7.1 Science to practice in culture-based fisheries in Sri Lankan reservoirs: synthesis and lessons learned

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Abstract

Culture-based fisheries (CBF) in Sri Lankan reservoirs play a pivotal role in enhancing rural livelihoods, yet their long-term sustainability is constrained by inefficiencies in reservoir selection, stocking strategies and fisheries management. This study introduces a performance-based reservoir classification system, moving beyond conventional hydrological classifications to incorporate ecological and bathymetric parameters for optimised stocking decisions. Findings indicate that bathymetry, often overlooked in stocking models, is a key determinant of giant freshwater prawn (GFP) productivity. Results indicate that optimal stocking densities should be adjusted based on reservoir type, with a maximum of 1,000, 1,500 and 2,000 post larvae (PL) per hectare for major, medium and minor reservoirs, respectively.

Genetic integrity of broodstock emerged as a significant concern, with potential risks associated with the repeated use of reservoir-derived stocks. The study underscores the need for a national broodstock management program integrating genetic monitoring, screening and controlled breeding protocols. Additionally, findings highlight inefficiencies in fishery extension services, including suboptimal resource allocation and inadequate monitoring frameworks, necessitating a data-driven decision support system for more effective management.

The introduction of trap-based fishing methods was explored as an alternative to conventional gillnets, with potential benefits for selectivity and product quality. However, policy considerations are essential to prevent conflicts in common-property reservoirs. Public–private interventions (PPI) were identified as a key driver for CBF expansion but concerns over regulatory oversight and equitable access must be addressed. The study also highlights the vulnerabilities of CBF to climate change, advocating for climate-smart stocking protocols and hydrological modelling to enhance resilience.

By aligning Sri Lanka's CBF strategies with international best practices, these findings provide a robust framework for enhancing productivity, ecological sustainability and socioeconomic resilience in inland fisheries. Future research should focus on digital bathymetric mapping, genetic conservation efforts and adaptive management models to further refine CBF sustainability.

***Keywords**: culture-based fisheries, freshwater prawn, reservoir classification, genetic conservation, climate adaptation, fisheries management*

Introduction

CBF, particularly in Sri Lanka, form a crucial component of the rural economy, providing livelihood opportunities and contributing to food security. The management and development of these fisheries, especially those involving high-value species such as the GFP (*Macrobrachium rosenbergii*), require a holistic and integrated approach to ensure their long-term sustainability. As highlighted by Lebel et al. (2006), social-ecological systems like CBF demand a systems-based approach, one that integrates ecological, economic and social factors to address complex issues and foster sustainable development. This approach contrasts with the traditional, isolated strategies that tend to overlook the interconnections within the system.

In a systems approach, researchers and policymakers utilise interdisciplinary thinking, considering the entire system and its dynamic interactions, rather than focusing on discrete components in isolation (Eelderink et al. 2020; Stringer et al. 2006). Such an approach is critical in situations where complex social, environmental and economic challenges intersect, especially when research outcomes transition into the policymaking phase. Effective decision-making in these circumstances requires critical thinking – an analytical process of evaluating information, making informed judgements and devising solutions grounded in logic and reason (Gray et al. 2019; Jentoft 2006). This is especially pertinent for CBF, where the balance between ecological sustainability and economic profitability is delicate and must be carefully managed.

The development of CBF in Sri Lanka, specifically those involving the GFP, is essential for improving the economic wellbeing of rural fishers, who depend heavily on these fisheries for their livelihoods. The GFP, with its high export demand and economic value, has been identified as a key resource that could boost rural economies if managed effectively (Chandrasoma et al. 2015; Digamadulla et al. 2023). In this context, the Wayamba University research group has embarked on a comprehensive series of scientific studies to optimise various facets of GFP-based culture fisheries in Sri Lanka's perennial reservoirs.

Given the challenges of sustainable development in this sector, we have outlined the following specific objectives for the study:

1. **Assess stocking practices** for GFP, particularly focusing on maximising the survival rate of early-stage prawns (PL-15), to ensure the successful establishment of prawn populations in reservoirs.
2. **Investigate reservoir production** of both finfish and GFP, aiming to identify management practices that will optimise the overall production and ecological sustainability of the reservoirs while maintaining biodiversity.
3. **Develop and assess novel harvesting techniques** for GFP that enable targeted harvesting. This will focus on maximising catch per unit effort (CPUE) and ensuring the quality of the harvested product, which is crucial for maintaining the value of the species in export markets.
4. **Evaluate post-harvest practices** to optimise product quality, ensuring it meets market requirements and enhances the economic potential of the fishery. This will feed directly into policy recommendations for the National Aquaculture Development Authority (NAQDA), particularly in the areas of stocking, monitoring and harvesting practices.

The outcomes of this study are intended to inform and guide evidence-based decision-making by providing a comprehensive framework, grounded in ecological, economic and social perspectives, for optimising GFP CBF in Sri Lanka. These findings aim to support policymakers and fishery managers in enhancing the sustainability and profitability of this vital rural industry, thereby contributing to its long-term resilience and success.

Materials and methods

This study employed a multi-phase, interdisciplinary approach to assess and optimise the sustainability and productivity of GFP CBF in Sri Lanka. The methods incorporated a combination of historical data analysis, field surveys, socioeconomic evaluations and experimental trials to provide a holistic understanding of the factors influencing GFP fisheries.

Data collection and historical analysis

An initial analysis of historical data from NAQDA was conducted to identify long-term trends, patterns and relationships between stocking practices and production outcomes from 2009 to 2019. This analysis aimed to discern key factors influencing GFP production, such as stocking density, fishing intensity and seasonal variations. The dataset was examined for spatial and temporal trends using statistical models to identify potential drivers of variability in prawn yields.

Reservoir selection and spatial-temporal assessment

A total of 48 reservoirs were selected for the study using a purposive sampling method, ensuring a diverse representation of different geographical regions, water quality conditions and ecological characteristics. These reservoirs were geo-referenced to enable a detailed spatial-temporal analysis of factors affecting GFP productivity. Spatial data was collected using Global Positioning System (GPS) devices and Geographic Information Systems (GIS) software to map reservoir locations and assess their limnological characteristics, such as water temperature, pH, dissolved oxygen (DO) levels and nutrient concentrations. Temporal data was gathered by monitoring seasonal fluctuations in environmental parameters, with particular attention to periods of high prawn activity and peak harvest times.

Stocking density and strategy assessment

The investigation of stocking densities and strategies (daytime versus nighttime stocking) involved direct observation and data collection across the 48 selected reservoirs. Stocking practices were evaluated in terms of prawn survival rates, growth performance and long-term sustainability. Data on stocking densities were collected through field visits, and comparisons were made between reservoirs with varying stocking regimes. In addition, stocking techniques were correlated with water quality variables and seasonal trends to determine optimal practices for maximising prawn survival and growth.

Stakeholder consultation and knowledge gap analysis

Reconnaissance surveys were conducted with the fisheries committees and local fishing communities to gather qualitative data on management practices, harvesting techniques and knowledge gaps in the sustainable management of GFP fisheries. These consultations provided valuable insights into the challenges faced by fishers and enabled the identification of critical issues related to stocking, fishing intensity and reservoir management. The

information gathered from stakeholders informed the development of context-specific management recommendations.

Harvesting techniques and trap efficiency study

To assess the efficiency of different harvesting methods, a series of trap trials were carried out in selected reservoirs. Various trap types, including the opera house trap, cylindrical cane trap and lobster trap, were tested for their effectiveness in capturing GFP, with a focus on optimising CPUE. The trials were conducted over several months to account for seasonal variations in prawn behaviour evaluated under laboratory experiments based on machine vision techniques. The traps were evaluated based on prawn capture rates, trap design, ease of use, and the potential to minimise damage to the prawns, ensuring high-quality harvests.

Socioeconomic and market assessment

A comprehensive socioeconomic survey was carried out to evaluate the market dynamics surrounding GFP production and its role in the livelihoods of rural fishermen. The survey focused on pricing trends, market demand, income levels and the financial sustainability of GFP fisheries. Data were collected through interviews with fishers, fish traders and key stakeholders in the aquaculture supply chain. Additionally, economic assessments of fishing practices and their contributions to local economies were performed.

Post-harvest product development and waste minimisation

Post-harvest investigations included the development of value-added products derived from soft-shell GFP and the exploration of zero-waste strategies. The extraction of collagen and chitin from prawn exoskeletons was explored as a means to increase the economic value of the industry while reducing environmental waste. Laboratory-based experiments were conducted to optimise extraction processes and evaluate the quality and commercial viability of these by-products.

Statistical and analytical methods

Data collected from field surveys, socioeconomic assessments and experimental trials were analysed using a combination of descriptive statistics, regression analysis and multivariate techniques. Statistical software, such as R, was used to identify significant relationships between environmental variables, stocking practices, production outcomes and socioeconomic factors. The results were interpreted in the context of best practices for sustainable GFP CBF, with recommendations aimed at improving both productivity and socioeconomic outcomes for local communities.

Results

Stocking practices for GFP to maximise early survival

In the extension of the CBF for GFP in Sri Lanka, several critical control points were identified to ensure the sustainability of the fishery. At the hatchery level, high early mortality was observed, primarily due to prolonged hatching periods. This delay in hatching was attributed to 3 key factors:

a. fluctuating or low ambient temperatures

b. suboptimal salinity or poor water quality, with hatcheries using direct seawater showing better performance

c. the absence of probiotics during feeding, which negatively impacted hatchery outcomes.

Upon release to the reservoirs, early mass mortality was observed, particularly for PL ≤9 mg, which were not well acclimatised to the reservoir environment and faced high

predation upon introduction. Subsequent trials revealed that releasing PL at the PL60 stage (60 days after 50% of eggs in the hatchery jar had hatched), when the PL reached a biomass of 15–30 mg, significantly improved survival rates. PL below 9 mg showed higher mortality and were identified as a critical factor in early extension failures. Furthermore, releasing prawns at night was found to significantly reduce early mortality, and spreading the release across multiple sites improved survival rates.

Optimisation of finfish and GFP production and sustainability in reservoirs

The current reservoir classification system used by NAQDA categorises reservoirs based on size: major (>800 ha), medium (200–800 ha) and minor (<200 ha). However, the present study demonstrated that this classification method was inefficient in determining the suitability of reservoirs for CBF extension. Instead, performance-based reservoir selection was found to be more effective, revealing significant variations in CBF performance within the same hydrological regime, while reservoirs of different sizes often exhibited similar performances.

Analysis of NAQDA data from 2009 to 2019 revealed spatial-temporal variability in production and stocking practices. Reservoirs with higher productivity exhibited a more stable stocking and production pattern, while others faced greater fluctuations, especially in response to climate change. The study further emphasised the impact of climate change on the sustainability of CBF, which had been largely overlooked in previous assessments.

A key outcome of this study was the optimisation of GFP stocking densities across various reservoir categories. While GFP stocking densities could potentially extend up to 4,000 PL/ha, for sustainability and profitability, we recommend maximum stocking densities of:

- major reservoirs – 1,000 PL/ha
- medium reservoirs – 1,500 PL/ha
- minor reservoirs – 2,000 PL/ha.

Reducing GFP catch losses and improving catchability

Efforts to reduce GFP catch losses due to scavenging by eels and tortoises, and the low catchability associated with gillnets, proved challenging. GFP, being bycatch in gillnets, often suffered significant losses due to their behaviour of scavenging on fish caught in the net. Additionally, as gillnets are typically suspended in columns, the catchability of bottom-dwelling GFP was limited. Migration patterns of GFP also posed a significant challenge, with females migrating downstream and males migrating upstream, further exacerbating catch losses. Poor handling and damage during capture also resulted in lower market acceptability and spoilage of GFP.

Despite these challenges, the study identified potential solutions, including the introduction of specific traps that could reduce catch loss and better target GFP, while minimising bycatch. Furthermore, soft-shell GFP, which naturally occur and contribute to post-harvest losses, could be utilised by developing value-added products and extracting chitin from shells, thus reducing waste.

Post-harvest practices to optimise product quality

Post-harvest losses, particularly due to soft-shell GFP, were found to contribute significantly to market wastage. About 30% of the total catch experienced post-harvest losses due to soft-shell condition, ligament detachment and damage to appendages.

To address this issue, the study focused on ways to utilise the muscle from soft-shell prawns, developing value-added products (a detailed description of this subject can be found in a separate paper in these proceedings). Furthermore, the shells were used for chitin extraction, employing low-cost methods that proved effective in extracting significant amounts of chitin. Future studies should focus on implementing zero-waste strategies for other fishery by-products to further improve the sustainability of CBF.

In addition, the sexual dimorphism of GFP was noted, with male prawns exhibiting morphological heterogeneity, such as blue claw, orange claw and small male morphs. These variations were priced differently in the market, with consumers treating each size category as distinct sub-products. The recognition of these morphs can provide valuable insights for market strategies aimed at improving the marketability and value of GFP, with a focus on promoting GFP as a 'go-blue' product sourced from reservoir-based natural product.

Maximising catch per effort and product quality using traps

Initial trials indicated that the opera house trap outperformed other gear types in Sri Lankan reservoirs. However, 2 key concerns arose regarding the catchability: whether it was primarily driven by the prawn's preference for green-coloured traps or by the optimal aperture size of the trap. Further investigations revealed that trap design, particularly the aperture size and colour, significantly influenced catch rates, with green-coloured traps yielding higher CPUE. Despite these findings, gillnets remained a common method of prawn capture in the region, albeit with lower efficiency and higher catch loss.

In response, we recommend further studies on trap modifications, including varying aperture sizes and materials, to enhance GFP catchability while minimising bycatch. Additionally, the advantages of traps over traditional gillnets in terms of selectivity, reduced bycatch and lower environmental impact suggest that traps could play a critical role in improving GFP catch efficiency and sustainability in Sri Lankan reservoirs.

Discussion

Adapting a performance-based reservoir categorisation system for sustainable CBF extension

The findings of this study strongly advocate for a shift from conventional reservoir classification (based solely on hydrological regimes) to a performance-based selection system tailored for CBF sustainability. Unlike traditional classification methods that primarily consider reservoir size (major, medium and minor), a performance-based categorisation integrates multiple ecological and operational parameters, including bathymetry, productivity and species-specific requirements. This approach aligns with global best practices observed in China's stocked reservoir fisheries (Gong et al. 2025) and Thailand's inland fishery enhancement programs (Edwards 2023). Given the pivotal role of bathymetric features in determining GFP stocking success, future research should focus on developing digital bathymetric models for reservoirs where such data are currently unavailable. Additionally, long-term validation of this categorisation model through multi-year trials is recommended to ensure its applicability across different ecological conditions.

Gene pool conservation of GFP broodstock for sustainable aquaculture

A critical concern emerging from our study is the genetic integrity of GFP broodstock. Hatcheries in Sri Lanka currently source broodstock from both riverine and reservoir populations, with reservoir-derived broodstock representing individuals that have undergone multiple generations in artificial stocking systems. This raises concerns about potential genetic bottlenecks, inbreeding depression and loss of desirable traits, which could impact growth performance and disease resistance (Khan et al. 2019). A preliminary study conducted by Wayamba University to assess the haplotype diversity of GPF brooders, collected from 3 state hatcheries and one private hatchery, based on the mitochondrial CO1 gene, revealed a very low level of haplotype diversity; however, the interpretation of these findings is constrained by the limited sample size of only 9 individuals. Comparable studies in India and Bangladesh have demonstrated that repeated use of farmed broodstock without genetic monitoring leads to reduced yield and lower survival rates in stocked populations (Sunny et al. 2025). To mitigate this risk, we recommend the establishment of a national broodstock management program incorporating genetic monitoring, screening and controlled breeding strategies. Additionally, research on the comparative fitness of wild and reservoir-derived GFP strains is essential to ensure long-term sustainability.

Enhancing the efficiency of inland fishery extension through strategic allocative management

Despite significant efforts by NAQDA to promote CBF in Sri Lanka, inefficiencies in extension services remain a major bottleneck. Identified challenges include:

- **ad hoc allocation of funds and human resources**, leading to suboptimal implementation of stocking programs
- **logistically unfeasible targets** in monitoring, control and surveillance (MCS) activities, making compliance enforcement difficult
- **lack of robust technical interventions** to optimise stocking densities, fishing practices and post-harvest management.

These challenges mirror inefficiencies observed in other Asian CBF programs, such as in Myanmar, where limited extension capacities have constrained aquaculture expansion despite high potential (Oo et al. 2019). To improve effectiveness, we propose an evidence-based decision-support framework for NAQDA, integrating real-time data analytics to optimise stocking schedules and resource allocation. Additionally, participatory training programs for fishers can enhance local engagement and compliance.

Evaluating policy implications before introducing trap fishing for GFP

While the introduction of trap-based fishing for GFP offers potential advantages over gillnets – reducing bycatch mortality and improving product quality – its implementation must be carefully assessed. Given the common-property nature of Sri Lankan reservoirs, the introduction of a new gear type may inadvertently lead to conflicts among user groups or facilitate unauthorised fishing activities. This has been observed in Cambodia, where poorly regulated trap fisheries contributed to overexploitation in Tonle Sap Lake (Chheng et al. 2022). To prevent similar challenges, a rigorous policy impact assessment should precede large-scale trap introduction, evaluating aspects such as gear standardisation, licensing frameworks and enforcement mechanisms.

Strengthening public–private intervention in CBF development

PPI is increasingly recognised as a vital mechanism for scaling up CBF, facilitating investment and improving market access. However, the effectiveness of existing public–private partnership (PPP) frameworks in Sri Lanka remains contested, due to inadequate monitoring mechanisms and the potential risk of private sector dominance. In particular, granting exclusive reservoir rights to a couple of exporters could enable monopolistic control over the market, further eroding the bargaining power of fishers and threatening equitable access to resources. Similar concerns have been raised in Vietnam, where privatisation of reservoir fisheries led to reduced equitable access for small-scale fishers (Nguyen et al. 2021). To address this, Sri Lanka's PPI strategy should be revisited to ensure that socioeconomic equity remains central to CBF development. A multi-stakeholder governance model, incorporating local fishing communities alongside government and private investors, could enhance transparency and long-term sustainability.

Adapting CBF to climate change: a holistic approach

The impacts of climate change on inland fisheries, particularly fluctuating water availability, demand urgent adaptive strategies. In Sri Lanka, reservoirs serve a dual purpose, with irrigation taking precedence over fisheries. Consequently, prolonged dry periods could disrupt CBF activities, reducing stocking success and productivity. Studies from Brazil's Amazon floodplain fisheries (Castello et al. 2019) and Australia's Murray–Darling Basin (Chu et al. 2025) underscore the need for climate-resilient management strategies, such as dynamic stocking models that account for seasonal hydrological variations. To ensure the long-term sustainability of CBF in Sri Lanka, we recommend:

- **developing climate-smart stocking protocols** based on reservoir water retention capacity forecasts
- **integrating remote sensing and hydrological modelling** to predict water availability for stocking decision-making
- **enhancing community-led adaptive management strategies** to improve local resilience to climate-related disruptions.

Conclusion

This study underscores the imperative for a science-driven, integrated approach to advance the sustainability of CBF in Sri Lankan reservoirs. Our findings highlight the critical importance of adopting a performance-based reservoir categorisation system, optimising stocking densities and preserving the genetic integrity of freshwater prawn broodstock. Additionally, strategic improvements in fishery extension services, thoughtful policy considerations before introducing trap fishing and an adaptive approach to climate change are essential to ensuring the long-term success of the sector.

By drawing on international best practices and evidence-based policy recommendations, Sri Lanka has the potential not only to enhance the resilience and productivity of its inland fisheries but also to serve as a model for sustainable aquaculture development in regions confronting similar challenges. Future research should prioritise the refinement of digital bathymetric modelling, the advancement of genetic monitoring tools and the reduction of post-harvest losses through zero-waste value chain approaches. Additionally, strengthening climate adaptation strategies will be vital to ensuring the long-term sustainability of CBF.

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