4.3 Maximum economic and sustainable yields in perennial reservoir fisheries of Sri Lanka: insights into stocking practices and fishing intensity for multi-species management

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Abstract

This study explores the maximum economic and sustainable yields in perennial reservoir fisheries in Sri Lanka, focusing on the multi-species management of carp, tilapia and FWP stocks. By analysing data from 18 irrigation reservoirs where CBF are conducted, we examine the relationships between fishing intensity, stocking density and economic outcomes. Our findings indicate that fishing intensity and stocking practices significantly influence fish yields and economic returns. The relationship between fishing effort and yield for carp species follows a second-order curve, suggesting optimal fishing pressures for carp species. For carp, the maximum sustainable yield was found at 226 kg ha^{-1} yr^{-1} at an optimal fishing intensity of 55 boats ha^{-1} yr^{-1}, having a maximum economic return (MER) of LKR16,000 ha^{-1} yr^{-1} for LKR2,600 ha^{-1} yr^{-1}. However, the FWP fishery did not show a significant relationship between fishing effort and yield, likely due to the incidental nature of prawn harvesting. The study reveals that tilapia's self-recruiting ability results in lower stocking costs and higher profitability compared to carp. By analysing the cost-effort and cost-stocking relationships, we highlight the importance of strategic investment in stocking and fishing practices to maximise returns without overcapitalisation. This study contributes valuable insights into the sustainable management of multi-species reservoir fisheries, emphasising the need for species-specific approaches to optimise both economic and ecological outcomes. Future research should further refine these models and incorporate socioeconomic factors for more adaptive and efficient management strategies.

Keywords: *maximum economical return, inland fisheries*

Introduction

The concept of maximum economic yield (MEY) has emerged as a cornerstone of sustainable fisheries management, ensuring optimal utilisation of aquatic resources while maximising economic benefits. MEY refers to the level of fishing effort that generates the greatest net economic returns, balancing revenues from fish harvests against the costs of fishing. As the MEY is always lower than the maximum sustainable yield (MSY), the maximum yield that can be removed from a population over an indefinite period, this approach not only safeguards fish stocks from overexploitation but also ensures long-term economic viability, particularly for resource-dependent communities. While MEY has been extensively studied in marine fisheries, its application to reservoir fisheries, which play a critical role in global food security and livelihoods, remains relatively underexplored.

Reservoir fisheries serve as vital sources of protein, employment and income for millions of people, especially in developing countries. In tropical regions, such as Sri Lanka and other parts of Asia, these fisheries contribute significantly to rural economies and food security. However, the management of reservoir fisheries often faces challenges such as overfishing, inefficient allocation of resources, and a lack of data-driven decision-making frameworks. Several studies have highlighted the importance of applying MEY principles in reservoir fisheries to address these issues effectively.

For instance, Amarasinghe and De Silva (1992) emphasised the need for optimising fishing efforts in tropical reservoirs to balance fish yield and economic returns. Their work demonstrated that sustainable exploitation could be achieved by incorporating ecological dynamics and socioeconomic factors into management strategies. Similarly, Salayo et al. (2008) stressed the economic inefficiencies arising from overcapitalisation in small-scale inland fisheries, advocating for MEY-based approaches to improve resource allocation. In a study of African reservoirs, Welcomme et al. (2010) highlighted that the implementation of MEY models not only enhanced economic returns but also contributed to ecological sustainability by reducing pressure on fish stocks.

Despite these findings, research on MEY in reservoir fisheries remains limited compared to marine systems. This gap underscores the necessity of comprehensive studies tailored to the unique characteristics of reservoirs, including their hydrological variability, fish species composition and multipurpose use. Understanding MEY in reservoir fisheries is particularly important in contexts where fisheries coexist with competing demands such as irrigation, hydropower and recreation.

This study aims to address the critical need for MEY-focused research in reservoir fisheries. By integrating ecological, economic and social considerations, it seeks to provide a robust framework for optimising fishing practices in inland reservoirs. The findings are expected to contribute to sustainable fisheries management and the development of policies that ensure the long-term viability of reservoir ecosystems and the livelihoods they support.

Methodology

In the present analysis, 18 irrigation reservoirs in Sri Lanka where CBF are carried out, and where there are available data on stocking, the fishing effort and yield data are available in the logbook records of the rural fisheries societies (RFS) were selected. In all 18 reservoirs, fishing craft is non-mechanised fibre-reinforced plastic outrigger canoes generally manned by 2 fishers. Fishing gear is gillnet of stretched mesh size ranging from 11.4–35.6 cm. In each canoe, on average, 6 gillnet pieces are carried by fishers to lay in the reservoir from late afternoon to early morning on the following day. Fishers in each boat are engaged in fishing approximately 300 days per year. Accordingly, fishing effort is expressed in the present analysis as the number of boats per year (that is, mean number of boats per day × 300 fishing days). Fish yields of 3 species categories (that is, cichlids, carps and FWP) were determined separately and expressed as kg ha^{-1} yr^{-1}, and annual stocking densities (SD) were expressed as a number of fingerlings for finfish and a number of post larvae per ha for FWP. Here, reservoir extents at full supply level (FSL) were obtained from the Irrigation Department. Depending on the information available from the logbooks of RFS in each reservoir, market prices of the 3 categories were recorded, and the value of fish yield (VFY) was estimated for each category. Also, based on the costs of fishing crafts and gear available in the fisheries databases, and nominal values of daily labour costs in rural areas of the country, the cost of fishing effort per ha (CFI) in each reservoir was computed. Similarly, based on the cost of fingerlings, and labour and transport costs, SD of each of the 3 categories of fish and FWP, costs of stocking (CSD) were computed for the 3 species categories separately.

Data for most reservoirs was available for the period 2021–2024, and the following relationships were determined between values of CBF yield of the 3 categories with costs of fishing effort per ha (that is, cost of fishing intensity), and costs of stocking per ha.

$VFY = a\ CFI - b\ CFI^2$ (1)

$VFY = c\ CSD - d\ CSD^2$ (2)

From the plots of CFI against VFP, and CSD against VFY, the following parameters were determined.

Model 1 above: MEY and FI_{MEY}

Model 2 above: FY_{opt} and SD_{opt}

Results and discussion

The relationship between carp yield (kg ha^{-1} yr^{-1}) and fishing intensity in the reservoirs exhibited a significant correlation, as illustrated in Figure 4.3.1 and Table 4.3.1. This relationship followed a second-order curve, indicating that the fisheries in these reservoirs are subject to optimal fishing pressure for carp species. The MSY for carp species is estimated to be 226 kg ha^{-1} yr^{-1} at the optimal fishing intensity (FI_{MSY}) of 55 boat-days ha^{-1} yr^{-1}.

The relationship between tilapia yield in these reservoirs and fishing intensity also followed a linear relationship (Figure 4.3.2), which was statistically significant at $p<0.05$ (Table 4.3.1). These findings suggest that the tilapia fishery in these reservoirs is operating under suboptimal fishing pressure.

However, the relationship between FWP yield and fishing effort did not exhibit statistical significance ($p>0.05$). This may be attributed to the nature of the fishery in these reservoirs, where freshwater prawns are harvested as bycatch due to the absence of species-specific fishing gear.

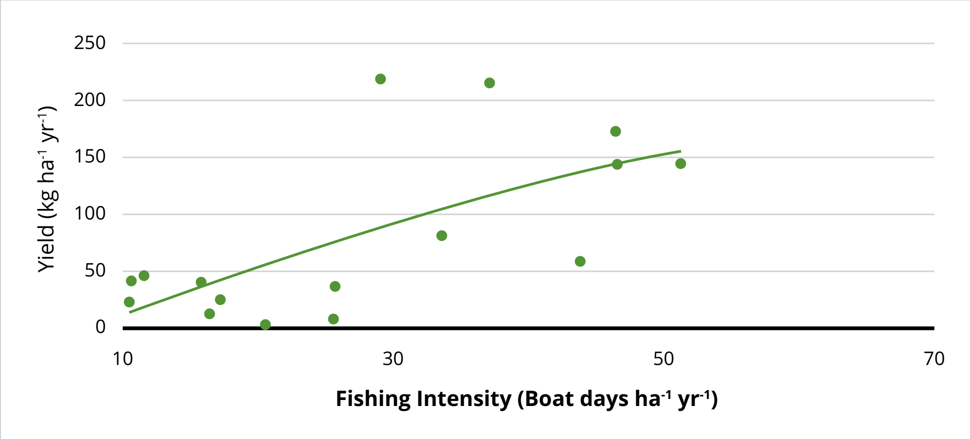

Figure 4.3.1: Relationship of fish yield and mean annual fishing intensity for carp species

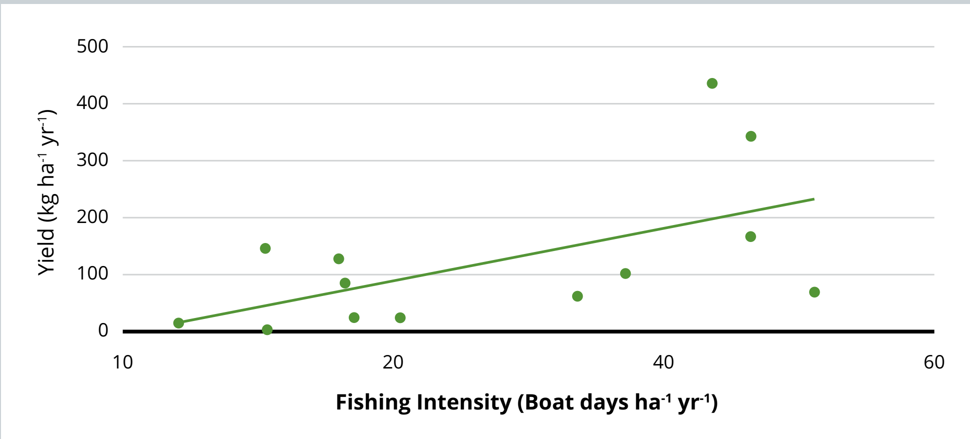

Figure 4.3.2: Relationship of fish yield and fishing intensity for tilapia species

Table 4.3.1: The statistical relationship between total yield (FY; kg ha^{-1} yr^{-1}) and fishing intensity (FI; boats ha^{-1} yr^{-1}) for different species (r = correlation coefficient; all relationships were significant at 0.05 level)

Species	Relationship	r
Carp species	$FY = -0.0234FI^2 + 4.9332FI - 33.48$	0.67
Tilapia species	$FY = 4.536x-0.4673$	0.57

The relationship between yield and fishing intensity for FWP was found to be statistically insignificant.

Figure 4.3.3 illustrates a quadratic relationship between revenue and cost of fishing intensity for carp species. However, for FWP, the relationship between revenue and cost of fishing intensity (Figure 4.3.4) indicates that the profit has not yet reached a plateau level.

The MER for the carp species was observed at approximately LKR16,000 $ha^{-1} yr^{-1}$, with a corresponding cost of fishing intensity of LKR2,600 $ha^{-1} yr^{-1}$. The relationship between the stocking rate and carp yields also exhibited a quadratic relationship (Figure 4.3.5) having an optimal stocking density of around 2,500 fingerlings per ha.

The yield of carp species demonstrates a significant relationship with stocking density (fingerlings ha^{-1} $year^{-1}$) (Figure 4.3.6). However, tilapia and FWP yield did not show a significant relationship with stocking density.

The relationship between value generated from carp species and the cost of stocking exhibited a second-order relationship. The MEY, recorded as approximately 24,000 units, was achieved at a corresponding stocking cost of 6,000 units (Figure 4.3.7).

Figure 4.3.7 illustrates that the MER obtained from tilapia species was LKR58,000 $ha^{-1} yr^{-1}$, with a corresponding stocking cost of about LKR1,000 $ha^{-1} yr^{-1}$. These results indicate that the cost of stocking tilapia fingerlings per ha of the reservoir is lower compared to the stocking cost of carp fingerlings. However, the revenue generated from tilapia was higher than that from carp. This difference can be attributed to the self-recruiting ability of tilapia, which enables them to

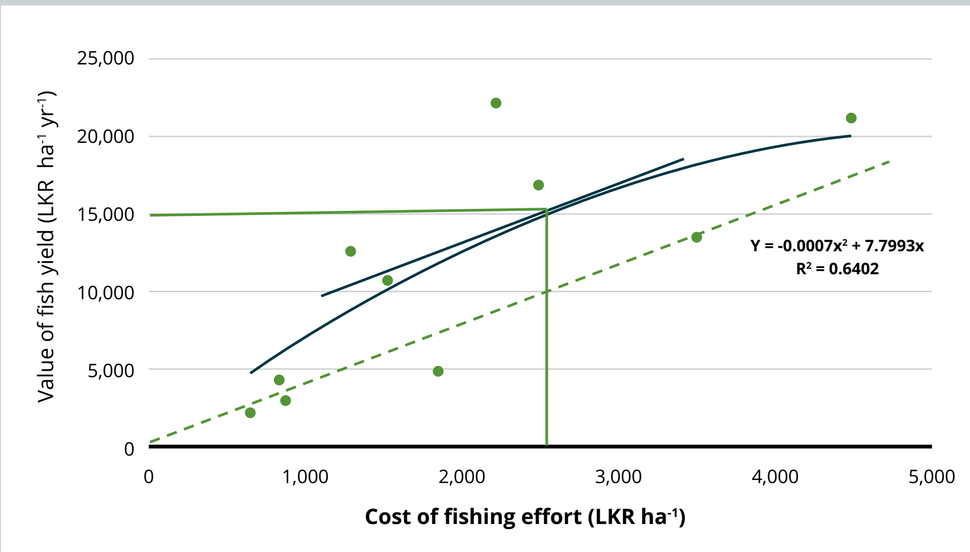

Figure 4.3.3: Relationship between value of fish yield LKR ha^{-1} yr^{-1} to cost of fishing effort for the carp species

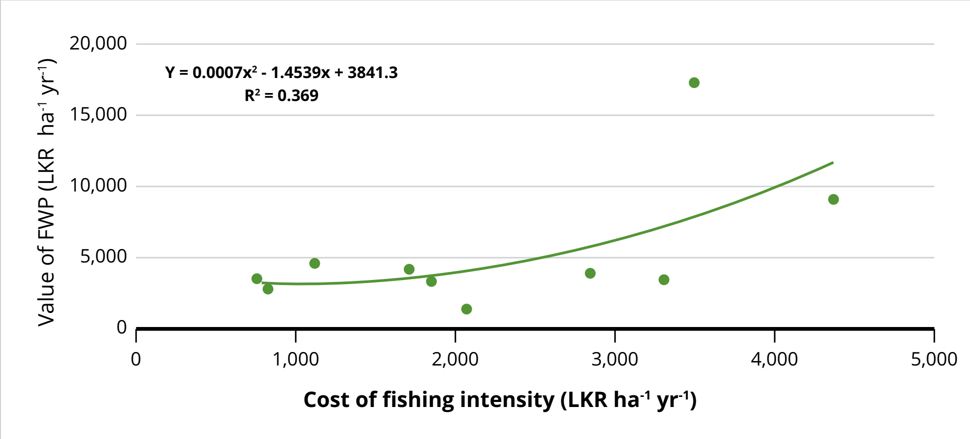

Figure 4.3.4: Relationship between value of fish yield to cost of fishing intensity for the FWP (*M. rosenbergii*)

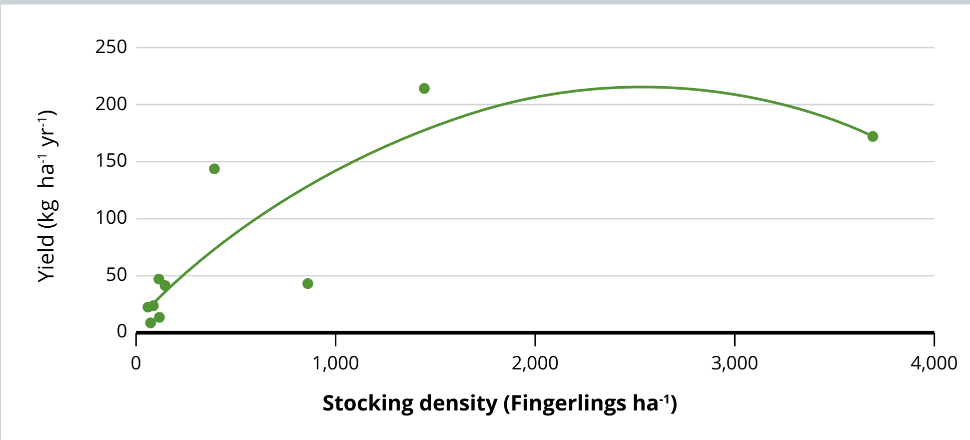

Figure 4.3.5: Relationship of carp yield (kg ha^{-1} yr^{-1}) to stocking density (fingerlings ha^{-1})

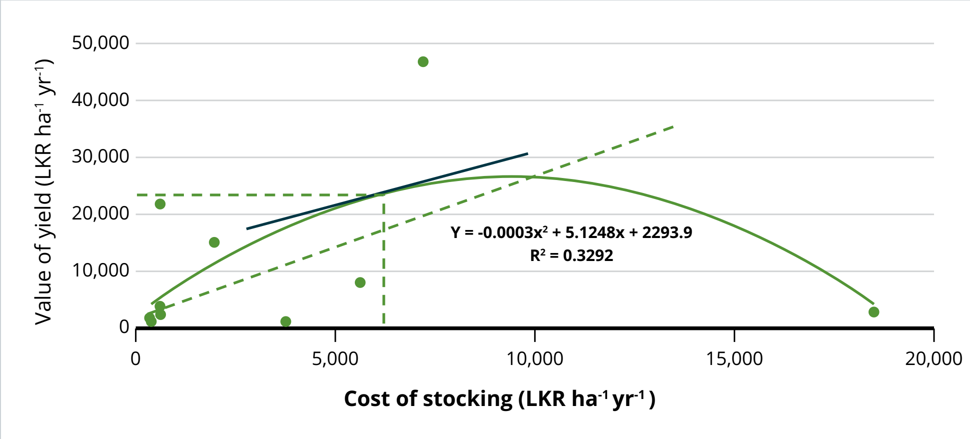

Figure 4.3.6: Relationship between value of carp species and cost of stocking

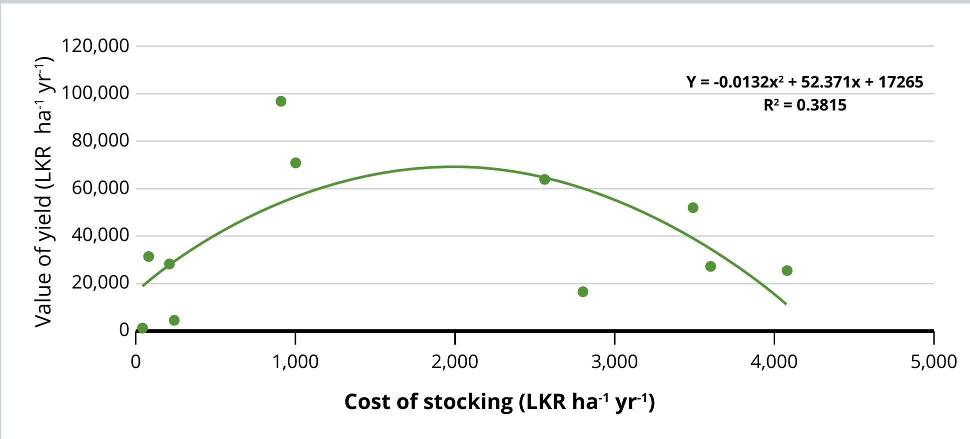

Figure 4.3.7: Relationship between value of yield and cost of stocking for tilapia species

naturally replenish their population without additional stocking of fingerlings. This self-sustaining population growth likely contributed to the higher income observed for tilapia.

The results of the bubble plot (Figure 4.3.8) indicate that in carp fisheries, high efficiency can be achieved at moderate levels of stocking and fishing intensity. This finding suggests the existence of an optimal range of investment in stocking and operational fishing intensity that maximises returns while avoiding excessive costs.

The bubble plot of the relationship between cost of fishing stocking and cost of fishing intensity for tilapia species (Figure 4.3.9) reveals substantial profits even at relatively low stocking costs and low-to-moderate effort levels. These scenarios suggest that efficient management practices or the self-recruiting nature of tilapia contribute to higher profitability with reduced financial input. Conversely, at high stocking and effort costs, the observed profit is comparatively low. This outcome indicates that excessive investment in stocking and operational efforts does not necessarily result in proportional returns, potentially due to factors such as overstocking, resource competition or operational inefficiencies.

The findings of this study provide significant insights into the relationship between fishing intensity, SD and yield for various species in reservoir CBF, with implications for sustainable fishery management. The results highlight the importance of optimising fishing pressure and stocking practices to achieve maximum economic and sustainable yields.

The second-order relationship observed between fishing intensity and yield for both carp and tilapia species (Figure 4.3.1 and Figure 4.3.2) suggests that these fisheries are subject to optimal fishing pressure. The MSY for carp species was estimated at 226.52 kg ha^{-1} yr^{-1} at a fishing intensity of 105.41 boat-days ha^{-1} yr^{-1}. These results align with the findings of Amarasinghe and De Silva (1992), who emphasised the importance of optimising fishing efforts to balance yield and sustainability in tropical reservoirs. Similarly, the significant second-order relationship for tilapia yield reinforces the conclusions of Welcomme et al. (2010), who reported that optimal fishing pressure enhances both economic and ecological outcomes in inland fisheries.

In contrast, the statistically insignificant relationship between FWP yield and fishing intensity may be attributed to the bycatch nature of the fishery, as species-specific fishing gear is not employed. This finding is consistent with the observations of Cowx (1999), who noted that the absence of targeted harvesting methods could lead to poor relationship between fishing effort and yield in multi-species fisheries.

The analysis of revenue and cost-effort relationships (Figure 4.3.3 and Figure 4.3.4) further underscores the importance of efficient resource allocation. The MER for carp was achieved at approximately 16,000 units with a cost of effort of LKR5,000 ha^{-1} yr^{-1}, while for tilapia, the MEY was LKR43,000 ha^{-1} yr^{-1} with a cost of effort of LKR2,600 ha^{-1} yr^{-1}. These results indicate that tilapia fisheries are more economically efficient than carp fisheries, possibly due to their self-recruiting ability. It is a fact that tilapia's capacity for natural population replenishment reduces reliance on stocking, thereby lowering operational costs and increasing profitability.

The significant relationship between carp yield and SD (Figure 4.3.5) further demonstrates the critical role of stocking practices in enhancing fishery performance. The MEY for carp

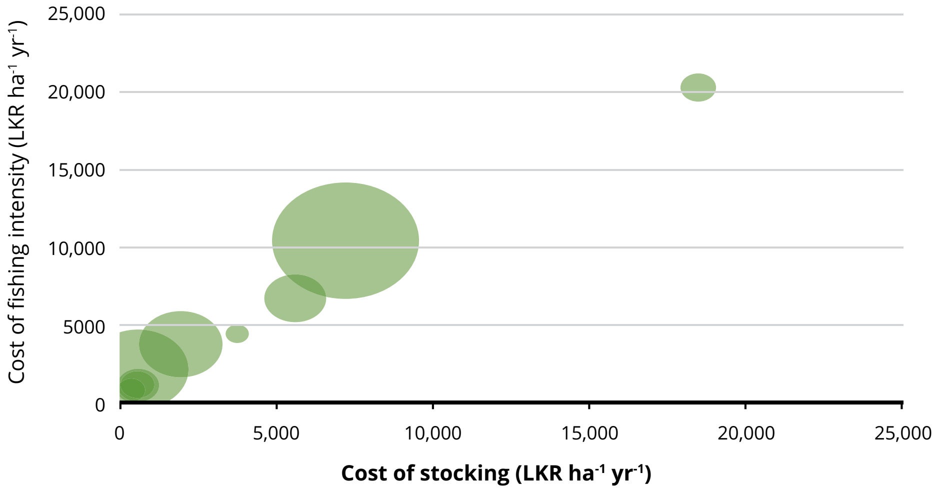

Figure 4.3.8: The relationship between cost of fishing stocking and cost of fishing intensity for carp species

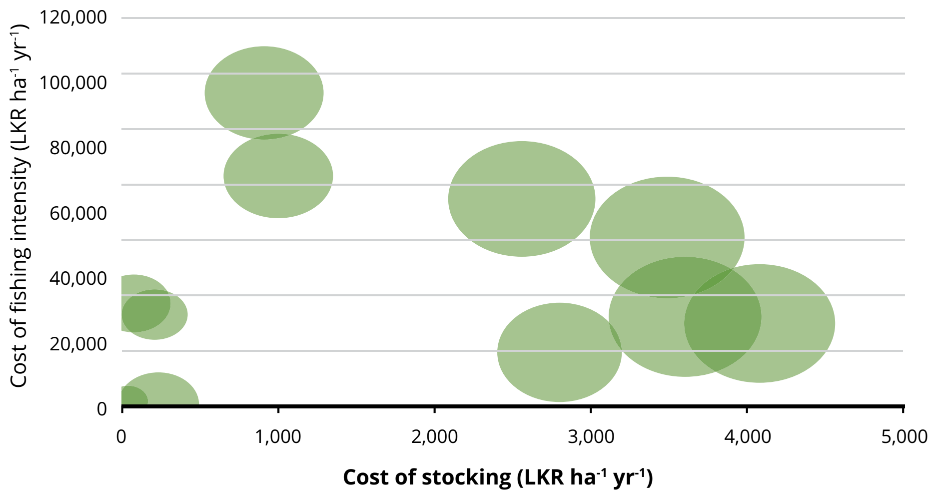

Figure 4.3.9: The relationship between cost of fishing stocking and cost of fishing intensity for tilapia species

was observed at a stocking cost of LKR6,000 ha^{-1} yr^{-1}, corresponding to a revenue of LKR24,000 ha^{-1} yr^{-1} (Figure 4.3.6). This result corroborates the findings of De Silva et al. (2006), who reported that strategic stocking enhances carp yield in reservoirs. Conversely, the lack of a significant relationship between SD and yield for tilapia and FWP can be attributed to the self-recruiting nature of tilapia and the incidental nature of FWP harvesting (De Silva 2010).

Interestingly, the cost-profit relationships illustrated in Figure 4.3.8 and Figure 4.3.9 reveal that high efficiency in carp fisheries can be achieved at moderate levels of stocking and fishing effort. This observation suggests that overinvestment in stocking and operational activities may lead to diminishing returns, consistent with the conclusions of Lorenzen (2008) regarding the risk of overcapitalisation in inland fisheries. For tilapia, substantial profits were achieved even at low stocking costs and effort levels, further highlighting the species' efficiency and resilience in reservoir ecosystems.

The bubble plots also indicate that excessive stocking and effort costs in both fisheries do not result in proportional returns. Factors such as resource competition, environmental carrying capacity and operational inefficiencies may contribute to this outcome. These findings emphasise the need for adaptive management strategies that account for species-specific dynamics, environmental conditions and socioeconomic factors.

Overall, this study demonstrates that both carp and tilapia fisheries in these reservoirs operate near optimal levels under current practices, while the FWP fishery shows potential for improvement. The application of MEY principles can enhance economic efficiency and sustainability in these systems. Future research should focus on improving gear specificity, refining stocking strategies and integrating socioeconomic considerations to optimise the performance of multi-species reservoir fisheries.

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