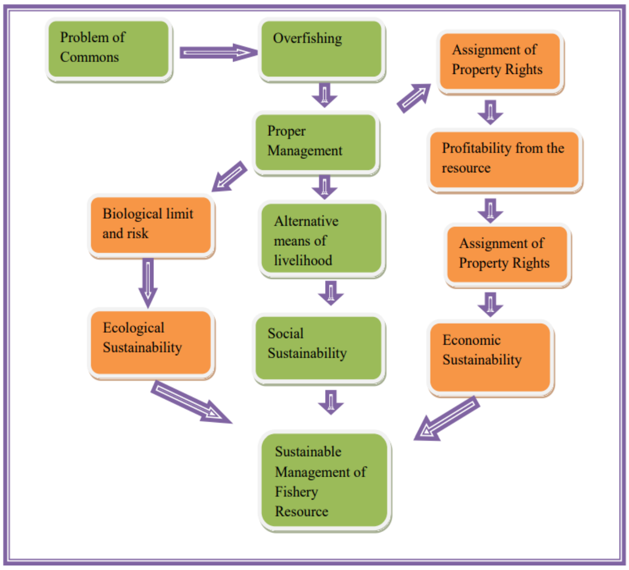

Fig. 2: Sustainability Framework Linking Fisheries Management with Livelihood Outcomes

This figure presents the interrelationship between ecological and economic sustainability, resource valuation, property rights, and livelihood enhancement through conservation. From the fundamental equation of fisheries, we have captured the balance between the net benefit of fisheries with that of the discount rate. This discount rate reflects the opportunity cost of fishing, which has an important bearing on the livelihood of the stakeholders. Livelihood is also linked with the valuation of the resource in the present study. Hence, the broad theme of sustainable livelihood is captured throughout the thesis. Such an interpretation of sustainability implies throughout the analysis. We are also careful in assigning property rights to the owners of the fishery. The methodology deals with the use of dynamic optimization techniques, contingent valuation exercises, and production analysis for analyzing our empirical results. Regression estimation has also been done for both time series data (quarter division) and cross-sectional data (logit analysis). Details about data are mentioned in general terms in this chapter and subsequent chapters as needed (Shiiba, 2022; Jalood, 2022).

4. System Design

However, such resources may effectively become nonrenewable and eventually go extinct if the rate of removal exceeds the rate at which biological processes can replace them. First, there were no restrictions on fishing, and the main problem for fishermen was the seasonal variations in the availability of various species, as well as the short- and long-term natural fluctuations in fish migration, species composition, weather, and climate. However, the freedom of individual fishermen to conduct their business has been increasingly restricted in several fisheries worldwide, especially throughout the 20th century. As seen in Figure 3, small decreases in intrinsic growth rate significantly reduce NPV under the logistic model, emphasizing how overexploitation impacts economic returns.

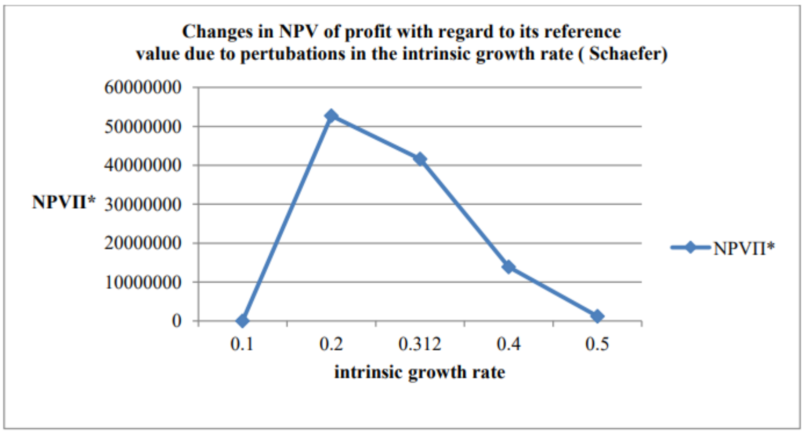

Fig. 3: Net Present Value Sensitivity to Growth Rate under Logistic Specification (Model A)

This figure shows the decline in profit (NPV) when the intrinsic biological growth rate falls below optimal levels under the logistic growth model. According to bioeconomic theory, the biological dynamics of the stock and the industry's economics—that is, the expenses of harvesting and the product's market price—determine the socially optimal level of effort and harvest for a commercial fishery. Estimating the ideal values of variables like stock, yield, and effort under many alternative regimes is our main goal. A cost-benefit analysis framework was applied to estimate the net economic value of MPAs. The average capital cost of establishing basic protective infrastructure and community engagement programs was estimated at ₹2.5 crore per MPA region annually. On the benefit side, reductions in average financial loss from seawater intrusion and storm damage translate to ₹12 crore in avoided losses per year, based on combined fisheries and tourism losses reported in Figures 3–8. When discounted over 10 years using a 5% discount rate, the Net Present Value (NPV) of marine conservation efforts exceeds ₹70 crore, confirming positive returns from MPA investment. Opportunity costs, such as foregone fishing in restricted zones, are estimated at ₹0.6 crore/year, which are outweighed by long-term resilience and ecosystem service gains.

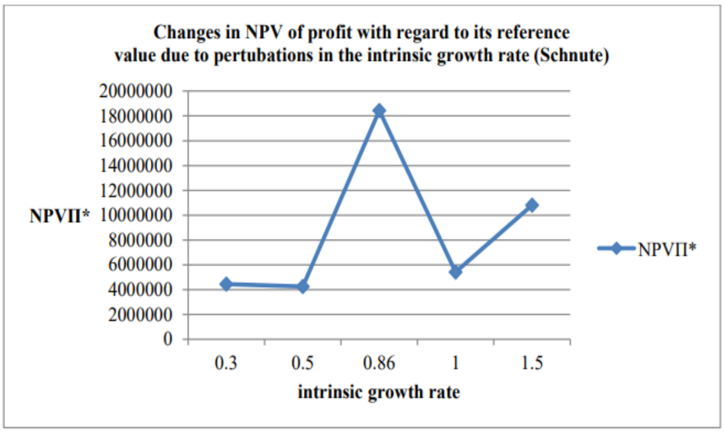

Fig. 4: NPV Response to Growth Rate Perturbations under Gompertz-Based CY&P Model

Compared to the logistic model, the CY&P specification shows more stable returns under similar perturbations, reflecting greater resilience to biological shocks. In contrast, Figure 4 shows that the CY&P model provides more stable NPV outcomes, indicating a preferable approach for long-term conservation planning under uncertainty. Harvest continues until it reaches the breakeven point, which is the effort level at which total revenues barely cover total costs, with no restrictions on admission or effort. The open-access equilibrium (OAE) is the name given to this equilibrium. However, due to the high level of effort, this unregulated equilibrium is socially inefficient (sub-optimal). Generally speaking, open access harvesting produces less harvest than the maximum sustainable yield (MSY). In addition, it is typically less expensive to land a catch of the same caliber. Because the maximum economic yield (MEY) equals the marginal revenue of an extra unit of effort (such as the addition of another trap or the entry of another vessel) with its marginal cost, it is the best option from the perspective of society. However, the management goal will determine the equilibrium solution for a particular fishery that considers the OAE, MSY, or MEY.

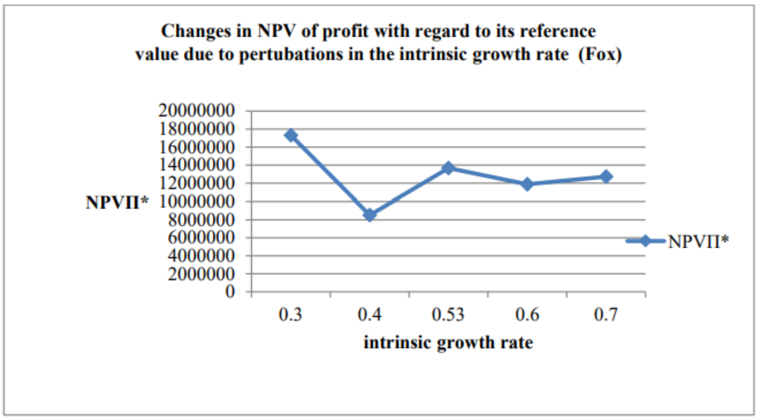

Fig. 5: NPV Comparison Across Three Harvesting Regimes: Open Access, MEY, and MSY

The figure demonstrates that Maximum Economic Yield (MEY) consistently results in the highest NPV, supporting its adoption as the optimal policy target. As shown in Figure 5, the MEY regime generates the highest long-term profits compared to Open Access or MSY, making a strong economic case for managed conservation zones. The Economic theory of fisheries requires special attention because the growth and decline of the fish population has been the subject of interest dating back through the ages. For this, we have classified our analysis into three different regimes such as the maximum sustainable, which refers to the biologically ideal regime; the open access; and the profit-maximising regime, which is the actual regime.

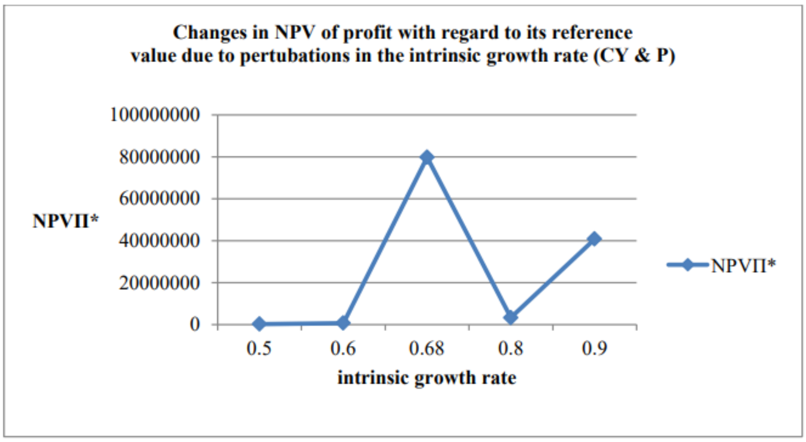

Fig. 6: Comparative NPV Variability under CY&P and Logistic Growth Models

Figure 6 reinforces the earlier findings by showing that the CY&P model maintains more consistent NPV values, which is critical for risk-sensitive marine policy evaluation. This figure illustrates the smoother NPV curve of the CY&P model, suggesting better predictive stability for policy planning. The parameters under logistic specification have been obtained by a simple algebraic method, whereas the parameters of Gompertz specification have been solved by an iterative method.

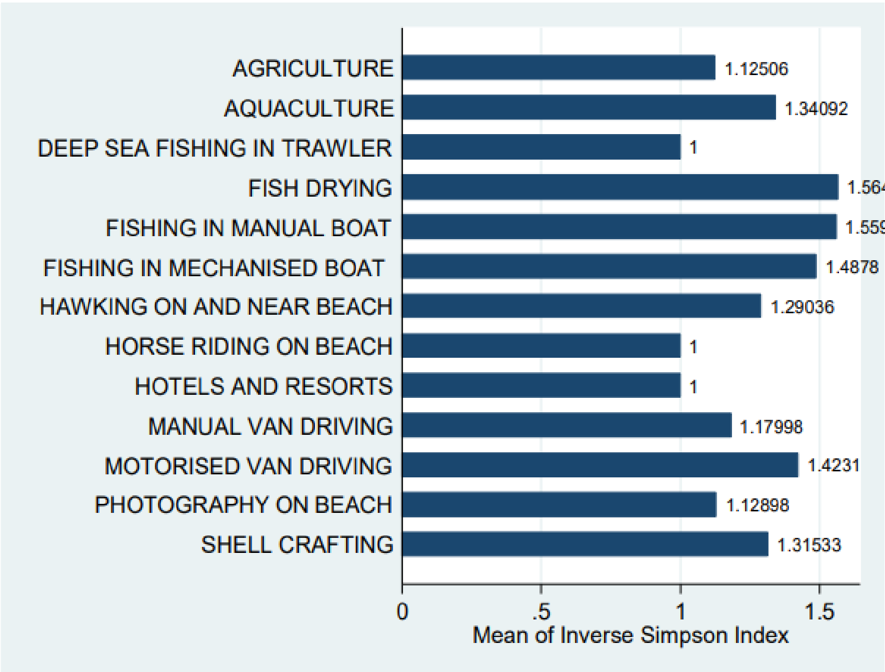

Fig. 7: Inverse Simpson Index for Individual Income Diversification

Figure 7 reveals that households with higher income diversification scores are better protected from fishery-related shocks, justifying livelihood diversification as a complementary conservation strategy. This metric captures the degree to which households engage in multiple income streams, which is a key determinant of their resilience to fisheries shocks. Comparing different models, it is observed that maximum effort is required under an open access regime where property right is not defined, but under open access, harvest is low compared to other regimes.

5. Conclusions

Marine fishery resources are renewable, but proper management of the harvest of this resource is necessary for the sustained growth of in future. In this study, alternative bioeconomic models have been presented that consider the levels of stock, effort, and yield under three alternative regimes. The suitability of four models with significantly differing biological production linkages for fishing in West Bengal is evaluated. The majority of bioeconomic studies in the standard literature on fisheries use biological parameters that have been computed using the Schaefer and Schnute models. This is because models that use the Gompertz curve, such as the Fox model and the CY& P model, seem to be less accepted than logistic models, which have a substantial body of theoretical literature demonstrating their application to fishery science. The CY & P model in our analysis fits the data best, followed by the Fox model. For studying the sustainability of West Bengal fishery, we have focused on the models with logistic specification as well as Gompertz specification. All the models have satisfied the basic relationship between different ecological and economic parameters. To better align with economic policy frameworks, this study discusses the potential use of market-based instruments such as environmental taxes on overfishing, subsidies for sustainable marine practices, and payment for ecosystem services (PES) schemes to incentivize conservation. Furthermore, the economic implications of marine protected areas can be integrated into environmental and natural capital accounting, enabling policymakers to embed ecological assets into national accounts. These instruments also support cost-accounting frameworks for assessing the fiscal sustainability of marine governance under the emerging Blue Economy strategy.

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