4.1 Bioeconomic considerations of culture-based fisheries in Sri Lankan reservoirs

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Abstract

The project highlights a number of key findings that can be applied to enhance the profitability and sustainability of Sri Lankan culture-based fisheries (CBF). The 2 main decision variables for the management of these fisheries are fishing intensity and stocking density. Strict government regulations are providing a strong institutional environment to allow effective management of fishing intensity (a rare thing for CBF globally) which is leading to the profitability of these enterprises. With these regulations in place, fishing intensity is largely managed by the number of fishing licences issued by reservoir fishing organisations (RFOs). Our research suggests that reservoirs are generally profitable if fishing intensity is restricted to less than 0.13 boats/ha/day (46 boats/ha/year). When holding fishing intensity under this level, the main lever for managing the profitability of the fishery is then stocking density.

Currently, the management of stocking densities in CBF of Sri Lanka is ad hoc. Ideally, the coordination of stocking programs would be led by a collective of leaders from reservoir fisheries organisations, supported by the National Aquaculture Development Authority (NAQDA), and would include transparent reservoir-specific decisions on stocking densities of various species based on the size of the reservoir.

Generally, major reservoirs are more profitable that medium or minor reservoirs due to economies of scale. Stocking in major reservoirs is often not needed, whereas medium reservoirs are profitable with a stocking density of greater than 3,000 post larvae (PL)/ha/year, and with higher stocking densities of between 5,000 and 15,000 PL/ha/year for minor reservoirs.

When considering individual fish species, inefficiency in the production of tilapia and carp is mainly due to inefficiencies in stocking density, whereas inefficiencies in the production of giant freshwater prawn (GFP) is due to inefficient fishing techniques.

A change of harvest technology rather than stocking densities is recommended for GFP. Stocking of tilapia in major reservoirs is often not needed, but stocking densities above 1,000 PL/ha/year for medium and minor reservoirs is recommended. There is significant scope for profit improvements with increased intensification of carp. We recommend stocking densities for carp above approximately 300, 600 and 1,000 PL/ha/year for major, medium and minor reservoirs, respectively.

Keywords*: bioeconomics, inland fisheries, culture-based fisheries, value chain*

Introduction

Sri Lanka is home to numerous reservoirs constructed primarily for the purpose of irrigation, hydroelectricity generation and drinking. It is possible that the country can boast the highest density of irrigation works globally (De Silva 1988). Irrigation authorities in Sri Lanka classify these reservoirs for the purposes of agrarian and fishery-related purposes as large (>800 ha), medium (200–800 ha) and minor (<200 ha).

These reservoirs provide significant livelihoods for local communities, including small-scale agriculture (especially irrigation of paddy rice farming), fishing, and associated services such as agricultural marketing and transportation linked to farming and fishing activities. The extensive network of reservoirs facilitates year-round agriculture and fisheries production, contributing significantly to food security and livelihoods for local communities (Krishnamurthy et al. 2023).

These reservoirs support populations of native and exotic fish and freshwater prawns. Many small indigenous cyprinid species are abundant, but remain largely unexploited due to poor consumer preference (Kumara et al. 2009). Two exotic cichlid species dominate: *Oreochromis mossambicus* and *O. niloticus* (commonly known as Mozambique tilapia and Nile tilapia, respectively). The productivity of some reservoirs has been enhanced with the application of CBF, where local fishing communities partner with the NAQDA of Sri Lanka to produce PL (prawn PL and finfish fry PL), and the stocking of these PL into the reservoirs. The main stocked species include tilapia, Indian major carps (also known as *Cirrhinus mrigala*, Catla catla, and *Labeo rohita*) and GFP (*M. rosenbergiim*). Unlike finfish, GFP are largely not consumed locally but sold to high-end restaurants and hotels in Sri Lanka and overseas. GFP are a high-value species, with reservoir sale prices double that of finfish, and up to 20 times more in consumer markets (Paranamana et al. 2025).

Given the heavy dependence of local communities on these reservoirs, the efficient and sustainable use of biological resources to create products and services is critical for livelihood development. Bioeconomic analysis is a key objective of ACIAR project 'Improved productivity, efficiency and sustainability of the CBF for finfish and GFP in Sri Lankan reservoirs' (FIS/2018/157). Specifically, the aim of the bioeconomic analysis is to assess the economic performance of reservoir fisheries and the identification of changes in management practices that could increase their economic value for local communities. The purpose of this paper is to summarise the project's bioeconomic findings, comparing these findings to that of other countries and fisheries, and identifying how these project findings can be applied for the enhancement of Sri Lankan CBF. The summary of project findings is taken from Digamadulla et al. (2025) and Adikari et al. (2025).

Project findings

Requirement of a unique CBF approach

CBF are a unique type of fish production system. They differ from capture fisheries, aquaculture and stock-enhanced fisheries, and as such the main decision variables that affect the profitability of production of CBF differ from those of other fish production systems. Capture fisheries are fish production systems where fish are caught directly from the natural environment. The main decision variable for capture fisheries is fishing effort – the total amount of fishing activity over a given period of time. CBF differs from capture fisheries as they include fish stocking as a mechanism to enhance fish catch.

Aquaculture involves breeding, rearing and harvesting of fish in a closed environment. The main decision variables for aquaculture include the time between releasing and harvesting fish, the quality of the water and the type and amount of feed used. CBF differs from aquaculture as it does not include the harvesting of all fish stocks. Rather harvests are limited with some natural recruitment.

Lastly, stock-enhanced fisheries involve supplementing wild fish populations with hatchery-raised PL. The main decision variables for this type of fishery include stocking density and fishing effort. CBF differs from stock-enhanced fisheries as cultured PL are released into an intensified closed fishery system, not into the wild. An adaption of traditional fisheries management is required for CBF. The main decision variables for CBF are stocking density and fishing intensity (fishing effort per unit area).

Regulations on fishing intensity

While the main decision variables for a CBF are stocking density and fishing intensity, the scope for adjusting fishing intensity is limited in Sri Lanka CBF due to strict government regulations. These regulatory instruments include the Fisheries and Aquatic Resources Act, No. 2 of 1996, the National Aquaculture Development Authority of Sri Lanka Act, No. 53 of 1998, and its amendment, the National Aquaculture Development Authority of Sri Lanka (Amendment) Act, No. 23 of 2006. The regulations placed on fishing intensity by these instruments include:

- **a.** that gillnet mesh size be not less than 8.5 cm
- **b.** the prohibition of fishing without a licence
- **c.** the ban on mechanised fishing vessels
- **d.** the ban on the use of any kind of encircling net
- **e.** the ban on the use of monofilament nets and trammel nets.

Fishing intensity is largely influenced by the number of fishing licences issued by fisheries authorities to RFOs, who carefully control licence numbers.

Stocking strategies

Stocking strategies of CBF in Sri Lanka are largely ad hoc. Recent government policies have emphasised and encouraged RFOs to be independent and self-sustaining, not reliant on NAQDA for fish stocking. But as yet a national and coordinated approach to fish stocking has not been implemented. RFOs determine stocking density. NAQDA supports RFOs that express demand for high stocking densities; however, the level of support provided by NAQDA is dependent on the availability of PL, and the availability of funds. The choice of stocking density is arbitrarily determined based on stock and funding availability, rather than on optimising profit. There is, however, a trend towards higher stocking densities in smaller reservoirs to ensure the profitability of these fisheries for relevant RFOs.

The efficiency of current stocking densities

When analysing 2019 and 2020 data for 24 Sri Lankan reservoirs of all sizes (major, medium and minor) for 3 key species (tilapia, carp and GFP), average stocking density was found to be 3,046 PL/ha/year and average production was found to be 266 kg/ha/year. Stocking density was highest for GFP at 2,109 PL/ha/year (69%) compared with carp (22%) and tilapia (9%). However, by weight, stocking density was highest for tilapia at 2.4 g/ha/year (74%) compared with carp (25%) and GFP (1%). This shows that the weight of PL when stocked is higher for tilapia and carp than GFP. Harvested production of tilapia somewhat mirrors stocking density by weight at 73% of catch (181 kg/ha/year). However, harvested production is lower than stocking densities by weight for carp (20%) and higher for GFP (7%).

Stocking efficiency (harvested production/ PL stocked/unit area) is 4 times higher for carp (0.82 g/PL stocked/ha) than tilapia and GFP. Our results suggest that further stocking or intensification of carp is likely to lead to higher stocking efficiency, production and profitability. However, further intensification of tilapia is unlikely to have the same results as the production of tilapia is high even at low or zero stocking density. In the case of GFP, production is expected to increase with increased stocking density. However, harvest efficiency is very low compared with the other specifies, indicating early mortality and inefficiency in catchability with gillnets. This suggests the focus should be on improving catchability rather than stocking densities for GFP.

The 'location effect' of fishing intensity and stocking density

On average across fish species and reservoir sizes, fishing intensity is approximately 0.13 boats/ha/day (49 boats/ha/year). As one would expect, fishing intensity decreases with reservoir area. However, there is some variation in these results, especially for reservoirs near urban areas where accessibility is higher. Moreover, reservoirs closer to hatcheries are more likely to have higher stocking densities. This 'location effect' of fishing intensity and stocking density has a significant impact of the reservoir's productivity and profitability.

Profitability of stocked species

Economic statistics for CBF in Sri Lanka are presented in Figure 4.1.1. A number of key findings can be drawn from these statistics:

- total revenue (quantity of fish caught multiplied by price) is significantly higher for tilapia than carp and GFP
- stocking costs are a small proportion of total costs for tilapia (2%) and carp (10%), but a significant proportion of total costs for GFP (62%)
- total costs are high for tilapia compared with carp and GFP
- the harvesting of all fish species is profitable, although tilapia is significantly more profitable than carp and GFP.

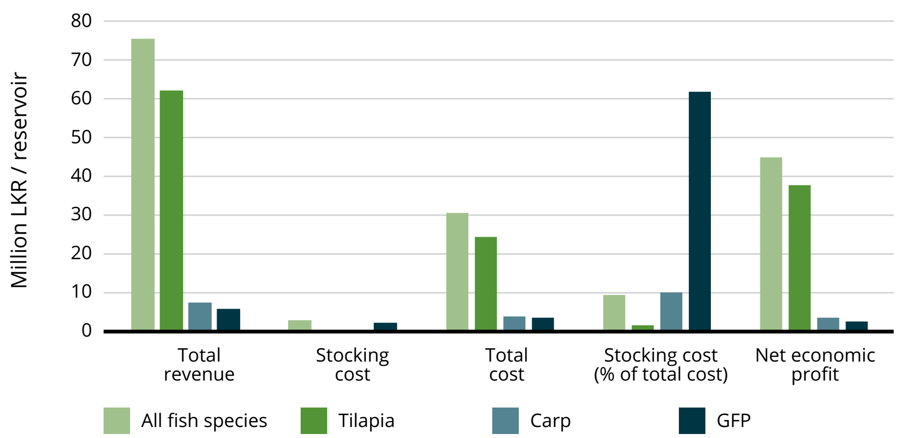

Figure 4.1.1: Economic statistics of CBF in Sri Lanka, 2019 and 2020

When considering the effect of reservoir size on profitability, generally the major reservoirs are more profitable that medium or minor reservoirs. This is due to economies of scale, where cost efficiencies are experienced by larger reservoirs.

With respect to fishing intensity, our research found that reservoirs are generally profitable if they implement a fishing intensity of less than 0.13 boats/ha/day (46 boats/ha/year). With respect to stocking density, there are differences across reservoirs of different size. CBF in larger reservoirs are generally more profitable due to economies of scale, and often stocking is not required to maintain profitability for fishers so long as fishing intensity is restricted to less than 0.13 boats/ha/day. However, stocking is required for the smaller reservoirs to maintain their profitability. Profit is maintained for medium reservoirs at about 3,000 PL/ha/year, and higher to between 5,000 and 15,000 PL/ha/year for minor reservoirs (again, so long as fishing intensity is restricted to below 1.25 boats/ha/day).

When considering individual species, the fishing intensity at the maximum sustainable yield is 226 kg/ha/year with a fishing intensity of 0.15 boats/ha/day (55 boats/ha/year). For tilapia, our results show a linear relationship between fishing intensity and yield so that an optimal fishing intensity could not be determined. For GFP, there is no relationship between fishing intensity and yield, suggesting that changes to stocking density or fishing intensity are not likely to affect yield until catchability is improved. While GFP are profitable in all reservoirs, low catchability is the constraining factor for GFP harvests.

With respect to stocking density, tilapia production is generally always lucrative in large reservoirs even without stocking, but profitable tilapia production requires stocking above 1,000 PL/year/ha in medium and minor fisheries due to higher fishing intensities. Stocking is required for carp to be profitable in all reservoir sizes, with thresholds of approximately 300, 600 and 1,000 PL/ha/year for major, medium and minor reservoirs, respectively. While revenue does increase with increasing stocking densities of GFP in all reservoir sizes, improving catchability through new net technology, rather than improving stocking density, should be the focus for GFP production.

Technical efficiency of Sri Lankan CBF

Our project results suggest that Sri Lankan CBF are inefficient, with scope for substantial improvement in productivity and profitability simply through the more efficient use of technology that is currently being used. Total revenue could be increased by an average of 52% through the more efficient use of current technology.

For carp and tilapia, there is a negative relationship between stocking density and profitability for technical efficiency of major reservoirs, and a positive relationship for medium and minor reservoirs. This suggests that while there is a scarcity in the availability of PL and funding for their stocking, technical efficiency is likely to be improved through higher stocking rates in medium and minor reservoirs. In the case of GFP, there is no significant relationship between improving efficiency by changing stocking density of any size of reservoir. This suggests that catchability is the main factor restricting profitability independent of stocking density.

Stakeholder perceptions

A primary survey was conducted at the end of 2020. A total of 176 stakeholders were interviewed, including fishers (95), collectors (14), seafood exporters (4), fish mongers (10), villagers (33), extension officers (8), policymakers in NAQDA (3), university academics (6) and research officers in research organisations such as the National Aquatic Resources Research and Development Agency (NARA) (3). Further consultation was conducted at the end of 2022 to gather insights from 96 stakeholders of the selected 24 Sri Lankan reservoirs. Various methods were employed in this second consultation process, including interviews, group discussions, communal gatherings, phone calls, emails and expert consultations. Results of these interview processes can be summarised in the following 5 points:

1. **Market-chain actors, especially middle persons, are perceived to be controlling price**, and undermining the independence and self-sustainability of RFOs. RFOs need to increase independence from market-chain actors in terms of the provision of loans (especially zero-interest loans), sanctions against loan defaults and the collection of fishing levies.
2. **RFOs are not able to achieve optimal stocking densities without governmental support**, but this cannot be done on an ad hoc basis or with bias, but through carefully managed stock development programs.
3. **Stakeholders strongly perceive that the stocking of reservoirs should be funded by RFOs** through levies from fishing licences, with strong pay-back measures. However, it is perceived that some government support will be needed to maintain optimal stocking densities.
4. **Despite the need for government support, the government should not be asked to pay the full cost of stocking**. There needs to be public–private partnerships between government and the RFOs. RFOs can bear a significant proportion of the cost of stocking through levy systems with some support from government.

5. **Larger reservoirs are more capable of self-funding stocking**, especially if stocking density focuses on the high-value GFP.

Comparison of culture-based fishing with other available livelihoods

Our bioeconomics research found the mean fisher income from CBF in Sri Lanka to be LKR40,000/month, although this differed significantly across locations and reservoir sizes. Paranamana (2025) conducted value chain analysis and found the mean income of fishers to be LKR46,669/month, 83% of which came from finfish and 17% from GFP. The social science work conducted by Ekanayake (2025) found the mean income of fishers to be LKR61,748/month, ranging from LKR51,327 to LKR71,786/month. He found that higher incomes were derived from major reservoirs compared with minor reservoirs, although fewer fishers derived their livelihoods from major reservoirs.

The World Bank (2021) presents summary statistics of incomes of rural workers in Sri Lanka by type of activity (Table 4.1.1). Our estimates of mean fisher income (LKR40,000–LKR61,748/month) compares favourably with other farm and non-farm activities. Fisher monthly income is higher than total monthly income of all types except non-farm public employment. CBF provide very valuable livelihoods to rural communities. This has strong potential to improve further in time, with strategic coordinated approaches to stocking density and further research into the catchability of GFP.

Comparative data from other countries and fisheries

CBF are not a new concept or practice. They are practiced in a number of different forms globally, including single ownership (as in the case of small reservoirs in Vietnam), collectively as a cooperative of small organisations (as in Bangladesh), or in large seasonal reservoirs by a number of collectives (as in Sri Lanka) (De Silva 2003). Although CBF is not a new practice, there is a paucity of research into the bioeconomics of this type of fishing system. There are numerous studies focusing on

Table 4.1.1: Monthly income of individual rural workers by activity type

		Mean monthly income (LKR)	Mean monthly income from main activity (LKR)
	Total	**31,162**	**25,252**
Non-farm (NF) activities	NF total	34,544	28,399
	NF self-employed	41,316	33,002
	NF wage	32,548	26,767
	NF public	50,209	38,609
	NF private	30,687	25,830
	NF skilled	37,492	30,610
	NF unskilled	21,958	18,724
Farm (F) activities	F total	21,630	16,919
	F self-employed	24,415	16,919
	F wage	17,909	14,705

the bioeconomics of capture fisheries and aquaculture, but very few focusing on CBF.

Pushpalatha and Chandrasoma (2009) and Pushpalatha et al. (2017) report increased production and monetary gains from the introduction of CBF in Sri Lankan reservoirs. Pushpalatha et al. (2017) notes that the profits from CBF have surpassed those of downstream paddy cultivation in some areas – the primary economic activity of these reservoirs. They also note that the stocking of GFP has led to small increase in production, but significant monetary gains due to the higher market price compared with finfish.

With respect to institutional structures for the management of CBF globally, most are open-access resources. Apart from the very small reservoirs of Vietnam, most CBF suffer from weak or non-existent institutional structures which leads in the collapse of CBF development programs. Where institutional structures are introduced, stock numbers and exploitation efficiency are often increased, but rarely yields. Pushpalatha (2001) stresses the importance of using existing organisational structures as a management tool, such as RFOs in Sri Lanka.

The lack of a strategic and self-sustaining development approach for stocking reservoirs is not unique to Sri Lanka, but is an issue across Asia. It is the most commonly recognised constraint in the development of CBF globally. Generally, the bottleneck is not the amount of fry produced but the limitations in facilities that are required to rear fry to the juvenile stage suitable for all forms of aquaculture, including CBF (De Silva 2003). China is perhaps one of few nations that has overcome this issue through good, long-term planning and considering fishery-related activities as important in any water resource development activity. Some nations are overcoming the issue of lack of seed stock by conducting fry-to-fingerling rearing in cages in large reservoirs (Bui and Nguyen 2001; Ariyaratne 2001). In addition, the increasing involvement of the private sector and non-government organisation (NGOs) in the seed stock supply in most developing countries is an encouraging sign (Pushpalatha 2001).

Applying project findings for the enhancement of Sri Lankan CBF

These findings can be applied to enhance the profitability and sustainability of Sri Lankan CBF.

Managing fishing intensity

Strict government regulations on the design and use of nets, the ban on mechanised fishing vessels and the prohibition of fishing without a licence, provides a strong institutional environment to allow effective management of fishing intensity. Such a strong institutional environment is rarely found in CBF globally and is allowing it to remain a profitable enterprise. With these regulations in place, fishing intensity is largely managed by the number of fishing licences issued by RFOs, who carefully control licence numbers. However, the current use of technology is inefficient with scope to increase productivity by more than 50% through the more efficient use of technology. This is especially true for GFP where mortality and damage is high due to the use of gillnets.

Our research suggests that reservoirs are generally profitable if they implement a fishing intensity of less than 0.13 boats/ha/day (46 boats/ha/year). If holding fishing intensity under this level, the main lever for managing the profitability of a fishery is stocking density.

Managing stocking densities for different sized reservoirs

Stocking in major reservoirs is generally not required to maintain profitability for fishers so long as fishing intensity is restricted to less than 0.13 boats/ha/day. There is more potential to increase profit in medium and minor reservoirs through targeted stocking strategies. As a rule of thumb, the profitability of medium reservoirs is optimised with stocking density of approximately 3,000 PL/ ha/year, and between 5,000 and 15,000 PL/ha/year for minor reservoirs.

Managing stocking densities for different species

With respect to tilapia, our results suggest that increasing stocking density or fishing intensity is unlikely to lead to significant production or profit increases for large reservoirs, as production of tilapia is high even at low or zero stocking density. Stocking tilapia PL above 500 PL/ha/year in medium and 1,000 PL/ha/year for minor reservoirs is generally required to optimise profits.

In the case of carp, production increases significantly with increasing stocking density and fishing intensity, indicating that further intensification of carp is likely to yield improvements of production and profitability. Stocking densities above approximately 300, 600 and 1,000 PL/ha/year for major, medium and minor reservoirs, respectively, lead to significant profitability for fishers.

When considering GFP, while there is some profitability to be gained from increased stocking density, the focus of management of GFP should be on improving catchability through a change in harvest technology, rather than increasing stocking densities.

Facilitating a strategic and coordinated program for managing stocking density

The management of stocking strategies in CBF of Sri Lanka is largely ad hoc. RFOs experience significant financial constraints to the funding of stocking programs and rely on NAQDA for providing PL. In turn, NAQDA experiences funding constraints leading to shortages in PL availability. This means that the choice of stocking density is arbitrarily determined based on PL and funding availability, as well as proximity to hatcheries, rather than on optimising profit. Some RFOs partner with private export companies for much needed private investment into seed stocking. These companies often pay fisher costs, which reduces the risk that fishers and RFOs face. However, this can lead to price controls along the chain. Recent government policies have emphasised the responsibility of RFOs to manage stocking, supported by, but not reliant on, NAQDA.

Achieving optimum stocking densities requires a coordinated approach across RFOs and supported by NAQDA and the private sector, both financially and through capacity building. It requires the consideration of fishery-related activities in water resource development activities. While we encourage the integration of information across supply chains, we value the independence of RFOs to fund stocking programs through levies for fishing licences. Ideally, the coordination of stocking programs would be led by a RFO collective of leaders, supported by NAQDA and the private sector, and would include transparent reservoir-specific decisions on stocking densities of various specifies based on the size of the reservoir. This will lead to improved availability of PL and the re-direction of juvenile stock of different species based on reservoir size. A transparent approach is likely to reduce ecological disturbances and social conflicts due to inequities. While it is likely that some government financial support is required to optimise stocking density and to coordinate stocking programs, encouraging the involvement of the private sector and NGOs in seed stock supply is likely to reduce this need for government support.

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