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Culture-based fisheries in Sri Lankan reservoirs: from science to practice



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ACIAR PROCEEDINGS

Culture-based fisheries in Sri Lankan reservoirs: from science to practice

Proceedings of an end-of-project workshop

ACIAR project 'Improved productivity, efficiency and sustainability of the culture-based fishery for finfish and giant freshwater prawn in Sri Lankan reservoirs' (FIS/2018/157)

Colombo, Sri Lanka, 19–20 February 2025

Clive M Jones and Upali S Amarasinghe (Editors)



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Cover: Giant freshwater prawns were introduced to the inland reservoir systems of Sri Lanka as a culturable species to diversify the catch and boost the income of rural fishing communities. A fishing canoe at Iranamaduru Reservoir. Photos: ACIAR and Professor MDST de Croos.

Foreword

In February 2025, the Australian Centre for International Agricultural Research (ACIAR) supported an end-of-project workshop for the project 'Improved productivity, efficiency and sustainability of the culture-based fishery for finfish and giant freshwater prawn in Sri Lankan reservoirs' (FIS/2018/157). This workshop served as a platform to present key research findings, facilitate critical discussion on the constraints and opportunities within the culture-based fisheries sector, and identify priority areas where further research could support sustainable development.

Sri Lanka is home to more than 12,000 reservoirs, one of the highest densities of freshwater bodies globally. Originally constructed for irrigation, domestic water supply and later hydropower generation, these reservoirs have increasingly been used to support culture-based fisheries. This approach, pioneered in Sri Lanka, involves the stocking of hatchery-reared fingerlings and juvenile prawns into reservoirs, allowing them to grow in largely natural environments before being harvested using traditional methods.

Culture-based fisheries have significantly enhanced inland fish production and emerged as a vital source of low-cost animal protein and household income for rural communities. By 2017, production from culture-based fisheries reached approximately 83,000 tonnes annually, contributing meaningfully to national food security and rural livelihoods. Organised through reservoir fishery organisations and supported by evolving market systems, the sector has demonstrated strong potential.

However, the absence of a solid foundation of science-based knowledge and evidence-based practice has limited its capacity for sustainable expansion and innovation.

These Proceedings present the research outputs of the project 'Improved productivity, efficiency and sustainability of the culture-based fishery for finfish and giant freshwater prawn in Sri Lankan reservoirs'. The project emerged in response to an ACIAR-commissioned scoping study in 2016, which examined opportunities for renewed engagement in agricultural research for development in Sri Lanka. The design of the large, multidisciplinary project was guided by baseline data generated from a small research activity (FIS/2017/002) on freshwater prawn culture and associated socioeconomics of fishing communities in the Northern Province, conducted between October 2017 and September 2019.

The work presented in these Proceedings represents a significant step forward in understanding and strengthening Sri Lanka's culture-based fisheries sector. It reflects the contributions of diverse stakeholders and offers a foundation for future collaboration, innovation and policy development in support of rural livelihoods and sustainable aquatic resource management.



Dr Nick Austin

Chief Executive Officer (Acting), ACIAR

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I want to especially acknowledge the project co-leader Professor Upali S Amarasinghe. Prof Upali is a world-renowned expert in culture-based fisheries and one of Sri Lanka's leading scientific minds. The project has been so fortunate to have had his leadership and capacity to immerse himself in every aspect of the research, across all the disciplines, making significant contributions throughout.

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To the engine of our project – the RAs, our wonderful research assistants. What an amazing group of young scientists. This project is unlike many supported by the Australian Centre for International Agricultural Research (ACIAR) in having so many research assistants conducting the bulk of the research. Many such projects have 3 or 4, but we currently have 12, all completing higher degrees, Masters or PhD, and in that aspect alone, this project has been exceptional in the extent of capacity building it has achieved. My deepest thanks to every one of you for your commitment to this project and your achievements.

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Acronyms and abbreviations

Term	Description
AAS	Atomic Absorption Spectroscopy
ACIAR	Australian Centre for International Agricultural Research
ADB	Asian Development Bank
AEZ	agroecological zoning
Alkt	alkalinity
ANOVA	analysis of variance
AqMCs	Aquaculture Management Committees
ARDQIP	Aquatic Resources Development and Quality Improvement Project
ASD	average swimming depth
BOD / BOD ₅	biochemical oxygen demand
BW	body weight
CA	catchment area
CBF	culture-based fisheries
CEA	Central Environmental Authority (Sri Lanka)
CFI	cost of fishing effort per hectare
CHIRP	Compressed High-Intensity Radar Pulse
Chl / Chl-a	chlorophyll or chlorophyll-a
CL	carapace length
Col	colour of water
Con	conductivity
CPR	common-pool resources
CPUE	catch per unit effort
CRM	certified reference material
CSD	cost of stocking
CTSI	Carlson Trophic State Index
DEM	Digital Elevation Model
Dep	depth
DO	dissolved oxygen
DOP	dissolved oxygen percentage
DYA	density weighting analysis
EDS	Energy-Dispersive X-ray Spectroscopy
EDTA	ethylenediaminetetraacetic acid
ePAR	extended Photosynthetically Active Radiation
FAO	Food and Agriculture Organization

Term	Description
FCS	Fisheries Cooperative Societies
FGD	focus group discussion
FI	fishing intensity
FISAT	FAO-ICLRAM Stock Assessment Tool
FL	fingerlings
FOs	farmers' organisations
FRP	fibre-reinforced plastic
FSL	full supply level
FTIR	infrared spectroscopy
FWP	freshwater prawn
GAD	gender and development
GAM	generalised additive models
GB	gradient boosting
GGGI	Global Gender Gap Index
GIS	Geographic Information System
GRD	ground range detected
GPS	Global Positioning System
GR	gravel and rocky substrates
GFP	giant freshwater prawn
GIFT	Genetically Improved Farmed Tilapia
GlcNAc	N-acetyl-glucosamine
Hard	hardness
HPLC	High Performance Liquid Chromatography
HRT	hydraulic retention time
IMC	Indian major carp
ICES	International Centre for Ethnic Studies (Sri Lanka)
IQF	individual quick freezing
IW	interferometric wide swath
LbI	length-based indicators
LGD	large group discussion
LIW	light intensity underwater
LWR	length-weight relationships
MCMC	Markov Chain Monte Carlo
MCS	monitoring, control and surveillance
MDF	market development facility
MEI	morphoedaphic index
MER	maximum economic return

Term	Description
MEY	maximum economic yield
MOF	Ministry of Fisheries
MP	microplastics
MPN	most probable number
MPL	maximum permissible levels
MSY	maximum sustainable yield
NAQDA	National Aquaculture Development Authority (Sri Lanka)
NARA	National Aquatic Resources Research & Development Agency
NEP	net economic profit
NGO	non-government organisation
Nit	dissolved nitrate
NMDS	non-metric multidimensional scaling
OHT	opera house trap
OM	sediment organic matter content
OP	open water
ORP	Oxidation Reduction Potential
PC	pits and channels
PC	principal component
PCA	Principal Component Analysis
PCoA	position of reservoirs in a multidimensional space
PEST	political, economic, social and technical
Pho	dissolved phosphate
PL	post larvae
PPI	Public–Private Intervention
PPP	Public–Private Partnership
PRA	Participatory Rural Appraisal
QIM	Quality Index Method
R&D	research and development
RC	reservoir capacity
RF	random forest
RFS	Rural Fisheries Society
RFO	Reservoir Fishing Organisation or Rural Fisheries Organization
RRA	Rapid Rural Appraisal
RRLF	reservoir water level fluctuation
Sal	salinity
SAR	Synthetic Aperture Radar

Term	Description
SD	stocking density/ies
SDD	Secchi Disk Depth
SEA	stocking efficiency per area
SEM	Scanning Electron Microscopy
SI	stable isotope
SIGI	Social Institutions and Gender Index
SIS	small indigenous fish species
SLA	Sustainable Livelihood Approach
SLC	Single Look Complex
SLF	Sustainable Livelihood Framework
SMI unit	Sediment Microplastic Isolation unit
SRA	small research activity
SVIR	small village irrigation reservoirs
SW	shell weight
SWOT	strengths, weaknesses, opportunities, threats
TCP	Technical Cooperation Programme
TDS	total dissolved solids
Tem	temperature
TIL	tilapia
TL	total length
TL	trophic levels
TN	total nitrogen
TP	total phosphorus
TS	target strength
TSI	trophic state indices
TSS	total suspended solids
Turb	turbidity
UNEP	United Nations Environment Programme
VA	vegetation-associated zones
VFY	value of fish yield
WHO	World Health Organization
WL	wood log

Units

Unit	Definition
%	per cent
°C	degrees Celsius
cm	centimetre
FAU	turbidity in water
ft	foot
g	gram
gcm or g/cm	grams per centimetre
ha	hectare
ha ⁻¹	per hectare
kg	kilogram
kg hr ⁻¹	kilograms per hour
kHz	kilohertz
km	kilometre
km/h	kilometre per hour
kPa	kilopascal
kV	kilovolt
L	litre
L _c	length at first capture
LKR	Sri Lanka Rupee
L _{M/K}	marketable size
m	metre
mg	milligram
mgL ⁻¹	milligrams per litre
mgm ⁻³	milligrams per cubic metre
mL	millilitre
mm	millimetre
MPa	megapascal
Mt	metric tonne (1,000 kg)
mV	megavolt
n	number
nm	nano metre
ORP	oxidation-reduction potential
p	p value
pH	pH value

Unit	Definition
ppm	parts per million
ppt	parts per thousand
PSI	pound per square inch
PSU	power supply unit
RPM	revolutions per minute
t	tonne
THB	Thai Baht
USD	US dollar
μgL^{-1}	micrograms per litre
μL	microlitre
μm	micrometre
μS	microSiemens
μScm^{-1}	microSiemens per centimetre
WmK	marketable size weight
y or yr	year
Y	Yield



1 Setting the scene



Researcher with 3 giant freshwater prawns, each weighing 800 g, from Iranamadu Reservoir. Photo: Professor MDST de Croos.



1.1 Introduction

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Development of culture-based fisheries (CBF) is of increasing interest around the world, to provide enhanced fisheries production in freshwater reservoirs primarily established for irrigation purposes. CBF have largely been established in developing countries in South and Southeast Asia, where they have become significant industries, providing great benefit to communities adjacent to reservoirs.

This report provides a summary of information presented at an end-of-project workshop held in Colombo, Sri Lanka, on 19 and 20 February 2025. This workshop represented the research output of a research project, supported by the Australian Centre for International Agricultural Research (ACIAR), 'Improved productivity, efficiency and sustainability of the culture-based fishery for finfish and giant freshwater prawn in Sri Lankan reservoirs' (FIS/2018/157). CBF in Sri Lanka include a range of lower-value finfish species primarily consumed locally and higher-value giant freshwater prawns that are mostly exported.

The project had an industry development and enhancement focus and the workshop provided opportunity for input from research scientists, higher degree university students, extension staff and government managers, to discuss the findings of the project and identify key issues that further research could address to progress expansion and improved productivity and viability of the Sri Lankan CBF industry.

To maximise the opportunity, the workshop (Appendix 1) was structured to include formal oral presentations representing the various research activities of the ACIAR project and summary papers from senior scientists to discuss the application of those findings, their likely impact and further research required. The presentations were scheduled within 4 sessions encompassing biophysical aspects, value chain for giant freshwater prawns, bioeconomics of CBF and social dimensions of livelihoods and gender.

A synopsis of significant findings, key issues and knowledge gaps was prepared for each session. This publication presents the written reports generated from each of the oral presentations.

1.2 Status of Sri Lankan culture-based fisheries: an overview

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Abstract

In Sri Lanka, due to the extensive availability of productive reservoir resources, there is a high potential for the development of CBF. With concerted research and development efforts on this fisheries enhancement strategy, CBF development in inland reservoirs is gaining momentum. In small village reservoirs of the country, there are no established fisheries and as such, CBF development in such reservoirs involves mobilising agricultural farmers to adopt this activity. In perennial reservoirs on the other hand, where there are established fisheries, fishers should be motivated to adopt CBF technologies. Giant freshwater prawn, *Macrobrachium rosenbergii*, is also used for CBF development in many reservoirs. Presently, freshwater prawn is caught as incidental catch in gillnets targeting finfish varieties. It is necessary to introduce an effective method of harvesting freshwater prawn, such as traps. Optimal stocking densities in relation to biological productivity of water bodies, post-harvest product qualities, bioeconomic aspects of CBF, value chain analysis, gender-related aspects and livelihood analysis, are the aspects that are effectively addressed by the research and development (R&D) project of ACIAR. Most importantly, there should be strategies for addressing the issue of fingerling scarcity, and for strengthening the extension mechanism of the National Aquaculture Development Authority (NAQDA) to introduce effective co-management for sustainability of CBF in Sri Lankan reservoirs.

Introduction

Intensification of food production systems has become an urgent need to feed humankind, and CBF are relatively environmentally friendly fisheries enhancement strategies to contribute to this need (De Silva 2003 and 2016). CBF development in the multitude of reservoirs is a recent trend in the Sri Lankan inland fishery sector (Wijenayake et al. 2005; Amarasinghe and Nguyen 2010; Amarasinghe and Wijenayake 2015; Pushpalatha and Chandrasoma 2010). Generally, CBF is recognised as a strategy which involves release of hatchery-reared fish fingerlings and/or post larvae of

culturable species such as freshwater prawns to open water such as reservoirs for subsequent capture. In Sri Lanka, CBF development in irrigation reservoirs is gaining momentum (Amarasinghe and Nguyen 2010; Amarasinghe et al. 2022; Kularatne and Amarasinghe 2025), and this contribution is an overview of CBF in the country.

Water resources for CBF development

The extant freshwater resources in the country, except for lotic systems such as rivers, streams and standing lentic waters such as floodplains, are exclusively formed by ancient irrigation reservoirs and recently

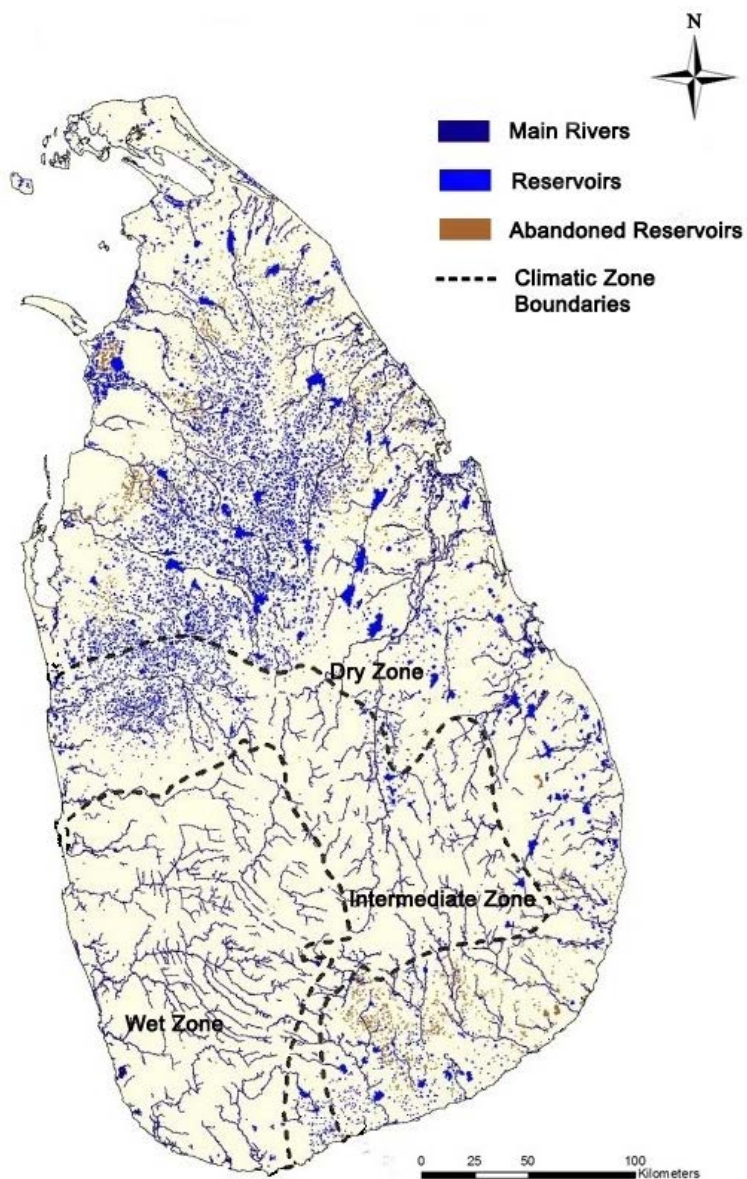


Figure 1.2.1: Rivers and reservoirs in Sri Lanka
(source: Jayasinghe and Amarasinghe 2018)

built multipurpose (mainly for generation of hydroelectricity) reservoirs. The cumulative extent of these reservoirs is estimated to be around 206,000 ha (Jayasinghe and Amarasinghe 2018; Figure 1.2.1), which forms about 3.1 ha for every km² of the island, perhaps the highest density of standing waters in the world (Fernando 1990). These reservoir resources of the country provide vital opportunities for the development of CBF. The reservoirs of Sri Lanka can be broadly divided into 2 categories:

- a. small village reservoirs
- b. perennial reservoirs.

Small village irrigation reservoirs

Small village irrigation reservoirs (SVIR) are those which consist of irrigable areas less than 80 ha. They are situated in the low rainfall zones of the country receiving less than 175 mm annual precipitation. These water bodies come under the jurisdiction of the Department of Agrarian Development. Mendis (1965 and 1977) has shown that as these water bodies, most of which go dry during the dry season in August to October, are biologically productive and that they can be utilised for stocking fish fingerlings for subsequent harvesting. Based on these findings, Rosenthal (1979) and Oglesby (1981) recommend adopting this strategy, which was subsequently adopted by the fisheries authorities as a means of inland fisheries development in Sri Lanka (Thayaparan 1982).

However, there are no established fisheries in almost all, if not all, SVIRs, and the water uses of reservoirs are managed by farmers' organisations (FOs) established under the legal provisions of Agrarian Development Act No. 46 (2000) and the Agrarian Development (Amendment) Act No. 46 (2011). Under these Acts, there are legal provisions for the FOs to incorporate CBF

as a community-based activity during the planning stage of an irrigation schedule for the 2 cultivation seasons in the command areas of each reservoir. In this context, CBF activities in SVIRs are jointly facilitated by the Department of Agrarian Development and NAQDA. A research project funded by ACIAR was instrumental to formulate scientifically sound better practice approaches for CBF development in these village reservoirs without interfering with ongoing agricultural farming practices (Amarasinghe and Nguyen 2010; Amarasinghe and Wijenayake 2015).

Perennial reservoirs

Unlike SVIRs, there are established capture fisheries in perennial reservoirs. Although the primary uses of these reservoirs are to irrigate agricultural lands and/or to generate hydroelectricity, they are secondarily utilised for the development of inland fisheries. Development of reservoir fisheries in Sri Lanka is a relatively recent development after the introduction of exotic cichlid species, *Oreochromis mossambicus* in 1952 and *O. niloticus* in 1975 into Sri Lankan freshwaters (Amarasinghe et al. 2022). Trends in the inland capture fisheries production, mainly based on the self-recruiting exotic cichlid stocks, are documented by Amarasinghe and Weerakoon (2009) and Amarasinghe et al. (2022). The perennial reservoirs of Sri Lanka are broadly categorised for irrigation purposes as minor (<200 ha), medium (200–800 ha) and major (>800 ha) reservoirs. These categories are also used by NAQDA for fisheries development purposes. Initial preliminary attempts to develop CBF in perennial reservoirs were made by Illukkumbura (1986) and Chandrasoma (2007). Pushpalatha and Chandrasoma (2010) also reported results of CBF activities in several minor perennial reservoirs of the country.

CBF management in reservoirs

As mentioned above, CBF development initially commenced in 1980s in SVIRs (Thayaparan 1982). As many of these village reservoirs are seasonal, with water retention period of 6 to 9 months, species suitable for CBF were essentially those which would grow to the marketable size within a short period, such as Chinese and Indian major carps and common carp. However, due to the absence of scientific inputs such as methodologies to select water bodies suitable for CBF development, lack of mechanisms for social mobilisation to get farming communities involved in the strategy, together with the abrupt government policy decision to discontinue state patronage for inland fisheries and aquaculture development during 1990 to 1994, CBF efforts did not sustain.

Renowned efforts for CBF development in irrigation reservoirs were made in the early 2000s based on the research findings of an ACIAR-funded R&D project, which were effectively utilised by an inland fisheries development activity under the auspices of the Asian Development Bank (ADB) (Aquatic Resources Development and Quality Improvement Project – ARDQIP) during 2002 to 2010. Under the ARDQIP, apart from CBF development in SVIRs, attempts were also made to introduce CBF to fisher communities in perennial reservoirs. CBF management approaches, however, are quite different in the 2 types of reservoirs due to the fact that the resource users in SVIRs are agricultural farmers without prior experience in fishing, whereas in perennial reservoirs, there are established fisher communities. In the following sections, these CBF management approaches are briefly mentioned.

CBF development in small village reservoirs

As most SVIRs dry off during August to October and get filled during inter-monsoonal rains in December to January, CBF planning should be based on a crop calendar where stocking should be done in January or so and harvesting after a growth period of 7 to 10 months (Wijenayake et al. 2021; Kularatne and Amarasinghe 2025). For this purpose, hatchery production of fish fry and rearing them up to fingerling size should be in tune with this period of fingerling requirement for stocking. The optimal stocking density of fingerlings of major carps was determined to be 2,500–3,000 per ha considering the effective reservoir area as 50% of the extent at full supply level (Wijenayake et al. 2005). In Sri Lanka, as in many parts of the world, stocked fish rely on natural food sources in the aquatic environment and as such, there is no supplementary feeding. As Chinese and Indian major carps with varying food habits are ideal candidates for simultaneous stocking, in conformity to the principles of polyculture (Bardach et al. 1972), and as cichlid species such as *O. niloticus* tend to mature early in small water bodies such as SVIRs, the CBF practices invariably stock fingerlings of major carps depending on the availability in hatchery production. Since 2007 or so, NAQDA hatcheries have been producing fingerlings of the Genetically Improved Farmed Tilapia (GIFT) strain of *O. niloticus*. However, GIFT strain, which is suitable for aquaculture systems involving supplementary feeding, is not appropriate for stocking in CBF where they are incapable of competing with wild counterparts of fish to ingest natural food resources (Wijenayake et al. 2010).

For sustainable CBF in SVIRs, socioeconomic settings of farming communities play a major role. According

to a socioeconomic analysis of agricultural farming communities in SVIRs where CBF was carried out, it was found that social mobilisation of rural communities to adopt CBF in village reservoirs would be easier when there are leadership qualities of members of aquaculture management committees (AqMCs), and good education levels among members of communities.

Kularatne et al. (2019) also evaluated technical efficiency of CBF in these irrigation systems and found that CBF production could be increased substantially with better management using existing technology and resources such as removing subsidies, improving consultation with extension officials and improving water user rights through introduction of a transferable community quota system. Furthermore, rainfall anomalies causing shifting of monsoonal rainfall pattern makes it difficult to plan CBF in SVIRs as the reservoir filling period cannot be accurately predicted (Wijenayake et al. 2021). Also, as the entire CBF activities in the country in different types of water bodies rely on induced breeding of major carps in state-owned hatcheries, fingerling scarcity is also a major constraint for further development of CBF in SVIRs, and as a result less than 6% of such water bodies are annually stocked (Wijenayake et al. 2021). It is also necessary that selection of suitable reservoirs for CBF development should be based on a multi-criteria decision-making approach consisting of several of those such as biological productivity, catchment land-use characteristics influencing nutrient enrichment in reservoirs, and socioeconomic factors (Wijenayake et al. 2016). Most importantly, there should be a mechanism for social mobilisation to adopt CBF by agricultural farmers through transforming agricultural farmers to fishers, and for introducing co-management where

both resource users and government fisheries officials take equal responsibilities for management decision-making (Kularatne and Amarasinghe 2025).

CBF development in perennial reservoirs

Although preliminary attempts were made in the 1980s to develop CBF in perennial reservoirs, methodical stocking commenced in 2003 as part of the ADB-funded development project, ARDQIP, utilising knowledge gained through the CBF initiative in SVIRs. As mentioned above, unlike in SVIRs, where agricultural farmers without previous experience in fishing are mobilised to adopt CBF, in perennial reservoirs mobilisation of experienced fishermen to adopt CBF is necessitated. Also, due to the water availability throughout the year, unlike in many SVIRs where CBF strategies are to be dependent on the monsoonal rainfall pattern, CBF development in perennial reservoirs does not have to rely on rainfall pattern.

In selected minor perennial reservoirs, social mobilisation was facilitated through implementation of a community-based approach termed as introduction of a 'business plan' (that is, entrepreneurship plan; Wijenayake et al. 2021). In the social mobilisation approach, members of fisher communities are trained on leadership qualities, simple accounting, bookkeeping and so on (Amarasinghe et al. 2022). The CBF efforts in minor perennial reservoirs resulted in increased annual fish yield from 57.3 kg ha⁻¹ to 208 kg ha⁻¹, resulting in a major contribution of stocked Indian major carps in the landings (Pushpalatha and Chandrasoma, 2010; Amarasinghe 2010). Pushpalatha et al. (2021) also reported spectacular increases of CBF production by 3,811% in Ampara wewa, 339% in Hambegamuwa, 502% in Jayanthi wewa, 414% in Senanayake Samudra and



216% in Urusita wewa, after introduction of CBF, showing the great potential for increasing inland fish production through CBF in perennial reservoirs. From these case studies, it was evident that the principal reason for success of CBF in these reservoirs was almost entirely due to the active participation of resource users (such as fishers) in management decision-making, the most important feature in fisheries co-management.

Giant freshwater prawn in CBF

NAQDA established a freshwater prawn (FWP), *M. rosenbergii* hatchery in Kandamodera, southern province in 2003 under the technical assistance of Food and Agriculture Organization (FAO), which has a production capacity of 17 million post larvae per year. Also, another FWP hatchery was established in Kallarawa in the eastern province, which has a capacity to produce 25 million post larvae annually. The FWP hatchery in Pambala, North Western Province produces 13.5 million post larvae annually. Also, there is a small FWP hatchery established by a private company. In the absence of well-developed aquaculture practices for *M. rosenbergii* in Sri Lanka, the oversupply of post larvae from the hatcheries was used for stocking in reservoirs to develop CBF.

Presently, FWP is caught as incidental catch in gillnets targeting finfish varieties. It is therefore necessary to introduce an effective method of harvesting FWP such as traps. Optimal stocking densities in relation to biological productivity of water bodies, post-harvest product qualities, bioeconomic aspects of CBF, value chain analysis, gender-related aspects and livelihood analysis are the aspects that are effectively addressed by the R&D project of ACIAR. When the cost of stocking of FWP incurred by the fisheries societies is compared with the value of

FWP harvest that they receive at the landing sites, the CBF production of FWP in reservoirs appears to be close to economic breakeven point.

Recommendations for future strategies and conclusion

Due to concerted R&D efforts, CBF in Sri Lankan reservoirs are gaining momentum. However, there are certain issues that are needed to be addressed as short-term solutions for their sustainability. There are differences in CBF management strategies that are to be adopted for SVIRs and perennial reservoirs. In SVIRs, there are no established fisheries, and as a result, the agricultural farmers using water resources should be educated through social mobilisation approaches to practice CBF. In perennial reservoirs, however, there are established fisheries and as such, only the technicalities related to CBF should be introduced to those communities.

There are certain mistakes of fisheries and aquaculture authorities in CBF development activities. Despite scientific evidence indicating that the GIFT strain of Nile tilapia, suitable for aquaculture systems such as pond culture and cage culture where supplementary feeding is done, it is not suitable to use in CBF (Wijenayake et al. 2010), stocking of GIFT fingerlings in reservoirs has been continued. It is also a fact that at present, pure Nile tilapia broodstocks are not available at NAQDA hatcheries and import of pure Nile tilapia is a lengthy process. It is therefore recommended that Nile tilapia broodstocks are developed from the wild-caught specimens in large perennial reservoirs such as Padaviya, Senanayake Samudra, Kaudulla, and so on. On the other hand, all scientific evidence indicates that significantly higher increases in CBF production in perennial reservoirs is due

to stocking of Indian major carps (catla, mrigal and rohu) and that tilapia stocking does not contribute significantly to increase of CBF production. While it is necessary to rebuild Nile tilapia stocks which have been deteriorated as a result of reduced genetic fitness caused by stocking of GIFT fingerlings in some reservoirs, proportion of stocking of Nile tilapia, where stocked, should be restricted only up to 10%.

As the size of fish fingerlings stocked in reservoirs is 5–6 cm, CBF harvests are heavily impacted by predation (Wijenayake et al. 2005). Stocking of advance fingerlings (>10 cm) is an effective means of overcoming this issue. As fry-to-fingerling rearing in floating net cages is already carried out in many reservoirs, this approach can be expanded to raise fingerlings up to bigger sizes (>10 cm) in net cages. It is possible to produce feed using hitherto unexploited or underexploited small indigenous fish species (SIS) occurring in reservoirs, to reduce feed cost. The dried fish powder of SIS can also be added to the fish feeds that are used for feeding fish fingerlings reared in floating net cages. Exploitation of SIS using small mesh (18 mm–37 mm) gillnets is possible without adverse effects on juveniles of finfish species in capture and CBF (Schiemer et al. 2024). For this purpose, legal provisions for exploitation of SIS using small mesh gillnets should be provided, which can easily be accommodated within the Fisheries and Aquatic (Amendment) Act No. 35 of 2013.

CBF production of *M. rosenbergii* in Sri Lankan is destined at the export market and as such, this CBF strategy supports fisher communities to uplift their living standards.

Another constraint to CBF sustainability is that in many parts of the country there are lower priorities for utilising SVIRs and

perennial reservoirs for CBF mainly due to conflicting interests of multiple users (Amarasinghe et al. 2022). Furthermore, due to weakening of the extension mechanism in NAQDA during the last decade or so, the success of CBF development in the village reservoirs has shown a downfall. Hence, there should be strategies for addressing the issue of fingerling scarcity, and for strengthening the extension mechanism of NAQDA to introduce effective co-management.

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1.3 The ACIAR-supported project – its goals and planned outcomes

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In 2016, the Australian Government through the auspices of ACIAR, was considering re-engagement with Sri Lanka after a long absence due primarily to the conflicts within Sri Lanka. ACIAR commissioned a scoping study and appointed retired Professor Sena De Silva (Deakin University) to conduct that study. The outcome was a recommendation to recommence funded research, and to start the program with a small research activity (SRA) to design a multidisciplinary project in aquaculture for freshwater shrimp, including a socioeconomic component, focused on communities in the Northern Province. The SRA was prepared and commissioned to James Cook University operating over a 20-month period through 2017 to 2019, in collaboration with NAQDA, Wayamba University of Sri Lanka and Ruhuna University. One of the project recommendations was that a large project be developed to build on the SRA work.

The large project, 'Improved productivity, efficiency and sustainability of the culture-based fishery for finfish and giant freshwater prawn in Sri Lankan reservoirs' (FIS/2018/157), is the subject of this report. It was approved in mid-2019 and due to commence 1 January 2020 and run 4 years to December 2023. Due to the COVID-19 pandemic at the time, followed by the political and economic crisis in Sri Lanka, the project's start was delayed until July 2021 with a scheduled end date of 30 June 2025. Although the project ran its course

over that 4-year time period, the first 12 months through to June 2022 were extremely difficult due to the impacts of the ongoing economic crisis in Sri Lanka, that resulted in rationing of electricity and fuel in particular which stymied field and laboratory work. The project team remained cohesive through that time despite the challenges, but the first year was largely lost due to the difficulty of performing research. In effect, the 4-year project was completed in a 3-year timeframe.

In the broadest sense, this ACIAR-supported project set out to enhance CBF in Sri Lanka's reservoirs.

There was a broad acceptance that the stocking of fingerling fish and post larval giant FWP was ad hoc and not based on rigorous science. The project sought to provide the science to enable informed decisions about stocking that will optimise fishery production, productivity, and social and economic benefits.

The project was multidisciplinary, including a broad range of biological and physical disciplines, including limnology, ecology, fisheries biology, biochemistry, investigations of value chain, bioeconomics, social science, livelihoods and gender. The research was gathered under 4 objectives. A logic framework was prepared to generate a theory of change, which was then used to guide the outcomes that were planned and the goals to be achieved.

The theory of change was structured with 3 pillars: biophysical research, government policy and planning, and industry and people development.

Outcomes for the biophysical research included aspects of giant FWP and fish biology and ecology, fisheries biology including stocking, population structure, harvesting and harvest quality, and relationships between giant FWP and fish fisheries and reservoir characteristics.

Planned outcomes for government policy and planning included providing government with the information generated for policy development, to provide a framework for assessing reservoirs as to their suitability for expansion of CBF and most importantly to enable science-based stocking strategies.

The third pillar of industry and people development sought to develop bioeconomic models of CBF to describe the value chain and define improvements, to identify barriers and enablers for CBF development, to improve social equity within the fisheries and to ensure the CBF industry of Sri Lanka was meeting its growth potential.

High-level goals of the project were:

- to improve equitable livelihood benefits to reservoir fishery
- to define reservoir stocking practices for prawns and fish that generate predictable production
- to improve yields and product quality of CBF in Sri Lankan reservoirs
- to contribute to government policy that actively and effectively supports CBF throughout Sri Lanka
- to assist in government planning that supports expansion of CBF to all suitable reservoirs within an environmental sustainability framework
- to maximise opportunity for Sri Lankan giant FWP to be recognised globally as a premium organic product
- to broaden employment opportunities for men and women in the Sri Lankan CBF sector
- to support career progression of female scientists and extension officers into senior and management positions.

While ambitious in scope, the project has largely achieved its objectives and the research outputs are presented in this report.

1.4 The role of the National Aquaculture Development Authority in the culture-based fisheries project

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Introduction

In Sri Lanka, development of CBF as an inland fisheries enhancement strategy dates back to the early 1980s, when the fisheries authorities of the country placed a high priority on this initiative. Accordingly, the Inland Fisheries Division of the Ministry of Fisheries has taken steps to develop CBF in small village reservoirs, most of which go dry for a few months during the dry season (commonly known as non-perennial or seasonal reservoirs), as they are proven to be biologically productive (Thayaparan 1982). However, due to lack of scientific inputs for selecting village reservoirs suitable for CBF development based on biological, economic and sociological aspects relevant to this development initiative as well as due to an abrupt policy decision to discontinue state patronage for inland fisheries development during 1989 to 1994, CBF development in inland reservoirs did not sustain.

Under an R&D project funded by ACIAR, scientific strategies for CBF development in small village reservoirs were developed (De Silva et al. 2006; De Silva 2011). Subsequently, ADB supported the project, 'Aquatic Resource Development and Quality Improvement Project (ARDQIP)' to develop inland fisheries and aquaculture sectors of Sri Lanka (ADB 2011), under which the scientific findings of the ACIAR-funded research activity on CBF development were successfully implemented. Most importantly, there are legal provisions to

develop CBF in inland water bodies of the country under the Agrarian Development Act of 2000. Co-management strategies for CBF in small village reservoirs were introduced and as a result, there is evidence about the sustainability of the fishery (Kularatne and Amarasinghe 2025). There was also a scientific initiative to develop CBF in perennial reservoirs under the AEDQIP, which produced encouraging results (Chandrasoma et al. 2015; Chandrasoma and Pushpalatha, 2018).

In Sri Lanka, NAQDA has been mandated for the development of CBF and aquaculture. Until adoption of inland fisheries enhancement in reservoirs in 1980s (Jayasekara 1989), the inland fishery was dominated by exotic cichlid species, *O. mossambicus* and *O. niloticus*. NAQDA has therefore taken steps to diversify species in the landings through regular stocking of fingerlings of Chinese and Indian major carps and common carp. As CBF development in inland reservoirs is a communal activity where there is a necessity to mobilise fishers' societies to adopt the strategy, as part of ARDQIP, an innovative approach for the purpose was initiated. This involved establishment of an active partnership of fisher communities through development of entrepreneurship (business) plans in individual reservoirs.

***M. rosenbergii* in culture-based fisheries**

A giant FWP, *M. rosenbergii*, hatchery was established in the North Western Province

of the country (Pambala) having an annual post larval production capacity of GFP of 13.5 million. Also, under the Technical Cooperation Programme (TCP) of FAO, another FWP hatchery was established in 2008 in the Southern Province (Kahandamodara). This hatchery has the capacity to produce 17 million FWP post larvae annually. The third FWP prawn hatchery with the annual post larval production capacity of 25 million was also established in 2017 in the Eastern Province (Kallarawa). As part of diversification of species in CBF, NAQDA initiated stocking of FWP post larvae in selected reservoirs.

Due to the lucrative export market for FWP, and availability in the landings of reservoirs, several private sector entrepreneurs, most notably Divron Bioventures Pvt Ltd and Southern Coast Pvt Ltd, were attracted as buyers of the commodity at the landing sites of reservoirs. In fact, the Market Development Facility (MDF) of the Australian High Commission in Colombo provided financial support to Divron Bioventures to establish a FWP prawn hatchery. Accordingly, this entrepreneur commenced stocking FWP post larvae in selected reservoirs in the Northern Province, with a mutual agreement facilitated by NAQDA to purchase the prawns for export market. At the ACIAR scoping study undertaken in Sri Lanka in July 2016 to support R&D in the agricultural sector, it was recognised that CBF of FWP in reservoirs of the country as a priority area, which ultimately led to the development of a SRA (FIS/2017/002). This SRA facilitated formation of a research team to develop FWP production and also to identify the knowledge and capacity gaps, and the R&D necessary for the potential of CBF of FWP to be realised. Based on the findings of the SRA, the present research project was implemented.

NAQDA's role in the ACIAR project

In the ACIAR project for the development of CBF in reservoirs with special reference to FWP, NAQDA's main role was to provide field-level support to the research teams in the universities involved in the project. As the major producer of post larvae of FWP in its 3 hatcheries, it was imperative that NAQDA provided stocking material to support the research plans. Accordingly, NAQDA stocked 48 reservoirs in 10 administrative districts according to the stocking plans prepared by the research teams (Table 1.4.1). In this juncture, NAQDA worked closely with Divron Bioventures Pvt Ltd and sought their support to stock some reservoirs.

Apart from facilitation of stocking of post larvae of FWP, NAQDA's aquaculture extension staff is involved in facilitating CBF development through social mobilisation. For this purpose, 48 community workshops were conducted to discuss advantages and disadvantages of adopting CBF of FWP in reservoirs. Through SWOT (strengths, weaknesses, opportunities and threats) analyses, fisher communities were convinced that adoption of CBF would be an effective means to generate supplementary income for the people.

The aquaculture extension officers of NAQDA also assisted the research team to develop good rapport with the fisher communities. This has considerably facilitated gleaning CBF stocking and production data from the logbook records of the fisheries societies. Also, members of the fisheries societies helped the research teams to collect water and sediment samples for studying water and sediment quality and biological productivity in reservoirs.

Table 1.4.1.1: Targeted and realised stocking of post larvae (PL) of FWP in selected reservoirs in 2021–2024

District	Reservoir	Extent (ha)	Targeted PL to be stocked				Realised number of PL stocked				Responsibility			
			2021	2022	2023	2024	2021	2022	2023	2024	2021	2022	2023	2024
Kilinochchi	Akkarayankulam	809	809,000	809,000	809,000	809,000	0	809,000	930,939	548,396	NAQDA	NAQDA	Divron	Divron
	Iranamadu	2,927	2,927,000	2,927,000	2,927,000	1,463,500	0	2,681,329	600,441	797,930	NAQDA	NAQDA	Divron	Divron
Mullative	Puthumurippu	151	302,000	302,000	302,000	302,000	0	302,000	392,828	468,132	NAQDA	NAQDA	Divron	Divron
	Muthiyankaddu	1,255	1,255,000	1,255,000	1,255,000	1,255,000	0	950,000	1,209,392	800,000	NAQDA	NAQDA	Divron	Divron
	Vavunikulam	1,275	2,550,000	2,550,000	2,550,000	900,000	0	1,993,168	217,366	413,890	NAQDA	NAQDA	Divron	Divron
Vavuniya	Bogaswewa	472	472,000	472,000	472,000	472,000	0	672,000	103,279	0	NAQDA	NAQDA	Divron	Divron
	Mamaduwa	243	486,000	486,000	486,000	486,000	0	490,000	0	150,000	NAQDA	NAQDA	Divron	Divron
	Kalmadu	102	153,000	153,000	153,000	153,000	0	153,000	155,070	150,000	NAQDA	NAQDA	Divron	Divron
	Morawewa	769	1,153,500	1,153,500	1,153,500	1,153,500	0	1,153,500	0	0	NAQDA	NAQDA	Divron	Divron
Trincomalee	Wendrasanwewa	410	615,000	615,000	615,000	615,000	0	615,000	616,504	949,127	NAQDA	NAQDA	NAQDA	Divron
	Mahadiulwewa	543	1,086,000	1,086,000	1,086,000	1,086,000	0	1,086,000	1,031,858	300,000	NAQDA	NAQDA	NAQDA	NAQDA
	Wanela	113	113,000	113,000	113,000	113,000	0	113,000	0	0	NAQDA	NAQDA	NAQDA	NAQDA
	Unnichchai	1,392	2,088,000	2,088,000	2,088,000	2,088,000	0	1811482	2,188,000	0	NAQDA	NAQDA	NAQDA	NAQDA
Batticaloa	Kaddumurivu	320	480,000	480,000	480,000	480,000	0	480,000	516,329	0	NAQDA	NAQDA	NAQDA	NAQDA
	Wadamunai	220	220,000	220,000	220,000	220,000	0	220,000	229,313	0	NAQDA	NAQDA	NAQDA	NAQDA
	Nachchaduwa	1,781	2,671,500	2,671,500	2,671,500	1,335,750	0	251,400	1,046,562	560,114	NAQDA	NAQDA	Divron	Divron
Anuradapura	Manankattiya	310	620,000	620,000	620,000	620,000	0	567,821	996,852	408,261	NAQDA	NAQDA	Divron	Divron
	Ranawa	60	120,000	120,000	120,000	120,000	0	0	0	117,640	NAQDA	NAQDA	Divron	Divron
	Hurululu wewa	1,619	3,238,000	3,238,000	3,238,000	3,238,000	0	0	0	0	NAQDA	NAQDA	NAQDA	NAQDA
	Maha wilaachchiya	971	1,456,500	1,456,500	1,456,500	1,456,500	0	0	1,456,500	0	NAQDA	NAQDA	NAQDA	NAQDA
	Mahakanadarawa	1,457	1,457,000	1,457,000	1,457,000	1,457,000	0	690,000	1,457,000	0	NAQDA	NAQDA	NAQDA	NAQDA
	Aluthdiulwewa	239	239,000	239,000	239,000	239,000	0	147,951	239,000	0	NAQDA	NAQDA	NAQDA	NAQDA
	Kiulekada	205	307,500	307,500	307,500	307,500	0	162,355	331,271	0	NAQDA	NAQDA	NAQDA	NAQDA

District	Reservoir	Extent (ha)	Targeted PL to be stocked				Realised number of PL stocked				Responsibility			
			2021	2022	2023	2024	2021	2022	2023	2024	2021	2022	2023	2024
Kurunegala	Maeliya	120	240,000	240,000	240,000	240,000	0	0	0	0	NAQDA	NAQDA	Divron	Divron
	Maha-Siyambalangamuwa	210	210,000	210,000	210,000	210,000	0	234,824	208,208	221,844	NAQDA	NAQDA	Divron	Divron
	Hakwatunaoya	389	778,000	778,000	778,000	778,000	0	800,000	791,943	300,000	NAQDA	NAQDA	NAQDA	NAQDA
	Usgala-Siyambalangamuwa	769	769,000	769,000	769,000	769,000	0	292,870	780,482	0	NAQDA	NAQDA	NAQDA	NAQDA
	Kimbulwanaoya	238	357,000	357,000	357,000	357,000	0	0	0	0	NAQDA	NAQDA	NAQDA	NAQDA
	Karavitararaya	256	256,000	256,000	256,000	256,000	0	267,616	265,910	0	NAQDA	NAQDA	NAQDA	NAQDA
Puttalam	Mahauswewa	212	318,000	318,000	318,000	318,000	0	100,000	324,305	0	NAQDA	NAQDA	NAQDA	NAQDA
	Kottukachchiya	70	70,000	70,000	70,000	70,000	0	0	70,628	0	NAQDA	NAQDA	NAQDA	NAQDA
	Maha Andarawewa	85	170,000	170,000	170,000	170,000	0	0	140,000	0	NAQDA	NAQDA	NAQDA	NAQDA
	Pahariya	74	111,000	111,000	111,000	111,000	0	150,000	0	0	NAQDA	NAQDA	NAQDA	NAQDA
	Devalahandiya	257	514,000	514,000	514,000	514,000	0	516,422	215,041	0	NAQDA	NAQDA	Divron	Divron
	Tabbowa	607	1,214,000	1,214,000	1,214,000	1,214,000	0	563,705	0	0	NAQDA	NAQDA	Divron	Divron
	Vijayakutupotha	243	364,500	364,500	364,500	364,500	0	666,667	217,674	0	NAQDA	NAQDA	Divron	Divron
	Ridiyagama	871	1,742,000	1,742,000	1,742,000	1,742,000	0	1,542,126	1,394,497	500,000	NAQDA	NAQDA	NAQDA	NAQDA
	Weerawila Wewa	567	567,000	567,000	567,000	567,000	0	567,000	531,693	150,000	NAQDA	NAQDA	NAQDA	NAQDA
	Maha Aluthgam ara	70	140,000	140,000	140,000	140,000	0	140,000	144,991	0	NAQDA	NAQDA	NAQDA	NAQDA
Monaragala	Maha wewa	80	80,000	80,000	80,000	80,000	0	110,000	83,955	53,000	NAQDA	NAQDA	NAQDA	NAQDA
	Mahagaliwewa	140	210,000	210,000	210,000	210,000	0	214,509	276,043	0	NAQDA	NAQDA	NAQDA	NAQDA
	Hamdegamuwa	210	420,000	420,000	420,000	420,000	0	420,000	425,261	0	NAQDA	NAQDA	NAQDA	NAQDA
	Handapanagala	226	452,000	452,000	452,000	452,000	0	452,000	458,081	0	NAQDA	NAQDA	NAQDA	NAQDA
	Kiribban wewa	375	375,000	375,000	375,000	375,000	0	375,000	389,076	0	NAQDA	NAQDA	NAQDA	NAQDA
	Muthukandiya	560	840,000	840,000	840,000	840,000	0	840,000	861,874	0	NAQDA	NAQDA	NAQDA	NAQDA
	Urusita wewa	262	393,000	393,000	393,000	393,000	0	393,000	422,192	0	NAQDA	NAQDA	NAQDA	NAQDA
	Balaharuwa wewa	150	150,000	150,000	150,000	150,000	0	150,000	150,000	0	NAQDA	NAQDA	NAQDA	NAQDA
	Gestupana wewa	80	120,000	120,000	120,000	120,000	0	120,000	120,000	0	NAQDA	NAQDA	NAQDA	NAQDA

Future strategies and conclusion

The comprehensive R&D project 'Improved productivity, efficiency and sustainability of the culture-based fishery for finfish and giant freshwater prawn in Sri Lankan reservoirs' (FIS/2018/157) has produced tangible outcomes for sustainable development of CBF of finfish and FWP. As revealed from the value chain analysis of FWP, there is an obvious imbalance of financial benefits to the market chain players in various nodes. Of the market-chain players, the producers (such as fishers), collectors and middlemen are least benefited financially while the major monetary beneficiary is the exporter. According to the existing strategy, members of the fisheries societies should bear the cost of stocking of FWP post larvae, which appears to be an additional financial burden to them. This benefit-sharing method therefore needs to be revisited, and accordingly, the exporters are needed to be motivated to bear the cost of stocking for sustainability of FWP CBF.

Also, there is additional research need in future for screening broodstock for better genetic quality. As the broodstock of *M. rosenbergii* is wild caught, their genetic variability may not be uniform, especially due to the fact that this species tends to interbreed with other *Macrobrachium* species in the wild.

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2 Culture-based fisheries – limnology, fisheries biology and ecology



A small portion of finfish (tilapia) at Mahadivulwewa Reservoir, Sri Lanka.
Photo: Professor Asanka D Jayasinghe.

2.1 Analysing the agrarian reservoir environment to optimise culture-based fisheries in Sri Lanka

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Abstract

Compared to the long agrarian history of Sri Lanka, inland fisheries in agrarian reservoirs are a recent development based mainly on introductions of exotic species. The aim of this short review is to analyse published information on agrarian reservoir environment and its suitability for fisheries production. In global scale, total fisheries production keeps rising due to both marine and inland aquaculture inputs, and a similar trend can be found in Sri Lanka as well. The development of culture-based fisheries (CBF) in agrarian reservoirs was not efficient at first, due to lack of knowledge on the limnological properties of the reservoirs. Since then, several scientists have formulated relationships between fish yield and the reservoir nutrient levels and other factors deciding primary production. Lately, indigenous riverine giant freshwater prawns (GFP) were introduced to the reservoir systems as a culturable species to diversify the catch and boost the income of rural fishing communities. Despite the continued stocking, the catch of GFP in return was not comparable. As a solution, proper scientific investigations on harvesting techniques, assessment of existing biomass, GFP distribution in microhabitats and their interactions with the agrarian reservoir environment and co-existing species, were subject to research.

Keywords: *culture-based fisheries, limnology, nutrient dynamics, giant freshwater prawn*

Introduction

Agrarian reservoirs are an intrinsic part of the hydraulic civilisation that ruled throughout more than 2500 years of written history of Sri Lanka (Brohier 1934; Brohier 1937; Shand 2002). It has resulted in more than 30,000 reservoirs and anicuts throughout the island especially in the dry zone (DAS 2000). It has been estimated to have about 3 ha of reservoir area for every km² of the island, probably the highest density of reservoirs in the world (De Silva 1988; Piet 1996). In the global context, major objectives of reservoir constructions are

hydroelectric power generation or irrigation and agriculture or both. Nevertheless, there may be secondary objectives such as flood protection, aesthetic value, religious reasons and fishing purposes (De Silva et al. 1991). In Sri Lanka, the vast majority of the reservoirs are meant for paddy cultivation since ancient times. Compared to the long agrarian history of Sri Lanka, inland fisheries development as a sector started in the last century with time-to-time introduction of exotic species suitable for lacustrine environment into those agrarian reservoirs.

Though there are some significant differences between reservoirs and natural lakes, after the initial filling period, a dammed reservoir behaves just like a natural lake (Straskraba 1998). Therefore, despite their origin, man-made lakes (= reservoirs) also synchronise well with nature as time goes on. Hence, apart from the major reasons for which the reservoirs are built such as agriculture, irrigation, hydroelectric power generation, they are important as freshwater habitats from an ecological point of view and as sources of cheap protein supply from fisheries. Owe to this comparatively shorter fisheries history, still there are information gaps regarding the suitability of the dry zone reservoir environment for achieving optimum fisheries production to contribute to the country's economy significantly. The aim of this short review is to analyse published information on agrarian reservoir

environment relating it to the associated fisheries production and find the way forward with the current research.

Significance of inland fisheries

Significance of inland fisheries is well demonstrated in global fisheries statistics compiled by the Food and Agriculture Organization (FAO) of the United Nations (Figure 2.1.1). According to FAO (2024) the total fish production in the world has increased from 20 million tonnes in the 1950s to 185 million tonnes in 2022. But the traditional majority of marine capture inputs has decreased its rate of increase and levelled off by the 1980s. The total production keeps rising thanks to the inputs from aquaculture both marine and inland. Of that aquaculture production, more than 26% comes from the non-fed aquaculture under which culture-based fisheries (CBF) are considered.

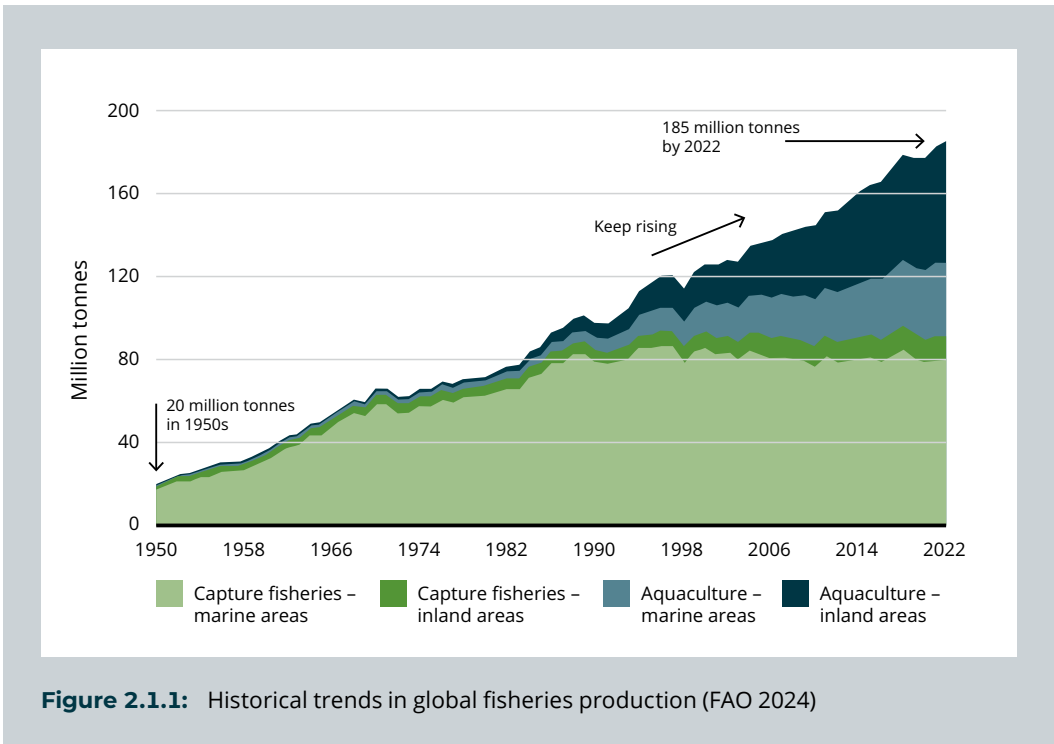


Figure 2.1.1: Historical trends in global fisheries production (FAO 2024)

Similar trends can be found in Sri Lanka as well (Figure 2.1.2) where inland fisheries contributed less than 10% of the total fish production in the 1970s and increased up to 20% by the 1980s (Silva et al. 2006). This boost occurred with the introduction of exotic tilapia into the reservoirs of Sri Lanka. However, cultural influences always took place deciding the existence of inland fisheries and the production

declined without government support to the sector. The situation was rectified later, thereafter inland fisheries gained momentum again as shown in Figure 2.1.3. Before losing government support the total inland fisheries had reached about 40,000 t/year. Though it dropped without government support, now it has passed the 80,000 t/year limit.

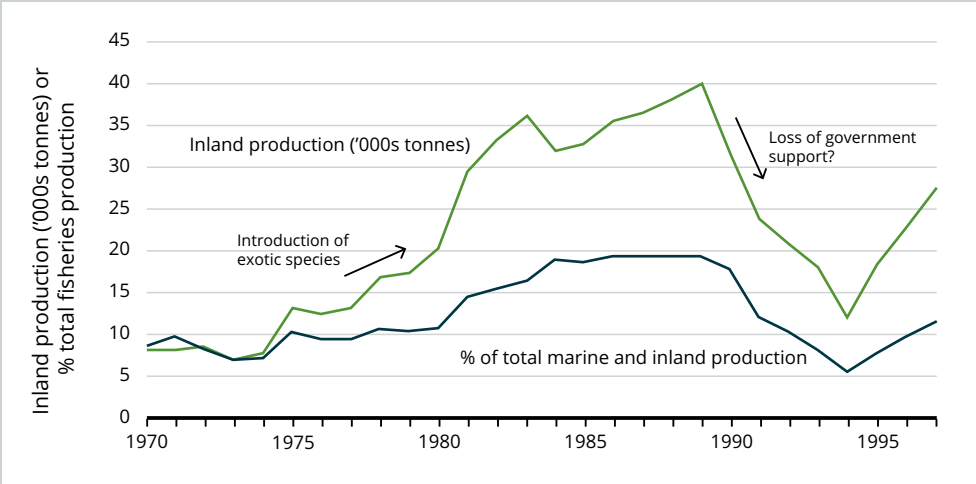


Figure 2.1.2: Inland fish production trends in Sri Lanka in 20th century (Silva et al. 2006)

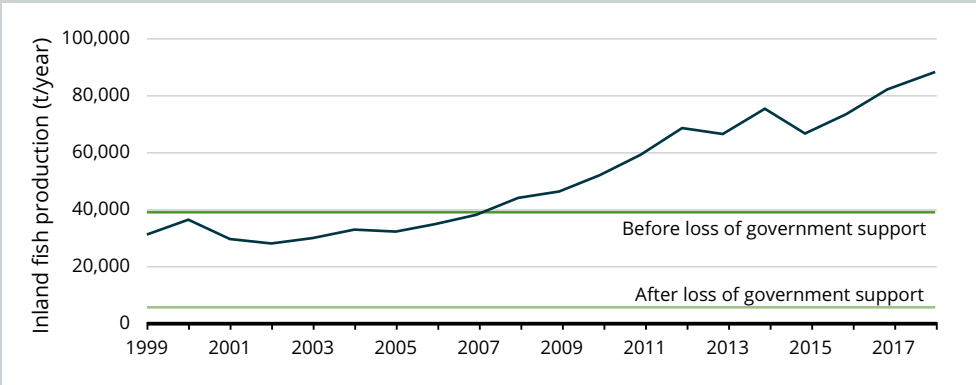


Figure 2.1.3: Recent trends in inland fish production based on the data of Ministry of Fisheries (MOF) (2019)

Culture-based fisheries in agrarian reservoirs

During the colonial period, paddy culture was neglected by the British rulers, so were the agrarian reservoirs. An economic value was induced to fish during the 1890s with the introduction of *Salmo trutta* and *Oncorhynchus mykiss* to hill country streams to develop sport fishing for British people (De Silva 1988). Subsequently, Chinese and Indian carps and tilapine species were introduced to lacustrine water bodies in order to develop commercial fisheries. Though fish production is on average higher in rivers than in lakes in other parts of the world (Randall et al. 1995), there is no riverine commercial fishery in Sri Lanka possibly due to rapid water flow, lack of extensive flood plains and low species richness (De Silva 1988). Indigenous species found in reservoirs are the same smaller riverine species spread through ephemeral water courses during rainy seasons. Introduction of exotic species filled the niches in reservoir environments supporting the development of inland fisheries. However, there is no evidence whether the authorities considered environmental aspects of agrarian reservoirs when carrying out those exotic fish introductions.

Culture-based fishing strategy is a hybrid of capture fishing and aquaculture. Here the farm-produced seed are released to a water body, which is beyond the control of fishermen and are recaptured upon reaching a desirable size. CBF can also be included under the fisheries enhancement strategy by definition, where there is human intervention in the life cycle of fish species (Lorenzen et al. 2001). The efficiency of harvesting in CBF is largely dependent on the size and depth of the culture system. Since it has been proven that the fish yield is inversely proportionate to the surface

area of a water body (Amarasinghe 1998; De Silva 2003), smaller reservoirs are better for inland fisheries enhancement.

Mendis (1965) pointed out first the suitability of non-perennial reservoirs of Sri Lanka for CBF enhancement. With that, there were infrequent instances of stocking and harvesting of tilapias in village reservoirs (Indrasena 1965). However, after the recommendations of FAO experts (Rosenthal 1979; Oglesby 1981), the fisheries authorities in Sri Lanka tried to formalise the development of CBF in non-perennial reservoirs since the early 1980s (Thayaparan 1982; Chandrasoma and Kumarasiri 1986). It was observed that through proper management of seasonal reservoirs, a yield over 1,000 kg ha⁻¹ yr⁻¹ could be easily obtained (Thayaparan 1982; Chandrasoma and Kumarasiri 1986). However, this program did not sustain after the 1980s. De Silva (1988) predicted such an occurrence and indicated that one of the primary reasons for failure would be the inappropriate selection of water bodies due to lack of knowledge on their limnological properties.

Limnological aspects for fisheries in agrarian reservoirs

It is evident that the management of lakes or reservoirs can be facilitated through investigation of their limnology (Dillon and Rigler 1974; Carlson 1977). Some have reported on the limnological characteristics of small water bodies in relation to CBF where such fisheries management practices occur, for example, oxbow lakes in Bangladesh (Hasan et al. 2001; Hasan and Middendorp 1998) and farmer-managed small reservoirs in Vietnam (Nguyen et al. 2001). During fish introductions, main physicochemical parameters of the water should be at a status similar to the place of fish origin and therefore should not be



limiting for the survival of those exotic species (Li and Xu 1995; Sugunan 1995). Therefore, CBF in Sri Lanka, which is relying on exotic species, should pay attention to the prevailing limnological conditions in the reservoirs for achieving better results.

In non-perennial reservoirs of Sri Lanka, some limnological measurements have been made as a routine, parallel to the data collection of CBF yield, without attempting to investigate the underlying relationships between fish yield and limnology (Thayaparan 1982; Chandrasoma and Kumarasiri, 1986). Gradually this trend was changed by the Sri Lankan scientists who understood the importance of studying limnological parameters of reservoirs in relation to the expected fisheries output (Amarasinghe et al. 1983; Amarasinghe and Upasena 1985; Amarasinghe 1998; Nissanka et al. 2000).

Figure 2.1.4 shows such important relationships derived for perennial reservoirs by taking 11 reservoirs as a sample. Relationship of chlorophyll-a content (Chl-a) is considered here with several independent variables, i.e. dissolved and total phosphorus; CA = catchment area; MEI_a = morphoedaphic index based on alkalinity (MEI_a = alkalinity in mgL⁻¹ / mean depth in m); MEI_c = morphoedaphic index based on conductivity (MEI_c = conductivity in μScm^{-1} / mean depth in m); RC = reservoir capacity in km³ and RA = reservoir area. Since chlorophyll-a is directly related to the primary production of the water body these relationships can be considered as proxies for fish production (Nissanka et al. 2000).

In a country with thousands of reservoirs scattered over a vast area, to get a generalised picture on limnological conditions, it is always better to select a larger sample size. Jayasinghe et al. (2005a) selected 45 seasonal reservoirs randomly

from 5 administrative districts and studied variations in 13 limnological parameters. When samples were ordinated in a Principal Component Analysis (PCA) based on their limnological conditions, chlorophyll-a showed a high variability across the dataset (Figure 2.1.5). Conductivity was not a limiting factor for those reservoirs as all of those were bearing higher values. Trophic status of the studied reservoirs was analysed following trophic state indices (TSI) described by Carlson (1977) and Carlson and Simpson (1996). In oligotrophic water bodies TSI calculated using Secchi disk depth (SDD), total phosphorus (TP) and chlorophyll-a (Chl-a) should be more or less similar. When TSI (Chl-a) is well below the other 2 indices, there is no comparable algae production in the water although there is higher turbidity and higher TP contents. That means water is turbid not because of algae but because of mud. Results showed that the non-perennial reservoirs of Sri Lanka were turbid with non-algal particulates and/or colour (Figure 2.1.6). As a result, fishery managers must rely more on chlorophyll values when estimating the productivity of those small waterbodies rather than using much easier tool like SDD (Jayasinghe et al. 2005b).

Morphometric parameters of reservoirs, catchment characteristics and land-use patterns also give clues regarding respective productivity levels of the reservoirs, which can be attributed to the fisheries production. De Silva et al. (2001) explained that the ratio of Forest Cover plus Shrub-Land to Reservoir Capacity had significant relationships with the fish yield. Similarly, the ratio of Forest Cover plus shrub-land to Reservoir Area was significant with the fish yield. For non-perennial reservoirs smaller in size, Jayasinghe et al. (2006) demonstrated that instead of conventional morphometric parameter

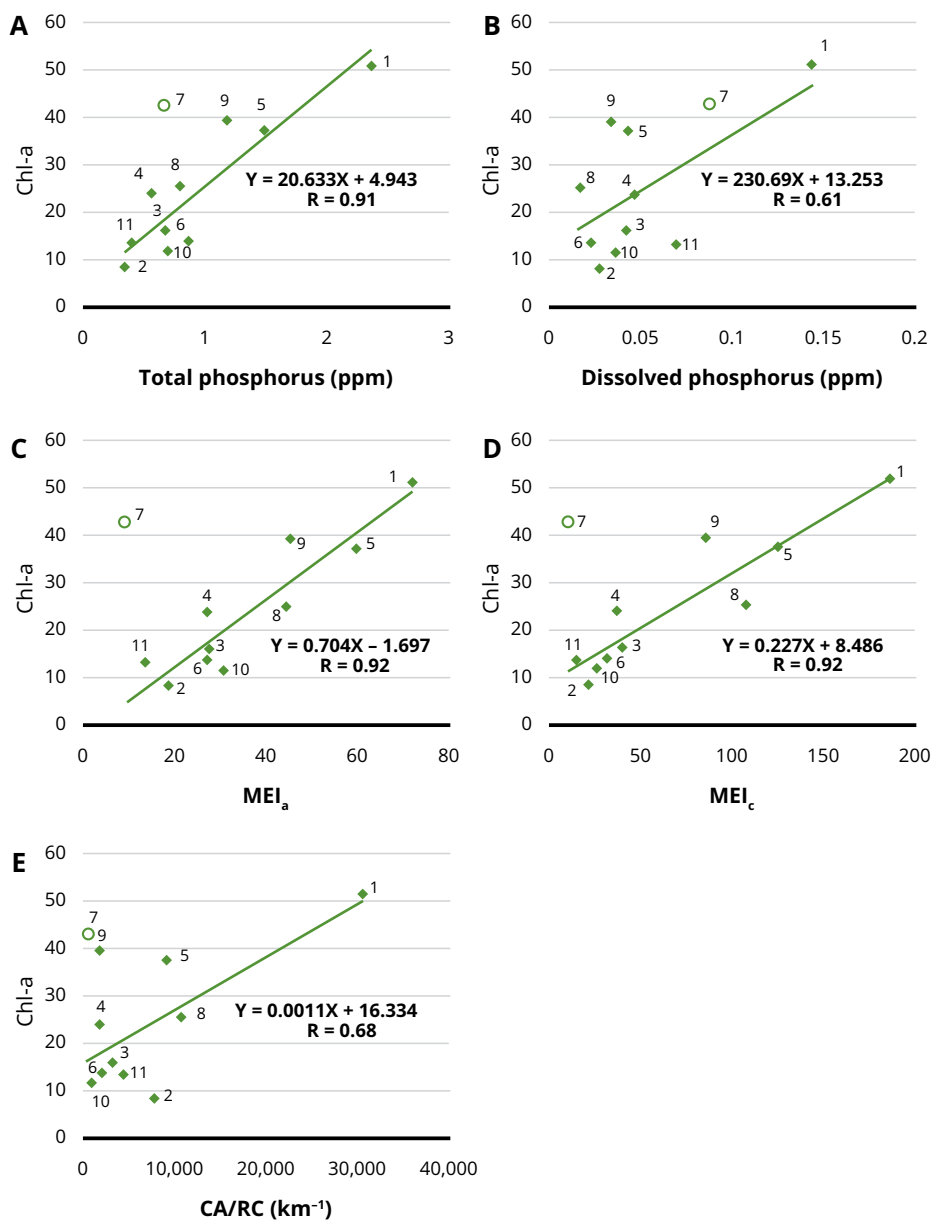


Figure 2.1.4: Relationship of chlorophyll-a content (Chl-a) with total and dissolved phosphorus; MEI_a = morphoedaphic index based on alkalinity; MEI_c = morphoedaphic index based on conductivity; and ratio between CA = catchment area and RC = reservoir capacity (Nissanka et al. 2000)

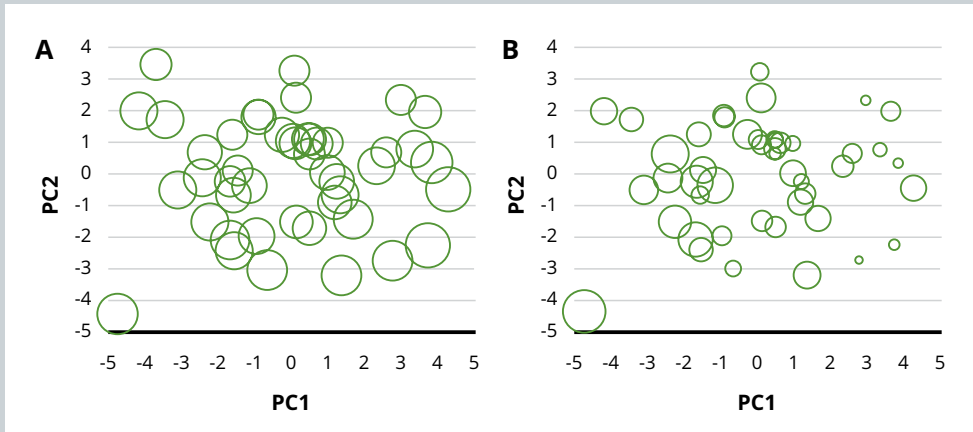


Figure 2.1.5: Bubble scale showing variations of (a) conductivity (b) chlorophyll-a among 45 seasonal reservoirs. Chlorophyll-a is showing a high variability across the dataset (Jayasinghe et al. 2005a)

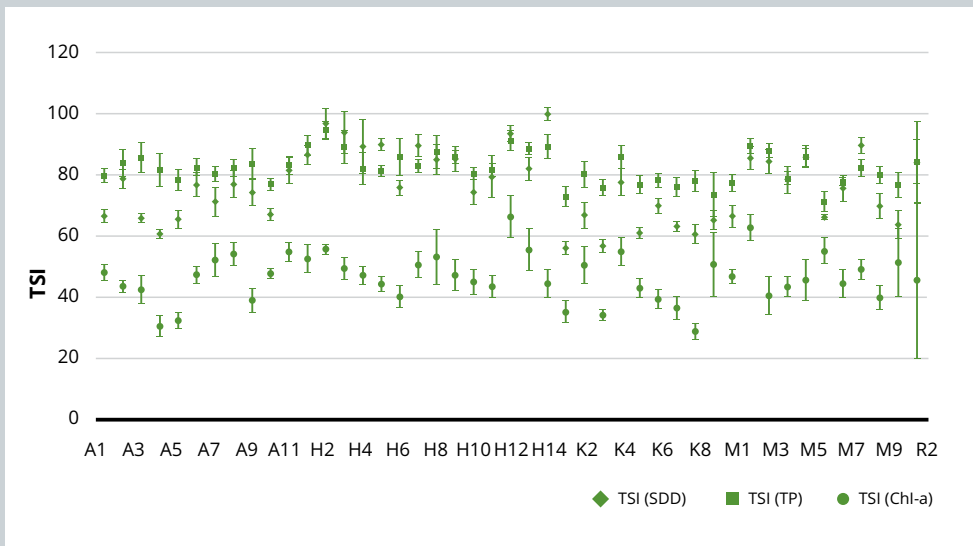


Figure 2.1.6: TSI measured using SDD, TP and Chl-a for 45 seasonal reservoirs. A, H, K, M and R depict the districts, Anuradhapura, Hambantota, Kurunegala, Monaragala and Ratnapura, respectively (Jayasinghe et al. 2005b)

‘shoreline development’ in limnology, using shoreline to area ratio would be meaningful to relate with fish production. Figure 2.1.7 shows how shoreline to area ratio correlates with the chlorophyll-a content in the reservoir. Shoreline development of non-perennial reservoirs are smaller probably because those are built in a semicircular manner with a linear earthen bund on one side to hold water to capacity and having dendritic margins only on the opposite side of the bund. On the other hand, non-perennial reservoirs in Sri Lanka have mean depths ranging from 1 to 4 m, and also basins with a gradual slope. This converts the whole reservoir a littoral zone promoting higher fish production.

Livestock farming is another significant human activity influencing the reservoir productivity. Most of the rural farming communities possess cattle and buffaloes for dairy production as well as in support of their day-to-day agricultural activities. All village livestock is grazing within the catchment of the village reservoir and contribute a large amount of nitrogen and phosphorus through their fecal matter (Jayasinghe and Amarasinghe 2007). It has been estimated that approximately 70% of phosphorus in feed concentrates of cattle is exported to land in excreta. Nevertheless, when inundated, the nutrient release rate from dung is normally higher than that of submerged vegetation (Nash and Halliwell

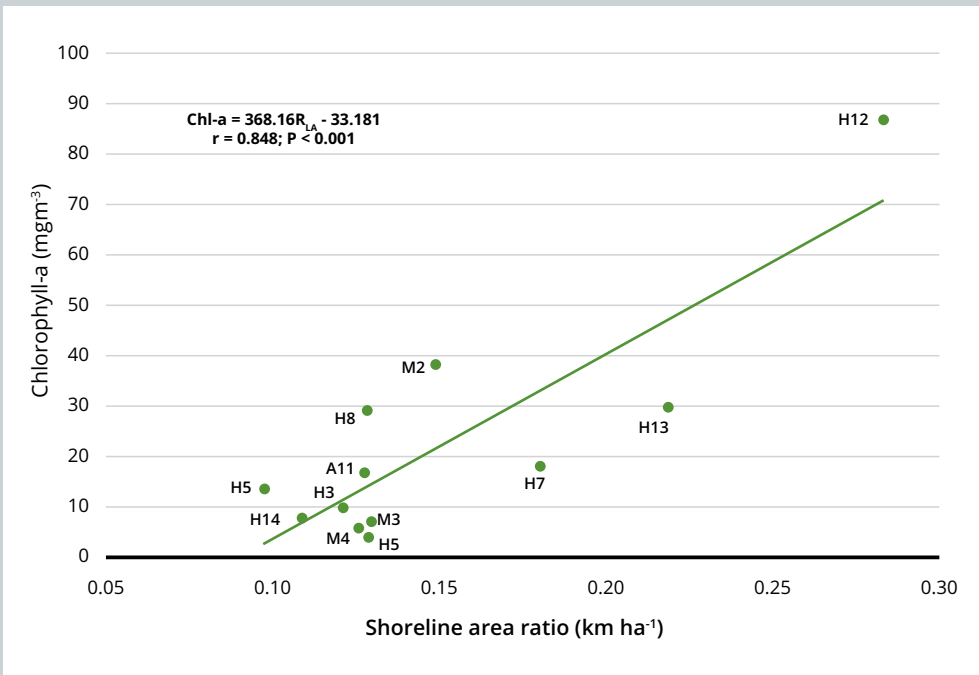


Figure 2.1.7: Relationship of shoreline to area ratio (km ha⁻¹) to surface Chl-a content (mgm⁻³) in 12 reservoirs examined (Jayasinghe et al. 2006)

2000; Bravo et al. 2003). Jayasinghe et al. (2016) estimated the total average cattle/buffalo-borne organic matter content in a model reservoir as 0.323 kg/buffalo. Jayasinghe et al. (2018) further clarified the relationships between the cattle/buffalo density and the nutrient and productivity parameters in the reservoir, thereby the fish yield as shown in Figure 2.1.8.

Recent trends in CBF and way forward

It has been several decades since CBF started to play a major role in fish production in Sri Lanka. It has relied mainly on exotic tilapia, Chinese carps and Indian carps until the indigenous riverine GFP was introduced to the reservoir systems as a culturable species to diversify the

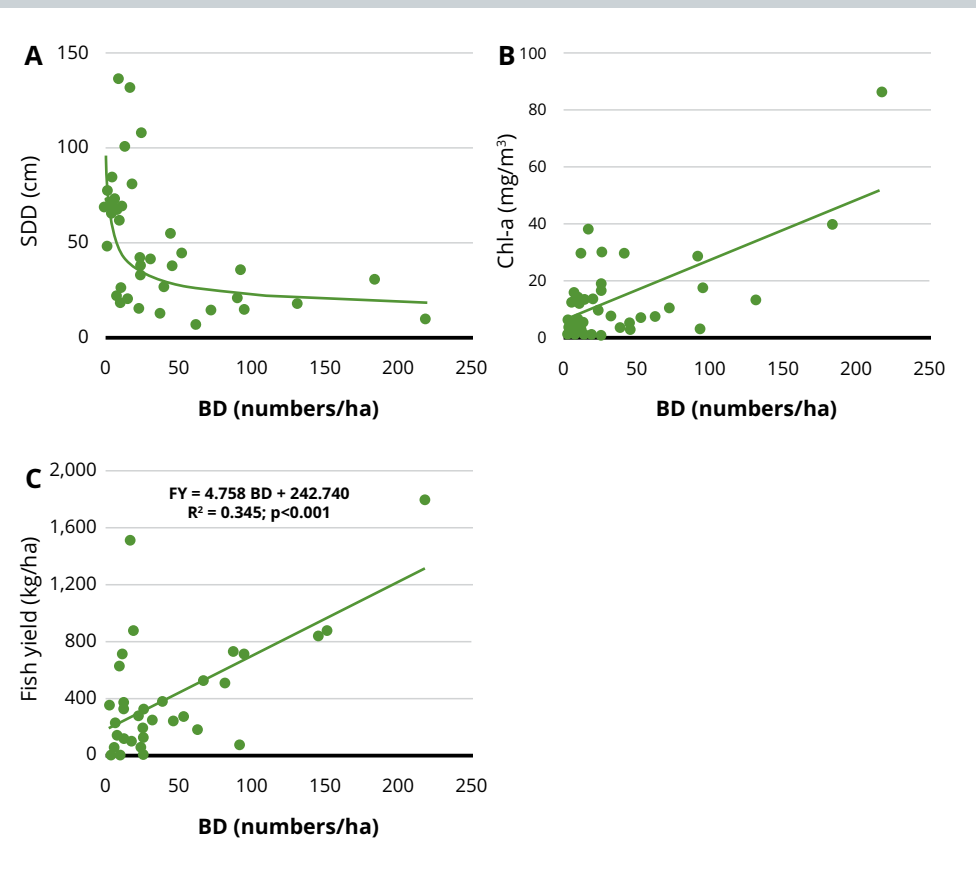


Figure 2.1.8: Correlations between the cattle/buffalo density (BD) in the reservoir catchment and (a) SDD; (b) Chl-a content; (c) total annual fish yield in seasonal reservoirs investigated by Jayasinghe et al. (2018)

catch and boost the income of rural fishing communities. Trials of introducing GFP to seasonal reservoirs were carried out since the start of this millennium (Wijenayake et al. 2005), although hatchery techniques to produce sufficient numbers of post larvae of GFP was not robust until 2007. According to Chandrasoma and Pushpalatha (2018), during the 2009 to 2015 period, over 12 million post larvae of GFP per year on average have been stocked into all 3 size categories of reservoirs: major perennials, medium perennials and minor perennials. Since then, this stocking continues to date despite lower GFP catches in return for higher inputs. As a solution, proper scientific investigations on harvesting techniques, assessment of existing biomass, GFP distribution in microhabitats and their interactions with the agrarian reservoir environment and co-existing species were essential. ACIAR funded these investigations, preliminary investigation was completed (Yomal et al. 2019, Yomal et al. 2020, Jones et al. 2021) and past stocking and harvesting data were analysed (Digamadulla et al. 2023). Detailed investigations on the agrarian reservoir environment and its effect on GFP and other CBF species are being conducted to date.

Status of the current research on agrarian reservoir environment and optimising CBF yield is being described in other chapters in this report. As recommended by Jones et al. (2021) further investigations of reservoir morphometry, sediment organic matter and other limnological factors are being conducted. In addition, the distribution of GFP, other exotic fish used in CBF and co-existing indigenous species in different microhabitats of the reservoir is being analysed (Mithila et al. 2023). The feeding interactions of all those economically important co-existing species are being

analysed using stable isotopic evidence rather than depending on the conventional gut content analyses (Silva et al. 2023). This novel technique gives evidence on long-term assimilation of different food types instead of something like taking a snapshot of the last meal through the gut content analyses. Also, it allows us to imagine predator-prey relationships occurring underwater, which are not easily visible, and to construct the agrarian reservoir food web giving an emphasis on CBF. Another important aspect is to think about food safety when utilising fish or GFP from CBF in agrarian reservoirs under the circumstance of heavy usage of agrochemicals in these environments. Initially, it was attempted to investigate the influence of potential heavy metal accumulation in a few reservoirs stocked with GFP (Lakchani et al. 2019). Then the experiments were expanded to pollution and pesticide residues in agrarian reservoirs in addition to heavy metals. Under that research, a review on methodologies used in analysing microplastics in freshwater environments has been already published (Lakchani et al. 2025) while the results of the other analyses are on the way.

Conclusion

Total fisheries production in Sri Lanka keeps rising due to both marine and inland aquaculture inputs, in which CBF play a major role. The efficiency of harvesting in CBF is largely dependent on the size and depth of the culture system. Chlorophyll-a content of the reservoir and its relation to alkalinity and conductivity along with reservoir capacity and area are important in determining fish production in perennial reservoirs. Non-perennial reservoirs are turbid with non-algal particulates and/or colour, therefore, have to rely on chlorophyll values when estimating the

productivity rather than using much easier tools like SDD. The whole reservoir acts as a littoral zone promoting higher fish production in non-perennial reservoirs. Shoreline to area ratio and cattle/buffalo densities in the catchment also correlate with the chlorophyll-a content in the reservoirs. Catches of recently introduced GFP were not comparable with continued stocking; therefore, proper scientific investigations have been initiated on harvesting techniques, assessment of existing biomass, distribution in microhabitats and their interactions with the agrarian reservoir environment and co-existing species.

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2.2 The culture-based fishery of giant freshwater prawn in Sri Lankan perennial reservoirs: evaluation of past stocking and production data

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Abstract

The present study has been articulated as a system approach to sustainably develop the high valued giant freshwater prawn (FWP) CBF in Sri Lankan perennial reservoirs. The approach comprised of (a) appraising past stocking practices; (b) assessing reservoir capacity and CBF performance with multiple strategic scientific studies; (c) investigating possible measures to increase the production and recapture; (d) identifying the market driving factors; and (e) understanding the constraints in the management of a socioecological system. Based on the scientific evidence, recommendations for better approaches for future FWP CBF have been suggested.

Keywords: culture-based fishery, giant freshwater prawn, reservoir

Introduction

In Sri Lanka, CBF of FWP (*M. rosenbergii*) is at the early stage of development. The National Aquaculture Development Authority of Sri Lanka (NAQDA) initiated the CBF of FWP in seasonal reservoirs in 2001 (Wijenayake et al. 2005; Amarasinghe and Wijenayake 2015), later extended to perennial reservoirs by 2011 (Chandrasoma

et al. 2015; Chandrasoma and Pushpalatha, 2018). Several recent studies identify that among all freshwater species, as FWP is high valued with solely exceptional export demand that has a potential to support the economic development of rural fisher communities (Asoka et al. 2015; Pushpalatha et al. 2017; Pushpalatha et al. 2020), the monetary return is high even under a low recapture scenario. In the



present analysis, we attempted to identify the knowledge gap for better performance of CBF of FWP that hinders the optimisation of production in Sri Lankan perennial reservoirs. This analysis is aimed at achieving sustainable and better harvesting of FWP to enhance income of reservoir fisher communities. For this purpose, the present study was equipped with a system approach:

- a. to evaluate the stock and recapture returns based on the data gleaned from NAQDA (2008 to 2019)
- b. to study the performance of FWP under the controlled stocking trials (2 cycles) in relation to biological productivity of the water bodies and identify those characteristics that will improve the effectiveness of the recapture strategy of FWP in Sri Lankan reservoirs
- c. to examine the most effective method of capture with regard to catch rate and quality of product to provide recommendations on the most appropriate gear type for FWP
- d. to map the value chain of GFP and address the related socioeconomic and livelihood features of the fishery.

Materials and methods

Information about reservoir extent, stocking and CBF harvest data from 2009 to 2019 was obtained from NAQDA. Further, the reservoirs were geo-positioned and spatial-temporal investigation was accompanied for the 769 reservoirs (Figure 2.2.1). Stocking densities (SD) of tilapia, carps and FWP were determined as numbers ha^{-1} , yr^{-1} and CBF yields for each species category as $\text{kg ha}^{-1} \text{yr}^{-1}$ in individual reservoirs for each year separately.

Further, data from an empirical study with different stocking strategies and stocking

densities (as detailed in Table 2.2.1) across 48 reservoirs (Figure 2.2.2), selected using a 'purposive sampling method' (Palys 2008) were also analysed. Through a reconnaissance survey conducted in the Fisheries Committees of the selected reservoirs, information about the nature harvesting and management strategies of CBF were gathered.

Along the 48 reservoirs, sampling was conducted at bi-monthly intervals to determine selected limnological features such as Secchi-depth, conductivity, pH, temperature, dissolved oxygen and chlorophyll-a using standard methods (APHA 2012). Information on fish harvests were gleaned from data log sheets of fisheries societies. Attempts were made to evaluate the most effective method of capture and assess product quality in relation to gear type and time of capture of GFP reservoirs.

All market actors involved in the market chain of the FWP were examined and their roles and inter-relationships within the selected reservoirs were determined through the questionnaire survey, considering both local consumption and export market. The value chain was examined to identify constraints and opportunities, possible market-based solutions and interventions. A need assessment was conducted considering several other key factors, including access to basic production inputs, risk coping mechanisms, relationships among value chain participants, policies and strategies, standards and branding mechanisms, 'kickstarting' of domestic markets, promotion of potential alliances with fair-trade chains, and product differentiation to create niche markets.

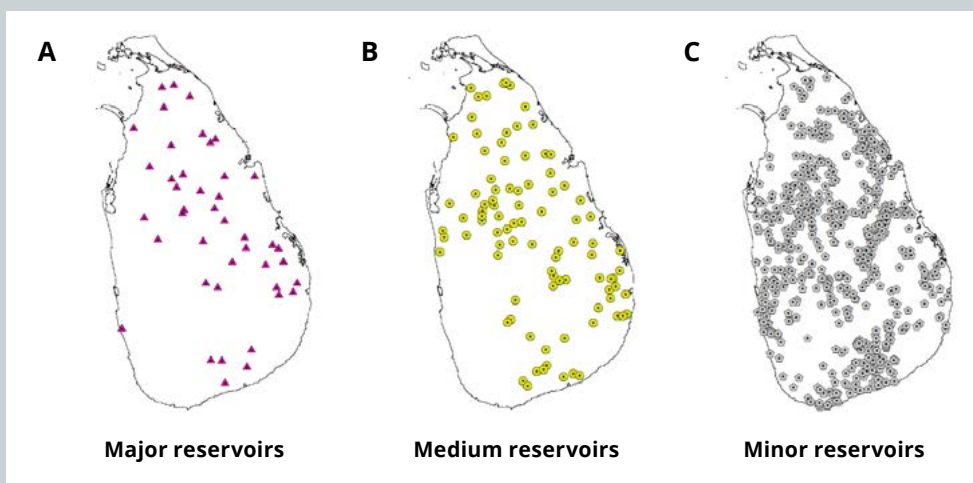


Figure 2.2.1: Distribution of perennial reservoirs in Sri Lanka where CBF was practised (according to the NAQDA database, 2009–2019)

(a) Major reservoirs (>800 ha reservoir extent), (b) Medium reservoirs (800–200 ha reservoir extent) and (c) Minor reservoirs (<200 ha reservoir extent).

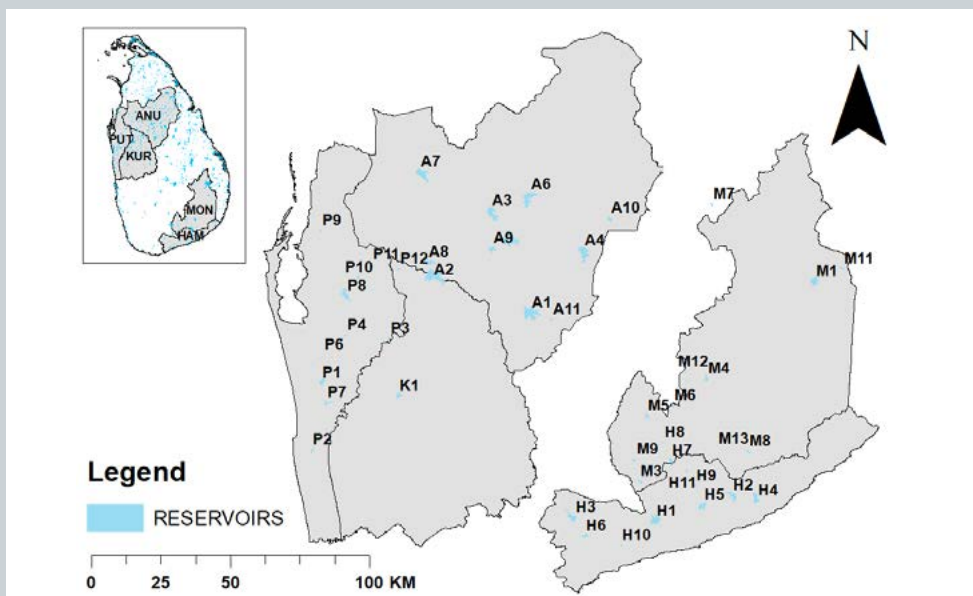


Figure 2.2.2: Selected 48 reservoirs for the current empirical study on GFP CBF

Note: For the detail of the code given in the map refer to Table 2.2.1. Selected reservoirs are located in 5 different districts: Anuradhapura (ANU), Puttalam (PUT), Kurunegala (KUR), Monaragala (MON) and Hambantota (HAM).

Table 2.2.1: Important details of selected 48 reservoirs for the empirical study

No.	RCode	District	Type	Reservoir name	Area (ha)	Stocking density (number of PL per ha)	Stocked PLs (number of PL)	Stocking strategy
1.	A1	Anuradhapura	Major	Kala Wewa	1,440	1,200	1,728,000	NIGHT
2.	A10	Anuradhapura	Medium	Kiwlekada	200	2,000	400,000	NIGHT
3.	A11	Anuradhapura	Minor	Mahaalagamawa	80	5,000	400,000	MINOR
4.	A2	Anuradhapura	Major	Rajanganaya	1,619	1,500	2,428,500	DAY
5.	A3	Anuradhapura	Major	Nuwara wewa	1,197	800	957,600	NIGHT
6.	A4	Anuradhapura	Major	Hurulu wewa	1,619	1,800	2,914,200	NIGHT
7.	A5	Anuradhapura	Major	Nachchaduwa	1,781	1,000	1,781,000	DAY
8.	A6	Anuradhapura	Major	Mahakanadarawa	1,457	2,000	2,914,000	NIGHT
9.	A7	Anuradhapura	Major	Maha wilachchiya	971	800	776,800	NIGHT
10.	A8	Anuradhapura	Medium	Angamuwa	445	800	356,000	NIGHT
11.	A9	Anuradhapura	Medium	Thuruwila	280	2,500	700,000	DAY
12.	H1	Hambantota	Major	Ridiyagama	871	2,300	2,003,300	DAY
13.	H10	Hambantota	Minor	Kattakaduwa maha wewa	80	1,800	144,000	DAY
14.	H11	Hambantota	Minor	Maha Aluthgamara	70	2,200	154,000	DAY
15.	H2	Hambantota	Medium	Weerawila Wewa	567	2,100	1,190,700	DAY
16.	H3	Hambantota	Medium	Muruthawela	516	1,800	928,800	DAY
17.	H4	Hambantota	Medium	Yoda Wewa	486	1,700	826,200	DAY
18.	H5	Hambantota	Medium	Badagiriya	381	2,100	800,100	DAY
19.	H6	Hambantota	Medium	Udukiriwila	263	1,700	447,100	DAY
20.	H7	Hambantota	Minor	Mahagalwewa	140	1,800	252,000	DAY

No.	RCode	District	Type	Reservoir name	Area (ha)	Stocking density (number of PL per ha)	Stocked PLs (number of PL)	Stocking strategy
21.	H8	Hamban-tota	Minor	Maha wewa	80	3,200	256,000	DAY
22.	H9	Hamban-tota	Minor	Pahala Andara	80	2,500	200,000	DAY
23.	K1	Kurunegala	Medium	Magalla wewa	263	1,000	263,000	DAY
24.	M1	Monaragala	Medium	Muthukandiya	560	1,900	1,064,000	DAY
25.	M10	Monaragala	Minor	Alugalge wewa	70	1,100	77,000	DAY
26.	M11	Monaragala	Minor	Sugaladevi wewa	50	1,000	50,000	DAY
27.	M12	Monaragala	Minor	Buduruwagala	125	1,600	200,000	DAY
28.	M13	Monaragala	Minor	Gestupana wewa	80	2,000	160,000	DAY
29.	M2	Monaragala	Medium	Kiribban wewa	375	1,800	675,000	DAY
30.	M3	Monaragala	Medium	Urusita wewa	262	1,600	419,200	DAY
31.	M4	Monaragala	Medium	Handapanagala	226	1,500	339,000	DAY
32.	M5	Monaragala	Medium	Hambegamuwa	210	1,400	294,000	DAY
33.	M6	Monaragala	Minor	Balaharuwa wewa	150	2,000	300,000	DAY
34.	M7	Monaragala	Minor	Demodara wewa	100	1,500	150,000	DAY
35.	M8	Monaragala	Minor	Milegama	80	1,500	120,000	DAY
36.	M9	Monaragala	Minor	Habaralu wewa	80	1,250	100,000	DAY
37.	P1	Puttalam	Medium	Devalahandiya	257	2,200	565,400	DAY
38.	P10	Puttalam	Minor	Pahariya	72	1,000	72,000	DAY
39.	P11	Puttalam	Minor	Saliyawewa	85	3,000	255,000	NIGHT
40.	P12	Puttalam	Minor	Thanguswewa	50	1,800	90,000	DAY
41.	P2	Puttalam	Medium	Karavitagaraya	256	2,000	512,000	NIGHT
42.	P2	Puttalam	Minor	Kottukachchiya	70	2,000	140,000	NIGHT
43.	P3	Puttalam	Medium	Mahauswewa	212	2,500	530,000	NIGHT
44.	P4	Puttalam	Minor	Kachchimaduwa	65	800	52,000	NIGHT
45.	P6	Puttalam	Minor	Viluka wewa	65	1,500	97,500	NIGHT
46.	P7	Puttalam	Medium	Vijayakatupotha	243	3,000	729,000	NIGHT
47.	P8	Puttalam	Medium	Tabbowa	607	1,500	910,500	NIGHT
48.	P9	Puttalam	Minor	EluwankulaMma	65	1,500	97,500	DAY

Notes:

- RCode is the code of reservoir name code.
- Type is given according to the NAQDA's reservoir classification (based on irrigation categories): Minor (<200 ha), Medium (<800 ha) and Major (>800 ha).
- Stocking strategy: DAY stocking is conducted in daylight (7 am to 6 pm) and NIGHT stocking is conducted in dark (7 pm to 3 am); twilight was systematically avoided.

Results

CBF efforts of NAQDA (2009 to 2019)

According to the NAQDA database, from 2009 to 2019, the average number of reservoirs where CBF was practised was 769 (0.1–7,793 ha), comprising 43 major, 90 medium and 636 minor reservoirs (Figure 2.2.1). The CBF catches were dominated by tilapia ($257,046 \pm 12,876$ kg) accounting for more than 70% of the annual total catch, whereas FWP was considerably low as $5,534 \pm 634$ kg. Significant annual, seasonal and monthly variations were observed ($p=0.000$) in trends of both stocking and catch. More specifically, the seasonal variation of FWP production, which is the most noteworthy finding, indicated higher production during both south-west and north-east monsoons registering FWP yield greater than 5 kg ha^{-1} (Figure 2.2.3). Stocking of FWP was significantly low during dry months of pre-south-west monsoonal season especially in May (Figure 2.2.4).

The comprehensive recapture analysis (Figure 2.2.5) implied the following scenarios in CBF extension:

- a. lack of CBF extension (i.e. absence of CBF in reservoirs that lacked extension)
- b. no reported stocking but with catches (i.e. inland capture fisheries or unreported previous stocking)
- c. stocked but no catches (i.e. unreliability of stocking and harvesting data or extension failures)
- d. information of stocking and catches (i.e. reliable information on CBF).

The examination on the correlation between consecutive production with previous stocking shown in Figure 2.2.6 suggests that lack of robustness due to combined effects of multiple ad hoc stocking practice.

Reservoir limnology and stocking trials

According to the findings depicted in Figure 2.2.7, Figure 2.2.8 and Figure 2.2.9 the CBF performance, apart from reservoir categorisation as major, medium and minor, multiple factors influencing CBF are evident. This warrants a new classification of reservoirs for future planning of CBF. Results of the analysis indicated that the optimum SD of post larvae (PL) of FWP was $1,000 \text{ PL ha}^{-1}$ in major reservoirs; $1,500 \text{ PL ha}^{-1}$ in medium reservoirs, and $2,000 \text{ PL ha}^{-1}$ in minor reservoirs. Further, the study suggests that stocking at night is efficient – after 8 pm and before 4 am, even without artificial light to prevent predation by small cyprinids and juveniles of other predatory fishes such as snakeheads and even tilapia. Further, avoiding shallower reservoir coves to stock PLs is important for the same reason.

Catch efficiencies of FWP

Both pond and field trials of traps showed that FWP had a higher affinity to traps that are green in colour with comfortable entrance aperture, but the sizes of prawns that were caught were less than 150 g. This size was appreciably lower than the mean weight of an individual caught to gillnets ($>250 \text{ g}$) in Sri Lankan reservoirs. The catch dynamics of the FWP showed that female catches peaked in December and January near the outlets while males were in middle and near inlets of a reservoir (Figure 2.2.10 Stratum 1).

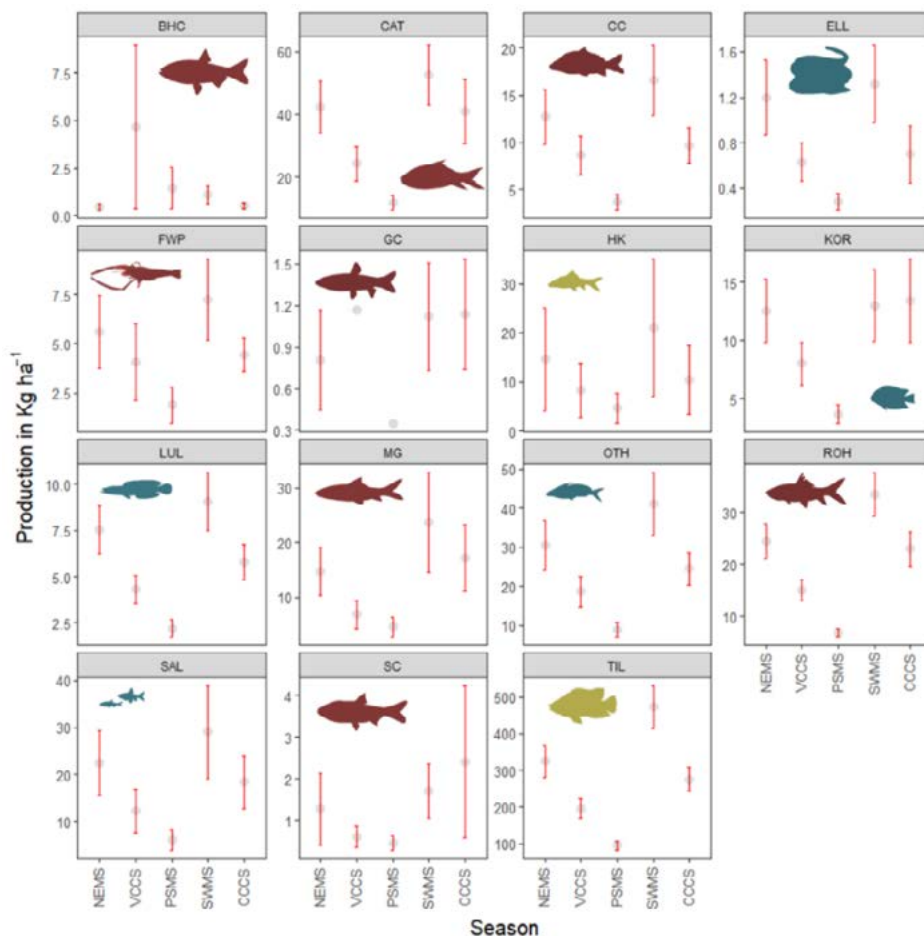


Figure 2.2.3: Plot of mean and standard error for seasonal production (kg ha^{-1}) in perennial reservoirs during 2011–2019 according to NAQDA species categories

Notes: Mean and standard error are indicated respectively by grey point and red stretched line. Seasons are: (a) the vernal convergence – convectional season (VCCS); March to April (b) the pre-south-west monsoonal season (PSMS); May (c) the south-west monsoonal season (SWMS); June to September (d) the convergence – convectional – cyclonic season (CCCS); October to November (e) the north-east monsoonal season (NEMS); December to February.

Species group: BHC – Big head Carp; CAT – Catla; CC – Common Carp; ELL – Eel; FWP – Giant freshwater prawn; GC – Grass Carp; HK – Lankan Labao; KOR – Pearl spot; LUL – Snakehead; MG – Mrigal; OTH – Indigenous Catfishes and Perch; ROH – Rohu; SAL – Indigenous minor Cyprinides; SC – Silver Carp; TIL – Tilapia.

Colours given to fishes depicts fishery category as reported by NAQDA: Green – Capture fishery; Yellow – Enhanced fishery; Red – Culture-based fishery.

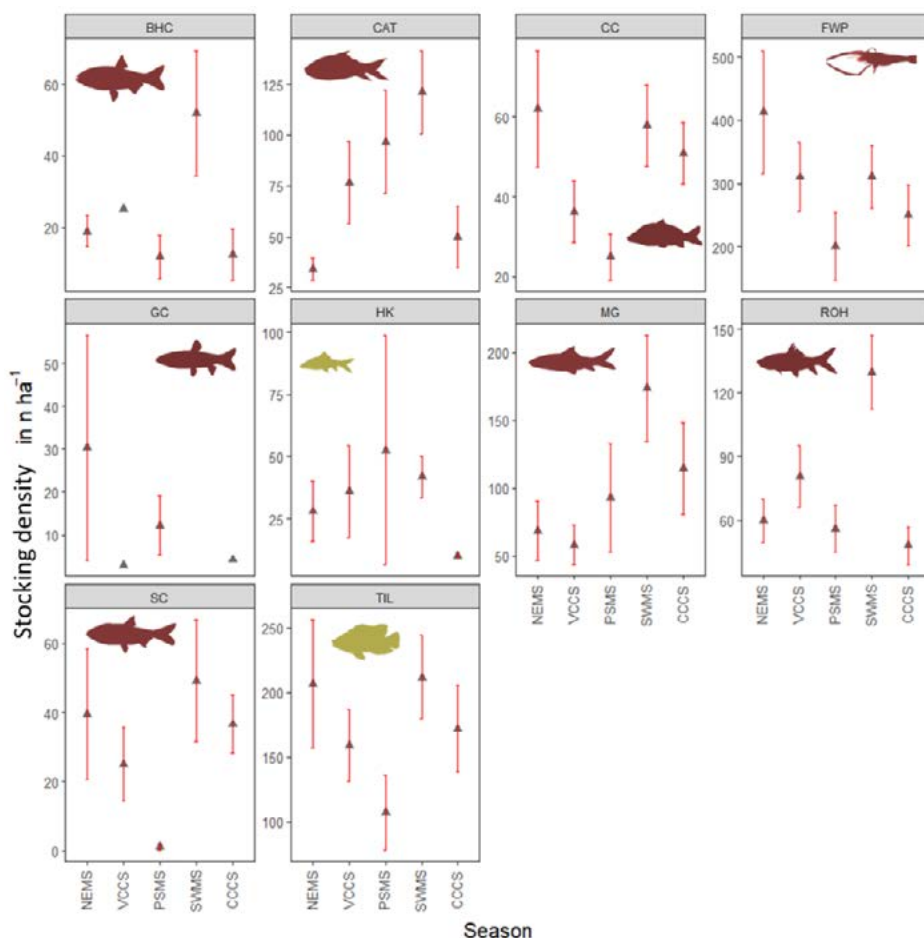


Figure 2.2.4: Plot of mean and standard error for seasonal stocking density (n ha⁻¹) in perennial reservoirs during 2011–2018/9 according to NAQDA species categories

Notes: Mean and standard error are indicated respectively by black triangle and red stretched line. Seasons are: (a) the vernal convergence - convective season (VCCS); March to April (b) the pre-south-west monsoonal season (PSMS); May (c) the south-west monsoonal season (SWMS); June to September (d) the convergence - convective - cyclonic season (CCCS); October to November (e) the north-east monsoonal season (NEMS); December to February.

Species group: BHC – Big head Carp; CAT – Catla; CC – Common Carp; ELL – Eel; FWP – Giant freshwater prawn; GC – Grass Carp; HK – Lankan Labeo; KOR – Pearl spot; LUL – Snakehead; MG – Mrigal; OTH – Indigenous Catfishes and Perch; ROH – Rohu; SAL – Indigenous minor Cyprinides; SC – Silver Carp; TIL – Tilapia.

Colours given to fishes depicts fishery category as reported by NAQDA: Yellow – Enhanced fishery; Red – Culture-based fishery.

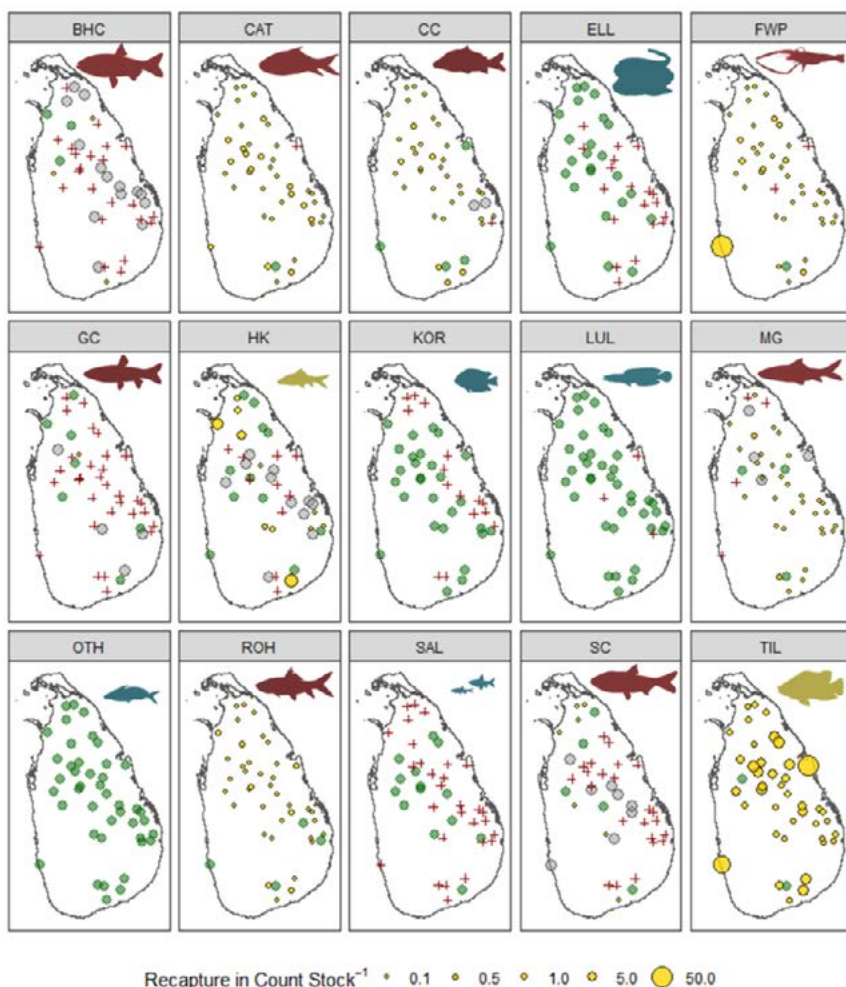


Figure 2.2.5: Thematic explanation of species or group specific reservoir fisheries status across all major perennial reservoirs of Sri Lanka, according to the NAQDA data (2011–2018/9)

Notes: Reservoirs with: (a) no stocking and catches, annotated by red '+', absence of fishery or reservoirs that lacked extension; (b) no stocking but with catches, interpreted by green points, inland capture fisheries or stocked prior to time of concern or possibly unreported stocking; (c) stocked but no catches, construed by grey points, stocking or extension failures; (d) information of stocking and catches, marked by graduated yellow points.

Species group: BHC – Big head Carp; CAT – Catla; CC – Common Carp; ELL – Eel; FWP – Giant freshwater prawn; GC – Grass Carp; HK – Lankan Labeo; KOR – Pearl spot; LUL – Snakehead; MG – Mrigal; OTH – Indigenous Catfishes and Perch; ROH – Rohu; SAL – Indigenous minor Cyprinides; SC – Silver Carp; TIL – Tilapia.

Colours given to fishes depicts fishery category as reported by NAQDA: Green – Capture fishery; Yellow – Enhanced fishery; Red – Culture-based fishery.

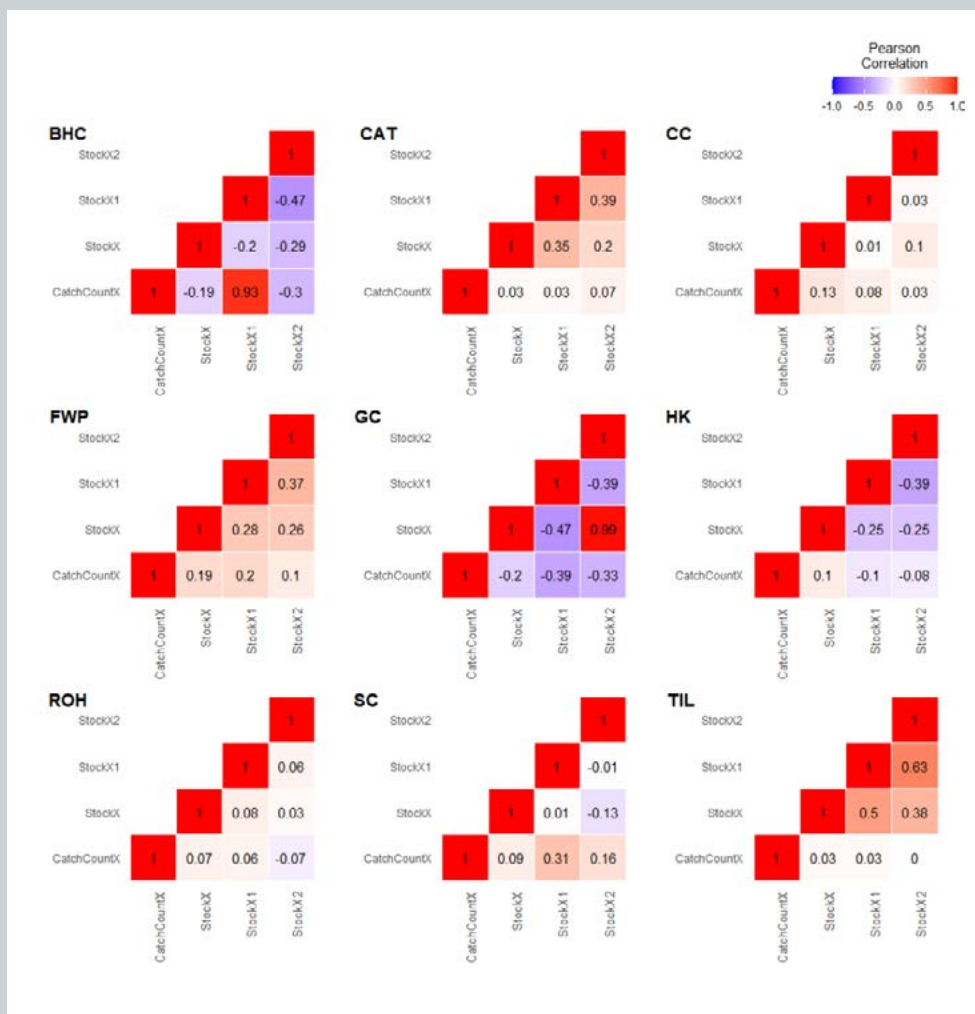


Figure 2.2.6: Pearson's Correlation between stocking and catch-converted counts (values given in intersections of 2 variables) in major perennial reservoirs during 2011–2019 according to NAQDA species categories

Note: CatchcountX is referred to catch-converted counts of year X, similarly, StockX is referred to stocking at year x. Meanwhile, StockX1 refers to stocking at year x-1 (Previous year) and StockX2 refers to stocking at the year x-2 (the year before the previous).

Species group: BHC – Bighead Carp; CAT – Catla; CC – Common Carp; FWP – Giant freshwater prawn; GC – Grass Carp; HK – Sri Lankan Labeo; ROH – Rohu; SC – Silver Carp; TIL – Tilapia. The shaded cells indicate significant correlations.

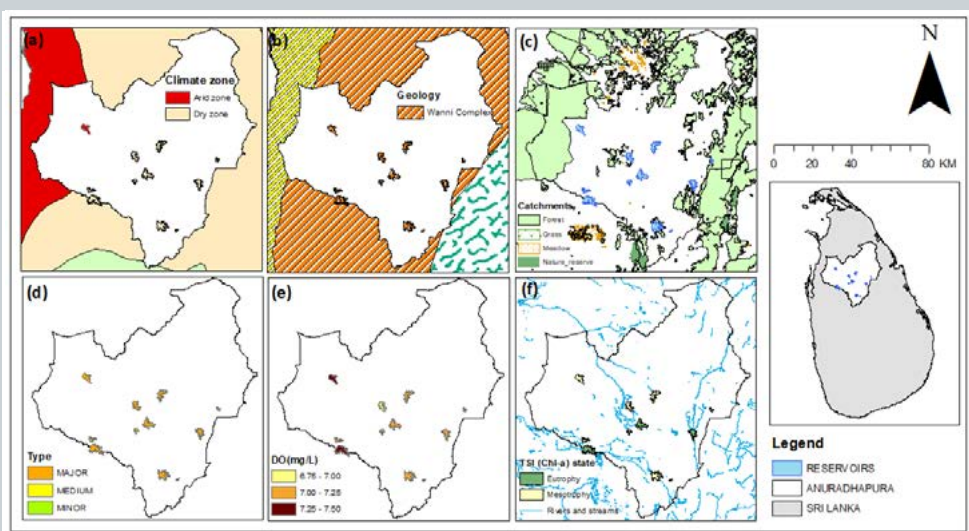


Figure 2.2.7: Maps of explanatory analysis developed for Anuradhapura district

Note: Characterisation of (a) climate zones and (b) base soil structure that a reservoir falls in; (c) Characterisation of catchments and land use; (d) Types of reservoirs; (e) Characterisation dissolved oxygen reported in the study; (f) Characterisation TSI (Chl-a) values of the study with canals and streams.

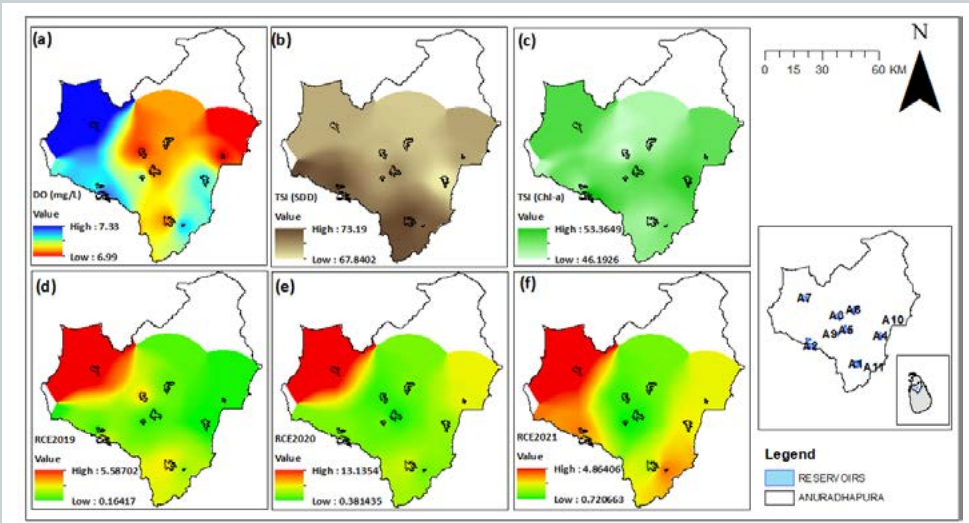


Figure 2.2.8: Maps produced in singular static density weighting analysis (DYA) for Anuradhapura district

Note: Selected environmental parameters: (a) Dissolved Oxygen; (b) TSI (SDD); (c) TSI (Chl-a); and annual recapture rates: (d) RCE 2019; (e) RCE 2020; (f) RCE 2021. RCE – Recapture efficiency of FWP.

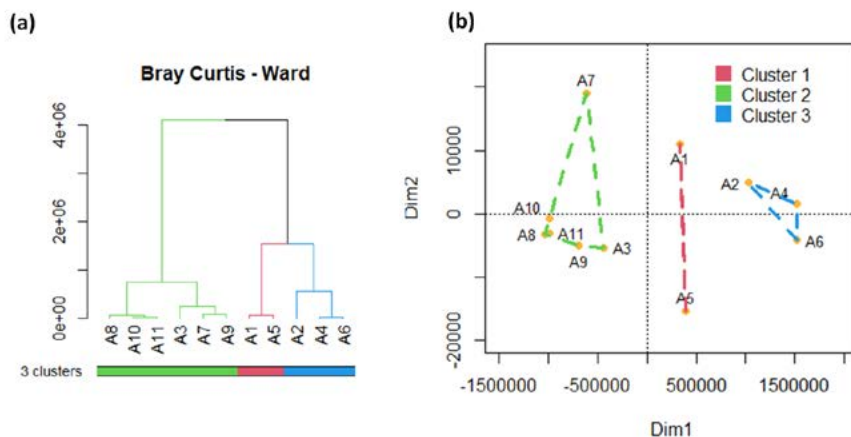


Figure 2.2.9: Results of cluster analysis and PCoA of 11 reservoirs in Anuradhapura district

Note: (a) Dendrogram of clusters and (b) position of reservoirs in a multidimensional space (PCoA).

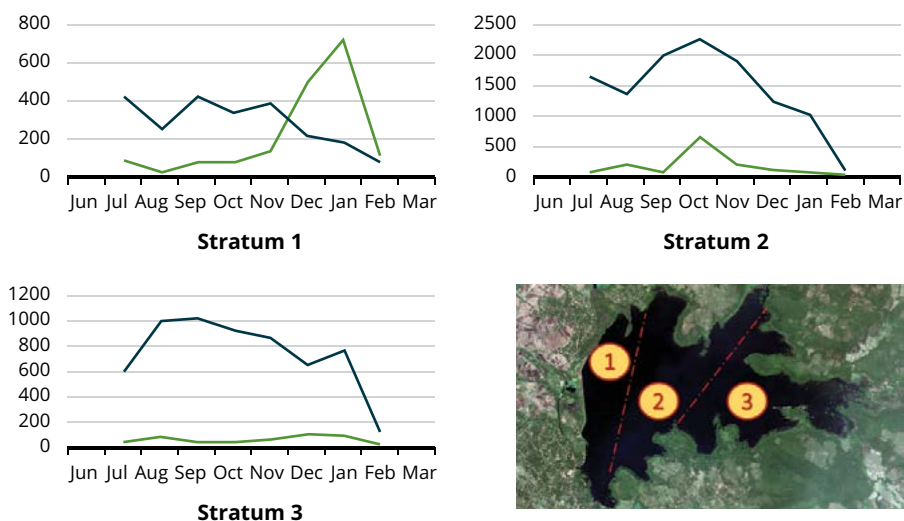


Figure 2.2.10: Catch dynamic of FWP observed in Huruluwewa

X axis – Months and Y axis – Catch in kg.

Market chain, socioeconomic and interventions

The market-chain analysis suggests that there is disparity in profit sharing across the market-chain actors, having greater benefits for middlemen and exporters at the current market scenario (Table 2.2.2). Although increases bring about significantly increased exports, the sustainability of

FWP CBF is questionable due to prevailing disparity of benefit sharing among the stakeholders (Table 2.2.3), which might be a point of concern in the policymaking process. Possible approaches such as public-private interventions to bear the cost of stocking of FWP PLs should be considered with their potential pros and cons.

Table 2.2.2: FWP price variations across the market chain (price in USD per kg)

Product and size categories of GFP		Reservoir or fisher price	Farm-gate or middleman price	Sri Lankan export price	Thailand retail selling price
FM and OC	130 g up	3.00	6.17	23.55	<26
FM and OC	150 g up	3.00	6.17	23.80	26
FM, OC and BC	200 g up	3.70	6.17	24.71	35
FM, OC, OBC and BC	250 g up	3.70	9.25	25.99	38
BC and OBC	300 g up	5.55	9.25	27.34	45
BC and OBC	350 g up	5.55	9.25	26.76	>45
OBC	400 g up	6.00	11.00	28.81	>45

Note: USD1 = LKR324 (2023); USD1 = THB35 (2023); FM: Female; OC: Orange Claw; BC: Blue Claw; OBC: Old-Blue Claw.

Table 2.2.3: Identified influential political, economic, social and technical (PEST) factors on CBF practices

Political	Economic	Social	Technical
Increased attraction of stakeholders. (***)	Comparatively higher price for GFP. (*)	Grievances regarding managerial disagreements. (**)	Poor financial handling in FO. (**)
Increased competition for accepting managerial positions in FO. (**)	More market attraction (increased vendors and middlemen). (***)	Conflicts with illegal fishers and buyers. (**)	Unavailability of a specific gear for GFP fishing. (**)
The incapability of FO in management. (**)	Individual tie-ups with a middleman for the loan. (****)	Increased participation of women in fishing. (*)	Lack of sound mechanism to control illegal fishing. (**)
Influences of regional and state political authorities. (*)	Increased trade deals with export companies. (**)		Lack of knowledge on stocking strategies and planning. (**)
Lack of control measures over illegal fishing. (****)			

Notes: Star marks depict the outcome of SWOT analysis over identified PEST factors: (*)=Strengths, (**)=Weaknesses, (***)=Opportunities and (****)=Threats. FO: Farmers’ organisations; GFP: Giant Freshwater Prawn.

Discussion

From this study, the suggested stocking densities can be implemented with night-time stocking. Further, from this analysis it is evident that spatial variations in FWP harvest are influenced by limnological characteristics such as dissolved oxygen (DO), trophic state indices, which should be taken into account for CBF planning rather than considering reservoir categorisation based on the reservoir size.

Although not attempted in the present analysis, it is apparent that seasonal availability of PLs of FWP from the hatcheries is greatly influenced by captive breeding success. Monsoonal rainfall patterns, low habitat temperature and quality of broodstock appear to affect hatchery performance of FWP. As such, hatchery inefficiencies should be studied further. The aspects that need further studies include:

- a. a prolonged hatching period of >60 days causing heavy mortality may be due to frequent precipitation that lowered the environment temperature
- b. the high performance in hatcheries could be achieved if source water has water salinity >50 ppt, not the lagoon water
- c. lack of probiotic use in state hatcheries but the private hatchery causes larval mortality
- d. molecular biological screening of broodstock to ensure better genetic quality.

Conclusion

This study has addressed several knowledge gaps that should be addressed in developing FWP CBF in Sri Lanka. We believe that strengthening the CBF extension mechanism together with capacity building through provision of science-based training to the extension staff is necessary for sustainable development of GFP CBF in Sri Lankan reservoirs. It is also recommended that future studies should focus on climate resilient development activities of CBF.

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2.3 Production trends and yield predictive models for culture-based fisheries in irrigation reservoirs of Sri Lanka

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Abstract

This study aims to develop empirical yield predictive models for CBF in perennial irrigation reservoirs of Sri Lanka, focusing on the GFP (*M. rosenbergii*), alongside carp and tilapia species. Conducted across 39 reservoirs, the research involved the collection of extensive data on species stocking densities, fish yields and various limnological parameters. Results indicate that stocking densities of carp and GFP significantly influenced yields, with optimal stocking densities identified as over 900 fingerlings ha⁻¹ yr⁻¹ for carp and approximately 1,000 post larvae ha⁻¹ yr⁻¹ for GFP in major reservoirs. Notably, the study found a significant relationship between fishing intensity and carp yield, although no such correlation was observed for GFP. Limnological assessments revealed that chlorophyll-a concentrations positively correlated with carp yields, while other parameters exhibited limited variability. TSI indicated that most reservoirs were classified as eutrophic. PCA highlighted key variables influencing productivity, with significant relationships established for carp yield. The study underscores the critical role of stocking strategies and limnological factors in optimising fish production, providing valuable insights for sustainable aquaculture development in Sri Lanka's inland water bodies. The predictive models developed offer a framework for enhancing CBF, thereby contributing to improved livelihoods in rural communities reliant on freshwater fish as a vital protein source.

Keywords: *culture-based fisheries, perennial irrigation reservoirs, yield predictive models*

Introduction

Sri Lanka is reputed to have a large number of irrigation reservoirs, some major reservoirs of which are over 2,000 years old. The cumulative extent of reservoirs is about 206,000 ha (Jayasinghe et al. 2005a). Based on their hydrological regimes, they are classified as perennial and seasonal reservoirs. These reservoirs, with a few exceptions, are irrigation reservoirs and are very diverse in size, age, hydrology and catchment features (Amarasinghe et al. 2005). Perennial reservoirs (around 200,000 ha) are divided into 3 broad categories; large (>800 ha), medium (200–800 ha) and small (<200 ha) based on the water spread at the full supply level. Reservoirs are primarily used for irrigation, hydroelectricity generation and drinking water supply, and inland fisheries are essentially a secondary use of them (Welcomme 2010; Amarasinghe and De Silva 2015).

The expansion of inland fisheries and aquaculture has been given a high priority in Sri Lanka because freshwater fish is a cheap source of animal protein for rural low-income communities. In the early 1980s, Sri Lanka initiated CBF (Pushapalatha and Chandrasoma 2010). This system was first introduced to seasonal reservoirs and later it was expanded to the perennial reservoirs (Thayaparan 1982; Chakrabarty and Samaranayake 1983; Chandrasoma and Kumarasiri 1986; De Silva et al. 2006b). The introduction of CBF into minor perennial reservoirs commenced in 2004 and gradually expanded to cover the other 2 size categories of perennial reservoirs: medium and large reservoirs (Chandrasoma and Pushpalatha 2018). CBF in Sri Lanka is well developed in reservoirs, and over the last 2 decades the fishery has enhanced inland fish production through a co-management strategy (De Silva 2003; Amarasinghe

and Nguyen 2010; Amarasinghe and Wijenayake 2015; Chandrasoma et al. 2015). Pushapalatha and Chandrasoma (2010) and Chandrasoma et al. (2015) mentioned that several strategies were implemented in recent years to encourage further development of existing CBF in Sri Lanka.

GFP, *Macrobrachium rosenbergii* (De Man 1879), is one of the most demanded and widely cultured crustacean species in the world (Smith et al. 2005; Hammed et al. 2012). The stocking program of GFP was initiated under the CBF approach in Sri Lanka and currently it is beginning to become one of the most important sectors of the national economy of Sri Lanka. GFP contributed around 0.6% to the total annual freshwater fish production of the country during 2010–2014 (Chandrasoma et al. 2015). Because of the high export potential of the GFP, the fisheries sector has given significant attention to developing the CBF of GFP. The preliminary research indicated that historical stocking and fishery production data for GFP was very limited and yields were highly variable. It was further evidence that this variation could neither adequately be explained by the stocking procedures nor by the physical attributes of the reservoirs. GFP dynamics cannot be evaluated in isolation and the dynamics of stocked finfish species have to be considered to obtain a complete understanding (Amarasinghe et al. 2021).

Simple empirical models have been used to predict fish yield in lakes and reservoirs for over 70 years (Ryder 1965; Henderson et al. 1973; Moreau and De Silva 1991). Rawson (1952) demonstrated the possibility of estimating fish yields of lakes based on mean depth. Some others also tried to assess fish yield potential from biotic and morphometric parameters (Hayes 1957; Northcote and Larkin 1956). Ryder (1965) developed morphoedaphic index



(MEI) by using the ratio of total dissolved solids to mean depth using 23 temperate lakes. Later many researchers used other dependent variables such as lake surface area, temperature and other parameters along with MEI for the prediction of fish yields in lakes and reservoirs in many countries (for example, Henderson and Welcomme 1974; Toews and Griffith 1979; Jenkins 1982; Schlesinger and Reglier 1982; Machena and Fair 1986). MEI along with fisheries variables such as numbers of fishers, boat and effort are used to predict the yield of African lakes (Henderson and Welcomme 1974). Maximum sustainable fish yield of Sri Lankan reservoirs was calculated (Wijeyaratne and Amarasinghe 1987; Nissanka et al. 2000). Nadarajah et al. (2018) used morphological, edaphic, and hydrological parameters together with fishing intensity to predict the fish yield in irrigation reservoirs of Sri Lanka. Rawson (1952) grouped lake productivity parameters into 3 groups (that is, climatic, morphometric and edaphic). Potential fish yield from morphological parameters such as reservoir area, volume, depth and shoreline development or gradient are some of the key morphological parameters to assess productivity. Wijeyaratne and Amarasinghe (1987) showed that maximum sustainable yield (MSY) in several reservoirs of Sri Lanka was correlated with the MEI. Amarasinghe et al. (2002) have shown that catchment features like the ratio of catchment land use patterns to reservoir capacity are important predictor variables of fish yields in Sri Lankan reservoirs. All these fish yield predictive models in Sri Lankan reservoirs have been developed for capture fisheries, except for the attempts made by Jayasinghe et al. (2005b) for predicting CBF yields in non-perennial reservoirs. Hitherto, no such predictive models have been developed for CBF yield

prediction in perennial irrigation reservoirs of Sri Lanka.

Thus, the present study proposes to develop empirical yield predictive models for the fisheries of perennial irrigation reservoirs of Sri Lanka, incorporating morphological, edaphic and hydrological parameters together with fishing intensity. In this study, a special emphasis will be paid to identifying potential for optimising GFP, *M. rosenbergii* fish yield.

Methodology

The study was carried out in 39 irrigation reservoirs (located in Anuradhapura, Batticaloa, Hambanthota, Kilinochchi, Kurunegala, Monaragala, Mulathive, Puttalam, Trincomalee and Vavuniya districts of Sri Lanka). Post larvae stocking of finfish species and GFP (*M. rosenbergii*) and harvest data of these species was collected from the database of NAQDA. Fingerlings and post larvae packing practices and harvesting data was obtained from the logbook records of the fisheries societies in reservoirs. Reservoir landing sites were visited from time to time for cross-checking the accuracy of data. Reservoir hydrological data such as surface area, minimum and maximum depth, reservoir volume, extent at full supply level (FSL), capacity at FSL, daily water level data, and inflow and outflow data catchment area was collected from the Department of Irrigation and Mahaweli Authority of Sri Lanka. All reservoirs were mapped using GPS (Trimble GeoExplorer 3; Trimble Navigation Ltd, California, USA) and reservoir area and shoreline length at full supply level was estimated. Each reservoir was visited at least once in 3 months covering wet, dry and intermediate seasons. In each reservoir, water samples were collected at least from 3 sampling sites,

packed in ice in an insulated Styrofoam box and were taken to the laboratory to determine chlorophyll-a, nitrate, ammonia, orthophosphate and total phosphorous contents. Air and water temperature, SDD, electrical conductivity (using a conductivity meter), and total alkalinity (using the titrimetric method) were determined in situ. The number of fishers involved and the number of boats used for fishing activity of each reservoir on each fishing day were collected from the logbook data of fisheries societies of the reservoirs. During field visits, the accuracy of logbook data was cross-checked. Shoreline development (D_L) and shoreline area ratio (R_{LA}) index, mean annual reservoir water level fluctuation (RRLF) index, hydraulic retention time (HRT) or water residence time, catchment area (CA) and reservoir capacity (RC) ratio, MEI and TSI were calculated using appropriate equations.

Results

The stocking density of fish fingerlings and post larvae of FWP of the 2022–2024 culture periods is illustrated in Table 2.3.1. Stocking density of carp, tilapia and FWP varied 90–1994 fingerlings $ha^{-1} yr^{-1}$, 115–1715 fingerlings $ha^{-1} yr^{-1}$ and 0–1937 post larvae $ha^{-1} yr^{-1}$, respectively. The carp, tilapia and FWP CBF activities in 37 perennial reservoirs during the 2022–2024 period varied considerably among the reservoirs, ranging from 15 $kg ha^{-1} yr^{-1}$ to 315 $kg ha^{-1} yr^{-1}$, 1 $kg ha^{-1} yr^{-1}$ to 358 $kg ha^{-1} yr^{-1}$ and 0 $kg ha^{-1} yr^{-1}$, respectively (Table 2.3.2).

A significant relationship was observed between carp and FWP stocking and yield during the 2022–2024 culture period ($p < 0.05$). However, carp production in these reservoirs was managed at a suboptimal level. In contrast, tilapia stocking did not exhibit a significant relationship with yield

(Figure 2.3.1). The relationship between carp species and major perennial reservoirs demonstrates a significant correlation, indicating that their management is currently under suboptimal conditions. The optimum stocking density for carp species in major reservoirs is estimated to be over 900 fingerlings $ha^{-1} yr^{-1}$. In contrast, the stocking of tilapia species did not exhibit a significant relationship with yield, suggesting that regular stocking of tilapia in major perennial reservoirs is not advisable. Additionally, the optimum stocking density for FWP in major reservoirs is approximately 1,000 post larvae $ha^{-1} yr^{-1}$.

However, both carp and FWP demonstrate optimal production in medium-sized reservoirs. The optimum stocking density for carp in these reservoirs is approximately 1,250–1,500 fingerlings $ha^{-1} yr^{-1}$, while the optimum stocking density for FWP is around 1,500 post larvae $ha^{-1} yr^{-1}$. In minor perennial reservoirs, carp stocking exhibits a strong significant relationship with yield, with an optimum stocking density exceeding 1,800 fingerlings $ha^{-1} yr^{-1}$. However, similar to major and medium reservoirs, tilapia stocking does not show any significant relationship with production. In contrast, FWP stocking demonstrates a significant relationship with yield, with an optimum stocking density exceeding 2,000 post larvae $ha^{-1} yr^{-1}$ (Figure 2.3.3).

Fishing intensity (number of boat days ha^{-1}) exhibits a significant relationship with the yield of carp and tilapia species ($p < 0.05$). However, no significant relationship is observed between fishing intensity and the yield of FWP (Figure 2.3.2).

Table 2.3.1: Fish and FWP stocking density of selected reservoirs

Reservoir name	Code	Mean SD fingerlings/PL/ha/yr		
		Carp	Tilapia	FWP
Aluthdiulwewa	A5	733.97	1,612.99	809.52
Mahakanadarawa	A3	138.65	205.39	736.79
Nachchaduwa	A4	434.28	384.64	388.21
Manakkatiya	A6	285.33	321.56	2,270.70
Ranawa	A8	1,579.42	1,584.39	0.00
Mahawilachchiya	A2	209.23	255.65	750.00
Unnichchai	B1	261.19	206.22	1,436.60
Wadamunai	B3	609.91	306.82	1,021.17
Redeeyagama	H1	259.15	772.90	1,800.51
Iranamadu	KL2	90.62	195.29	494.00
Puthuurippu	KL3	281.46	841.06	2,963.01
Muthukandiya	MO4	836.87	455.24	1,519.53
Hambegamuwa	MO1	1,391.19	300.52	2,012.53
Hadhapanagala	MO2	1,424.81	807.99	2,060.13
Getupana	MO7	343.13	488.75	1,500.00
Kiriibbanwewa	MO3	1,640.61	1,715.17	1,086.92
Mullativu	MU1	164.73	543.05	776.22
Karavitagaraya	P2	321.66	319.15	812.32
Kottukachchiya	P6	891.79	1,652.94	1,933.06
Mahauswewa	P3	388.42	385.39	980.92
Mahadiulwewa	T1	135.89	180.48	1,950.15
Kalmadu	V2	122.55	550.75	1,510.15
Urusitawewa	MO5	1,994.63	1,497.09	1,555.71
Weerawila	H2	351.32	523.27	968.78
Usgala siyabalangamuwa	KU2	366.61	165.39	827.93
Hakwatunaoya	KU1	343.41	1,196.31	2,046.20
Tabbowa	P4	396.90	115.32	898.96
Phariya	P8	1,166.67	333.33	1,666.67
Morawewa	T2	139.53	188.88	750.00
Vijayakotupotha	P5	1,317.90	1,321.13	3,191.37
Dewalahandiya	P1	769.77	1,249.16	4,937.28

Table 2.3.2: Fish and FWP yield of selected reservoirs

Reservoir name	Code	Mean production kg/ha/y		
		Carp	Tilapia	FWP
Aluthdiulwewa	A5	76.77	44.83	2.45
Mahakanadarawa	A3	44.39	113.95	2.25
Nachchaduwa	A4	58.00	107.35	0.46
Manakkatiya	A6	25.00	21.33	3.77
Ranawa	A8	269.22	357.98	0.00
Mahawilachchiya	A2	60.95	223.18	1.22
Unnichchai	B1	85.00	84.27	0.67
Wadamunai	B3	23.50	160.52	1.74
Redeeyagama	H1	78.00	13.43	4.65
Iranamadu	KL2	69.00	42.79	1.56
Puthuurippu	KL3	15.00	35.00	33.23
Muthukandiya	MO4	75.00	1.38	2.89
Hambegamuwa	MO1	210.00	40.84	2.65
Hadhapanagala	MO2	167.00	64.72	6.85
Getupana	MO7	72.82	34.61	0.45
Kiriibbanwewa	MO3	110.00	43.12	3.46
Mullativu	MU1	75.00	81.91	3.28
Karavitaraya	P2	40.04	9.94	0.47
Kottukachchiya	P6	114.23	49.33	5.37
Mahauswewa	P3	115.97	98.30	7.05
Mahadiulwewa	T1	77.56	33.26	2.09
Kalmadu	V2	55.00	62.26	3.04
Urusitawewa	MO5	315.00	5.79	0.49
Weerawila	H2	40.00	1.16	0.12
Usgala siyabalangamuwa	KU2	150.00	14.04	0.57
Hakwatunaoya	KU1	87.00	9.27	0.15
Tabbowa	P4	55.00	4.61	1.57
Phariya	P8	150.00	23.91	0.82
Morawewa	T2	70.00	8.85	0.20
Vijayakotupotha	P5	168.00	8.01	2.69
Dewalahandiya	P1	35.00	5.53	1.66

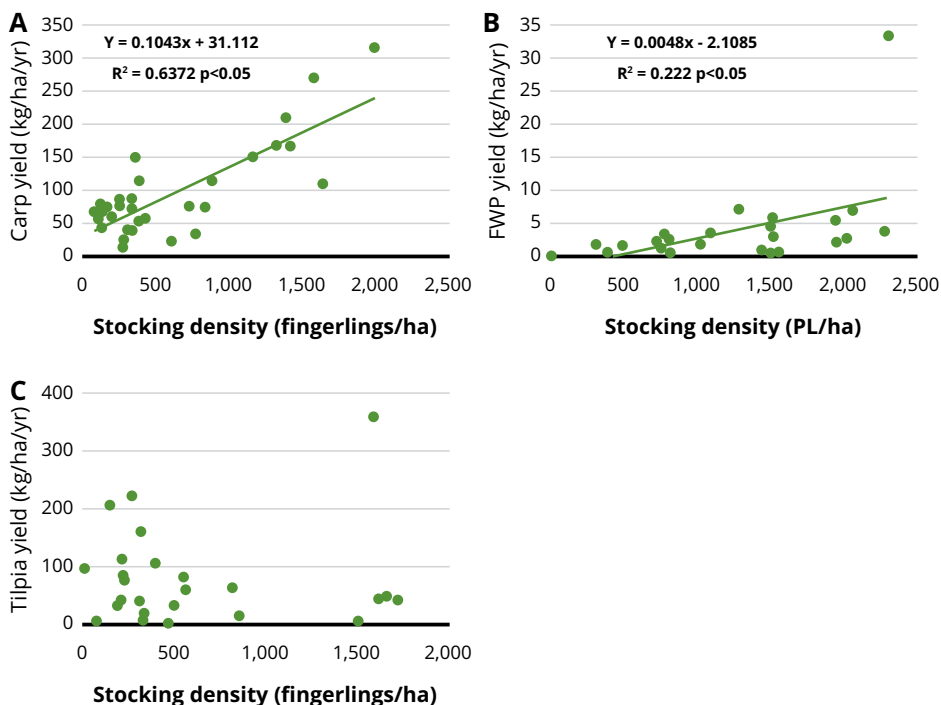


Figure 2.3.1: Relationships of stocking and yield

Note: (a) carp species (b) freshwater prawn (c) tilapia species

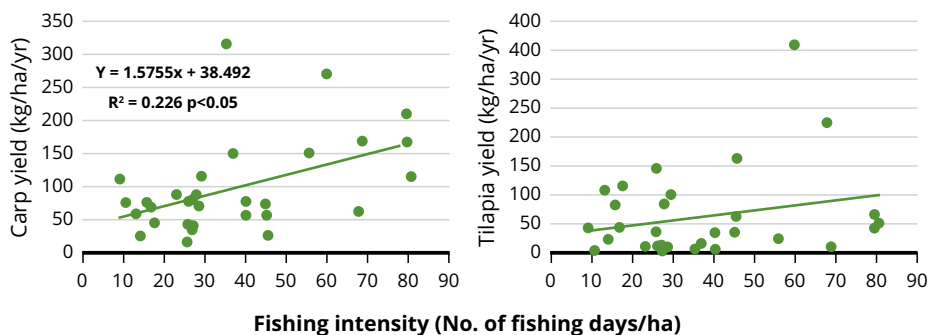


Figure 2.3.2: Relationship of fishing intensity (number of boat days ha^{-1}) with yield ($kg\ ha^{-1}\ yr^{-1}$)

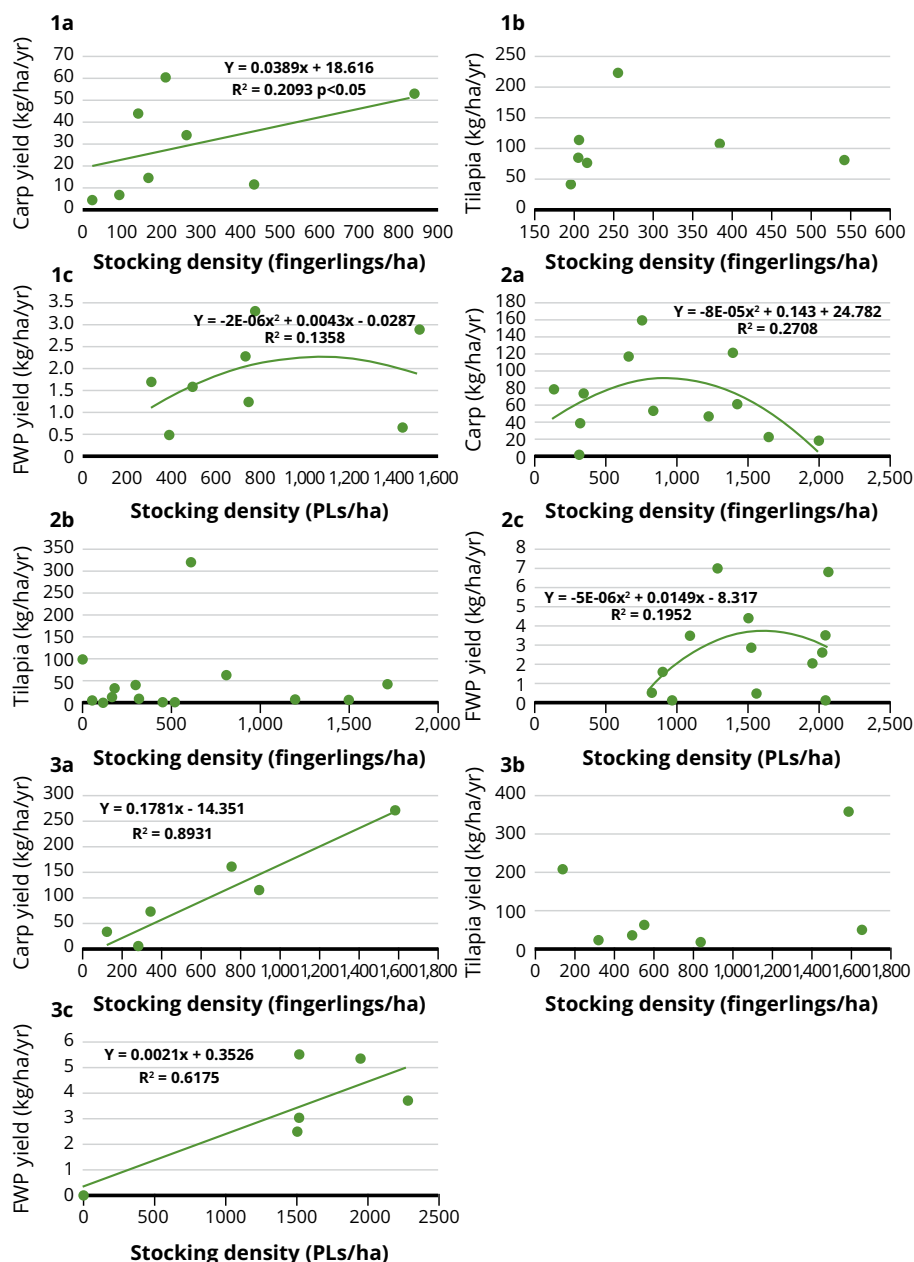


Figure 2.3.3: Relationship between stocking and yield

Note: 1a, 2a, 3a – carp species in major, medium and minor perennial reservoirs, 2a, 2b, 3a – tilapia species in major, medium and minor perennial reservoirs, 3a, 3b, 3c – FWP in major, medium and minor perennial reservoirs.

In the 39 perennial reservoirs studied, the limnological parameters measured did not show much variation with the time. Therefore, mean values of the limnological parameters measured during all sampling visits from December 2022 to December 2024 period (Figure 2.3.4) in each reservoir were considered for further calculations. Surface water temperature in 39 reservoirs ranged from $28.1\pm1.5\text{ }^{\circ}\text{C}$ to $31.7\pm0.7\text{ }^{\circ}\text{C}$, pH 7.64 ± 0.1 to 8.87 ± 0.3 . The range of conductivity was from 53.93 ± 9 to $1108.25\pm90\text{ }(\mu\text{S cm}^{-1})$ and alkalinity 43.42 ± 10.1 to 518.33 ± 125.5 . Chlorophyll-a of the selected reservoirs were varied 3.20 ± 0.2 to 27.83 ± 5.1 and total phosphorus of the surface water ranged from 0.21 ± 0.05 to 1.2 ± 0.5 . Chlorophyll-a shows positive correlation with the carp yield whereas other species did not show significant correlation with chlorophyll-a (Figure 2.3.5).

The TSI for SDD (TSI-SDD), total phosphorus (TSI-TP), and chlorophyll-a (TSI-Chl-a) were estimated using the equations described in the methodology. Analysis of 39 reservoirs revealed the pattern $\text{TSI (TP)} = \text{TSI (SDD)} > \text{TSI (Chl-a)}$, indicating that underwater light attenuation is primarily influenced by non-algal particulate matter or water colour (Figure 2.3.6). The exceptionally high values of TSI (SDD) and TSI (TP) observed in these reservoirs are attributed to non-algal turbidity. Consequently, the classification of Sri Lanka's perennial reservoirs based on these 2 indices is not appropriate. Therefore, TSI (Chl-a) was used to classify the trophic status of the reservoirs to support the development of CBF. Also, in 37 reservoirs carp yield is significantly related to TSI (Chl-a) (Figure 2.3.7). Nevertheless, TSI (SDD) and TSI (TP) were not significantly related to the fish yield ($p>0.05$).

Carlson and Simpson (1996) has been used to classify reservoirs based on the Carlson trophic states index (CTSI) (Table 2.3.3).

Table 2.3.3: Category of Carlson Trophic State Index (CTSI)

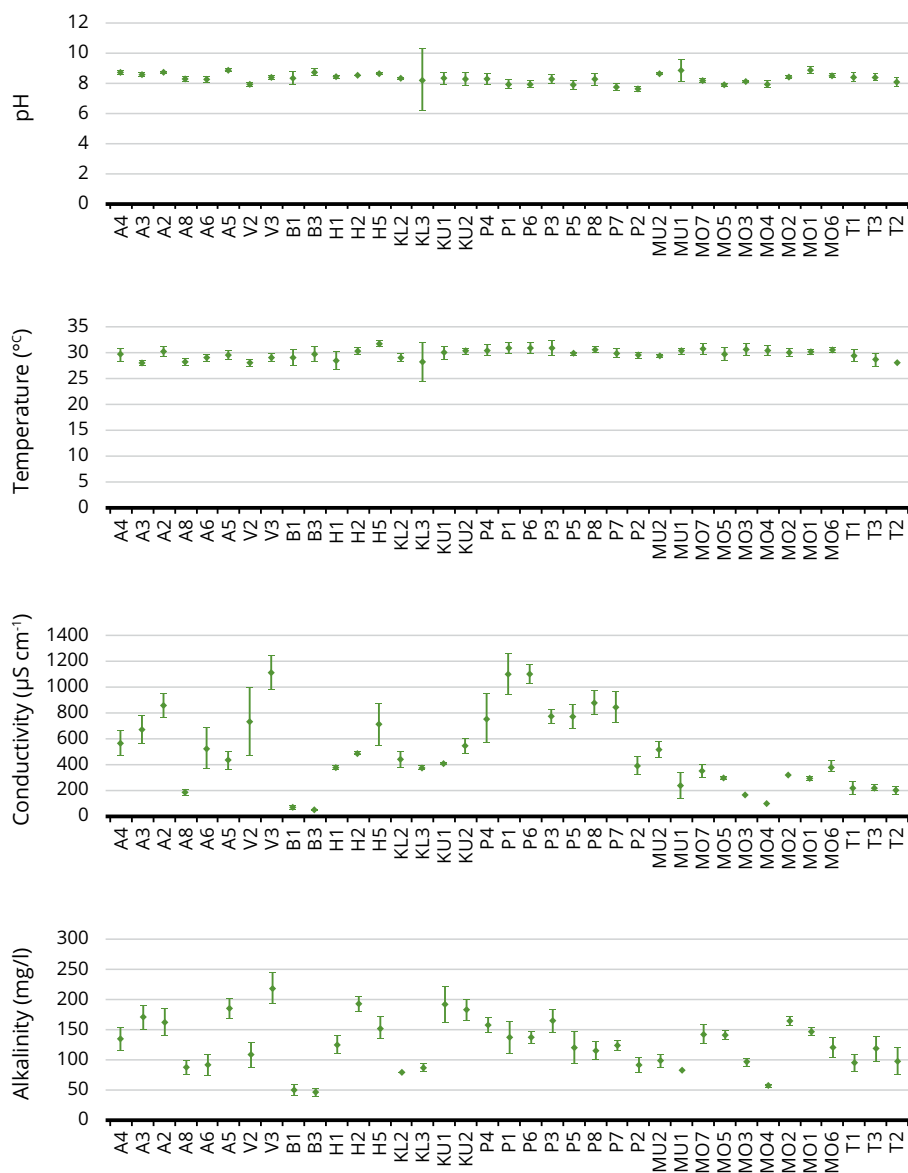
Category	Range
Oligotrophic	0–30
Mesotrophic	30–50
Eutrophic	50–70
Hyper-eutrophic	70–100

Based on the calculated CTSI values, the selected reservoirs are classified as eutrophic, as they fall within the CTSI range of 50–70 (Figure 2.3.8).

Carp yield of the 37 reservoirs exhibited significant linear relationship with the TSI Chl-a (Figure 2.3.9).

Eleven limnological parameters (temperature, pH, DO, conductivity, alkalinity, NO_3 , total phosphorus, orthophosphate, ammonia, SDD and chlorophyll-a) were used in the first PCA. Of these parameters, conductivity, alkalinity, chlorophyll-a, total phosphorous and SDD showed high variability across the dataset. For the final PCA, conductivity, alkalinity, chlorophyll-a, total phosphorous and SDD were used as input parameters, with the results presented in Table 2.3.4.

The PCA score plot of the 3 principal component axes (PC1, PC2 and PC3) explains the cumulative variances of 40.17%, 64.85% and 81.5%, respectively. The negative loading along the PC1 axis was related to high level of alkalinity and SDD, whereas positive loading on the same axis was related to high conductivity, total phosphorus and chlorophyll-a. On the PC2 axis, negative loading was related to a high level of chlorophyll-a, total phosphorous and SDD. While the positive loading was



(continued over page)

Figure 2.3.4: Variation of water pH, temperature (T in °C), conductivity (Con. in $\mu\text{S cm}^{-1}$), alkalinity (Alk. in mg l^{-1}), chlorophyll-a (Chl-a in $\mu\text{g l}^{-1}$), total phosphorous (TP in mg l^{-1}) and Secchi Disk Depth (SDD in cm) in 39 reservoirs

Note: Error bars denote the standard errors of mean.

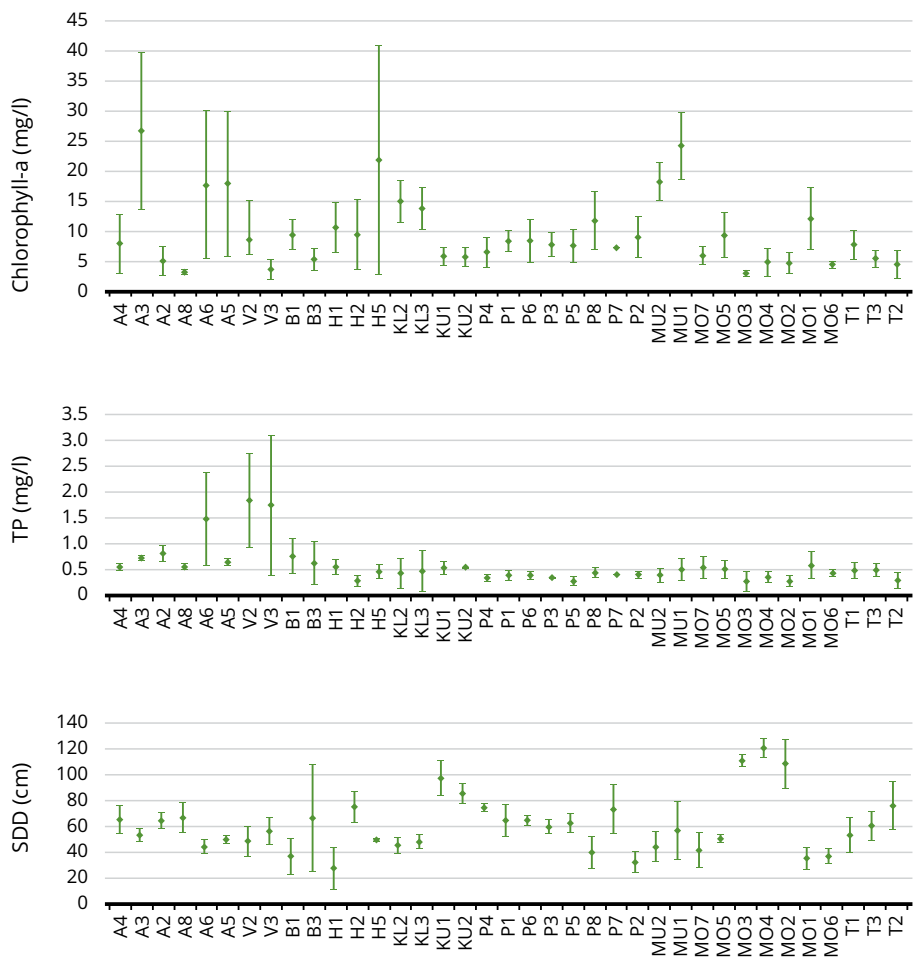


Figure 2.3.4: (Continued)

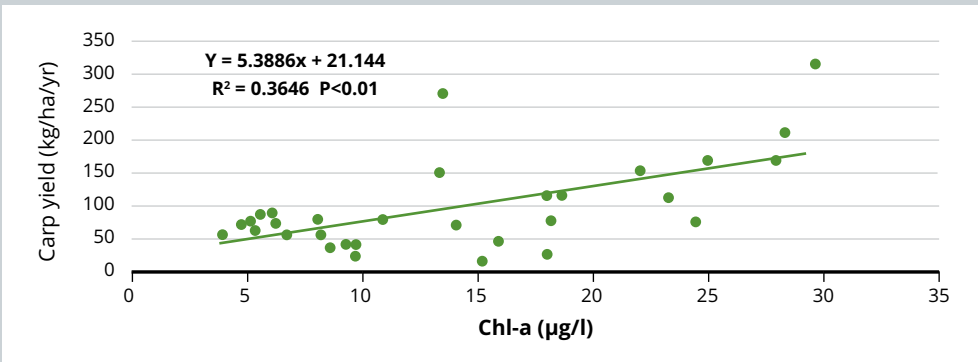


Figure 2.3.5: Relationship of chlorophyll-a and carp yield of 39 reservoirs

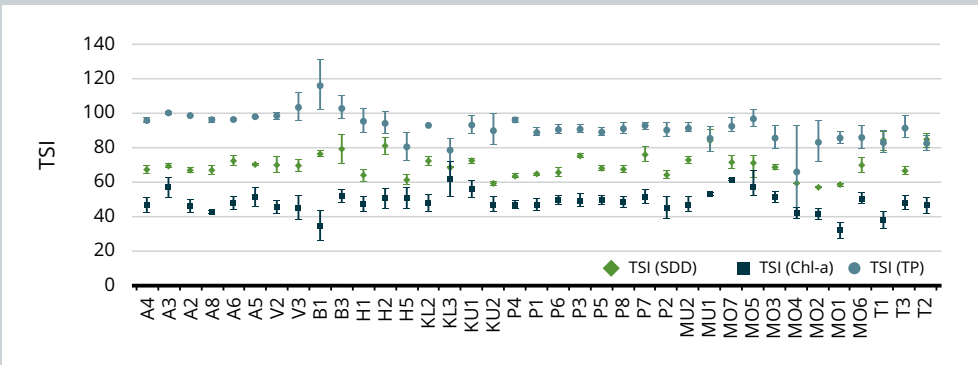


Figure 2.3.6: TSI of 3 definitions in 39 reservoirs

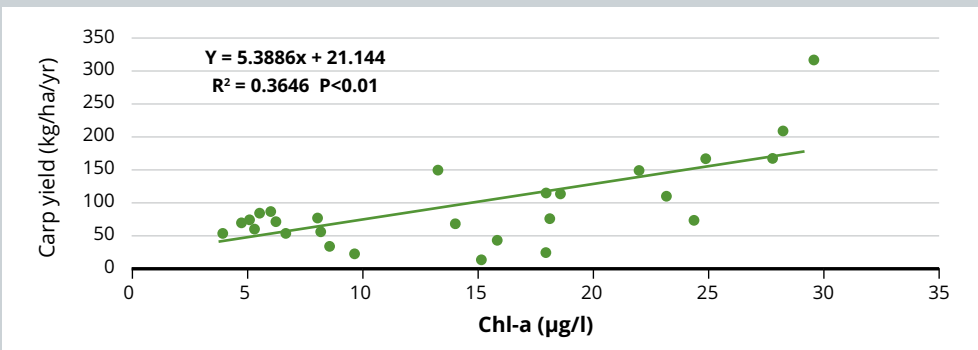


Figure 2.3.7: Relationship between TSI based on chlorophyll-a and carp yield in 39 reservoirs

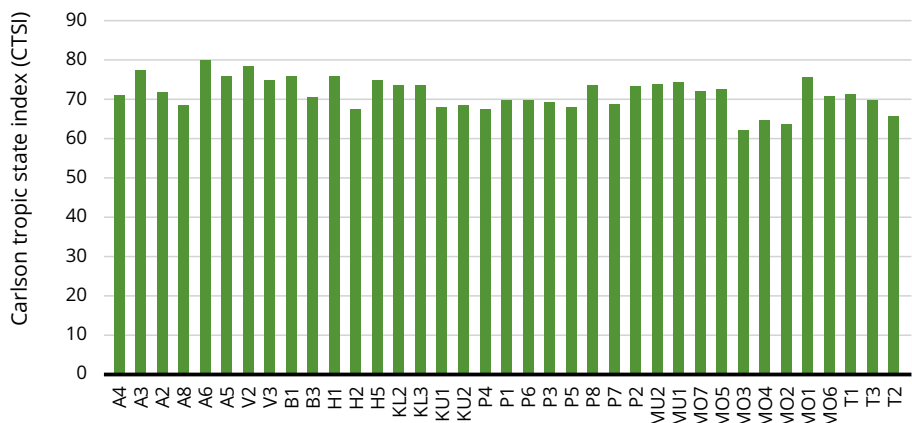


Figure 2.3.8: Variation of CTSI of selected reservoirs

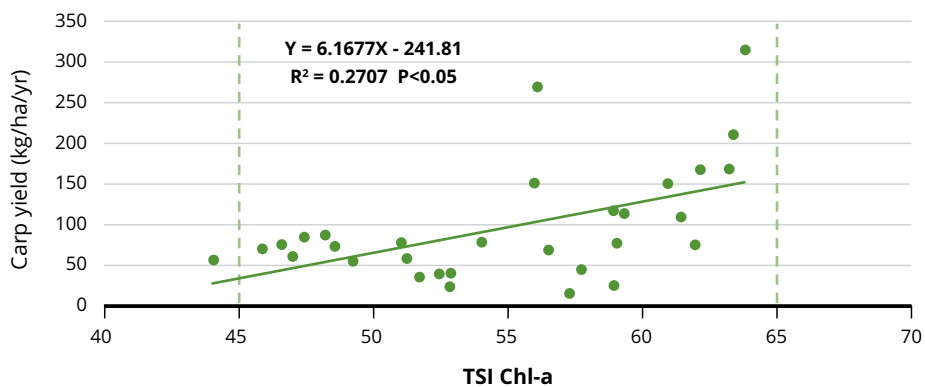


Figure 2.3.9: Relationship between carp yield and TSI Chl-a

related to a high level of conductivity and alkalinity. When PC1 scores are considered, reservoirs with positive scores represent more productive perennial than those with negative PC1 scores. The fish yield

of 37 reservoirs was positively correlated ($p < 0.1$) to the PC1 scores. However, other 2 species of tilapia and FWP yield was non-significant with the PC1 scores (Figure 2.3.10).

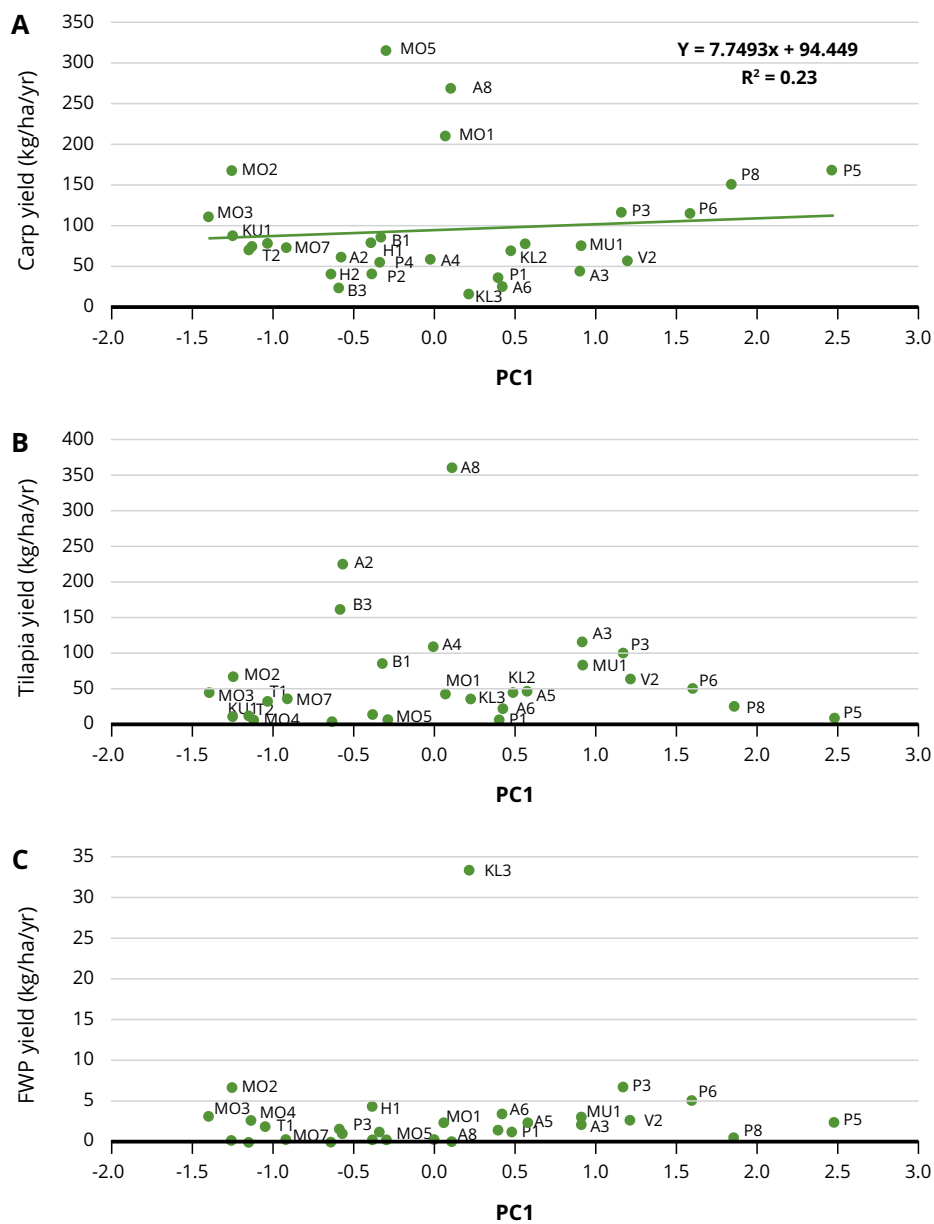


Figure 2.3.10: The relationship between PC1 scores and yield (a) carp (b) tilapia (c) FWP in 39 perennial reservoirs

The cluster analysis distinguished between 2 major clusters at a similarity level of 94% and 3 clusters at a level of 95.5%. There were just 3 reservoirs in the first cluster, which were spread across the districts of Anuradhapura, Killinochchi and Hambanthota. There were 12 and 21 reservoirs in the other 2 clusters, respectively. Stocking and the yield of clusters 3 and 5 were significantly ($p<0.05$) correlated. Carp yield (kg/ha/yr) and stocking (number of fingerlings) of cluster 3 and cluster 5 were found to

have a significant linear relationship. Similarly, the chlorophyll-a concentration of 2 clusters also exhibited a significant linear relationship with the carp yield. All relationships for tilapia and FWP were non-significant ($p>0.05$). In addition, the natural logarithmic value of MEI based on the alkalinity and conductivity also shows a significant relationship with carp yield. Accordingly, yield predictive models were developed for each clusters separately (Table 2.3.5 and Table 2.3.6).

Table 2.3.4: The final results of the PCA of the limnological parameters in 39 perennial reservoirs

Parameter	PC1	PC2	PC3
Eigen value	2.008	1.234	0.834
% variance explained	40.169	24.678	16.673
Cumulative %	40.169	64.849	81.520
Variables			
Conductivity	0.142	0.197	0.918
Alkalinity	-1.03	0.900	0.207
Chlorophyll-a	0.746	-0.283	0.327
Total Phosphorus	0.802	-0.166	0.183
Secchi disc depth	-0.793	-0.404	-0.121

Table 2.3.5: Yield predictive models for cluster 03 reservoirs

Relationship	r	R ₂
$Y = 12.928 + 0.825 \text{ SD}$	0.825	0.681
$Y = -50.650 + 0.842 \text{ Chl-a}$	0.808	0.653
$Y = 10.424 + 0.783 \text{ FI}$	0.783	0.613
$Y = -7.541 + 0.689 \text{ SD} + 0.200 \text{ Chl-a}$	0.838	0.702
$Y = 4.472 + 0.554 \text{ SD} + 0.923 \text{ FI}$	0.849	0.720
$Y = -91.715 - 5.18 \text{ SD} + 0.775 \text{ Chl-a} + 1.012 \text{ FI}$	0.940	0.883
$Y = -632.944 + 0.057 \text{ SD} + 0.920 \text{ FI} + 0.734 \text{ TSI Chl-a}$	0.952	0.907
$\text{LnY} = -1.582 + 0.938 \text{ Ln MEIa}$	0.938	0.880

r=Correlation coefficient R²= Coefficient of determination

Table 2.3.6: Yield predictive models for cluster 05 reservoirs

Relationship	r	R2
$Y = 34.838 + 0.888 \text{ SD}$	0.880	0.774
$Y = 24.017 + 0.794 \text{ Chl-a}$	0.794	0.630
$Y = -502.840 + 0.803 \text{ TSI Chl-a}$	0.783	0.613
$Y = -85.303 + 0.730 \text{ SD} + 0.597 \text{ TSI Chl-a}$	0.884	0.782
$Y = 25.364 + 0.863 \text{ SD} + 0.55 \text{ FI}$	0.884	0.782
$Y = 25.335 + 0.748 \text{ SD} + 0.138 \text{ Chl-a} + 0.043 \text{ FI}$	0.940	0.883
$Y = -85.728 + 0.725 \text{ SD} + 0.044 \text{ FI} + 0.163 \text{ TSI Chl-a}$	0.881	0.777

r=Correlation coefficient R²= Coefficient of determination

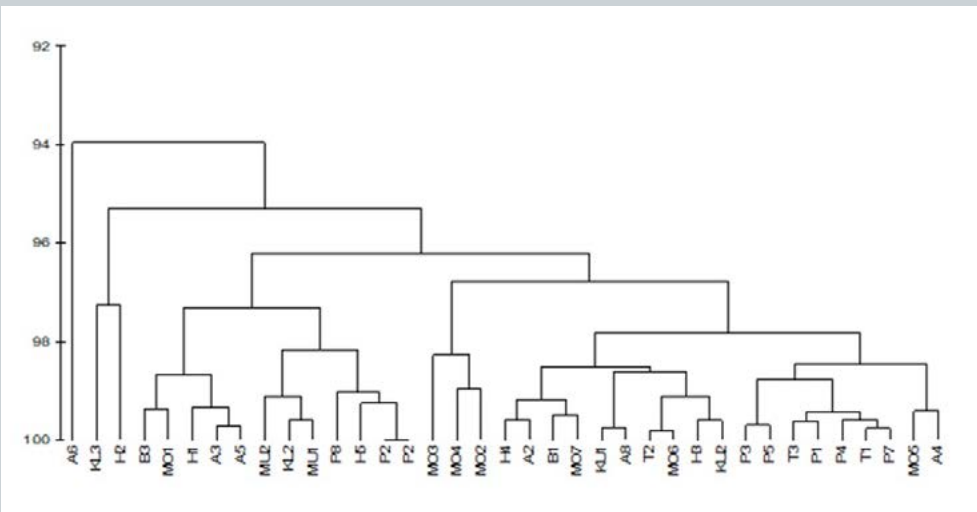


Figure 2.3.11: Dendrogram of the Bray-Curtis similarity analysis of 39 reservoirs

Several studies have examined the relationships between stocking densities, fish yields and limnological parameters in Sri Lankan reservoirs. The present study's findings align with previous research, particularly in terms of the positive correlation between stocking density and fish yield. Jayasinghe et al. (2005a) reported that increased stocking densities led to higher fish production in CBF, consistent with our findings. Similarly,

Jayasinghe et al. (2005b) demonstrated that stocking density and primary productivity significantly influence fish yield, a relationship also observed in the present study. Further, the study confirms the findings of De Silva (1988), who emphasised the importance of nutrient availability, particularly phosphorus and nitrogen, in determining fish yield. Furthermore, Jayasinghe et al. (2005a) highlighted the role of TSI in predicting fish production,



which our research also supports. In contrast, some studies, such as those by Wijenayake et al. (2005), suggest that beyond a threshold, excessive stocking can negatively impact fish growth and survival due to competition for resources. Overall, the findings of this study reinforce the established understanding of the factors influencing fish yield in Sri Lankan reservoirs while providing new insights into optimising stocking strategies. The results of this study align with previous research on the relationship between limnological parameters and fish yield in tropical reservoirs. Similarly, De Silva et al. (2006) highlighted the influence of SDD and nutrient availability on fisheries productivity in tropical lacustrine ecosystems. In comparison, Nguyen et al. (2005) found a positive correlation between conductivity and fish yield in managed aquaculture systems, emphasising the role of water chemistry in determining fish production potential. However, unlike some previous studies, where tilapia yield was significantly correlated with productivity indicators (for example, FAO 2010), this study did not find a strong relationship between PC1 scores and tilapia or FWP yields. This discrepancy may be due to species-specific ecological adaptations and stocking variations in the studied reservoirs. Further research incorporating stocking density and trophic interactions may be necessary to refine these predictive models. The findings of this study align with previous research on limnological parameters and fish yield relationships in freshwater reservoirs. Several studies have demonstrated significant correlations between chlorophyll-a concentration, SDD, and total phosphorus with fish yield (Henderson and Welcomme 1974; Melack 1976). Our results further corroborate these observations, as chlorophyll-a and SDD

showed significant relationships with carp yield.

Moreover, past studies have indicated that MEI-based models provide reliable yield predictions, particularly for stocked reservoirs (Ryder et al. 1974; Schlesinger and Regier 1982). The present study supports this claim, with significant relationships observed between the natural logarithmic values of MEI and carp yield in both clusters. Additionally, the importance of stocking density in determining carp yield has been emphasised in previous works (De Silva et al. 1991; Wijenayake et al. 2005), and our findings reinforce the role of stocking in yield optimisation.

However, unlike some previous studies that reported significant relationships between tilapia yield and limnological factors (Moreau and De Silva 1991), our results did not find significant associations between tilapia and FWP yield. This discrepancy might be due to variations in ecological conditions, species composition, or management strategies across different reservoirs.

Overall, the results of this study highlight the importance of limnological parameters and stocking in predicting fish yield in perennial reservoirs. The derived models offer valuable insights for fisheries management and sustainable aquaculture development in Sri Lanka's inland water bodies.

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2.4 Giant freshwater prawn and finfish distribution in microhabitats in irrigation reservoirs of Sri Lanka

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Abstract

This investigation examined spatial distribution patterns of GFP (*M. rosenbergii*) and associated ichthyofauna across distinct microhabitats within irrigation reservoirs utilised for CBF in Sri Lanka. Methodology employed stratified random sampling across 185 sampling stations distributed among 5 reservoirs. Limnological parameters were quantified in situ, and fish and prawn populations were sampled via overnight deployments of multi-mesh gillnets (25–100 mm mesh sizes). Statistical analysis through PERMANOVA revealed significant spatial heterogeneity in species assemblages across microhabitat types ($p < 0.05$). Wood log (WL) habitats exhibited significantly different community structures compared to gravel and rocky substrates (GR), vegetation-associated zones (VA), and pits and channels (PC). Notably, open water (OP) microhabitats demonstrated no statistically significant differences in species composition when compared with other microhabitat types. Principal species contributing to microhabitat-specific community differentiation included members of the family Channidae and various size classes of cyprinid species. *M. rosenbergii* was identified as a significant contributor to dissimilarities between GR and VA habitats. These findings demonstrate the ecological importance of microhabitat heterogeneity in structuring aquatic communities and provide empirical evidence to be considered in the management of CBF in tropical reservoir ecosystems.

Keywords: culture-based fisheries, fish assemblages, microhabitats, spatial heterogeneity

Introduction

Fish species exhibit varying habitat requirements and preferences, with their presence and abundance being strongly influenced by habitat characteristics across different spatial scales (Choi et al. 2021). Aquatic habitats are considered the most complex and dynamic environments, requiring fish to navigate multiple interacting stressors. Fish must continuously adapt to fluctuations in key environmental conditions while also facing biotic challenges and anthropogenic pressures (Rodgers and Isaza 2024). Fish habitats consist of physical, chemical and biological components essential for growth, survival and reproduction. These components may include specific characteristics of a location occupied by a fish or the broader network of areas necessary to complete its life cycle and sustain a population. Fish habitats can be classified as essential, critical and preferred (Newcomb et al. 2006). Essential habitats are crucial for spawning, breeding, feeding, and growth to maturity. Preferred habitat refers to areas that organisms select more frequently than other areas available in their environment. Critical habitats provide specific conditions, such as resources, shelter or environmental features that support the organism's survival, reproduction and overall wellbeing (Johnson 1980).

Habitat data can be measured with qualitative or quantitative approaches. Qualitative data are typically recorded using categorical methods and can be classified as descriptive, ordinal (ranked categories) or nominal (binary classifications such as yes–no or presence–absence) (Zar 1996). Continuous data, measured on ratio and interval scales, represent variables along a continuum. These data include

environmental parameters such as velocity, depth, DO and substratum particle size, which can take any value within a given range and allow for precise quantification and analysis. In lentic ecosystems, habitat conditions can be characterised using both continuous and ordinal parameters. Continuous variables include depth, turbidity, DO, temperature, SDD, nutrients (for example, phosphorus and nitrogen) and total dissolved solids, while ordinal variables encompass physical structure, vegetation, substrate type, bank slope and shoreline complexity (Zar 1996).

The scale of the habitats can be categorised to primarily 3 stages, which include microhabitat (for example, depth, cover, substrate and velocity at a specific fish location), mesohabitat or channel unit (for example, coves, island complexes, littoral zones, pools, riffles, runs or glides) and macrohabitat (for example, variables that extend longitudinally over a larger area in streams or stratify vertically in reservoirs and lakes, such as DO, pH, and temperature) (Newcomb, Orth and Stauffer 2006). Olentino, Lubich and Yamamoto (2024) mentioned that logs are commonly formed microhabitat type in lakes and creeks, and species adapt to these environments' physical space. However, several factors can influence the distribution of species such as food availability, predation intensity and the physical–chemical conditions of the environment.

Temporal scale is a crucial factor when analysing physical mechanisms that determine channel quality and habitat area development, as well as changes in fish habitat utilisation during significant life history phases. Modifying or creating habitat features by hydrological events such as floods and effective stream discharge affects the aquatic ecosystem in temporal



scale. As a result, lentic systems alter vertically in habitat availability through seasons due to changes in depth, DO and temperature (Newcomb, Orth and Stauffer 2006). For example, in Sri Lanka, man-made tanks, which have been constructed to collect rainwater in dry areas, show maximum capacity at the rainy season with diminishing water level during the rest of the year, changing reservoir morphometry significantly (Jayasinghe et al. 2006). Although, the variations in microhabitats of those agrarian reservoirs in terms of influences on fish production have not been studied well.

The multiple use of irrigation water for various forms of food production is becoming increasingly important, particularly as its positive impacts are largely beneficial to rural communities. Therefore, the introduction of CBF in the reservoirs has resulted in increased availability of fish in rural areas, enhancing food security, providing more livelihood opportunities and strengthening the rural community (Pushpalatha et al. 2017). CBF has been recognised as a form of aquaculture which is commonly practiced in small water bodies, both perennial and seasonal, that retain water for at least 6 to 8 months each year (FAO 2015). CBF involves practices of stocking water bodies that lack the capacity to sustain fisheries through natural fish reproduction. These fisheries rely on managed and owned stocks, either through individual or collective arrangements, to enhance fishery productivity (De Silva, Ingram and Wilkinson 2015). Optimal stocking densities, species combinations and ratios, as well as the ideal timing and size of harvesting, are key factors influencing inland fish production and CBF (Wijenayake et al. 2005). In Sri Lanka, 137 freshwater fish species have been identified, including 23 estuarine,

24 alien and 53 native species (Rajeevan, Edirisinghe and Athauda 2021). Due to lack of natural lakes in the country, there are no lacustrine species that evolved in a way suitable for CBF development in agrarian reservoirs. Therefore, the reservoirs are stocked with exotic fish fingerlings such as *Catla catla*, *Labeo rohita*, *Cyprinus carpio*, *Cirrhinus mrigala*, *Hypophthalmichthys molitrix*, *Oreochromis* spp. and post larvae of indigenous *M. rosenbergii* or GFP (Pushpalatha and Chandrasoma 2010; Wijenayake, Najim and Amarasinghe 2021). There is no comprehensive information on the distribution and interaction of those species in microhabitats of the reservoirs. Therefore, the objective of this study was to categorically identify microhabitats based on physical characteristics and limnological variables, and assess the diversity and distribution of CBF species along with other major indigenous fish species in those microhabitats.

Methodology

Site description

Five reservoirs, located across 4 different districts in Sri Lanka, were selected for this study (Table 2.4.1 and Figure 2.4.1). These reservoirs are situated within the dry and intermediate climatic zones of the country. The sampling period was from June 2023 to November 2024.

Identification of microhabitat types

Water surface and bottom characteristics were determined based on visual observations and information provided by the local community. The reliability of community-reported information was verified through visual observations, inputs from local divers, and GPS tracking of locations during low water level periods. Sediment samples were collected using an Ekman grab and the substrate was classified

Table 2.4.1: Details of the reservoirs selected for this study

Reservoir	District	Area (km ²)	GPS location		Code
			Latitude	Longitude	
Maha Aluthgamara	Hambantota	0.70	6.366048	81.08699	RNO1
Urusita	Monaragala	2.62	6.332508	80.93322	RNO2
Maha Siyambalangamuwa	Kurunegala	2.10	7.94247	80.46651	RNO3
Tabbowa	Puttalam	6.07	8.073094	79.95563	RNO4
Vijayakatupotha	Puttalam	2.43	7.72048	79.89404	RNO5

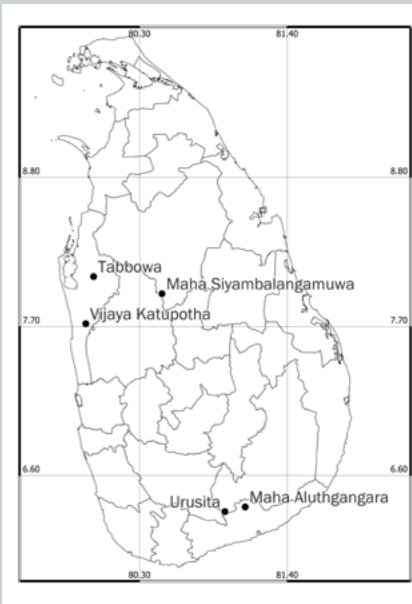


Figure 2.4.1: Location of the reservoirs

subsequently into distinct categories. Depth variations of the reservoir were measured using sonar devices (Humminbird Helix 5 and Deeper Fish Finder).

Based on the visual observations and physical characteristics, the microhabitats were classified into 3 depth layers as the water surface, water column and sediment substrate (above the bottom). Each layer was further subdivided into

distinct categories according to specific characteristics (Table 2.4.2). Water surface characteristics were categorised into 3: open surface, shaded by terrestrial plants, and covered with macrophytes. Water column and above-bottom characteristics were categorised as: open water column, covered by macrophytes (vegetation), covered by wood logs, covered by rocks and rocky crevices, and covered by grass. Sediment substrate was classified into 3: muddy, sandy (particle size 125 µm to 2 mm), and gravel (particle size 2 mm to 2 cm). Based on the above categories, there were 5 distinct microhabitat types (Table 2.4.3). At each sampling site, the environmental layers were identified into their respective categories, thereby to the corresponding microhabitat types.

Sampling in microhabitats

Stratified random sampling was used as a methodology to sample the sites. Physical, chemical and biological parameters mentioned in Table 2.4.4 were collected from each sampling site.

Multiparameter water quality probe (YSI Pro DSS) was used to assess the key physicochemical characteristics of the water. Underwater light intensity was quantified using an Extended Photosynthetically Active Radiation (ePAR) sensor (Apogee). Total Suspended Solids (TSS), water colour, and turbidity were



Table 2.4.2: Microhabitat characteristics and different categories

Environmental characteristic layers	Sub category
Water surface characteristics	Open surface
	Shaded with terrestrial plants
	Covered with macrophytes
Water column and above bottom characteristics	Open water column
	Covered by macrophytes
	Covered by wood logs
	Covered by rocks and rocky crevices
	Covered with grass
Sediment substrate characteristics	Muddy
	Sandy
	Gravel
	Mud and sand
Depth variations	Plain bottoms
	Pits and channels

Table 2.4.3: Identified microhabitat types/groups

Number	Microhabitat type	Code
1	Open water column	OP
2	Gravel and rocky surfaces and crevices	GR
3	Vegetation-associated areas	VA
4	Wood logs	WL
5	Pits and channel paths	PC

analysed using a colorimeter (Lovibond MD 600). Dissolved nitrate concentrations were determined using the zinc reduction method, while dissolved phosphate concentrations were measured using the phosphor-molybdenum blue method, both by employing the protocols of Lovibond MD 600 colorimeter. Water depth was recorded using sonar devices (Humminbird Helix 5 and Deeper Fish Finder). In situ chlorophyll-a concentrations were assessed with the Pro DSS Total Algae-Phycocyanin (TAL-PC) sensor. Alkalinity was determined via acid-base titration with sulfuric acid (H₂SO₄), while water

hardness was measured through EDTA (ethylenediaminetetraacetic acid) titration. Sediment samples were collected using an Ekman grab, and soil organic matter content was determined via the Weight Loss on Ignition (WLOI) method.

Fish sampling was conducted using a multi-mesh gillnet with mesh sizes of 7.6, 8.9, 9.5, 10.2, 11.4, 12.7, 14.0, 15.2 and 19.7 cm. A total of 185 sampling points were surveyed using multi-mesh gillnets across all 5 reservoirs throughout the sampling period. Gillnets were deployed overnight (12-hour duration) to assess finfish diversity and abundance, along with GFP abundance.

Table 2.4.4: Physical, chemical and biological parameters measured at each sampling site

Parameter type	Parameter	Code
Physical parameters	Light Intensity Underwater	LIW
	Temperature	Tem
	Conductivity	Con
	Total Dissolved Solids	TDS
	Colour of water	Col
	Turbidity	Turb
	Total Suspended Solids	TSS
	Depth	Dep
Chemical parameters	Dissolved Oxygen	DO
	Dissolved Oxygen Percentage	DOP
	pH level	pH
	Salinity	Sal
	Oxidation-Reduction Potential	ORP
	Hardness	Hard
	Alkalinity	Alkt
	Dissolved Nitrate	Nit
	Dissolved Phosphate	Pho
Biological parameters	Chlorophyll	Chl
	Sediment Organic Matter Content	OM
	Species-wise Fish Abundance	

Data analysis

Species abundance data were square root-transformed, LIW, TSS and Turbidity were log transformed and Nit, Pho, Chl, and OM were Box-Cox transformed after assessing their degree of normality based on the Shapiro-Wilk test. Species were classified according to their respective families. Non-metric multidimensional scaling (NMDS) was used to examine distribution patterns of families according to their abundance at each microhabitat type. NMDS ordination plots were produced based on Bray-Curtis distance, and goodness-of-fit was assessed in terms of loss of stress. Environmental variables and microhabitat types were fitted onto the NMDS ordination plot to identify the patterns between habitats

and ecological variables. The significance of the fitted vectors was assessed using 999 permutations, with 95% significance. The PERMANOVA test was performed to identify significant differences in microhabitat types based on species composition. Multi-level indicator species analyses were conducted using the 'indicspecies' package in R (De Caceres and Legendre 2009). SIMPER statistical analysis was carried out by the 'vegan' package in R (Perry, Staveley and Gullström 2018). Sampling groups were considered significantly different if $p < 0.05$.

Results

Of the reservoirs studied, Maha Aluthgam Ara functioned as a seasonal tank due to

its smaller surface area, and a complete drawdown was experienced during the sampling period as a result of drought conditions and water extraction for agricultural purposes. In contrast, Urusita Reservoir maintained stable water levels throughout the sampling period. Siyambalangamuwa, Wijayakatupotha and Tabbowa reservoirs exhibited fluctuations in water levels; however, those changes were not critical due to their relatively larger surface area and storage capacity.

A total number of 819 individuals belonging to 15 species were collected at 154 microhabitat sites. Species were identified under 9 different families (Table 2.4.5). Cyprinidae was the dominant family represented by 5 species. Due to their size variation, Cyprinidae family was divided into 3 size groups.

The PERMANOVA test revealed that species composition in WL differed significantly from that in GR, VA and PC. However, species composition in the OP did not differ significantly from any other microhabitat type (Table 2.4.6). The species contributing to the significant differences in species composition between microhabitat types were identified using SIMPER analysis. This analysis quantified the percentage contribution of each species or factor to the overall dissimilarity between microhabitat types (Table 2.4.7).

The family Channidae, along with large-sized and medium-sized cyprinids, significantly contributed to the dissimilarities between WL and VA microhabitats. Both small-sized and medium-sized cyprinids were major contributors to the dissimilarities between WL and PC microhabitats. Only *Pterygoplichthys* spp. (Family Loricariidae) significantly contributed to the dissimilarities between VA and PC

Table 2.4.5: List of sampled fish species and their associated families

Family	Species
Cichlidae	<i>Oreochromis</i> spp.
	<i>Etroplus suratensis</i>
Oxudercidae	<i>Awaous grammepomus</i>
Palaemonidae	<i>Macrobrachium rosenbergii</i>
Cyprinidae	<i>Catla catla</i>
	<i>Labeo rohita</i>
	<i>Hypophthalmichthys molitrix</i>
	<i>Systemus sarana</i>
	<i>Cyprinus carpio</i>
Channidae	<i>Channa striata</i>
Loricariidae	<i>Pterygoplichthys</i> spp.
Mastacembelidae	<i>Mastacembelus armatus</i>
Bagridae	<i>Mystus ankutta</i>
Siluridae	<i>Ompok bimaculatus</i>

Table 2.4.6: Results of the PERMANOVA test comparing microhabitat types

Comparison	F_Value	P_Value
GR_vs_VA	1.0896828	0.349
GR_vs_WL	5.8503455	0.002**
OP_vs_GR	2.4436421	0.052
OP_vs_VA	1.8261469	0.12
OP_vs_WL	1.9159714	0.146
PC_vs_GR	0.7952869	0.564
PC_vs_OP	0.7787421	0.532
PC_vs_VA	1.2634141	0.262
PC_vs_WL	3.3097463	0.026 *
WL_vs_VA	3.6104965	0.016 *

Note: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; OP= Open water column; GR=Gravel and rocky surfaces and crevices; VA=vegetation associated areas; WL=Wood logs; PC=Pits and Channel Paths.

Table 2.4.7: Family with significant differences as shown by SIMPER analysis between microhabitat types

Family	GR_vs_VA	GR_vs_WL	OP_vs_WL	PC_vs_VA	PC_vs_WL	WL_vs_VA
Bagridae	0.61	0.615	0.82	0.244	0.397	0.73
Channidae	0.973	0.341	0.008*	0.783	0.154	0.015*
Cichlidae	0.896	0.866	0.229	0.749	0.827	0.946
Cyprinidae – Large	0.894	0.036*	0.015*	0.835	0.04	0.038*
Cyprinidae – Medium	0.986	0.005**	0.002**	0.951	0.001**	0.001***
Cyprinidae – Small	0.672	0.568	0.255	0.582	0.592*	0.323
Loricariidae	0.492	0.56	0.771	0.04*	0.164	0.165
Mastacembelidae	0.991	0.407	0.025*	0.827	0.212	0.213
Oxudercidae	0.869	0.411	0.105	0.556	0.317	0.056
Palaemonidae	0.033*	0.088	0.985	0.156	0.653	0.203
Siluridae	0.897	0.523	0.206	0.562	0.274	0.393

Note: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; OP= Open water column; GR=Gravel and rocky surfaces and crevices; VA=vegetation associated areas; WL=Wood logs; PC=Pits and Channel Paths.

microhabitats. In comparisons between OP and WL microhabitats, the Channidae and Mastacembelidae families, along with small-sized and medium-sized cyprinids, contributed significantly to the observed differences. Similarly, medium-sized and large-sized cyprinids were the primary contributors to the dissimilarities between GR and WL microhabitats. Additionally, GFP *M. rosenbergii* (Family Palaemonidae) significantly contributed to the dissimilarities between GR and VA microhabitats.

The multilevel species indicator analysis has shown that several families can be identified as indicators for several microhabitat types (Table 2.4.8). Medium-sized cyprinids were designated an indicator of the WL microhabitat types. GFP was designated an indicator of the GR and VA microhabitat types. Family Loricariidae (*Pterygoplichthys* spp.) was designated an indicator of the GR, VA and PC microhabitat types. Figure 2.4.2 shows the key indicator families for different microhabitat types

as resulted by multi-level indicator species analysis. Medium-sized cyprinids, Palaemonidae, and Loricariidae were the most significant indicator families contributing to different microhabitat types.

The NMDS ordination plot illustrates the distribution patterns of fish families and the microhabitat-based variation in species composition. The distribution of medium-sized cyprinids and cichlids varies distinctly among microhabitat types, as evidenced by the ordination plot (Figure 2.4.3).

The environmental variables were fitted into fish composition ordination plot and the significance of the environmental variables which influence the fish community composition across microhabitats was examined. Turbidity (Turb) and Conductivity (Con) are the strongest environmental drivers of fish community composition across microhabitats. Nitrate, pH, chlorophyll and organic matter also significantly influence species distributions. DO, hardness, Oxidation-Reduction Potential (ORP) and

Table 2.4.8: Result of the multi-level indicator species analysis

Family category	Presence or absence of species					Index	Stat	p value
	OP	GR	VA	WL	PC			
Bagridae	1	1	1	0	1	27	0.211449	0.11
Channidae	0	0	1	0	0	3	0.179311	0.22
Cichlidae	1	0	0	0	1	9	0.164527	0.32
Cyprinidae – Large	1	1	0	1	1	28	0.103723	0.76
Cyprinidae – Medium	0	0	0	1	0	4	0.312951	0.01**
Cyprinidae – Small	1	1	1	0	0	16	0.126942	0.59
Loricariidae	0	1	1	0	1	23	0.24478	0.04*
Mastacembelidae	1	1	1	0	1	27	0.186242	0.21
Oxudercidae	0	1	1	0	0	10	0.160097	0.37
Palaemonidae	0	1	1	0	0	10	0.263597	0.02*
Siluridae	1	1	1	0	1	27	0.201599	0.16

Note: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; OP= Open water column; GR=Gravel and rocky surfaces and crevices; VA=vegetation associated areas; WL=Wood logs; PC=Pits and Channel Paths.

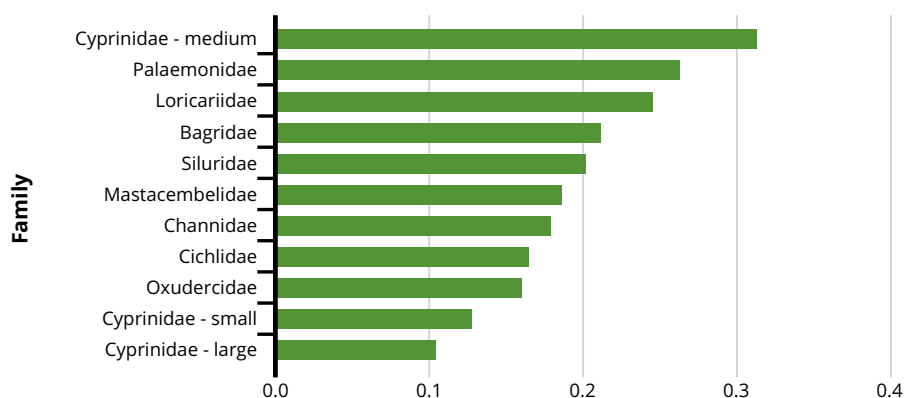


Figure 2.4.2: Multi-level indicator species analysis for families

Note: X axis shows the stat value from the analysis.

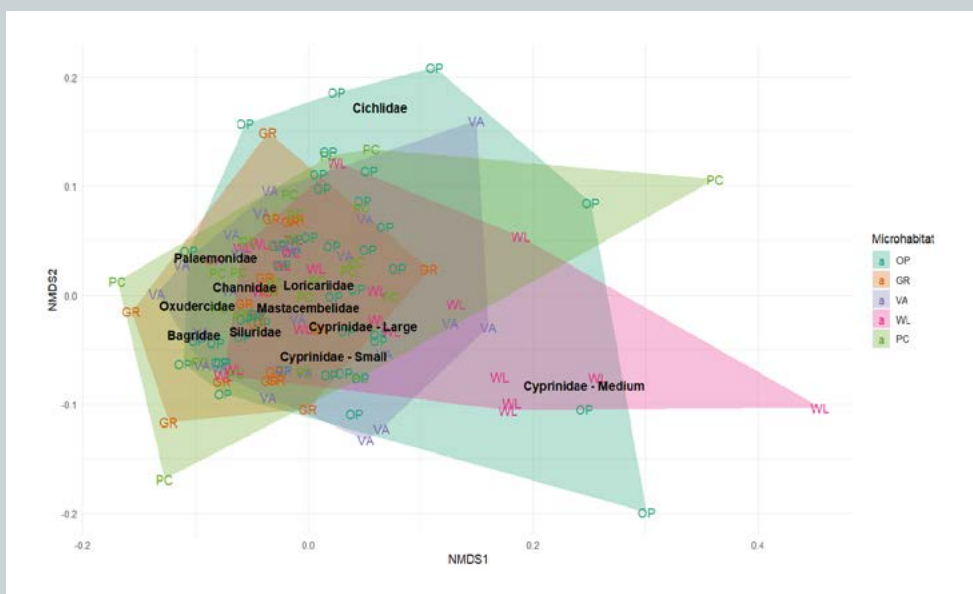


Figure 2.4.3: NMDS ordination plot (distribution of families and microhabitats based on Bray-Curtis dissimilarity)

Note: OP= Open water column; GR=Gravel and rocky surfaces and crevices; VA=vegetation associated areas; WL=Wood logs; PC=Pits and Channel Paths.

phosphate (Pho) have negligible effects on structuring the fish community, as indicated by the p-values of the test (Table 2.4.9). The NMDS ordination plot shows that the species composition of WL microhabitat has been significantly influenced by chlorophyll content (Figure 2.4.4).

Discussion

In any civilisation, the management and manipulation of water resources play a crucial role in ensuring the long-term sustainability of agriculture. Throughout history, civilisations have developed intricate irrigation systems, reservoirs and water distribution networks to optimise agricultural productivity and adapt to environmental challenges. In Sri Lanka, some of the largest reservoirs are over 2,000 years old. Approximately 260,000 ha

make up the total area of all reservoirs. The reservoirs, either perennial or seasonal, range from a few ha to 4,000 ha in size. Fish culturing and CBF in those reservoirs evolved later as a secondary operation to fulfil the nutrient requirement of the rural village communities adjacent to reservoirs. Now, inland fisheries are contributing more than 24% of the total fishery production in Sri Lanka (MOF 2023). More than 90% of the inland fisheries harvest gains from medium and large perennial reservoirs (Pushpalatha and Chandrasoma 2010).

Seed stocking in CBF should be accomplished promptly and is essential for higher fish yields. These seeds are juvenile stages of fish, which are directly introduced to the water bodies. The species which have higher growth rates, feed

Table 2.4.9: Results of environmental variable fitting to NMDS ordination of species composition

Environmental variable	r ²	p value
LIW	0.064	0.01**
Tem	0.0596	0.014*
DO	0.0016	0.882
pH	0.0546	0.022*
Con	0.1085	0.001**
ORP	0.0155	0.331
Hard	0.0094	0.522
Turb	0.1664	0.001***
Nit	0.0636	0.01*
Pho	0.0077	0.575
Chl	0.0678	0.009**
Dep	0.0447	0.038*
OM	0.0574	0.01**

Notes: LIW = Light Intensity Underwater, Tem= Temperature, Con = Conductivity, Turb= Turbidity, Dep= Depth, DO= Dissolved Oxygen, ORP= Oxidation-Reduction Potential, Hard= Hardness, Alk = Alkalinity, Nit = Dissolved Nitrate, Pho = Dissolved Phosphate, Chl = Chlorophyl, OM = Sediment Organic Matter Content); Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

lower in the food chain and utilise naturally produced food organisms are used in CBF in combination with indigenous species (De Silva, Ingram and Wilkinson 2015). The fishery enhancement, through stocking, is carried out for several purposes: to augment depleted stocks, for conservation and to augment sport fisheries (Welcomme and Bartley 1998). The water bodies which are stocked with seeds can be managed effectively; therefore, the recapture rate of the stocked seed is very high. The fish yield per unit area in these systems is often comparable to or may even exceed that from semi-intensive aquaculture practices in ponds in the tropical regions (De Silva 2003).

Although CBF activities have been identified useful in most Asian countries including Sri Lanka, this sector has not been well-developed due to lack of understanding on science behind the interactions of CBF

species with their introduced environment. In this study, we tried to understand mainly the distribution of stocked exotic fish species and indigenous GFP in microhabitats of 5 selected irrigation reservoirs. The fish abundance in those man-made environments was dominated by exotic fish species such as *Oreochromis* spp., *Catla catla*, *Labeo rohita*, *Hypophthalmichthys molitrix* and *Cyprinus carpio*. In the preliminary step, different microhabitats in the reservoirs were identified by their appearance, and variations among them if any, were analysed through physicochemical parameters and fish diversity and distribution. Different variations in microhabitat types were grouped.

Fish assemblages in aquatic ecosystems are strongly influenced by the structural complexity and ecological functions of vegetation-associated microhabitats

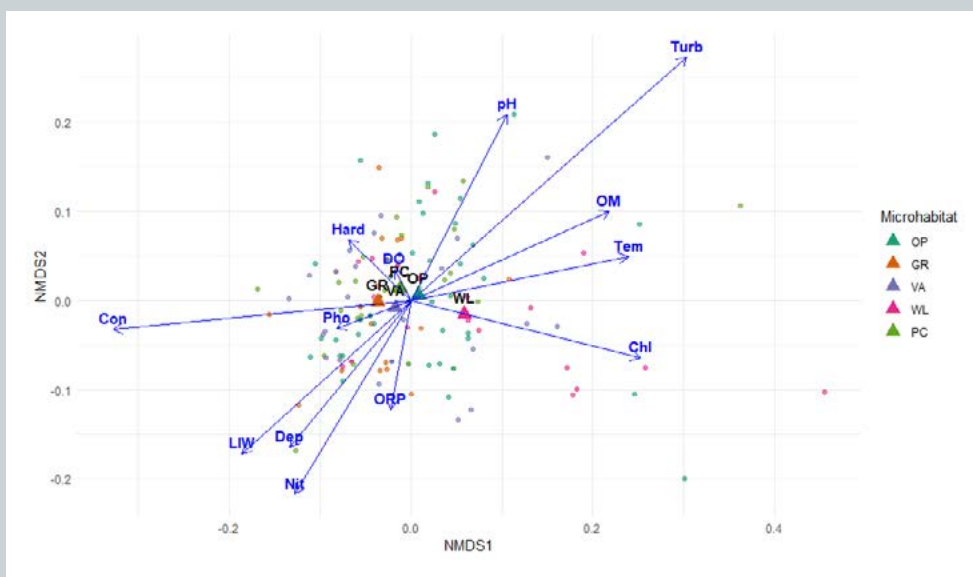


Figure 2.4.4: NMDS ordination plot based on species composition of 154 samples, with superimposed influence of environmental variables and microhabitat categories

Notes: LIW = Light Intensity Underwater, Tem= Temperature, Con = Conductivity, Turb= Turbidity, Dep= Depth, DO= Dissolved Oxygen, ORP= Oxidation-Reduction Potential, Hard= Hardness, Alk = Alkalinity, Nit = Dissolved Nitrate, Pho = Dissolved Phosphate, Chl = Chlorophyll, OM = Sediment Organic Matter Content, OP= Open water column; GR=Gravel and rocky surfaces and crevices; VA=vegetation associated areas; WL=Wood logs; PC=Pits and Channel Paths.

(Reyjol et al. 2001). Wood log structures, fallen trees and their roots provide shelter and create microhabitats for fish (Reyjol et al. 2001; Mchenry et al. 2007; Olentino, Lubich and Yamamoto 2024). The open water column is also identified as a separate microhabitat type with deviation of bottom types like mud and sand (Heck Jr, Hays and Orth 2003; Vlach, Dusek and Svatora 2005). Gravels and rocky surfaces and crevices are also identified as possible fish microhabitat types, at the preliminary step (Reyjol et al. 2001; Vlach, Dusek and Svatora 2005).

Fish species were grouped into families according to the classification, and the family Cyprinidae was grouped into

3 length classes due to their size variations between species. PERMANOVA test revealed that WL was with significantly different species combination from GR, VA and PC microhabitats. WL microhabitats mainly consist of dead terrestrial plants and roots that were drowned when the reservoirs were built, and some have fallen into the water at a later time. Multi-level indicator species analysis indicates that medium-sized cyprinids have significantly contributed to WL microhabitats. Only medium-sized and large-sized cyprinids were the present species in WL according to multi-level indicator species analysis. SIMPER analysis indicated that medium-



and large-sized cyprinids significantly contributed to the dissimilarities between GR and WL, OP and WL, and VA and WL. Small- and medium-sized cyprinids significantly contributed to the dissimilarities between PC and WL. This strongly suggests that family Cyprinidae mostly assemblages in WL microhabitats.

SIMPER analysis indicated that family Channidae, family Mastacembelidae, and medium- and large-sized cyprinids significantly contributed to the dissimilarities between OP and WL, but according to the PERMANOVA test, OP has no significant difference with any other microhabitat in relation to the measured environmental parameters. SIMPER analysis indicated that *M. rosenbergii* (family Palaemonidae) or GFP significantly contributed to dissimilarities between GR and VA, and serves as an indicator species for both microhabitat types. Therefore, we can determine that GFP assemblages are more frequently occurring in GR and VA microhabitats than other microhabitat types.

SIMPER analysis indicates that family Channidae (*Channa striata*) and both medium- and large-sized cyprinids significantly contribute to the dissimilarities between WL and VA. Predators like Channidae might co-occur in a particular microhabitat because of the occurrence of potential prey fish. Family Loricariidae (*Pterygoplichthys* spp.) significantly contributes to the dissimilarities between PC and VA and serves as an indicator species for GR, PC and VA microhabitats. Increased surface area for periphyton cover may attract *Pterygoplichthys* spp. into those microhabitats due to their algae-scraping feeding behaviour. *Pterygoplichthys* spp. is considered an invasive species that harms the reservoir ecosystem leading to population declines of other native fish

species, and it might negatively affect CBF (Gurevitch and Padilla 2004). Becoming an indicator species of 3 microhabitats could be a point of concern for CBF in irrigation reservoirs in the future. According to the multi-level indicator species analysis, medium-sized cyprinids, Palaemonidae, and Loricariidae were the most significant indicator families contributing to different microhabitat types.

The NMDS plot indicates that medium-sized cyprinids, and the families Palaemonidae and Cichlidae exhibit distinct distributions across sites, whereas other fish families show relatively similar distributions. The distribution of Cichlidae is more strongly associated with OP microhabitats, while medium-sized cyprinids are primarily associated with WL microhabitats. *Oreochromis* spp. in the Cichlidae family are known for their nest-building behaviour, constructing nests on the reservoir bottom for breeding (Jere et al. 2021). For that behaviour, clear bottoms with less vegetation cover is essential. During periods of low water levels, the exposed reservoir bottom in open water microhabitats became visible, revealing the nest structures built by *Oreochromis* spp. In contrast, most other species display similar distributions across sites, with significant overlap among the OP, GR, VA and PC microhabitats. This overlap suggests that these microhabitat types share a largely similar species composition. However, the WL microhabitat exhibits a distinct species composition, differentiating it from the other microhabitat types.

Of the measured environmental variables, Light Intensity Underwater (LIW), temperature, pH, conductivity, turbidity, dissolved nitrate, chlorophyll level, depth, and soil organic matter content have significantly influenced the species composition. Turbidity and conductivity

are the strongest environmental drivers shown, suggesting that water quality plays a key role in structuring fish assemblages. Chlorophyll level, nitrite, and soil organic matter content indicate that productivity and nutrient levels also influence the species composition. Environmental variables fitted in the NMDS ordination plot suggest that species composition of OP, GR, VA, and PC microhabitat categories have no strong correlation with the environment. However, WL microhabitat is positively associated with higher chlorophyll levels. Mchenry et al. (2007) observed that higher chlorophyll levels in lotic ecosystems along with significantly greater invertebrate densities on wood than on cobble areas. Higher primary productivity and invertebrate densities can be a reason for higher assemblages of medium-sized cyprinids in WL microhabitats.

Dynamics of microhabitat types in a reservoir are closely influenced by the fluctuating water levels. As the water level decreases, fish are confined to specific microhabitat types, which were previously in deeper locations.

At maximum water levels, fish have access to a greater variety of microhabitats, including those that are less accessible at lower water levels. Therefore, as the water level recedes, the number and types of available microhabitats diminish. For example, microhabitats such as VA are typically abundant in shallow waters when the reservoir is at its full capacity. With the reduction in water level, these VA microhabitats are often lost from the ecosystem. Fish species that are primarily dependant on VA microhabitats must relocate to alternative habitats. Therefore, water level plays a crucial role in determining the distribution and availability of microhabitats for fish, influencing their habitat preferences and the structure of fish assemblages.

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2.5 Reservoir food web with an emphasis on culture-based fisheries

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Abstract

In Sri Lanka, reservoir ecosystems are abundant and significantly contribute to CBF, enhancing inland fish production, food security and economic benefits. Although, studies on reservoir food webs and species interactions are scarce and the influence of those interactions on CBF is still unclear. On top of that, there is no published information on using stable isotope (SI) analysis as a tool to assess trophic interactions in reservoir food webs in Sri Lanka. This study aimed to use SI analysis to examine the trophic relationships between species utilised in CBF and native species in reservoir ecosystems in Sri Lanka. Samples were collected from 6 reservoirs by visiting once every 3 months from May 2023 to June 2024 period. Samples included basal resources (plankton, detritus, aquatic plants) and consumers (culture-based fish species, macrobenthos and indigenous fish species). Tissue samples of all species were dried, powdered and sent to James Cook University, Australia, to determine $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotope ratios. Multivariate statistical analyses and Bayesian mixing models provided insights into species interactions supporting the development of a conceptual food web. The dietary proportions for CBF species, estimated using the SIMMR model, indicated that plankton (50.1%) was the dominant food source, emphasising the importance of pelagic nutrient pathways. Detritus (29.4%) served as the primary benthic resource. The trophic position analysis calculated using freshwater mollusks as baselines, revealed that *M. rosenbergii* (3.49), *Catla catla* (3.06), *Hypophthalmichthys molitrix* (3.08), and *Oreochromis niloticus* (2.88) occupied mid-to-high trophic levels. *Labeo rohita* (2.36) and *Cirrhinus mrigala* (2.00) were positioned at lower trophic levels, relying more on macrophytes and macrophytic detritus. Predators such as *Anguilla bicolor* (4.3) and *Channa* spp. (3.93) occupied the top trophic levels, with potential predation on highly valued GFP and other CBF species. These findings on trophic relationships provides a baseline for better management of CBF in reservoirs in Sri Lanka.

Keywords: stable isotope analysis, culture-based fisheries, *Macrobrachium rosenbergii*, trophic position, reservoir food webs



Introduction

Food webs illustrate complex feeding interactions within an ecosystem, describing how energy and nutrients move through different trophic levels (Garvey and Whiles 2016). Reservoirs are man-made environments synchronising with nature as time permits. With time, different species choose a reservoir environment as their habitat where species interactions and nutrient flows critically shape the structure of the reservoir food web. The majority of the agrarian reservoirs in Sri Lanka are several centuries, if not millennia, old and provide opportunities to study species interactions in quasi natural environments.

Perennial and seasonal reservoirs in Sri Lanka play a crucial role in sustaining aquatic biodiversity and supporting CBF. These reservoirs provide essential food resources and shelter for both indigenous and stocked fish species. Perennial reservoirs, which retain water throughout the year, create stable ecological conditions that support species such as *O. niloticus*, *L. rohita*, *C. mrigala*, *Hypophthalmichthys molitrix* and *C. catla*, which are commonly stocked under CBF programs in Sri Lanka (Jayasinghe et al. 2006). In contrast, seasonal reservoirs, which undergo periodic drying, create fluctuating habitats that influence fish population structures and trophic interactions. The controlled stocking and harvesting of CBF species in both types of reservoirs contribute significantly to inland fish production, enhancing food security and providing economic benefits to local communities (Chandrasoma and Pushpalatha 2018; De Silva et al. 2006).

Despite the growing importance of CBF in Sri Lanka, there is a lack of research to examine reservoir food webs and utilise the knowledge on species interactions for better management of CBF. Using novel

techniques like SI analysis to understand feeding relationships in these ecosystems is non-existent. SI analysis is a powerful tool for examining energy flow and nutrient pathways in aquatic food webs (Fry 2006; Peterson and Fry 1987). The SIs of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) are widely used to assess dietary variability, feeding strategies, trophic positions, trophic niche shifts and nutrient sources in ecosystems (Layman et al. 2012; Post 2002). Generally, $\delta^{15}\text{N}$ serves as an indicator of trophic position, as it reflects an organism's resource use and increases predictably with each trophic level (Post 2002). In contrast, $\delta^{13}\text{C}$ is used to trace the original source of carbon in food webs, distinguishing between different basal energy sources such as planktonic and benthic production (Peterson and Fry 1987). Advances in Bayesian mixing models and isotopic niche analysis have further enhanced the application of SI analysis, allowing for precise estimations of prey contributions and the trophic niche space occupied by consumers within an ecosystem (Layman et al. 2007; Parnell et al. 2010; Abrantes, Barnett and Bouillon 2014). These advancements provide a robust framework for understanding species interactions, energy transfer and ecosystem stability.

Understanding the trophic interactions between CBF species and native species is essential for sustainable fisheries management, as food web dynamics influence species competition, resource partitioning and ecosystem resilience (Córdova-Tapia, Contreras and Zambrano 2015). This study aims to address this knowledge gap by determining the trophic interconnectedness of CBF species with native species, assessing the contributions of pelagic and benthic nutrient pathways in structuring reservoir food webs, and investigating the dietary contributions

of various prey sources to economically important CBF fish species and indigenous species. Additionally, this research seeks to identify potential predators of CBF species, especially the high-valued GFP (*M. rosenbergii*), providing insights into their ecological role within the reservoir ecosystem. Therefore, the primary objective of this study is to construct the food web of Sri Lankan reservoirs using SI analysis with a specific focus on CBF and economically important GFP. The findings of this study are expected to contribute to improved CBF management strategies and sustainable utilisation of reservoir resources ensuring long-term productivity and ecological balance.

Material and methods

We studied freshwater fish communities and their dietary sources in 6 perennial reservoirs located in the dry zone of Sri Lanka. These reservoirs included 4 medium-sized ones as classified by NAQDA: Weerawila in Hambantota District, Tabbowa and Vijayakatupotha in Puttalam District, and Urusitawa in Monaragala District. Additionally, 2 minor reservoirs – Maha Aluthgam Ara in Hambantota District and Siyabalangamuwa in Kurunegala District – were also studied (Table 2.5.1). These reservoirs were multifunctional, serving

as sources of irrigation, water supply and CBF. Medium reservoirs exhibited diverse habitat characteristics, including vegetation cover and mixed substrate types (sandy, muddy and rocky), whereas minor reservoirs were less diverse in habitat features. The NAQDA stocks these reservoirs annually with GFP post larvae and fingerlings of various exotic CBF species, including *O. niloticus*, *L. rohita*, *C. mrigala*, *C. catla* and *H. molitrix*. Samples were collected from all 6 reservoirs every 3 months from May 2023 to June 2024 to ensure sufficient replication for SI mixing model analysis.

Sampling and preparation of fish and GFP for SI analysis

Fish and GFP were collected either using gillnets deployed by local fishers or multi-mesh gillnets set by us in specific microhabitat locations within each reservoir. The gillnets were deployed at designated sites in the evening prior to each sampling day. The following morning, after sampling potential food resources from the same habitats, the overnight catch from the nets was retrieved. For each fish, total length, standard length and weight were recorded. A sample of dorsal white muscle tissue (approximately 1% of body weight) was dissected from the left side of the body and preserved in 70% ethanol.

Table 2.5.1: Location and features of the 6 study reservoirs and their trophic difference represented by mean values of the chlorophyll-a content

Reservoir	Latitude and longitude	Max surface area (km ²)	Max depth (m)	Mean (±SE) Chl-a (µg.L ⁻¹)
Weerawila	6.29 °N, 81.24 °E	5.011	13	4.91±2.50
Tabbowa	8.07 °N, 79.96 °E	5.372	19	11.05±9.07
Vijayakatupatha	7.72 °N, 79.90 °E	1.615	13	11.74±7.73
Urusitawa	6.33 °N, 80.93 °E	1.410	23	17.17±8.97
Maha Aluthgam Ara	6.37 °N, 81.09 °E	0.820	12	20.23±26.34
Siyabalangamuwa	7.94 °N, 80.46 °E	0.792	18	32.64±30.47



For fish samples less than 3 cm in standard length, the whole bodies of fish were used after removing the head, intestine and scales. For GFP, morphometric and meristic parameters, as outlined by Munasinghe and Thushari (2010) were recorded. GFP were then dissected, and tail muscle tissue (2–5 g) was taken for SI analysis, removing shell material, which can be enriched in $\delta^{13}\text{C}$ and would not reflect the actual assimilated diet of consumers (Kirby, Soniat and Spero 1998). For the time between sampling and sample preparation for SI analysis at the laboratory, all samples were preserved in 70% ethanol to ensure consistency (Hobson, Gibbs and Gloutney 1997). Since ethanol preservation was applied to all fish and GFP samples, it was assumed that any preservation effects on isotopic values would be consistent across species. Samples were sent to the SI analysis facility at James Cook University, Australia, and before sending, muscle tissues were washed 3 times with distilled water and oven-dried at 60 °C for several days until they could be easily powdered using a ceramic mortar and pestle (Hobson, Gibbs and Gloutney 1997; Vander Zanden et al. 1998).

Sampling potential basal resources and other consumers for SI analysis

Basal resources sampled for SI analysis included plankton (categorised into 2 size classes: 35–100 μm and >100 μm), detritus, emergent aquatic plants, submerged aquatic plants and riparian plants. Plankton samples were collected using 2 types of plankton nets: one with a 20 cm diameter and 100 μm mesh size, and another with a 30 cm diameter and 35 μm mesh size.

To prepare plankton samples in the 35–100 μm size range, approximately 25 L of surface water was collected at a depth of 0.5 m in the water column with a measuring

basket and pre-filtered through the 100 μm mesh net to remove larger plankton and other debris. Then, the filtrate was passed through a 35 μm mesh net to remove tiny particles. The resulting filtrate was filtered again through a pre-combusted GF/C filter using a Buchner funnel fitted to a vacuum pump. Plankton larger than 100 μm was directly collected by dragging the 100 μm plankton net horizontally at a depth of 0.5 m in the water column. Debris and filamentous algae in the sample were removed by filtering through a 1 mm mesh before final filtration was passed through a pre-combusted GF/C filter. All GF/C filters containing plankton were oven-dried at 50 °C for 8 hours to prepare them for SI analysis (Keough, Sierszen and Hagley 1996; Mateo et al. 2008).

Detritus, emergent aquatic plants, submerged aquatic plants and riparian plants were handpicked from the littoral zones of the reservoirs. These samples were thoroughly rinsed with distilled water several times to remove sediments, organisms and other attachments. Detritus samples were further treated with 1 mol.L⁻¹ HCl to remove carbonates before drying. Mollusks and aquatic insects were collected from the littoral zone using a hand net. Depending on the time required for transport to the laboratory, mollusks and aquatic insects were kept alive in distilled water for 24 hours either in situ or in the laboratory to allow gut clearance. Mollusks were dissected to extract adductor muscle tissue, while the entire bodies of aquatic insects were prepared for SI analysis. All collected samples were oven-dried at 60 °C for at least 48 hours and then ground into a homogeneous fine powder using a mortar and pestle. The powdered samples were stored in clean containers in a desiccator until they were ready for SI analysis.

SI analysis

SI analysis was done using a Smart EA isolink elemental analyser connected to a Delta V Plus isotope ratio mass spectrometer via a ConFlo IV interface. Samples (0.8–1.2 mg) were combusted at 1020 °C, and the resulting CO₂ and N₂ gases were analysed for δ¹³C and δ¹⁵N values. International standard USGS40 (L-glutamic acid) and laboratory standards chitin and taipan were used for calibration. Data processing included drift and linearity corrections, with normalisation to Viana Pee Dee belemnite for carbon and to atmospheric nitrogen for nitrogen. The instrument had a precision of ≤0.06‰ (1σ) for isotope ratio measurements. SI ratio was expressed as:

$$\delta X (\text{‰}) = [((R_{\text{sample}})/(R_{\text{standard}})) - 1] \times 1000$$

Where X is either ¹³C or ¹⁵N SI ratio, and R is either the ¹³C: ¹²C ratio for carbon or ¹⁵N: ¹⁴N ratio for nitrogen.

Arithmetic lipid correction

All fish and GFP samples were lipid-corrected following the method described by (Taylor et al. 2017). The equation, which adjusts for lipid-related δ¹³C depletion based on the C:N ratio is:

$$\delta^{13}\text{C}_{\text{normalized}} = \delta^{13}\text{C}_{\text{bulk}} + (93/(1+(\text{C:N})^{3.4}))$$

Where δ¹³C_{bulk} is the measured δ¹³C value of the untreated sample, δ¹³C_{normalised} is the lipid corrected δ¹³C value, C:N serving as a proxy for lipid content. The empirically derived constants 93 (scaling factor) and 3.4 (exponent) account for the nonlinear relationship between C: N and lipid depletion. This model was selected for its broad applicability across taxa and greater accuracy than previous lipid normalisation equations (McConnaughey and McRoy 1979; Kiljunen et al. 2006; Post et al. 2007), as it was developed using a large dataset, including freshwater aquatic organisms.

Food-web structure and SI mixing models

This study aimed to develop a conceptual food web with an emphasis on CBF in Sri Lanka. The Tabbowa, Weerawila and Siyabalangamuwa reservoirs were selected for food web construction, as they encompass most of the fish species found in Sri Lankan reservoir ecosystems. To determine whether these reservoirs share similar isotopic baselines, multivariate statistical analyses were conducted using R statistical software (version 4.4.2). PERMANOVA was performed with δ¹³C and δ¹⁵N isotope values as response variables and reservoirs and basal resource groups (plankton, detritus, submerged plants, emergent plants and benthic algae) as grouping factors. Analyses were conducted on Euclidean distance measures using untransformed data. Levene's test confirmed the homogeneity of variances, and PERMANOVA (α = 0.05) was used to assess significant differences among reservoirs and basal resource groups, with significance determined using Type I (sequential) sums of squares and 999 unrestricted permutations. Given the observed isotopic similarity across reservoirs, the data from these 3 reservoirs were combined to establish a consistent baseline for food web construction, ensuring a comprehensive representation of ecological patterns in δ¹³C and δ¹⁵N values.

The assessment of food web structure was based on trophic enrichment factors of 1.5±0.5 ‰ for δ¹³C and 3.2±0.5 ‰ for δ¹⁵N (Sweeting et al. 2007). SI Mixing Models in R (R 4.2.2) with the SIMMR package were used to estimate the contribution of multiple sources to each consumer species. SIMMR is a package designed to solve mixing equations for stable isotopic data within a Bayesian framework using Markov Chain

Monte Carlo (MCMC) fitting algorithms (Parnell et al. 2013; Phillips et al. 2014). The model generates posterior probability distributions described by average estimates of the source contributions and their associated credible intervals. Convergence and diagnostic statistics were evaluated using the Gelman-Rubin test, with all variables achieving values close to one, indicating convergence. Thereafter, the model fit was checked with a posterior predictive check, and it was investigated if all data points would fall approximately within the fitted value intervals. Within the SIMMR package, the program JAGS was used to run the mixing model (Parnell et al. 2013).

Consumer trophic positions

Consumer trophic levels (TL) were calculated based on the formula proposed by (Post 2002) and based on fractionation of 3.2 ± 0.5 ‰ for $\delta^{15}\text{N}$ (Sweeting, Polunin and Jennings 2006):

$$\text{TL} = (\lambda + (\delta^{15}\text{N}_{\text{consumer}} - \delta^{15}\text{N}_{\text{base}}) / \text{TEF})$$

Where $\delta^{15}\text{N}_{\text{base}}$ is the mean $\delta^{15}\text{N}$ value for a representative primary consumer, and TEF is the mean trophic fractionation which is 3.2 ‰. In this study, freshwater mollusks were used as baseline primary consumers to estimate trophic positions, with bivalves (*Lamellidens marginalis*, Unionidae) representing pelagic primary production and gastropods (Viviparidae) representing benthic primary production (Winemiller et al. 2011). Primary consumers were selected over primary producers due to their ability to integrate isotopic signals from multiple sources, providing a more stable and ecologically relevant baseline (Anderson and Cabana 2007). The mean $\delta^{15}\text{N}$ values of these mollusks were used to establish the baseline trophic level ($\lambda = 2$) for calculating the trophic positions of higher consumers. Using primary consumers

as baselines reduces isotopic variability caused by environmental fluctuations, and simplifies food web reconstruction (Peterson and Fry 1987; Post 2002). Their filter-feeding and grazing habits make them reliable indicators of energy flow pathways, ensuring more accurate estimations of trophic interactions in reservoir ecosystems (Cabana and Rasmussen 1996).

Results

SI signatures of basal resources and consumers

A total of 515 samples were checked for SI ratios to investigate the trophic structure of Sri Lankan reservoir ecosystems. The dataset includes 4 basal resource types, 6 invertebrate groups, 27 fish species and GFP along with apex predators such as the great cormorant and crocodile (Table 2.5.2). This paper primarily emphasises CBF species with GFP along with their indigenous competitors and predators for food web construction. Apart from *Oreochromis niloticus*, which belongs to the family Cichlidae, all other CBF species – *C. catla*, *C. mrigala*, *L. rohita* and *H. molitrix* – belong to the family Cyprinidae. These fish species primarily inhabit benthopelagic zones, utilising both the water column and bottom habitats within the reservoir ecosystem.

Table 2.5.2: Carbon and nitrogen SI ratios (mean±standard deviation) of fish species, invertebrate groups, and basal carbon sources sampled from Weerawila (H2), Tabbowa (P4), Vijayakatupatha (P5), Urusitawa (Mo5), Maha Aluthgam Ara (H3), and Siyabalangamuwa (Ku5), Iranamadu (Ki2)

Species	Family	Reservoir	N	δ13C	δ15N
Fish species					
<i>Oreochromis niloticus</i>	Cichlidae	H3	7	-23.57±2.12	9.85±1.26
		Ku5	12	-26.20±1.14	7.63±0.94
		P4	12	-26.30±1.66	7.94±0.94
		Mo5	9	-31.79±0.35	6.93±1.29
		P5	12	-28.63±1.19	6.83±1.24
		H2	10	-27.13±2.96	10.12±0.85
<i>Cirrhinus mrigala</i>	Cyprinidae	H3	6	-26.64±0.82	5.05±1.08
		Ku5	4	-28.34±2.75	3.64±0.90
		P4	8	-28.52±2.05	3.64±1.48
		Mo5	10	-32.75±1.19	7.43±0.79
		P5	10	-29.83±1.38	4.41±0.57
		H2	8	-28.44±2.15	8.66±1.39
<i>Labeo rohita</i>	Cyprinidae	H3	6	-22.11±0.86	8.76±0.75
		Ku5	5	-25.88±1.38	5.86±0.10
		P4	1	-26.43	6.84
		Mo5	6	-32.24±0.35	5.58±0.86
		P5	11	-29.05±1.22	6.37±0.46
		H2	5	-25.54±2.01	7.77±0.52
<i>Hypophthalmichthys molitrix</i>	Cyprinidae	Ku5	4	-24.22±1.05	6.87±0.11
		P4	4	-26.62±0.49	7.43±0.37
		Mo5	7	-31.53±0.43	9.55±0.30
<i>Catla catla</i>	Cyprinidae	Ku5	6	-27.04±1.17	9.25±0.63
		P4	1	-30.51	7.99
		Mo5	8	-31.63±0.36	7.74±0.92
		P5	4	-30.76±1.09	8.28±0.11
<i>Amblypharyngodon melettinus</i>	Cyprinidae	P4	3	-26.93±0.33	6.74±0.14
<i>Awaous grammepomus</i>	Gobiidae	H3	3	-23.91±1.79	9.57±1.17
		Ku5	4	-25.51±0.73	10.36±0.32
		P4	8	-26.36±0.57	9.49±0.58
		P5	5	-29.27±1.25	8.89±0.93
		H2	1	-28.01	11.59

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Species	Family	Reservoir	N	δ13C	δ15N
<i>Coptodon rendalli</i>	Cichlidae	Ku5	2	-25.95±0.82	7.82±0.21
		P4	7	-19.35±0.94	9.90±0.30
<i>Cyprinus carpio</i>	Cyprinidae	P4	1	-27.32	7.24
<i>Dawkinsia sp.</i>	Cyprinidae	P4	2	-24.82±1.36	9.03±0.25
<i>Dawkinsia singhala</i>	Cyprinidae	P4	4	-26.0±1.36	9.03±0.25
<i>Etrophus suratensis</i>	Cichlidae	Ku5	10	-24.93±0.99	9.556
		P4	12	-26.45±0.47	8.56±0.17
		Mo5	2	-34.25±6.11	7.59±1.88
		P5	5	-25.51±2.09	9.26±0.91
<i>Heteropneustes fossilis</i>	Heteropneustidae	P4	5	-25.62±1.13	9.12±0.71
		P5	1	-31.67	5.65
<i>Labeo dussumieri</i>	Cyprinidae	H2	1	-27.84	6.59
<i>Mystus ankutta</i>	Bagridae	P4	3	-26.90±1.46	11.53±3.95
<i>Oreochromis mossambicus</i>	Cichlidae	H3	2	-24.88±0.22	9.18±0.38
		Ku5	6	-26.73±0.67	7.84±0.49
		P4	3	-23.27±5.24	8.72±1.14
		Mo5	1	-31.70	8.5
<i>Pseudotropheus maculatus</i>	Cichlidae	P4	6	-26.73±0.67	7.84±0.49
<i>Pterygoplichthys gibbosus</i>	Loricariidae	P4	2	-27.73±1.28	5.69±0.13
		Mo5	3	-31.38±0.63	7.68±0.29
		P5	4	-29.34±1.11	8.21±1.01
<i>Puntius bimaculatus</i>	Cyprinidae	P4	3	-24.0±0.7	9.02±0.64
<i>Puntius dorsalis</i>	Cyprinidae	Ku5	1	-25.36	8.03
		P4	3	-25.09±0.97	7.80±0.19
		P5	1	-28.42	7.08
<i>Puntius sarana</i>	Cyprinidae	H3	2	-22.26±0.61	10.31±0.19
		P4	4	-26.59±0.07	7.34±0.59
		Mo5	7	-30.98±0.76	9.66±0.77
		P5	2	-28.82±1.39	8.19±0.72
		H2	6	-27.68±1.06	11.41±0.59
<i>Rasbora microcephalus</i>	Cyprinidae	H3	1	-25.15	8.44
		P4	4	-25.67±0.33	9.89±0.42
<i>Channa marulius</i>	Channidae	Ku5	1	-24.18	10.64
<i>Ompok bimaculatus</i>	Siluridae	Ku5	2	-25.63±0.05	9.98±0.54
		P4	5	-27.26±2.21	9.32±0.88
		P5	5	-25.19±1.05	10.19±0.55

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Species	Family	Reservoir	N	δ13C	δ15N
<i>Channa striata</i>	Channidae	P4	1	-25.06	10.42
		Mo5	2	-30.39±0.57	10.95±0.77
		P5	1	-27.61	11.24
		H2	9	-26.7±1.37	12.14±1.95
<i>Anguilla bicolor</i>	Anguillidae	H2	1	-23.55	13.02
<i>Mastacembellus armatus</i>	Mastacembelidae	P4	6	-25.19±1.05	10.19±0.55
Invertebrates					
<i>Macrobrachium rosenbergii</i>	Palaemonidae	H3	5	-23.43±0.52	11.09±0.44
		Ku5	8	-25.26±0.68	10.08±0.65
		P4	10	-25.81±1.40	9.70±0.80
		Mo5	2	-29.39±1.00	10.52±1.55
		P5	8	-28.30±1.29	9.37±0.56
		H2	10	-28.78±2.24	11.39±0.98
Aquatic insect larvae	-	H3	2	-32.61±1.36	5.92±0.71
		Ku5	2	-32.71±0.93	5.66±0.26
		P4	4	-27.29±5.50	6.41±0.78
		Mo5	3	-33.39±2.37	4.42±0.88
		P5	5	-32.21±3.2	4.64±1.15
		H2	2	-28.56±1.53	7.36±0.92
Freshwater shrimp (<i>Caridina simoni</i>)	Atyidae	P4	3	-27.58±1.35	5.89±0.58
		Mo5	2	-31.29±0.69	7.56±1.82
		P5	3	-29.67±1.6	7.68±0.89
		H2	1	-25.86	8.3
Freshwater crab	Gecarcinucidae	Mo5	2	-31.5±0.07	8.12±1.80
		P5	1	-31.64	10.08
Plankton >100 µm	-	Ku5	3	-30.09±0.75	8.02±0.31
		P4	3	-32.76±0.86	8.36±0.47
		H2	3	-32.76±1.15	8.02±0.31
Freshwater bivalves (<i>Lamellidens marginalis</i>)	Unionidae	P4	2	-29.35±0.41	4.72±0.02
		P5	1	-32.61	4.37
Freshwater snails	Viviparidae	H3	3	-32.71±0.35	5.58±0.90
		Ku5	3	-34.16±1.22	6.40±1.92
		P4	3	-31.09±1.85	5.51±1.30
		Mo5	6	-33.00±0.53	6.4 ±1.10
		P5	3	-34.59±0.25	5.63±2.14
		H2	3	-27.62±1.55	6.43±1.37

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Species	Family	Reservoir	N	δ13C	δ15N
Basal resources					
Plankton (35–100 μm)	-	Ku5	3	-29.10±1.14	5.53±1.01
		P4	4	-30.23± 0.16	5.49±0.15
		H2	2	-30.68±0.94	7.49±0.15
Detritus	-	H3	2	-24.56±0.23	4.51±1.62
		Ku5	3	27.37±2.04	3.18±0.64
		P4	4	-24.57±4.16	3.35±1.48
		Mo5	3	-28.62±0.59	6.97±2.39
		P5	3	-24.91±6.62	2.51±1.05
		H2	4	-25.32±4.86	4.61±2.06
Emergent plants	-	P4	2	-18.65±6.99	4.59±0.76
		Mo5	1	-17.48	6.02
		H2	6	-18.44±3.32	5.16±2.41
Submerged plants	-	H3	1	-32.71±0.35	5.58±0.90
		Ku5	2	-28.01±2.28	4.05±0.57
		P4	6	-29.22±1.62	2.93±3.02
		Mo5	3	-31.31±0.60	2.81±2.79
		P5	4	-28.19±0.72	3.49±1.77
		H2	3	-29.53±0.46	6.15±1.00
Benthic algae	-	P4	3	-13.87±1.82	3.41±3.16
		H2	2	-30.93±0.64	5.73±0.42
Other species					
<i>Phalacrocorax carbo</i>	Phalacrocoracidae	P5	1	-26.33	9.96
Crocodile	Crocodylidae	Ki2	1	-21.57	9.37

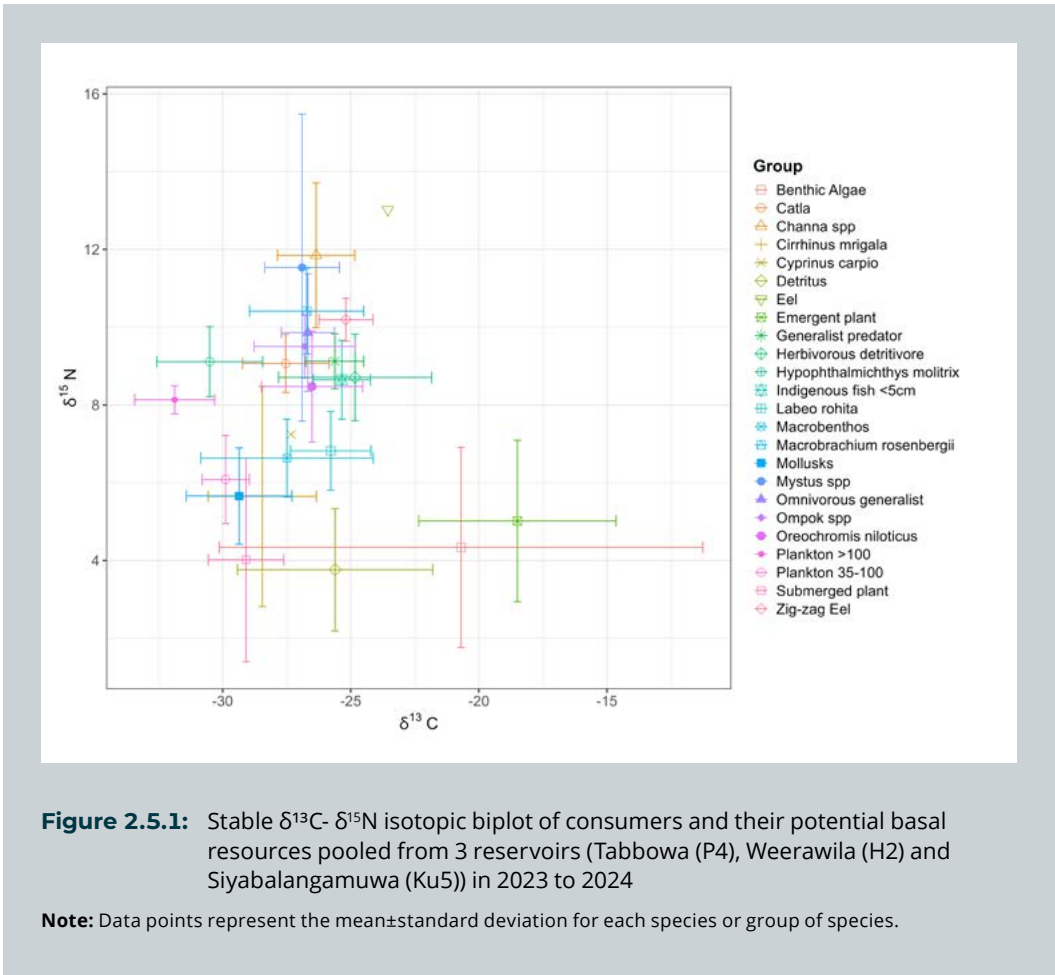
Tabbowa (P4), Weerawila (H2) and Siyabalangamuwa (Ku5) reservoirs were selected for the conceptual food web development of Sri Lankan reservoirs. Across these reservoirs, the $\delta^{13}\text{C}$ values of basal resources ranged from -30 ‰ to -11 ‰ (Figure 2.5.1). Among these, submerged plants exhibited the lowest $\delta^{13}\text{C}$ values, while detritus showed relatively enriched $\delta^{13}\text{C}$ values ranging from -28 ‰ to -24 ‰. Statistical analysis using the Kruskal-Wallis test ($H = 18.47$, $df = 2$, $p < 0.001$) and Dunn's post-hoc test indicated that detritus was not significantly different from submerged or emergent plants (Detritus

vs. Emergent plant: $Z = -2.218$, $p = 0.0797$; Detritus vs. Submerged plant: $Z = 2.253$, $p = 0.0727$). These findings suggest that a significant portion of detritus is likely derived from macrophyte-derived organic matter.

The 35–100 μm plankton size group exhibited more enriched $\delta^{13}\text{C}$ values compared to the $>100 \mu\text{m}$ size group, suggesting differences in carbon sources between these fractions. In contrast, the $>100 \mu\text{m}$ plankton group displayed higher $\delta^{15}\text{N}$ values (8.02–8.36 ‰) than the 35–100 μm group (5.49 – 7.48 ‰), indicating a clear trophic separation

between these size classes. The >100 μm fraction likely consists of larger herbivorous and omnivorous zooplankton, such as copepods, cladocerans and large rotifers, which feed on smaller phytoplankton and microzooplankton. This trophic enrichment follows the established pattern of nitrogen isotope fractionation, where $\delta^{15}\text{N}$ values increase by approximately 2–4 ‰ per trophic level due to stepwise nitrogen assimilation and excretion processes (Minagawa et al. 1984). These results align with the expected food web structure, where phytoplankton (35–100 μm) serve

as primary producers with lower $\delta^{15}\text{N}$ values, while larger zooplankton (>100 μm) occupy a higher trophic level due to their consumption of microzooplankton and phytoplankton. The $\delta^{13}\text{C}$ values of consumer fish and GFP in the reservoirs ranged from -23 ‰ to -30 ‰, while $\delta^{15}\text{N}$ values ranged from 3 ‰ to 13 ‰ (Figure 2.5.1) indicating diverse nutrient pathways and trophic positions. The variation in $\delta^{15}\text{N}$ values reflects different trophic levels, from primary consumers to higher-level predators.



The differences in SI values ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) among reservoirs were analysed using PERMANOVA, considering the basal resource groups: plankton, detritus, submerged plants, emergent plants and benthic algae. The analysis, conducted using Euclidean distance with 999 permutations, revealed that reservoir location had no significant effect on isotopic composition ($F = 1.2335$, $p = 0.306$), explaining only 4.9% of the total variance ($R^2 = 0.04888$), with the remaining 95.1% attributed to within-reservoir variation.

These results suggest that the isotopic composition of basal resources is relatively uniform across reservoirs (Figure 2.5.2), therefore combining basal resource data from different reservoirs for food web construction is feasible. Pooling the data can provide a representative baseline for food web analysis without introducing significant spatial bias, as the isotopic differences are primarily driven by within-reservoir factors rather than reservoir location.

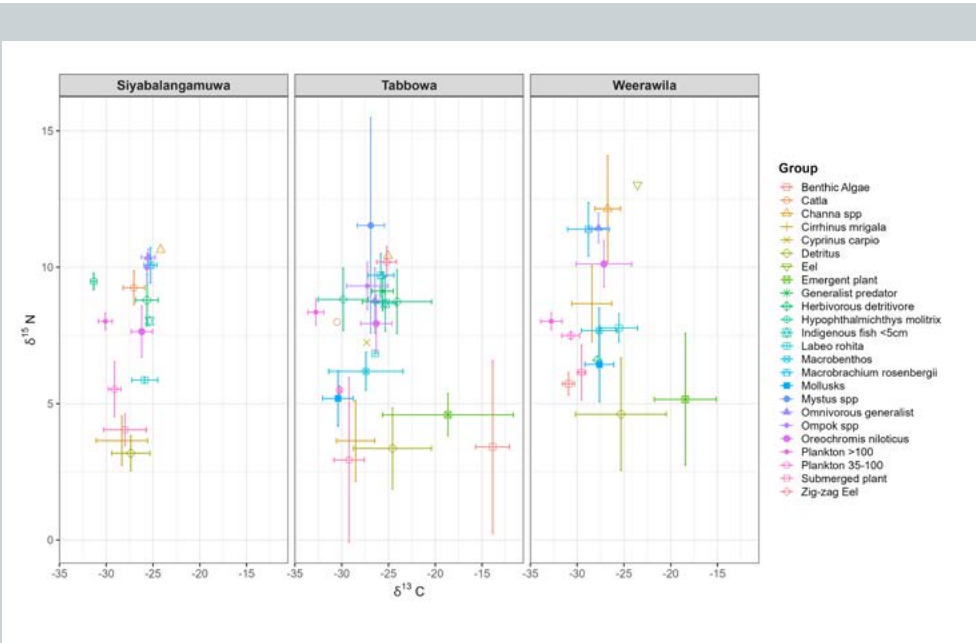


Figure 2.5.2: Separate stable $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ isotopic biplots of Tabbowa (P4), Weerawila (H2) and Siyabalangamuwa (Ku5)

Note: Data points represent the mean±standard deviation for each species or group of species.

Feeding ecology of GFP

The SIMMR model utilised SI values ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) and trophic enrichment factors (Sweeting et al. 2007) of GFP muscle tissue to estimate the proportional contributions of potential dietary sources, which included benthic algae, detritus, emergent plants, macrobenthos, mollusks, indigenous fish species (<5 cm) and submerged plants. It revealed that indigenous fish species (<5 cm) contributed the highest proportion to the diet (mean = 0.402 ± 0.124), followed by mollusks (mean = 0.255 ± 0.150) and macrobenthos (mean = 0.196 ± 0.189) (Figure 2.5.3 b). These findings suggest that GFP primarily shows carnivorous behaviour, relying heavily on animal-based food sources, which is consistent with previous studies indicating its opportunistic feeding behaviour and preference for protein-rich prey (Kurup, Harikrishnan and Sureshkumar 2000; New 2002). The relatively minor contributions from submerged plants (mean = 0.063 ± 0.053), detritus (mean = 0.035 ± 0.026) and benthic algae (mean = 0.025 ± 0.017) align with earlier observations that plant material and organic detritus are secondary dietary components, often consumed when preferred prey is scarce (Mariappan et al. 2000).

The posterior density plots and credible intervals (Figure 2.5.3 a) indicate variability in dietary intake, highlighting the species' ability to adjust its feeding strategy based on resource availability. Compared to previous studies in natural freshwater ecosystems, which reported a higher reliance on detritus and plant matter in heavily vegetated habitats (Bakhtiyar, Lakshnotra and Langer 2013), the present findings suggest that in the studied reservoirs, carnivorous feeding predominates, likely due to the greater availability of small fish species and mollusks.

The SIMMR matrix plot (Figure 2.5.3 c) presents the pairwise relationships between dietary sources of GFP, revealing strong negative correlations between Macroinvertebrates and small indigenous fish species <5 cm (-0.692), as well as between Macroinvertebrates and Mollusks (-0.682). These negative correlations suggest potential dietary trade-offs, indicating that GFP may dynamically adjust its diet in response to prey availability. In contrast, a weak positive correlation (0.264) is observed between indigenous fish species <5 cm and submerged plants, suggesting some degree of simultaneous consumption. The small fish species collected from these reservoirs – such as *Pseudotropheus maculatus*, *Puntius dorsalis*, *Puntius bimaculatus*, *Rasbora microcephalus*, *Dawkinsia singhala* and *Amblypharyngodon melettinus* – are often found in the littoral zone, where dense vegetation is prevalent. This habitat overlap may explain the observed co-occurrence in the diet of GFP. However, the relatively low correlation value (0.264) suggests that GFP does not heavily rely on submerged plants when consuming small fish species, and the association may be incidental rather than a primary dietary preference.

Feeding ecology of CBF fish species

The primary CBF fish species in Sri Lankan reservoirs include tilapia species such as *Oreochromis niloticus* and various carp species, including *L. rohita*, *C. mrigala*, *C. catla*, *H. molitrix*, *H. nobilis*, *Ctenopharyngodon idella* and *Cyprinus carpio*. However, due to the unavailability and insufficient sample number of *H. nobilis*, *C. idella* and *C. carpio* from the sampled reservoirs, these species were not included in the SIMMR Bayesian mixing model analysis. The analysis focused on the remaining species, with most sampled individuals being adults (Table 2.5.3), thereby providing insights into the feeding ecology of their adult life stage in reservoir ecosystems.

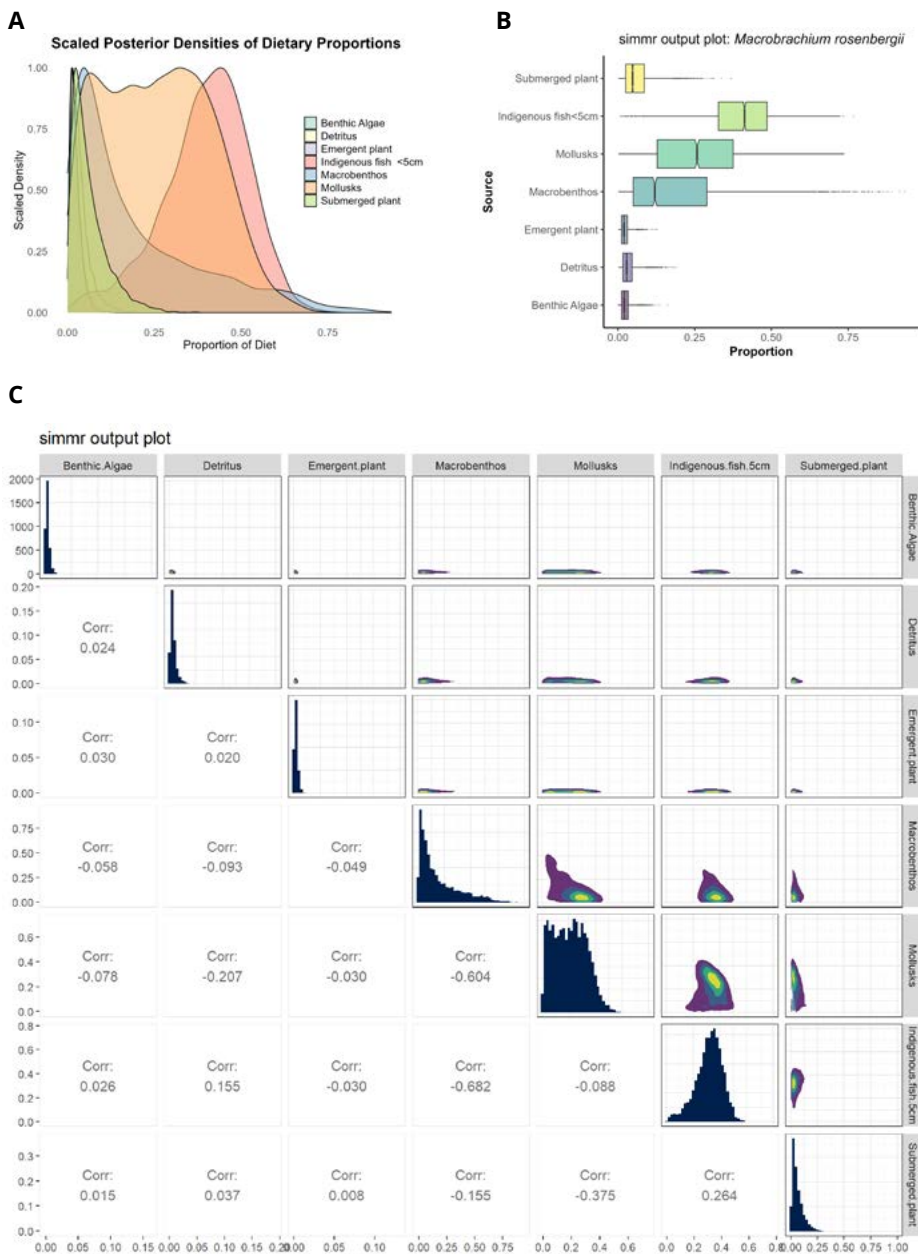


Figure 2.5.3: Posterior distributions of dietary source proportions for GFP estimated using SIMMR

Note: (a) Scaled Density Plot, (b) Boxplot of Relative Proportions (c) Matrix plot showing correlations between dietary components.

Table 2.5.3: Total length (TL), standard length (SL) and weight of culture-based fish species sampled from 3 reservoirs (Ku5=Siyabalangamuwa, P4=Tabbowa, H2=Weerawila)

Species	Reservoir	TL range (cm)	SL range (cm)	Weight range (g)
<i>Catla catla</i>	Ku5	34.1–53.5	25.8–44.1	410–2,495
	P4	22.5	18.7	198
<i>Cirrhinus mrigala</i>	Ku5	45.8–49	38–41.2	1,096–1,391
	P4	42.7–57.8	35–48.7	853–1,803.8
	H2	32.7–52.1	27.1–42.3	411.8–1,362
<i>Labeo rohita</i>	Ku5	29.5–50.8	19.7–40.5	307–1,685.8
	P4	48.5	39.3	979
	H2	28.5–46.2	22.6–36.8	276–1,252.6
<i>Hypophthalmichthys molitrix</i>	Ku5	45.2–57.5	38.1–48.4	899–2,096
	P4	40.3–54.1	34.1–46.2	680–1,402
<i>Oreochromis niloticus</i>	Ku5	17.5–26.3	14–21.9	109–394.4
	P4	21–35.7	17.2–29.4	197–879
	H2	15.1–40.1	16.7–34.2	162.2–516.2

The SIMMR model was applied to *O. niloticus* using 4 basal dietary sources: detritus, plankton (35–100 µm), plankton (>100 µm) and macrobenthos. The macrobenthos category included insect larval stages, which were directly observed in the gut contents of the sampled *O. niloticus*. These dietary sources, confirmed through gut content analysis, represent the primary food items utilised by the species in the studied environment. A related study by Temesgen et al. (2022) reported a diverse range of dietary components in the gut contents of *O. niloticus*, including phytoplankton, zooplankton, insects, detritus, macrophytes, fish parts and nematodes. The results of the SIMMR model indicated that *O. niloticus* predominantly feeds on detritus (40.9%), followed by plankton (35–100 µm) (29.7%). Macrobenthos contributed 16.6%, while plankton (>100 µm) accounted for 12.8% (Figure 2.5.4 a). Among the dietary sources, detritus exhibited the highest proportion with the lowest uncertainty, with a 95% credible interval ranging from 24.5% to 55.9%. The density distribution for detritus displayed a narrow peak, indicating greater

confidence in its contribution. In contrast, plankton (35–100 µm) exhibited a broader peak, suggesting higher uncertainty in its dietary contribution (Figure 2.5.4 b). The posterior predictive check revealed that 42.7% of the observed data fell outside the predicted range, indicating a moderate model fit with some unexplained variation.

The SIMMR model was applied to culture-based cyprinid species, with dietary sources identified through gut content observations and validated using secondary literature. For *H. molitrix*, the dietary sources included plankton (35–100 µm), plankton (>100 µm) and detritus (Jayasinghe et al. 2015; Tumolo and Flinn 2019). A similar composition was applied to *C. catla* (Lalit 2015; Mishra 2020). For *C. mrigala* and *L. rohita*, submerged plants were also included as dietary sources (Soni and Ujjania 2018; Mishra 2020). The results showed that plankton (35–100 µm) contributed 48.7% of *H. molitrix*'s diet (Figure 2.5.5 a) and 40% of *C. catla*'s diet (Figure 2.5.5 b). *C. mrigala* primarily relied on submerged plants (55.9%, Figure 2.5.5 c), while *L. rohita* showed a strong dependence on macrophytic detritus (46.5%, Figure 2.5.5 d).

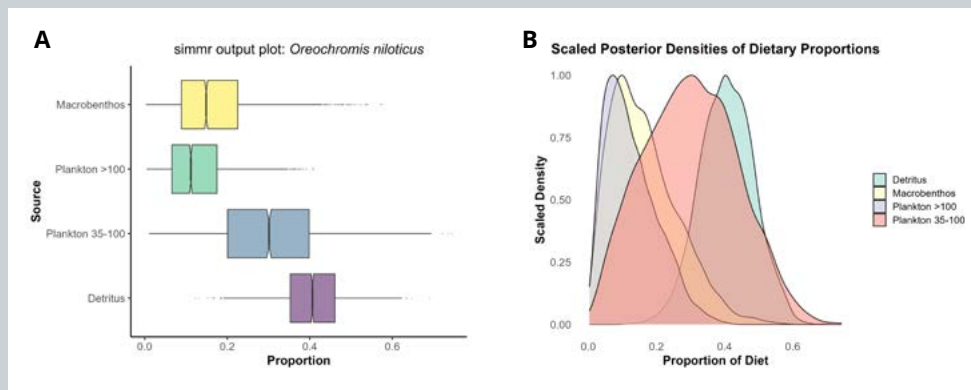


Figure 2.5.4: Relative dietary proportions of *Oreochromis niloticus* (a) dietary boxplot (b) scaled density plot resulted from SIMMR model

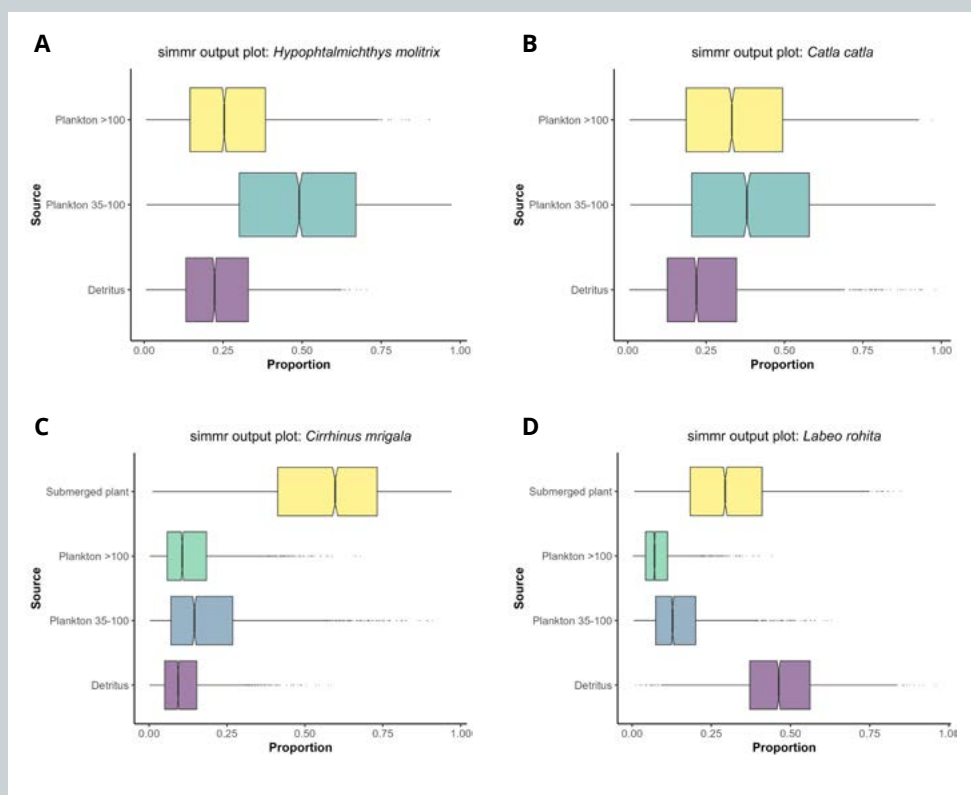


Figure 2.5.5: Dietary boxplots of (a) *Hypophthalmichthys molitrix* (b) *Catla catla* (c) *Cirrhinus mrigala* (d) *Labeo rohita* resulted from SIMMR model

Feeding ecology of potential predators of CBF species

Piscivorous fish species, including *C. striata* and *C. marulius*, along with generalist predators such as *A. bicolor*, *M. armatus* and *O. bimaculatus* were incorporated into the model based on ecological evidence supporting their predation on CBF species. Additionally, local fishers' observations suggest that these predators actively prey on GFP, particularly when they are entangled in gillnets. These species are known to feed on fingerling and juveniles of CBF fish, as well as the post-larval stages of GFP highlighting their role as key predators within the reservoir ecosystem.

The SIMMR model was used to determine the dietary contributions of piscivorous and generalist predator species by incorporating each CBF species as an individual dietary source, while indigenous fish species smaller than 5 cm were pooled together with mollusks, macrobenthos and other relevant dietary sources as a single category as appropriate. The selection of dietary sources for each predator was based on gut content observations, fishers'

ecological knowledge and experience, and existing literature to ensure a comprehensive understanding of their trophic interactions. *Channa* spp. was modelled with macrobenthos, mollusks and indigenous fish species less than 5 cm in standard length, along with an assessment of their predation on GFP. Only small fish species were incorporated into the model, as existing literature does not indicate that *Channa* spp. prey on adult cyprinids and cichlids (Das et al. 1998; Amin et al. 2005) and no evidence of such predation was observed in their gut contents. The SIMMR model results indicate that *Channa* spp. exhibits a generalist predatory feeding strategy, with GFP contributing the highest proportion (34.7%) to their diet, followed by mollusks (25.0%), indigenous fish species <5 cm (21.0%) and macrobenthos (19.3%) (Figure 2.5.6 a).

For the SIMMR model of *A. bicolor*, *O. niloticus* was incorporated as a dietary source along with other potential prey items based on gut content observations (Rupasinghe and Attygalle 2006; Sidqi et al. 2018). The model results indicate that

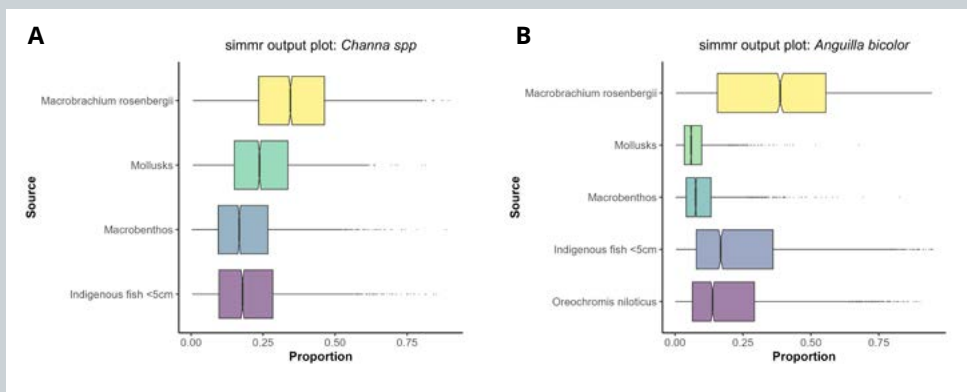


Figure 2.5.6: Relative dietary boxplots of (a) *Channa* spp. (b) *Anguilla bicolor* as explained by the SIMMR model

A. bicolor exhibits a generalist predatory feeding strategy, with GFP contributing the highest proportion (37.3%), followed by indigenous fish species <5 cm (24.0%) and *O. niloticus* (21.6%). Macrobenthos (9.6%) and mollusks (7.4%) contributed to a lesser extent (Figure 2.5.6 b), suggesting occasional consumption of benthic invertebrates. The relatively high reliance on GFP and small fish species aligns with its piscivorous tendencies, where it actively preys on available fish and crustaceans, demonstrating opportunistic feeding behaviour influenced by the prey availability within the reservoir ecosystem. The relatively high reliance on GFP suggests that it is an important prey item for *Channa* spp. and *A. bicolor*. As GFP frequently become entangled in gillnets during fishing operations they can be easily accessible to these predators.

To assess the trophic interactions and dietary composition of *M. armatus* and *O. bimaculatus*, a SIMMR Bayesian model was employed, incorporating indigenous fish species <5 cm in standard length, mollusks, and macrobenthos as dietary sources. Mollusks, including freshwater bivalves and snails, and macrobenthos, consisting of insect larvae and *C. simonii*, were selected based on existing literature (Gupta and Banerjee 2016; Kashyap et al. 2023; Serajuddin et al. 1998). Furthermore, to evaluate potential predation on GFP, it also was integrated as an additional dietary source. The SIMMR Bayesian model results indicate that *M. armatus* and *O. bimaculatus* exhibit generalist predatory feeding strategies, consuming a diverse range of dietary sources. *O. bimaculatus* primarily relied on mollusks (42.4%) and macrobenthos (22.9%), followed by *O. niloticus* (13.2%), indigenous fish species <5 cm (11.7%) and GFP (9.8%) (Figure 2.5.7 a). Similarly, *M. armatus* showed a relatively

even dietary distribution, with mollusks (25.0%), macrobenthos (22.5%), indigenous fish species <5 cm (21.6%) and *O. niloticus* (18.2%), while GFP contributed 12.8% (Figure 2.5.7 b). The substantial intake of mollusks and macrobenthos in both species highlights their benthic foraging behaviour, utilising available invertebrate resources in the reservoir ecosystem. The inclusion of *O. niloticus* and GFP suggests opportunistic attacking on bigger preys, further supporting their role as mesopredators within the food web.

The SIMMR model demonstrated a moderate overall fit, with a mean proportion of observed data outside the predictive range of 41.8%, indicating some variation in model accuracy across species. *M. armatus* (16.6%) and *O. bimaculatus* (14.3%) exhibited the strongest model performance, suggesting that their dietary contributions were well represented with minimal unexplained variation. *Channa* spp. (36.4%) showed a moderate level of deviation, likely reflecting dietary flexibility or unaccounted variability in prey selection. In contrast, *A. bicolor* exhibited the highest deviation (100%), though this is likely attributable to the limited sample size (n=1) rather than actual dietary inconsistency. These findings indicate that the model effectively captured the dietary patterns of *M. armatus* and *O. bimaculatus*, while the greater discrepancies observed for *Channa* spp. and *A. bicolor* suggest the need for a more comprehensive dietary representation or increased sample sizes to enhance predictive accuracy.

Trophic structure of consumers in the reservoir ecosystem

The estimated trophic positions of consumers in the reservoirs' food web ranged from 2.0 to 4.3, with primary consumers positioned near the baseline

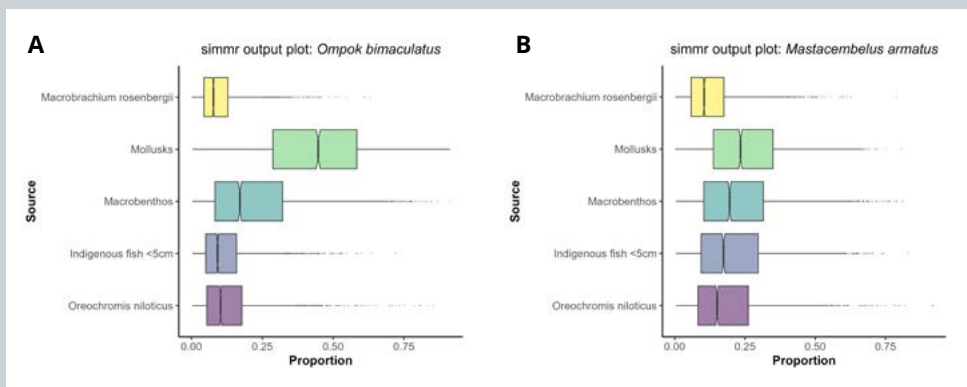


Figure 2.5.7: Relative dietary proportion boxplot of (a) *O. bimaculatus* (b) *M. armatus* as explained by the SIMMR model

(TP = 2), while top predators like *A. bicolor* and *Channa* spp. occupied higher trophic levels (~4.0). GFP (TP = 3.49) was identified as an omnivorous consumer with a carnivorous tendency (Figure 2.5.8).

Conceptual reservoir food web with an emphasis to CBF

The food web structure of the studied reservoirs was constructed using dietary proportions estimated from the SIMMR model, highlighting trophic interactions among culture-based fish species and native fish species. The dietary proportions (Figure 2.5.9) based strong trophic links (>40% contribution) were represented by double-line red arrows, while moderate contributions (20–40%) by solid blue arrows. Dietary contributions between 10–20% were represented by solid black arrows, whereas the least contributions (0–10%) were depicted using dashed black arrows. The results confirm that the reservoir ecosystem supports a complex trophic structure, with both pelagic and benthic nutrient pathways contributing to CBF fish production.

Discussion

Understanding food web structures and trophic dynamics of CBF species and non-CBF native fish species in reservoir ecosystems is essential for developing strategic improvements in fisheries management based on scientific knowledge. This study applied SI analysis to investigate trophic interactions in 6 reservoirs representing spatial differences across 4 dry zone districts in Sri Lanka. Eventually, 3 reservoirs were selected for food web construction, as they encompass most of the fish species found in Sri Lankan reservoir ecosystems. Each reservoir was differing in habitat complexity and productivity. However, those reservoirs did not show significant differences among basal resource groups, in terms of observed isotopic similarity across reservoirs, therefore could be combined to establish a consistent baseline for food web construction.

By analysing carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotopic signatures, this study identified the trophic niches of various

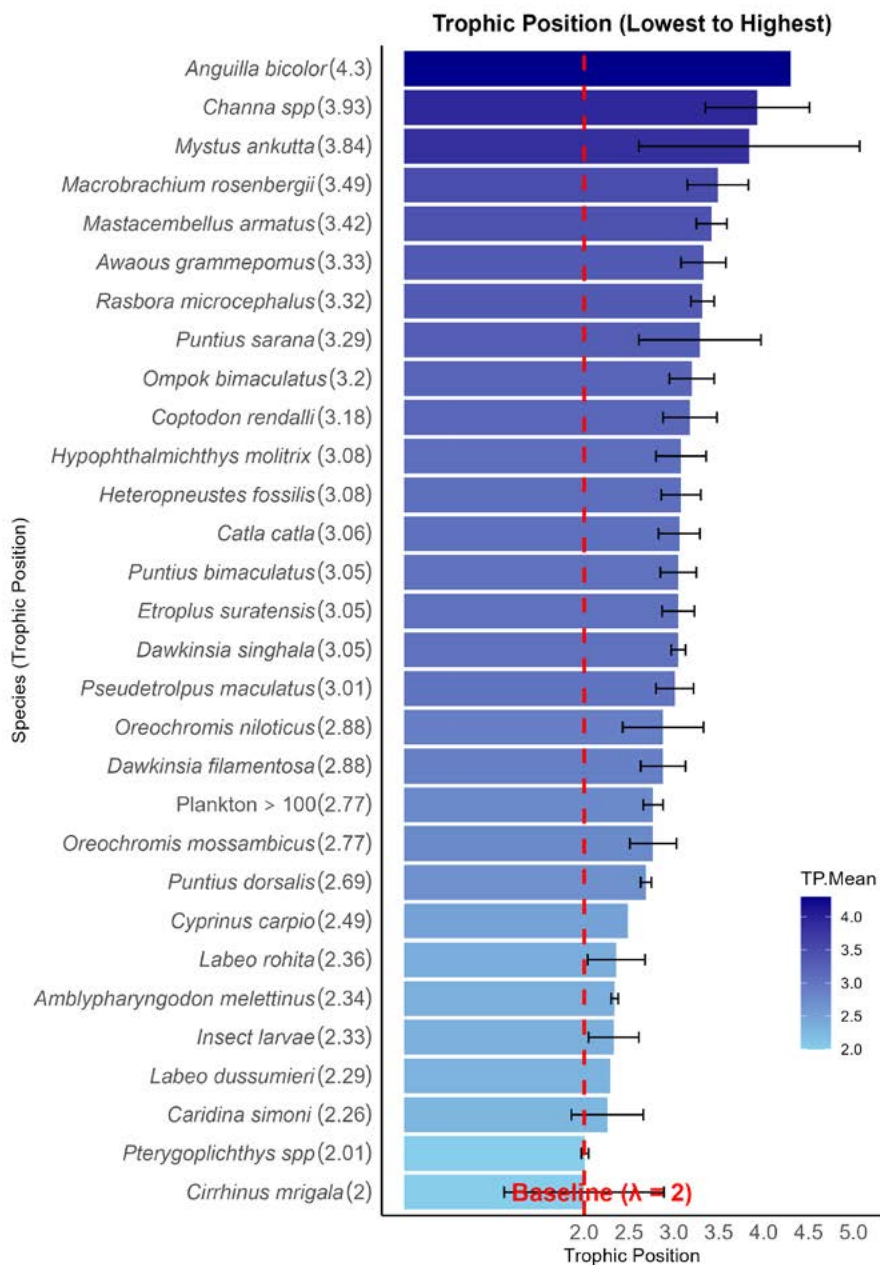


Figure 2.5.8: Mean trophic position of the consumers, with error bars indicating dietary variability

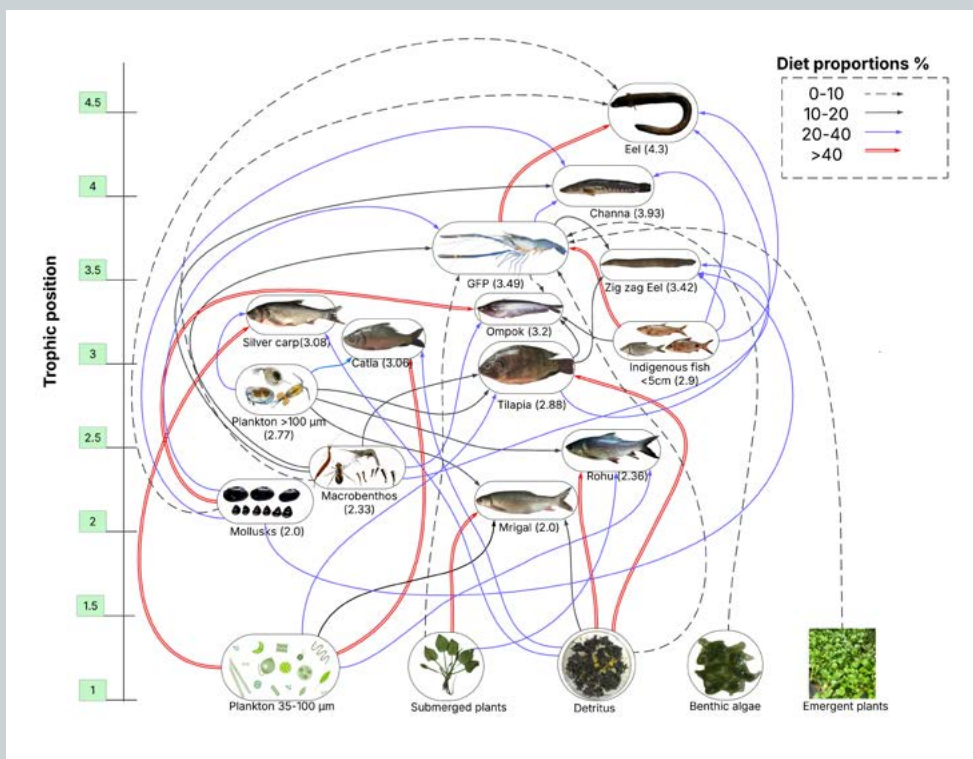


Figure 2.5.9: Conceptual reservoir food web structure and trophic interactions with an emphasis to CBF species in Sri Lankan reservoir ecosystem

consumers and quantified the contributions of basal dietary sources to CBF species. The assessment of pelagic and benthic dietary sources provides valuable insights into optimising species stocking proportions, which is an essential part of the CBF management. It ensures balanced nutrient pathways and enhanced fisheries productivity in reservoir ecosystems. In this study, a total of 515 samples were checked for SI ratios to investigate the trophic structure of Sri Lankan reservoir ecosystems. Although, species other than CBF were not abundant in the catches of fishers since those species were not their primary target. Smaller species were not in the catch due to the selectivity

of fishing gear for larger individuals, therefore, needed extra effort to collect smaller indigenous fish specimens. Also, the bigger indigenous fishes like eels were not common in gillnet catches due to their specific elongated body shape. On top of that, eels were not a target species of fishers due to lack of interest, taste or mythical beliefs. Apex predators other than fish such as the great cormorant and crocodile are poorly represented here because there was no active sampling process targeting those species. For example, one tissue sample of a crocodile could be obtained since there was its carcass floating in the reservoir on that particular sampling day.



The recent introduction of GFP into CBF in many reservoirs has generated greater economic and social benefits compared to finfish, as these high-value prawns are primarily supplied to Colombo restaurants and export markets (De Silva, Amarasinghe and Nguyen 2006; Digamadulla et al. 2023). Therefore, a comprehensive understanding of GFP's feeding ecology is crucial for sustainable fisheries management. The SIMMR analysis confirmed that GFP exhibits an opportunistic omnivorous feeding strategy, with a strong preference for animal-based prey, reinforcing its carnivorous tendencies within the reservoir ecosystem. These findings align with previous studies indicating that GFP primarily consumes protein-rich prey, such as small fish, mollusks and benthic invertebrates (Kurup, Harikrishnan and Sureshkumar 2000; New 2002). Furthermore, the TP analysis, calculated using the equation proposed by (Post 2002), provided additional support for the SIMMR results, positioning GFP at a higher trophic level (TP = 3.49). This further validates GFP's role as a secondary consumer within the reservoir ecosystem, emphasising its reliance on animal-based food sources and its functional significance in the trophic structure.

According to fishers, a major constraint to GFP fisheries is predation within the reservoir, which impacts optimal harvest yields. The SIMMR model applied to piscivorous and generalist predator species, including *A. bicolor*, *Channa* spp., *M. armatus* and *O. bimaculatus*, confirmed that these species actively prey on GFP, contributing to its population decline. This predatory pressure underscores the need for effective fisheries management strategies, such as predator control measures, optimised stocking densities and habitat modifications, to enhance GFP survival and

improve harvest efficiency. The trophic structure of the reservoir ecosystem suggests that GFP plays a dual role as both a predator and prey species, contributing to energy transfer between trophic levels. However, its high predation pressure from piscivorous fish species presents a significant challenge for sustainable fisheries management.

The *O. niloticus*, a cichlid fish species, was introduced to Sri Lanka in 1956 to enhance inland fisheries (De Silva 1988). Since then, it has become a dominant species in many of the country's reservoirs (Amarasinghe and De Silva 2015). Rural inland communities in Sri Lanka have shown a growing preference for *O. niloticus* over stocked cyprinid species, likely due to its high reproductive capacity, adaptability and consistent availability (Amarasinghe and De Silva 1999). Consumer preference on taste of tilapine fishes over other Chinese and Indian carps could be another reason, although it has not been empirically quantified. According to existing ecological knowledge, *O. niloticus* is omnivorous with herbivorous tendencies, feeding primarily on algae, plant material and detritus, but also consuming zooplankton and benthic invertebrates depending on availability (Moriarty 1973; Getachew and Fernando 1989). The diet of *O. niloticus* is highly plastic, shifting between phytoplankton, detritus, periphyton and zooplankton depending on food availability and environmental conditions (Attayde and Menezes 2008; Britton et al. 2007). However, based on SIMMR model, *O. niloticus* in the studied reservoirs primarily fed on detritus, followed by plankton 35–100 µm, which mainly consists of phytoplankton. Zooplankton (>100 µm) contributed the least, while macrobenthos, including insect larvae, accounted for 16.5%, reinforcing its omnivorous detritivore

classification. Findings from Temesgen et al. (2022) were partially consistent with our study, reporting that larger individuals of *O. niloticus* (total length >20 cm) primarily consumed detritus, macrophytes and fish parts. In contrast, several studies have reported differing dietary patterns for *O. niloticus*, suggesting that its diet is predominantly composed of phytoplankton (Attayde and Menezes 2008; Worie Assefa, Getahun and Workiyie Worie Assefa 2015; Tesfaye et al. 2021; Akbal Husen et al. 2024). In another case, Ethiopian lakes reported high detritus consumption in *O. niloticus*, particularly in nutrient-rich environments (Worie Assefa, Getahun and Workiyie Worie Assefa 2015), where organic matter accumulation supports microbial biofilms and decomposed macrophytes. This aligns with tilapia's ability to digest fibrous detrital material using gut microbiota, facilitating the assimilation of organic-rich detritus (Moriarty 1973). In the present study, submerged macrophytes were excluded from the model due to isotopic overlap with macrophytic detritus, which might influence dietary proportion estimates. Decomposed macrophytes often retain $\delta^{13}\text{C}$ signatures similar to live macrophytes, making them indistinguishable in isotope models (Fry 2006; Post 2002).

According to this study, the filter-feeding species *H. molitrix* and *C. catla* derived the majority of their dietary contributions from plankton 35–100 μm (phytoplankton), followed by plankton >100 μm (zooplankton), positioning them at approximately similar mid-trophic levels of 3.08 and 3.06, respectively, within the reservoir food web. These findings are consistent with previous studies, such as Tumolo and Flinn (2019), which reported a predominant reliance on phytoplankton, followed by zooplankton, in a mainstream reservoir ecosystem. This phytoplankton-

dominant filter-feeding behaviour has been confirmed by multiple studies (Spataru and Gophen 1985; Xie and Yang 2000; Huang et al. 2024). Similarly, gut content analyses conducted in large river systems (Williamson and Garvey 2005; Minder et al. 2018) confirmed that *H. molitrix* primarily consumes phytoplankton, with zooplankton as a secondary dietary component. An SI study on a drinking water reservoir by Huang et al. (2024) reported similar findings, indicating that *H. molitrix* primarily feeds on phytoplankton, with zooplankton as a secondary food source, and occupies a mid-trophic level. Other SI analyses (Xie and Yang 2000; Jayasinghe et al. 2015) suggest that the diets of *H. molitrix* may consist of nearly equal proportions of phytoplankton and zooplankton. As concluded by Jayasinghe et al. (2015), the foraging behaviour of this filter feeding Chinese carp is opportunistic and might even go for macrophytic detritus in the bottom at organically polluted environments.

In the studied reservoirs, *C. catla* exhibited a more balanced dietary preference, consuming plankton 35–100 μm (40%) and plankton >100 μm (35.6%), suggesting a broader reliance on both phytoplankton and zooplankton. This pattern is consistent with the diet study conducted by Sangeetha and Susithra (2023) in the Thenpenai River, India. However, the present findings contrast with the previous gut content analyses, which typically classify *C. catla* as a zooplankton feeder (Lalit 2015; Mishra 2020; Surya Prakash 2020). Furthermore, Soni and Ujjania (2018) documented the presence of detritus in the diet of *C. catla*, which aligns with our findings, where detritus emerged as the secondary dietary source.

C. mrigala from 3 reservoirs exhibited a predominant reliance on submerged plants, contributing 55.9% to its diet.



Plankton (35–100 µm) and plankton (>100 µm) were identified as secondary dietary sources, contributing 19.4% and 13.5%, respectively, while detritus accounted for 11.2%. However, Mishra (2020) reported that *C. mrigala* primarily relies on decaying vegetation, which contrasts with our findings. In gut content analyses of the present study, we observed decaying macrophytes in the samples, indicating that submerged plants and their decomposition products form a significant portion of their diet. The predominance of submerged vegetation in the Tabbowa and Weerawila reservoirs may have influenced the dietary composition of *C. mrigala*. Habitat conditions, such as the availability of macrophytes, likely play a key role in shaping the species' feeding behaviour, emphasising the ecological variability of *C. mrigala* across different environments. According to literature, *C. mrigala* is a bottom-dwelling species with an iliophagous feeding habit and a predominantly detritivorous dietary preference (Mishra 2020). However, the present study indicates that *C. mrigala* is having a more flexible feeding strategy than previously documented. It is physiologically equipped to consume submerged plant material due to its anatomical and digestive adaptations. Its subterminal mouth allows it to forage efficiently along the substrate, where it can access fragmented macrophytes and organic detritus as part of its diet. From a digestive perspective, *C. mrigala* possesses a relatively long alimentary canal, a characteristic adaptation among herbivorous and detritivorous fish, enabling efficient digestion of plant material and organic detritus. Furthermore, the species thrives in vegetation-rich, muddy-bottomed environments, where submerged plants are abundant, making them a viable dietary component (Mishra 2020).

These physiological and behavioural traits collectively suggest that *C. mrigala* is well-adapted to utilising submerged macrophytes as a significant food source, contrary to the documented feeding habits.

In its juvenile and adult stages, *L. rohita* functions primarily as a herbivorous column feeder, demonstrating a preference for algae, periphyton and submerged vegetation. However, gut content analysis reveals the presence of decayed organic matter, sand and mud, suggesting incidental bottom-feeding, likely occurring while foraging on periphyton or detritus-associated plant material (Mishra 2020). In this study, *L. rohita* from 3 reservoirs demonstrated a significant reliance on macrophytic detritus (46.5%), with submerged plants as the second most significant dietary source (30.2%), indicating its dependence on macrophyte-derived nutrients either directly or through decomposed detritus. Anatomically, *L. rohita* possesses a nibbling-type mouth with soft, fringed lips and sharp cutting edges, along with an absence of teeth in the buccopharyngeal region, which facilitates the consumption of soft aquatic vegetation without the need for active prey seizure or crushing (Majumder et al. 2018).

The SIMMR model showed a moderate overall fit across the 4 cyprinid species, with a mean proportion outside predictive range of 0.347 (34.7%), indicating that, on average, 34.7% of the observed data fell outside the model's predictions. *C. catla* exhibited the best fit (proportion outside = 0) with consistent dietary patterns, while *L. rohita* showed a reasonable fit (proportion outside = 0.364), reflecting some variability in benthic and plant-based resource use. *H. molitrix* and *C. mrigala* had higher proportions outside predictive range (0.5 and 0.525, respectively), indicating greater dietary variability likely influenced by

habitat-specific factors such as macrophyte abundance and plankton distribution in the reservoirs.

The mean dietary contributions of the 4 dietary sources to the CBF species indicate varying reliance on pelagic and benthic nutrient pathways. The estimated mean dietary proportions show that plankton is the dominant food source, contributing 50.1% to the overall diet, highlighting the importance of pelagic nutrient pathways in sustaining the fish community. Detritus, as the primary benthic source, accounts for 29.4%, emphasising its role in the system's energy flow. Submerged plants contribute 17.2%, acting as an intermediate resource that may support both pelagic and benthic pathways (Teubner et al. 2022). According to the results, macrobenthos plays a minor role, contributing only 3.3% to the overall diet. Similarly, a study on the Lake Liambezi food web found that particulate organic matter was the primary driver of the ecosystem (Peel et al. 2019), highlighting the ecological significance of pelagic nutrient pathways. As filter-feeding cyprinids efficiently utilise planktonic resources, their feeding behaviour plays a crucial role in pelagic energy transfer supporting nutrient cycling and maintaining ecosystem productivity. However, according to Jayasinghe et al. (2015), even the filter feeder like *H. molitrix*, which has heavily specialised gill rakes for filtering smaller particles suspending in the water column, has shown opportunistic feeding on detrital macrophyte particles in an urban reservoir. It can be assumed that any fish or GFP which are highly motile, can shift their feeding strategies depending on the resources available in the vicinity.

The conceptual reservoir food web created in this study gives an emphasis to CBF species and their trophic interactions with other indigenous fish fauna. It confirms the

fishers' belief that indigenous top predatory fish like *Channa* spp. and *Anguilla* spp. destroy the potential catch of high-valued GFP. But it disproves the belief that GFP reduces the catch of tilapia and other CBF species. In these man-made environments with a short history compared to the evolutionary time scale, all indigenous species can be considered as aliens as much as the exotic CBF species. While CBF species are stocked into the reservoirs time to time by NAQDA, indigenous species find their way to this lacustrine ecosystem along the ephemeral water ways in the rainy seasons. Since most of the agrarian reservoirs are scattered in the dry zone of Sri Lanka with a similar climatic environment, they can be considered within the same biome or aquatic life zones. In this way, the situation can be generalised to all dry zone reservoirs in Sri Lanka and to similar tropical lacustrine habitats around the world.

Conclusion

This study provides a comprehensive assessment of trophic interactions and food web structure in Sri Lankan reservoir ecosystems, offering valuable insights into the feeding ecology of CBF species, native fish populations, and the recently introduced CBF candidate *M. rosenbergii* (GFP). The application of SI analysis and SIMMR Bayesian mixing models has enhanced our understanding of the dietary niches of key fish species, elucidating their trophic positions, dietary preferences and interspecies interactions. Ultimately, this study underscores the importance of a balanced trophic structure in reservoir fisheries, where both culture-based and indigenous species contribute to ecosystem stability. Understanding the feeding ecology and trophic interactions of these species provides a scientific foundation for sustainable fisheries management,

ensuring the long-term productivity of Sri Lankan reservoirs while maintaining ecological integrity and resource sustainability. Future research should focus on seasonal dietary shifts, prey availability assessments and the impact of environmental changes on trophic interactions to further refine management strategies for CBF in reservoirs.

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2.6 Identifying appropriate length-based indicators (L_{bl}) and an alternative fishing gear application for giant freshwater prawns to achieve the preferred size of first capture

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Abstract

The recently introduced GFP (*M. rosenbergii*) in Sri Lanka's CBF reservoirs is becoming a high-valued CBF product with export potential by providing a high margin income to fishers. Extensive stocking of GFP is done together with tilapia and carp species and regular stocking of carp and GFP is necessary for the development of CBF in reservoirs as they do not breed naturally in Sri Lankan reservoirs. Therefore, some length-based indicators (L_{bl}) are not appropriate for assessing the current status of Sri Lankan CBF irrigation reservoirs and this study was conducted to determine the optimal sizes of first capture and the sizes of consume acceptability of CBF species rather than using exploitation status. Length-weight sampling was conducted from January 2023 to December 2024 in selected perennial irrigation reservoirs and the results showed that the capture of undersized species (below marketable size: L_{MK}) reached maximum up to 30%, 36%, 30% and 60% for *O. niloticus*, *L. rohita* and *M. rosenbergii* male and female, respectively. To avoid undersized GFP at the landing sites, an application of trap size selectivity using experimentally selected opera house trap (OHT) was also conducted at Vindrason reservoir, Kantale, Sri Lanka. The experiment included treatments with 8 cm, 11 cm and 13 cm diameter aperture size and deployed in 24 hours, and the results showed that the highest catch per unit effort (CPUE) (0.038 kg hr⁻¹) and mean weight (0.69 kg) were recorded for 13 cm and 11 cm diameter OHT, respectively.

Keywords: culture-based fishery, *Macrobrachium rosenbergii*, length-based indicators, marketable size length, opera house trap, catch per unit effort

Introduction

Sri Lanka is a good example of R&D efforts on CBF, which generate significant secondary employment and income opportunities for the Sri Lankan fisheries economy. In Sri Lanka's CBF reservoirs, extensive stocking is done mainly for tilapia species, carp species and GFP (*M. rosenbergii*); recently introduced species. For the development of CBF in reservoirs, regular stocking of carps and GFP is necessary as they do not reproduce naturally in Sri Lankan reservoirs. It has also been reported that in many reservoirs in the country, where the genetically improved farmed tilapia (GIFT) strain of *O. niloticus* (Nile tilapia) has been intensively stocked, yields have declined significantly, and the harvested fish are of poor quality. This may call for rebuilding tilapia stocks in reservoirs by stocking pure Nile tilapia and reducing the existing poor quality GIFT strain through heavy exploitation. Extensive stocking of GFP with carp and tilapia in dry zone reservoirs has been done but the prawn yields have been negligible and there is a large gap between the high stocking density of GFP and the yield captured because of relatively low recapture rates (De Silva et al. 2006).

Studies on the population dynamics and stock assessment of target species of fisheries are therefore imperative to sustain their fisheries and benefits to society. It has also been shown that GFP dynamics cannot be assessed in isolation and that the effects of the dynamics of stocked finfish species must be an integral part of a complete understanding (Jones et al. 2021). It is therefore a fact that LBI as suggested by Cope and Punt (2009) and Froese (2004), that is, Indicator 1: 'Let them spawn'; Indicator 2: 'Let them grow' and Indicator 3: 'Let the mega spawners live', are

not appropriate to assess the current status of CBF in Sri Lankan irrigation reservoirs. Therefore, the conventional means of optimising fishing strategies through stock assessment approaches are irrelevant. Instead, such stock assessment approaches can be applied to make recommendations on the preferred sizes of first capture, which have consumer acceptability.

Currently under the legal provisions of the Fisheries and Aquatic Resources Act (1996) fishing gear is restricted to gillnets with a mesh size greater than 8.5 cm as part of the management of CBF, and they are targeted at the finfish species including tilapia and carp. Although the potential of CBF for GFP in Sri Lanka's reservoirs is high, the full potential is not being realised as by-catch in finfish fisheries. GFP are caught in the gillnets, although there is a high incidence of damage to the prawns, which reduces their value. It is believed by fishers that GFP could be caught more effectively and with less damage, if a specific gear was used to target the prawns. Traps are used to catch GFP in other Southeast Asian countries such as Thailand, Cambodia and Vietnam are rarely used in Sri Lanka, and the practice is limited to a few fishers in some districts, and use is seasonal (Jutagate and Kwangkhang 2015). This is probably due to fishers' inexperience with GFP and lack of exposure to trap types that could be used. Therefore, there is precedent and technologies that can be applied in Sri Lanka to increase GFP capture.

This paper investigates the optimal sizes of first capture and sizes of consumption acceptability of GFP, carp and Nile tilapia in selected perennial irrigation reservoirs of Sri Lanka using length-based stock assessment procedures, with a view to identifying appropriate LBI and an alternative gear application for GFP to ensure sustainability of CBF in Sri Lanka.

Materials and methods

Length data were obtained by measuring the carapace length, total length, major cheliped length of each GFP, and standard length and total length of finfishes to the nearest 0.1 cm using a tape measure at the local landing centres in 5 reservoirs – Ridiyagama (871 ha), Vendrason (410 ha), Urusita-wewa (262 ha), Karawitagaraya (256 ha) and Kottukchchiya wewa (70 ha) – for stock assessment of *M. rosenbergii*, *L. rohita* and *O. niloticus*. Body weights of all species were also measured to the nearest 0.1 g using a portable scale at the landing site, and sampling was conducted monthly from January 2023 to December 2024. Length-frequency data were analysed using the FAO-ICLARM Stock Assessment Tool (FISAT) to estimate von Bertalanffy growth parameters, mortality rates and exploitation levels. Length at first capture (L_c) was subsequently derived from length-converted catch curves.

Length-weight relationships (LWR) of 3 species categories were determined and average marketable size weight (W_{mk}) values collected from landing sites and fisher data were converted to marketable size/consumer acceptable length (L_{mk}) using LWRs. The frequencies of fish and GFP smaller than L_c and L_{mk} in the cumulative length frequency samples and time required to grow up to L_c and L_{mk} (in months) were determined.

Initially, a survey was carried out to understand GFP behaviours along with the gear approach at Wayamba University of Sri Lanka using different traps including OHT, a circular crab pot and a cylindrical cane trap (common rattan) and the experiment was conducted in a fibreglass tank aquarium using 10 GFP (male:female = 1:1). After comparing the trap interaction of GFP, the selected OHT was demonstrated to

evaluate the gear efficiency of capturing GFP together with an umbrella-shaped trap, which was already imported from Thailand and modified as according to use in Sri Lanka irrigational reservoirs. This field activity was conducted in a selected medium-size reservoir, Vendrason wewa, Kantale (410 ha), which already had a high potential of GFP harvest. Each trap was deployed for 24 hours and CPUE was determined to evaluate gear efficiency. Finally, recommendations were made for sustainability of CBF in reservoirs.

Results

Lbls to make recommendations on the preferred sizes of CBF species

Length-based stock assessment results indicated that *O. niloticus* (tilapia) was underexploited in all 5 reservoirs ($E < 0.5$; Table 2.6.1). There is also evidence that the stocking of carelessly selected GIFT strain of *O. niloticus* over about a decade has degraded the quality of the Nile tilapia stocks, which had to be rebuilt by stocking hatchery-reared fingerlings of pure *O. niloticus*. Although Lbl-based recommendations are not necessary for *O. niloticus* – stocks that need to be rebuilt – the present analysis showed that the maximum harvest of undersized fish is about 30–60%. The *L. rohita* (rohu) species was found to be underexploited ($E < 0.5$) in all 5 reservoirs except Vendrason wewa and Kottukchchiya wewa ($E = 0.53$ and $E = 0.55$ respectively; Table 2.6.1). In all 5 reservoirs studied, undersized male and female GFP ($< L_c$ and $< L_{mk}$) were almost above 20% (Table 2.6.1).

Because *L. rohita* and GFP do not reproduce in almost all reservoirs in Sri Lanka, natural recruitment of these species does not occur. Instead, annual stocking is required to maintain CBF. Therefore, conventional

length-based stock assessment approaches to determine optimal fishing strategies (for example, optimal L_c and optimal E) are not sufficient to make recommendations for CBF management. In particular, species that require regular stocking should be harvested to allow younger individuals to utilise food and other resources in the ecosystem for future harvesting.

The Lbl proposed by Cope and Punt (2000) and Froese (2004), that is, Indicator 1: ‘Let them spawn’; Indicator 2: ‘Let them grow’ and Indicator 3: ‘Let the mega spawners live’, are essentially appropriate for naturally recruiting fish stocks because they depend on the size at maturity. The present analysis therefore proposes a new set of Lbl. As it is imperative in CBF management, the harvest should consist of fish and GFP that are acceptable to consumers. Therefore, it is proposed that L_c and L_{mk} of naturally non-recruiting finfish and GFP be considered appropriate Lbl for CBF management in Sri Lankan reservoirs.

Recommendations on an alternative fishing gear application to reduce the capture of undersize GFP at landing sites

The traditional method of fishing with gillnets is relatively inefficient for catching GFP: it is size selective and allows juveniles to escape, thus preventing over-exploitation of the fishery. Such size selectivity needs to be considered in the development of traps targeting GFP, in accordance with the minimum acceptable market size.

To date, GFP production in CBF has generally resulted in low yields and low escapement rates (Jones et al. 2021). The first CBF experience with GFP in Sri Lanka was unsuccessful, contributing only 0.7% of the fish harvest (Wijenayake et al. 2010; Chandrasoma and Pushpalatha 2018.). More recently, a study by Rajeevan et al. (2018) reported a comparatively higher recapture rate of 2.48% in the reservoir gillnet fishery in Sri Lanka. A recapture rate (proportion of prawns caught relative to

Table 2.6.1: Exploitation rates of *O. niloticus*, *L. rohita*, *M. rosenbergii* male and female in selected CBF reservoirs and L_{mk} range, mean lengths at first capture ranges (L_c), % below L_c and L_{mk} range and corresponding time needed to grow up to L_c and L_{mk} ranges for 5 reservoirs

CBF spp.	Exploitation					L_c (cm)	L_{mk} (cm)	% fish $< L_c$	% fish $< L_{mk}$	$T L_c$ (months)	$T L_{mk}$ (months)	
	Ridiyagama	Urusita wewa	Vendrason	Kottukchchiya	Karawitagaraya							
<i>O. niloticus</i>	0.17	0.36	0.3	0.39	0.46	20–27	22–24	14–60	4–30	5–6.5	3.9–6.7	
<i>L. rohita</i>	0.47	0.37	0.53	0.55	0.35	38–42	35–40	0.1–36	1.5–20	16–28	13–20	
<i>M. rosenbergii</i>	Male	0.25	0.25	0.19	0.12	0.25	6.3–8.3	7–8	11–48	13–33	6–13	7.9–9
	Female	0.24	0.17	0.25	0.22	0.26	5.4–6.5	5.5–7	4–31	28–59	6.1–9	9–12.2

the number stocked as PLs) of less than 3% is far below what is required to achieve sustainability, given the relatively high cost of producing prawn PLs in government hatcheries. An acceptable recapture rate would be 5 to 10%, which is likely only achievable with the development of specific fishing gear and techniques to target GFP.

The crab pot and cylindrical cane trap were not effective in capturing GFP in both the laboratory and reservoir experiment. The OHT was more successful in catching GFP than the modified umbrella trap (catching frequency is 0.7 and 0.3, respectively) (Figure 2.6.1). Catch of GFP was achieved in

the baited OHT and modified umbrella trap with a weight range of 50–150 g and 90–170 g and carapace length (CL) range from 4.5–6.0 cm and 5.5–6.0 cm for males and females, respectively.

The results for the different aperture size OHT experiment, which was done to evaluate the size selectivity of GFP, shows that the highest weight GFP captured was in the 11 cm diameter trap. However, considering the range of carapace lengths, using a 13 cm diameter OHT could avoid capturing undersized male GFP (smaller male) (Table 2.6.2).



Figure 2.6.1: (a) Opera house trap (so-called because of its shape that mimics the Sydney Opera House) and (b) modified umbrella trap

Table 2.6.2: The evaluate mean weight (kg), mean CPUE (kg hr⁻¹) and carapace length of captured male and female GFP to selected 3 diameter (8 cm, 11 cm, 13 cm) OHTs

		Opera house trap diameter		
		8 cm	11 cm	13 cm
Mean weight (kg)		0.56	0.69	0.63
mean CPUE (kg ha ⁻¹)		0.029	0.036	0.038
Carapace length range (cm)	Male	4.5–6	4.5–6.5	6–7.5
	Female	5–6	5–6	6–7

Conclusion and recommendations

Exotic carps and *M. rosenbergii* do not spawn naturally in many Sri Lankan CBF reservoirs, and therefore there is no need to consider exploitation if their regular stocking continues. Therefore, marketable size should be the most important factor in CBF. There must be fisheries management practices to catch fish with GFP above L_{mk} . The time required to grow to the desired size (L_c and/or L_{mk}), is also a concern for the management of CBF because there should be sufficient time to harvest both finfish and GFP after stocking. The LBI indicate that there is a need to implement strategies to reduce the catch of undersized GFP in the landings. At present, GFP are caught as a bycatch in the gillnets used to harvest finfish and the catching efficiency of GFP is rather inefficient, so the introduction of an effective passive gear (such as a prawn trap) is urgently needed.

In terms of catch frequencies, the baited OHTs were more successful in catching GFP than the modified umbrella traps. Increasing the size of the trap aperture also resulted in the avoidance of undersized GFP at landing sites. However, the catch rates were lower than those of the gillnets operated in the vicinity. However, zero damage to GFP by the use of traps achieved considerable success, especially in terms of economic benefits. More comprehensive studies are needed to examine the use of traps in the reservoir environment to achieve optimal catch of prawns within a proper legal approach that ensures the sustainability of the GFP fishery.

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2.7 Influence of limnological characteristics on culture-based fisheries in irrigation reservoirs of Sri Lanka

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Abstract

This study investigates the limnological variations in perennial reservoirs in Sri Lanka across monsoon seasons and their impact on nutrient dynamics, primary production and CBF harvest. Surface water and bottom sediment were sampled from 3 random locations of the limnetic zone of 48 reservoirs on a bimonthly basis from February 2023 to April 2024. Significant seasonal shifts in physicochemical and hydrological factors were observed, influencing nutrient availability, DO levels and overall reservoir productivity. The study highlights the role of sediments as both a nutrient sink and a source, with phosphorus and nitrogen dynamics varying between wet and dry seasons. Fish production was predominantly shaped by limnological conditions, rather than stocking densities alone. GFP yields were significantly correlated with reservoir elevation, alkalinity and sediment phosphorus content. Similarly, finfish harvest, particularly for GIFT tilapia, catla, rohu and mrigal, was strongly influenced by key water quality parameters such as alkalinity, hardness and chlorophyll-a levels. The findings suggest that optimal fish yields require balanced water chemistry and reservoir morphometry, rather than increased stocking efforts. This study underscores the necessity of integrating seasonal limnological variations into fisheries management strategies to enhance fisheries production and maintain ecological stability in irrigation reservoirs. Future research should focus on the long-term impacts of climate change and anthropogenic activities on reservoir limnology and sustainability of fisheries.

Keywords: *culture-based fisheries, limnology, nutrient dynamics, fish production, Giant Freshwater Prawn*

Introduction

Aquatic foods play an important role in global food supply ensuring both physical and economic access to basic nutrition for the continuously increasing world population (Godfray et al. 2010; Golden et al. 2021; Worldometer 2024). These foods contribute significantly to food security and improve nutritional levels on a global scale, providing over 50% of the animal protein consumed in Asian and African countries (Boyd et al. 2022; FAO 2024).

Aquaculture and capture fishery are the 2 primary approaches for producing aquatic foods. While aquaculture involves farming aquatic organisms, capture fisheries focus on harvesting naturally available wild fish stocks (FAO 2022). CBF have been identified as stock enhancement practices associated with low cost and higher production, mainly in developing nations (De Silva 2003). Whether in aquaculture or fisheries, habitat quality is crucial for the healthier production of inhabitant fish fauna. Therefore, understanding the relationship between the limnological conditions of inland water bodies can be instrumental for the better management of fisheries associated with these water bodies.

Culture-based fisheries

CBF involve both aquaculture and fisheries phases. Aquaculture, or 'farmed' phase, focuses on preparing seed stock material, while the fisheries phase involves capturing the released aquatic animals once they reach marketable size (Wijenayake et al. 2016). The goal is to enhance the total production or specific elements of production when natural processes fail to ensure sustainability (FAO 2010).

In common operations, inland water bodies with low natural recruitment are stocked with intended fish species at

predetermined densities. Stocked fish use naturally available resources for their growth, survival and reproduction. The main difference is that CBF stocks are owned and managed by a specific organisation or individual, whereas stock enhancement supports wild populations without ownership. These organisations or individuals are responsible for water body preparation, obtaining seed stock, watching over and capturing fish at a marketable size. In perennial reservoirs, fish are intermittently captured using gillnets, cast nets or pole fishing. In contrast, non-perennial reservoirs are completely harvested during the dry season, when the water levels are minimal (De Silva et al. 2006).

CBF are less resource-intensive – they can utilise existing water resources as secondary users in a non-consumptive manner, they are less complicated than conventional aquaculture practices, they are a communal activity which benefits rural communities in the vicinity of the water body – and the government or organisations find CBF attractive due to their sustainable manner (De Silva 2003; Hudson et al. 2014). With these advantages, CBF are gaining popularity in Asian countries, and have proven to be an effective way to fight malnutrition, especially in developing nations (Wijenayake et al. 2016).

Culture-based fisheries in Sri Lanka

The Sri Lankan freshwater irrigation system in the dry climatic zone is an ancient iconic structure with more than 12,000 man-made reservoirs (De Silva et al. 2018; Panabokke et al. 2002). These reservoirs are approximately 2,000 years old and developed around the concept of 'village, temple, reservoir and pagoda'. Excavating the reservoir provided soil for the pagoda



around which a temple was built, with the village forming around the temple. This structure fostered a self-sustaining ecosystem, where the reservoir played a crucial role in supporting agriculture and water needs, reflecting ancient society's integrated approach to sustainable resource management (Rathnayake 2023).

To support these rural communities, Mendis and Indrasena recognised reservoirs as good candidates for CBF activity in 1965 (Hudson et al. 2014). Since then, development of CBFs has consistently been supported by ongoing research and development efforts (Amarasinghe and Wijenayake 2015; Digamadulla et al. 2023; Jayasinghe et al. 2005a, 2005b, 2006; Jayasinghe et al. 2018; Jones et al. 2021; Kularatne et al. 2018; Nissanka et al. 2000; Pushpalatha and Chandrasoma 2010; Pushpalatha et al. 2020; Sanuja et al. 2024; Wijenayake et al. 2016; Wijenayake et al. 2005; Wijenayake et al. 2021). Although the marine fisheries production in Sri Lanka is declining (Fisheries 2023), inland fish production is thriving, with more than 90% of inputs from the seasonal and perennial reservoirs where CBF are operational (Jones et al. 2021). Thus, CBF can provide fish (a cheap source of animal protein) to rural communities with low incomes, thereby generating employment and supplementary income for farmers. Therefore, these reservoirs have great potential to increase the socioeconomic aspects of rural communities (Ekanayake et al. 2023; Pushpalatha and Chandrasoma 2010).

Each reservoir has a fisheries organisation which has the ownership of stocks and manages all CBF activities within the reservoir under the supervision of NAQDA, Sri Lanka. Fish production from these reservoirs mainly consists of exotic fish species, including Indian carps – rohu (*L. rohita*), mrigal (*C. mrigala*) and catla

(*C. catla*); Chinese carps – grass carp (*C. idella*), silver carp (*H. molitrix*), bighead carp (*H. nobilis*); and common carp (*C. carpio*) (Jones et al. 2021). The GFP (*M. rosenbergii*), recognised as a more valuable species compared to other cultured species, is also cultured in these reservoirs (Sanuja et al. 2024). Additionally, a self-recruiting species, GIFT, an improved strain of *O. niloticus*, represents the highest landing for CBF production (Athauda and Chandraratna 2020).

Factors influencing production

The GFP established recapture rate in CBF is still very low (<5%) (Pushpalatha and Chandrasoma 2010; Asoka 2015; Rajeevan et al. 2018; Jones et al. 2021). CBF activities can be significantly affected by changes in water quality as the cultured organisms may not have any chance to escape from the confined conditions (Bastian et al. 2025). According to the NAQDA database, CBF production of reservoirs in Sri Lanka is drastically varying throughout the year. In some studies, reservoir surface area has been used to understand the production variations (Digamadulla et al. 2023; Jayasinghe et al. 2006). According to Sugunan (2000), wind-induced turbulence, vertical stratification of pH, DO, total alkalinity and specific conductivity are important factors related to the production of reservoirs in India, whereas mean depth and low nutrient levels do not affect the changes in production.

Although several numbers of studies are available about CBF in non-perennial reservoirs in Sri Lanka (Jayasinghe et al. 2005a, 2005b, 2006; Pushpalatha and Chandrasoma 2010; Wijenayake et al. 2005), CBF in perennial reservoirs have not been well studied yet. Furthermore, productivity of reservoirs depends upon geochemical, meteorological, morphometric and

hydrographic variables. Further investigations of reservoir morphometry, sediment organic matter and other limnological factors have been suggested by Jones et al. (2021) for the perennial reservoirs in Sri Lanka.

Objectives of this research

The aim of the study is to explore how limnological characteristics affect CBF production by studying perennial reservoirs of varying sizes and conditions, incorporating water quality, sediment quality, reservoir morphometry and meteorological data. The hypothesis to be tested is that limnological characteristics are significant factors influencing the production performance of CBF in perennial reservoirs of Sri Lanka.

Specific objectives are to:

1. identify the major seasonal limnological gradients in reservoirs
2. assess the seasonal variability in nutrient dynamics of reservoirs
3. determine important environmental parameters and their limitations affecting species-wise production
4. identify the reservoir with the highest and lowest potential for each CBF species.

Materials and methods

The present study was carried out in 48 perennial reservoirs utilised for CBF in the dry zone of Sri Lanka. Sampling locations are shown in Figure 2.7.1 and the relevant details are shown in Table 2.7.1.

Surface water and bottom sediment were sampled from 3 random locations of the lacustrine region of each reservoir on a bimonthly basis from February 2023 to April 2024. The majority of water quality and sediment quality parameters were collected in situ during field sampling, and the remaining parameters were measured in the laboratory. Water and sediment samples were collected, preserved and transported to the laboratory for the analysis. All the laboratory analyses were performed by author at the Department of Limnology and Water Technology, Faculty of Fisheries and Marine Sciences & Technology, University of Ruhuna, Sri Lanka.

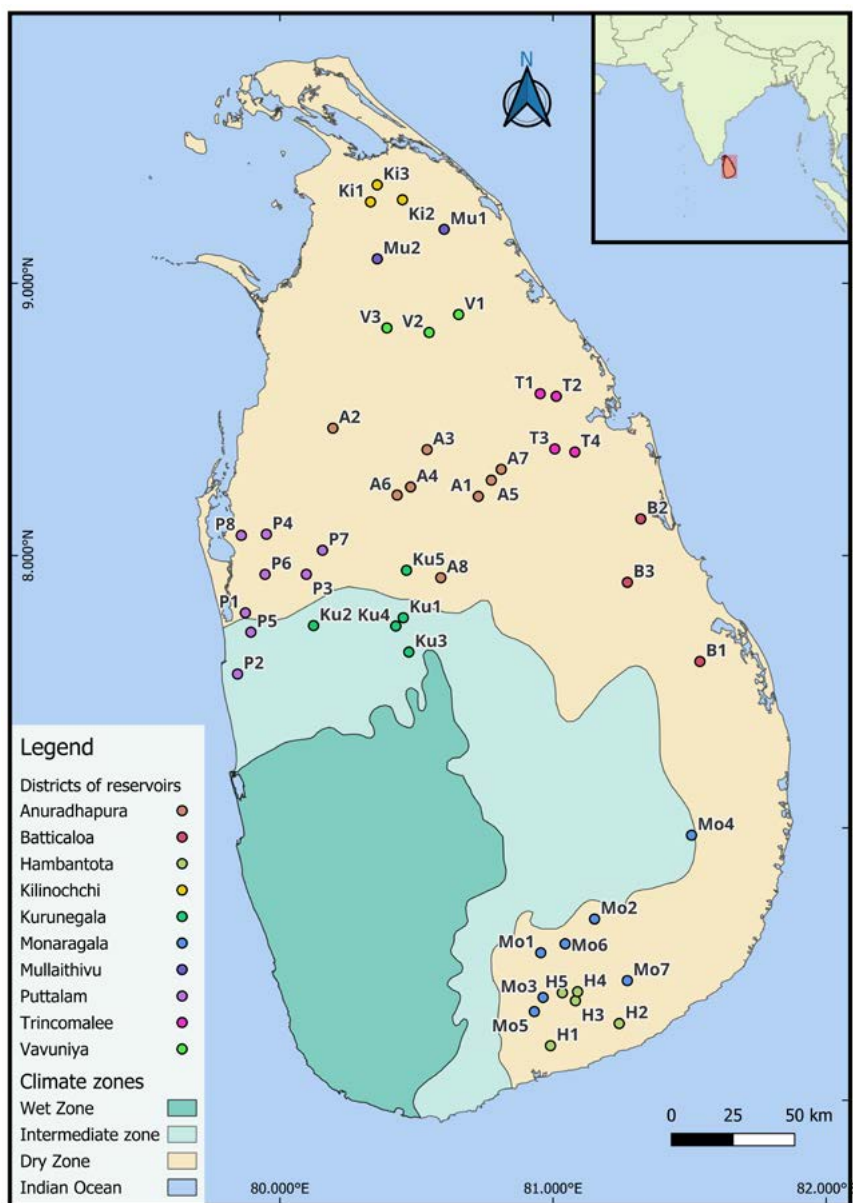


Figure 2.7.1: Distribution of reservoirs selected for the study across the country

Table 2.7.1: Description of selected reservoirs with their locations

District	Name of reservoir	Code	Latitude	Longitude	Area (ha)
Anuradhapura	Hurulu wewa	A1	8.211 180°	80.726 887°	1,198
	Maha wilachchiya	A2	8.466 018°	80.199 686°	1,189
	Mahakanadarawa	A3	8.387 917°	80.543 948°	1,287
	Nachchaduwa	A4	8.252 547°	80.481 158°	1,517
	Aluthdiulwewa	A5	8.276 868°	80.775 253°	206
	Thuruwila	A6	8.220 648°	80.430 154°	337
	Kiulekada	A7	8.321 877°	80.807 084°	252
	Ranawa	A8	7.918 079°	80.589 373°	59
Batticaloa	Unnichchai	B1	7.609 435°	81.540 600°	1,145
	Kaddumurivu	B2	8.131 919°	81.319 971°	242
	Vadamunai	B3	7.902 815°	81.271 569°	250
Hambantota	Ridiyagama	H1	6.206 802°	80.986 333°	876
	Weerawila Wewa	H2	6.287 436°	81.238 285°	406
	Maha Aluthgam ara	H3	6.365 208°	81.086 881°	82
	Maha wewa	H4	6.398 522°	81.094 304°	50
	Mahagal wewa	H5	6.395 397°	81.037 610°	168
Kilinochchi	Akkarayankulam	Ki1	9.297 348°	80.327 640°	801
	Iranamadu	Ki2	9.317 675°	80.449 785°	2,220
	Pudumurippu kulam	Ki3	9.361 711°	80.354 326°	299
Kurunegala	Hakwatunaoya	Ku1	7.772 887°	80.461 248°	362
	Magalla wewa	Ku2	7.743 964°	80.125 216°	218
	Kimbulwanaoya	Ku3	7.640 269°	80.484 219°	196
	Maeliya	Ku4	7.741 792°	80.425 194°	44
	Siyambalangamuwa	Ku5	7.943 953°	80.463 618°	79
Monaragala	Hambegamuwa	Mo1	6.541 986°	80.956 525°	149
	Handapanagala	Mo2	6.665 547°	81.151 660°	264
	Kiribban wewa	Mo3	6.375 799°	80.970 030°	324
	Muthukandiya	Mo4	6.979 702°	81.503 215°	608
	Urusita wewa	Mo5	6.332 615°	80.933 658°	141
	Balaharuwa wewa	Mo6	6.574 274°	81.044 326°	68
	Gestupana wewa	Mo7	6.437 688°	81.273 191°	36
Mullaitivu	Muthiyankaddu	Mu1	9.201 521°	80.607 541°	1,088
	Vavunikulam	Mu2	9.089 970°	80.351 369°	1,040
Puttalam	Devalahandiya	P1	7.787 486°	79.879 212°	195
	Karavita wewa	P2	7.568 043°	79.848 560°	102
	Mahauswewa	P3	7.926 054°	80.096 962°	188

(Continues on next page)

District	Name of reservoir	Code	Latitude	Longitude	Area (ha)
	Tabbowa	P4	8.072 554°	79.955 442°	537
	Vijayakatupotha	P5	7.720 039°	79.895 142°	162
	Kottukachchiya	P6	7.930 162°	79.945 732°	105
	Maha Andarawewa	P7	8.017 970°	80.155 109°	103
	Viluka wewa	P8	8.074 776°	79.856 607°	120
Trincomalee	Mahadiulwewa	T1	8.599 225°	80.953 527°	603
	Morawewa	T2	8.590 722°	81.010 197°	652
	Wendrasan wewa	T3	8.390 288°	81.007 964°	376
	Wanela	T4	8.381 168°	81.081 127°	107
Vavuniya	Bogaswewa	V1	6.637 291°	80.909 609°	77
	Mamaduwa	V2	8.818 677°	80.547 824°	132
	Kalmadu	V3	8.838 036°	80.391 005°	72

Limnological data

Water temperature (°C), DO saturation (%), DO (mg L⁻¹), specific conductivity (μS cm⁻¹), electrical conductivity (μS cm⁻¹), resistance (kΩ cm⁻¹), total dissolved solids (mg L⁻¹), salinity (PSU), pH, oxidation reduction potential (ORP) (mV), and atmospheric pressure (psi) were measured in situ using a multipara water quality meter (YSI Inc., Yellow Springs, OH, USA). SDD was measured in centimetres using a standard 20 cm Secchi disc. The colour of water (Pt-Co) and total suspended solids (TSS) (mg L⁻¹) were measured using a Hach DR 1900 portable spectrophotometer (Hach®, Loveland, CO, USA). TSS was calibrated with the American Public Health Association (APHA) standard method 2540-D (APHA 2017). Turbidity (FAU) was measured using Lovibond MD 600 colorimeter (Tintometer GmbH, Dortmund, Germany). Alkalinity of water was determined using 2 consecutive titrations: phenolphthalein alkalinity (mg L⁻¹ as CaCO₃) and total alkalinity (mg L⁻¹ as CaCO₃) using methyl orange in titration (Dhoke 2023). Water hardness (mg L⁻¹ as CaCO₃) was determined using the EDTA titrimetric method according to the APHA standard method 2340-C (APHA 2017).

Laboratory analyses were performed for the following parameters: chlorophyll-a (μg L⁻¹) amount in the surface water (0 to 3 ft) of reservoirs was determined using the standard acetone method 10200-H (APHA 2017). Total phosphorus (TP) (mg L⁻¹) in water was quantified with acidic digestion with potassium persulfate and ascorbic acid method 4500-P E (APHA 2017). For the total nitrogen (TN) (mg L⁻¹) in water, samples were digested with potassium persulfate (APHA 2017; Studt et al., 2020) and quantified using the sodium salicylate method (Monteiro et al. 2003; Yang et al. 1998).

In situ sediment quality parameters were recorded parallel to the water quality data collection. Sediment samples were obtained using a standard (6×6") Wildco® Ekman bottom grab (Wildlife Supply Company®, FL, USA); the top layer (<1 cm) was collected. pH and ORP were measured using the multipara water quality meter. The sediment colour spectrum was measured following CIE Lab standards using Miniscan EZ 4500L colorimeter (HunterLab, Reston, VA, USA). Collected sediment samples were transported to the laboratory in ice and

were frozen at -18 °C until further analysis. For the analysis, samples were dried approximately at 105 °C for 8 hours, and ground using a mortar and a pestle.

Sediment TP was determined using the ascorbic acid method, followed by acid-persulfate digestion (Nelson 1987). Sediment TN was determined using an alkaline-persulfate digestion (Smart et al. 1983) and quantified using the sodium salicylate method (Monteiro et al. 2003; Yang et al. 1998). 'Loss on ignition' was used to determine the organic matter percentage 2540-E (APHA 2017).

Reservoir morphometry

The QGIS software (version: 3.34.4 LTR) was used to delineate watershed boundaries using a prepared Digital Elevation Model (DEM), which was based on Sentinel-1 Synthetic Aperture Radar (SAR), Interferometric Wide Swath (IW) and Single Look Complex (SLC) Level-1 images (Qin 2018). These images were acquired during the dry season from the Copernicus Data Space Ecosystem for the study area. The images were pre-processed to clean and convert the phase information into elevation using SNAP (version: 9.0.0) software. The generated DEM was used to delineate and calculate the watershed areas of each reservoir using PCRaster Tools (0.3.0) in QGIS (Karssenberget al. 2010).

Sentinel-1 Ground Range Detected (GRD), Level 1 SAR images of the study area for each exact or possible nearest sampling date were pre-processed using SNAP software (ESA 2019). Then the shorelines of reservoirs were extracted using QGIS software by visually confirming with the same temporal Sentinel-2 and L2A images.

Harvest data

For each reservoir, monthly cumulative harvest in kilograms was collected from the logbooks from each fisheries society and the cumulative catch per month in kilograms of GFP and finfish was recorded separately.

Data analysis

Average values of environmental parameters obtained from bimonthly sampling in reservoirs were analysed using multivariate statistics and machine learning techniques. Major environmental parameters were selected based on their correlations, variance within the dataset, and theoretical and practical importance. Parameters with highly skewed data distributions were log-transformed. All parameters were scaled and used for dimensionality reduction through PCA. Selected morphometric parameters were superimposed on the PCA plot using *ordisurf* where necessary.

Hierarchical clustering (using Euclidean distance and Ward's linkage) was performed to identify distinct clusters within the sample distributions. The identified clusters were visualised in the PCA plot to determine the corresponding limnological gradients and associated seasonal variations.

Tree-based machine learning models, including Random Forest, Gradient Boosting and Adaboost were applied to identify key parameters influencing fish harvest of each species. The selected parameters were then used in tuned regression (decision) trees to cluster the samples. Decision trees were then constructed using both post- and pre-pruning methods to assess the natural boundaries of the selected parameters. The clustered groups in the tree leaves were subjected to analysis of variance (ANOVA) based on their harvest.

These analyses were conducted using the Orange data mining software (version 3.38.1) and RStudio (version 2024.12.0+46). Maps were created using QGIS Desktop (version 3.34.13).

Results

Major limnological gradients

The PCA plot of the first 2 principal components with selected parameters revealed that the first 5 principal components (PCs) accounted for 94% of the variation within the samples, with the first 2 being particularly important, explaining 53% of the environmental variation (Figure 2.7.2). Two major groups of correlated parameters were identified using the PCA plot:

- Dissolved oxygen in water (DO), sediment total nitrogen (sediment TN), and sediment total phosphorus (sediment TP) were positively correlated with each other and loaded positively on the PC1 axis.
- Total nitrogen in water (water TN), total phosphorus in water (water TP), and chlorophyll-a were highly correlated with dissolved ions in water, and these parameters were negatively loaded on the PC1 axis.

A clear negative linear relationship was observed between dissolved ions, chlorophyll-a, water nutrients, and the surface area of the reservoirs.

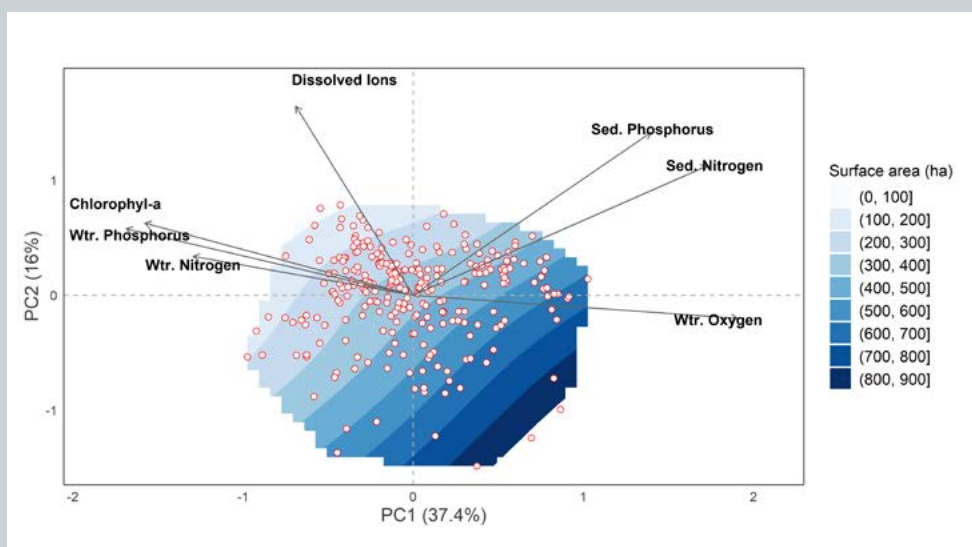


Figure 2.7.2: Two-dimensional PCA score plot using the first two principal components to ordinate reservoir samples, showing parameter loadings and the reservoir surface-area gradient

Note: The arrows represent the magnitude and direction of the contribution of each parameter to ordination. The surface area of the reservoirs representing the samples was laid in the background as blue colour gradient using the *ordisurf* function.

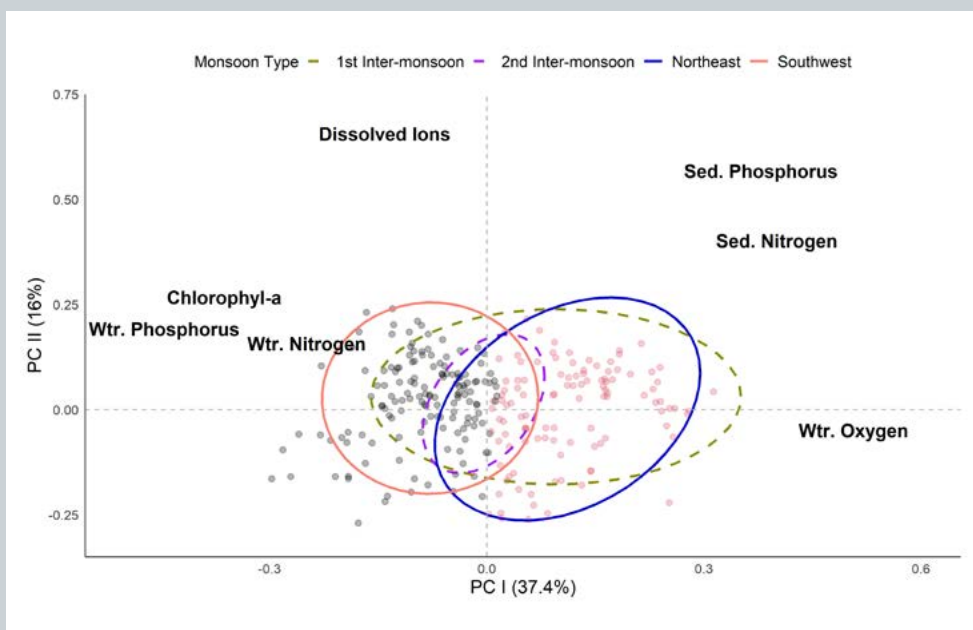


Figure 2.7.3: Two-dimensional PCA score plot using the first two principal components to ordinate reservoir samples, highlighting k-means clusters and seasonal (monsoon) groupings

Note: Samples were coloured (black and pink) according to the 2 identified clusters using the k-means method. Bigger circles represent the 2 monsoons (solid line) and 2 inter-monsoon periods (dotted line) in which 95% confidence interval of the samples were taken.

The 2 unsupervised clusters resulted by k-means method were clearly distinguishable along the PC I axis and samples grouped according to their monsoon period are shown in Figure 2.7.3. The pink cluster clearly deviated toward the positive side of the PC 1 axis, which was loaded with sediment nutrients and DO in water. The black cluster clearly deviated toward the negative side of the PC 1 axis, which was loaded with water nutrients, primary production and dissolved ions in water.

According to Figure 2.7.4, more than 96% of the south-west samples were associated with the black cluster and 92% of the north-east monsoon samples were clearly associated with the pink cluster in the PCA plot. While 80% of the first inter-monsoon samples were classified as more related to the north-east monsoon than south-west, second inter-monsoon is not explained clearly. Classified temporal sampling points according to k-means clusters are shown in Figure 2.7.5.

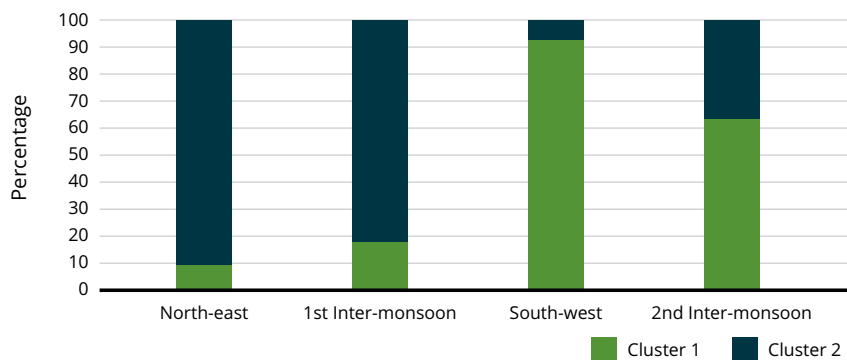


Figure 2.7.4: Percentage of each monsoon sample separated by hierarchical clustering tool using k-means clustering

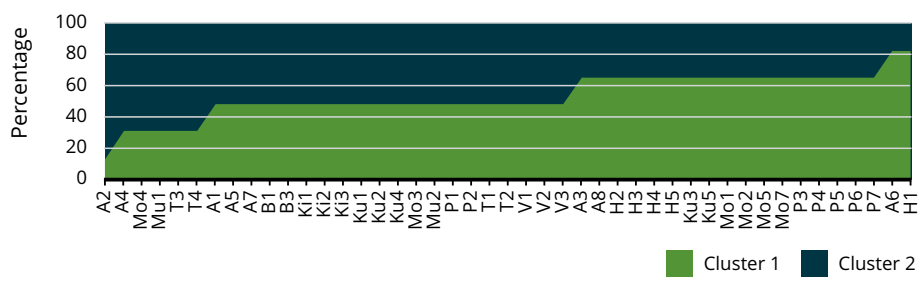


Figure 2.7.5: Percentage distribution of samples of each reservoir in clusters indicated in the PCA

The temporal trend of TP and primary production in reservoirs is shown in Figure 2.7.6. During the dry season, TP in water gradually increases while sediment TP decreases. Conversely, during the rainy season, sediment TP gradually increases and water TP decreases drastically. Figure 2.7.7 illustrates the temporal trends of TN and primary production in

reservoirs. During the dry season, TN in water fluctuates, increasing and decreasing alongside spikes in chlorophyll-a, while sediment TN remains relatively stable. In contrast, sediment TN steadily increases during the rainy season. Additionally, a spike in chlorophyll-a was observed just before the onset of the rainy season in both Figure 2.7.6 and Figure 2.7.6.

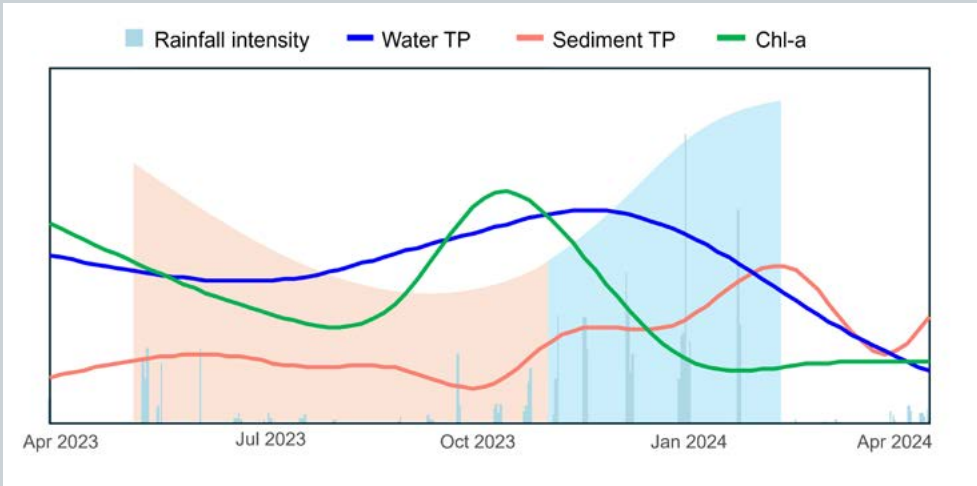


Figure 2.7.6: Temporal trends of scaled parameters: sediment TP, water TP, chlorophyll-a as lines and rainfall intensity laid at back as shades of columns in light blue

Note: Background colours: orange represents the dry period and blue represents the wet period. The white band cutting through the background shading represents the percentage change of reservoir surface area compared to the full supply level.

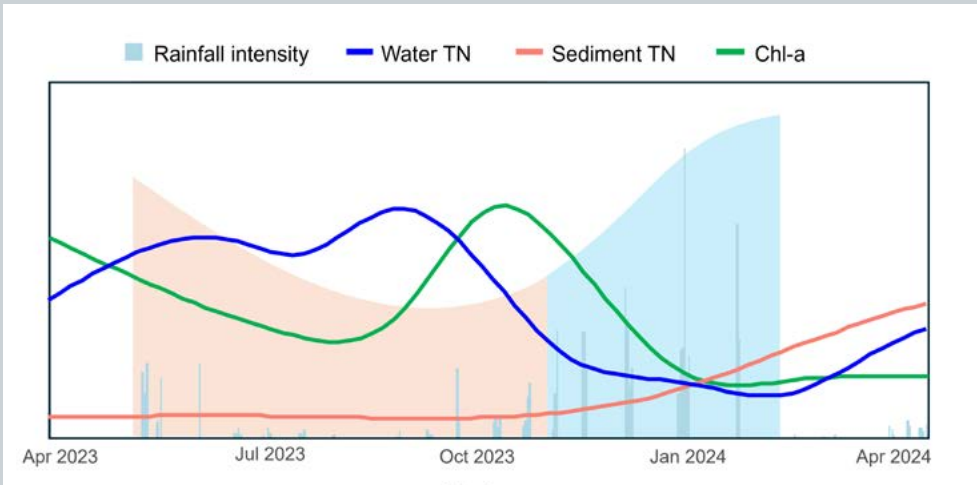


Figure 2.7.7: Temporal trends of scaled parameters: sediment TN, water TN, chlorophyll-a as lines and rainfall intensity laid at back as shades of columns in light blue

Note: Background colours: orange represents the dry period and blue represents the wet period. The white band cutting through the background shading represents the percentage change of reservoir surface area compared to the full supply level.

Fish production in reservoirs

Reported total fish production including GFP and finfish from the reservoirs was 11,428 mt for the study period from February 2023 to April 2024. Cross comparison of species-wise harvest was unable to proceed because of practical issues; fishers tend to record only total finfish harvest and GFP harvest separately rather than recording all species.

Giant freshwater prawn harvest

According to tree-based machine learning models (Figure 2.7.8) and generalised additive models (GAM) (Figure 2.7.9), reservoir elevation was the primary factor that significantly influenced the non-linear pattern of GFP harvest. Suggesting a negative relationship, GFP harvest was significantly higher where tank elevation was below 77 ft ($p < 0.05$) and significantly

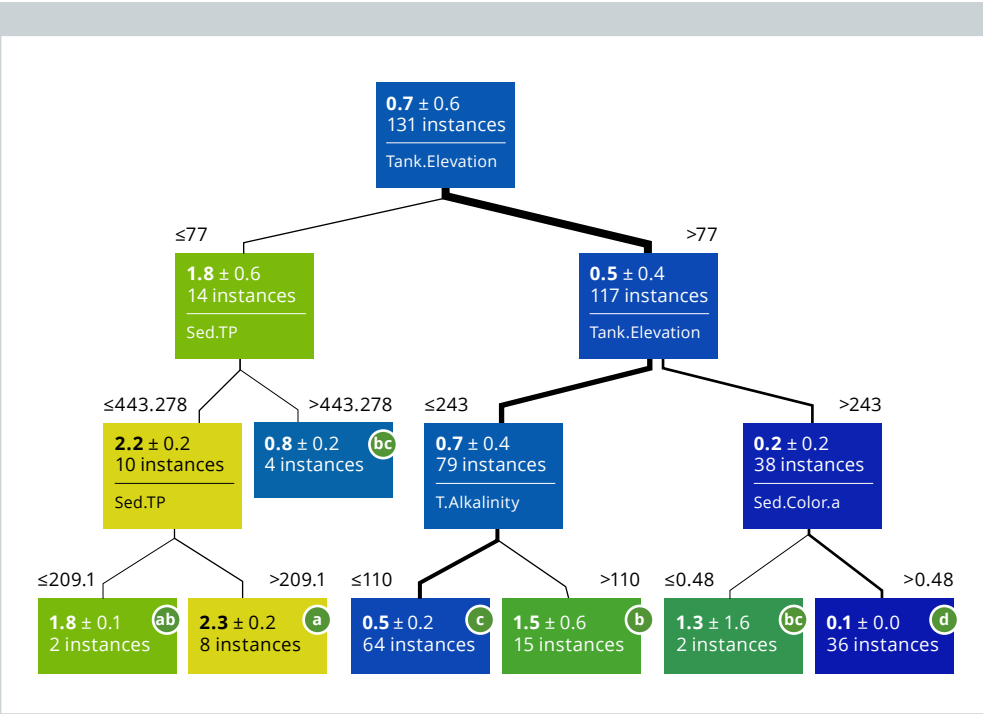


Figure 2.7.8: A single decision tree ($R^2 = 64\%$) developed using the most important parameters for GFP harvest, identified through tuned Random Forest (RF) and Gradient Boosting (GB) machine learning techniques

Notes: Each square contains information on the mean monthly harvest (bold text $\pm$ SE) at the top, the number of samples in the middle, and the parameter used for the next split at the bottom. The squares are connected by lines of varying thickness, representing the fraction of data in each branch. The value at the end of the branch is the cutoff value of parameter. The colours of the squares follow a gradient from dark blue to bright yellow, indicating an increasing trend in harvest. Lower case letters indicate significantly different groups, with harvest levels increasing alphabetically.

lower when elevation was above 243 ft ($p < 0.001$). Furthermore, the reddish colour of sediment (Sed.Color.a), total alkalinity and sediment TP were relatively more important in identifying underlying patterns compared to other parameters. GFP stocking was not a significant parameter. Reservoirs expected to exhibit significant performance are shown in Table 2.7.2. However, Maeliya, Hakwatunaoya, Mamaduwa, Hambegamuwa, Kimbulwanaoya, Mahakanadarawa, Kiulekada and Muthukandiya did not fall within the optimal range of limnological parameters for maximum GFP harvest.

A significantly higher GFP harvest was observed under the following combined situations:

- tank elevation is 77 ft or below, with sediment TP lower than 443 mg kg^{-1}
- tank elevation is between 77 ft and 243 ft, with total alkalinity exceeding 110 mg L^{-1} .

It was significantly lower when:

- tank elevation is between 77 ft and 243 ft, with total alkalinity lower than 110 mg L^{-1}
- tank elevation is between 77 ft and 243 ft, with a reddish colour in sediment > 0.48 .

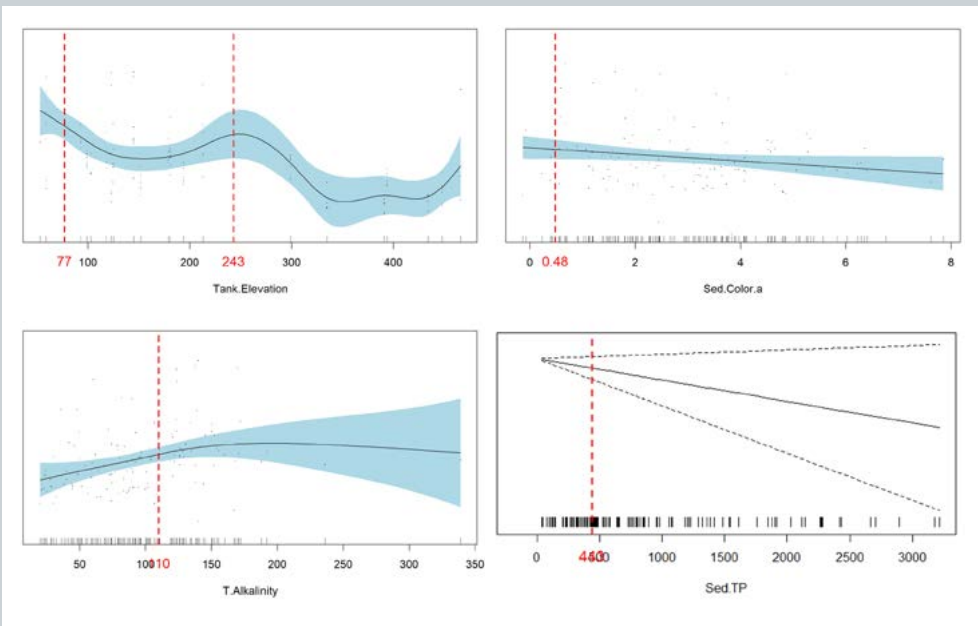


Figure 2.7.9: Multivariate GAMs showing the GFP harvest variation in y axis with the error in its smooth term and selected major factors in x axis with its original scale values (variance explained = 42%)

Table 2.7.2: List of reservoirs within the limit of significant environmental parameters (mean±SD) for expected higher GFP harvests based on the decision tree model

Name	Code	Elevation (ft)	T Alkalinity (mg L ⁻¹)	Sediment TP (mg L ⁻¹)
Maha wilachchiya	A2	181	186.8±29.2	1074.1±504.3
Ridiyagama*	H1	59	140.5±21.5	704.6±391.8
Weerawila Wewa*	H2	73	162±54.3	450.1±250.2
Maha Aluthgam ara	H3	191	128.6±39.8	792.6±587.8
Maha wewa	H4	230	122.4±38	1249.1±821.4
Mahagal wewa	H5	243	151±38.5	1367±1275.8
Pudumurippu kulam**	Ki3	77	64.3±24.2	251.7±60.6
Magalla wewa	Ku2	168	123.1±6.7	257.2±97.7
Urusita wewa	Mo5	145	141.6±42.9	1326.1±979
Gestupana wewa	Mo7	181	132.4±48.1	753.1±543.3
Devalahandiya*	P1	53	100.6±17.7	643.3±221.8
Karavita wewa*	P2	39	54.7±18.1	746.3±742.8
Mahauswewa	P3	179	125.9±34.3	480.4±221.7
Tabbowa*	P4	66	157.9±36	619.6±410.4
Vijayakatupotha*	P5	53	99.5±28.1	606.9±573.7
Kottukachchiya	P6	123	112.4±25.3	474.1±238
Wendrasan wewa	T3	181	82.7±22.2	1404.3±785.2
Wanela*	T4	72	130.2±42.2	858.4±526.8
Bogaswewa	V1	197	134.7±62.6	555.3±117.9
Kalmadu	V3	235	188.3±67.7	538.5±172.3

Notes: * Significantly preferred environmental conditions at least one time, ** Significantly preferred environmental conditions in all the samples.

GIFT tilapia harvest

Water hardness was identified as the primary driver of tilapia harvest, exhibiting a significant positive relationship. Yields were notably higher when water hardness exceeded 88 mg L⁻¹ (p<0.05). Stocking had not appeared as a major parameter in the analysis. Additionally, organic matter percentage, total alkalinity and electrical conductance were important compared to other parameters. Several different nodes in the decision tree confirmed that tilapia production was positively related to hardness (Figure 2.7.10).

Significantly higher tilapia harvest was observed where:

- hardness was higher than 140 mg L⁻¹, with total alkalinity higher than 90 mg L⁻¹.

It was significantly lower when:

- hardness was lower than 88 mg L⁻¹ with mostly total alkalinity lower than 90 mg L⁻¹.

Reservoirs within the limit of significant environmental parameters are shown in Table 2.7.3. Based on the decision tree model, Karavita wewa, Wendrasan wewa, Unnichchai tank, Akkarayankulam, Kiribban wewa and Muthukandiya exhibit hardness and sediment TP levels do not fall within the optimal range of limnological parameters.

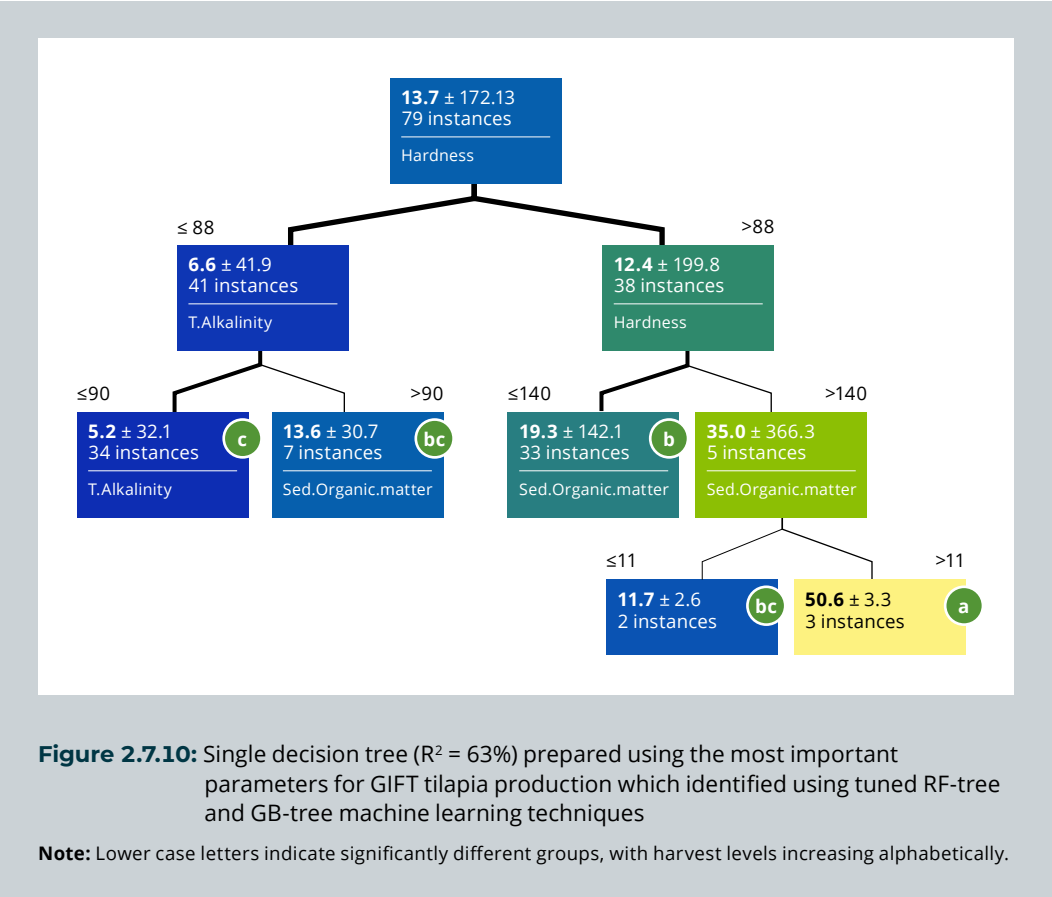


Table 2.7.3: List of reservoirs within the limit of significant environmental parameters (mean±SD) for expected higher tilapia harvests based on the decision tree model

Name	Code	Hardness (mg L ⁻¹)	Sediment TP (mg kg ⁻¹)	T Alkalinity (mg L ⁻¹)
Ridiyagama*	H1	133±6.6	704.6±391.8	140.5±21.5
Tabbowa*	P4	163.5±32.7	619.6±410.4	157.9±36
Wanela	T4	114.4±28.8	858.4±526.8	130.2±42.2
Weerawila Wewa	H2	131.9±20.2	450.1±250.2	162±54.3
Devalahandiya	P1	189.7±77.1	643.3±221.8	100.6±17.7
Vijayakatupotha	P5	133.5±42.3	606.9±573.7	99.5±28.1
Kottukachchiya	P6	203.2±95.3	474.1±238	112.4±25.3
Bogaswewa	V1	157.7±67.6	555.3±117.9	134.7±62.6
Maha wilachchiya	A2	151.8±39.1	1074.1±504.3	186.8±29.2
Kalmadu	V3	217.3±68.5	538.5±172.3	188.3±67.7
Mahauswewa	P3	132.1±33.8	480.4±221.7	125.9±34.3
Maha wewa	H4	138.4±44.5	1249.1±821.4	122.4±38
Mahagal wewa	H5	126.6±36.4	1367±1275.8	151±38.5
Siyambalangamuwa	Ku5	142.5±38.9	819.5±834.8	154.2±46.6
Thuruwila	A6	128.9±26.2	571.9±565.3	152.5±32.2
Nachchaduwa	A4	132.1±39.8	956.2±475	129.7±36.6
Maha_Andarawewa	P7	163.1±72.6	698.8±360	85.8±23.5
Hakwatunaoya	Ku1	124.4±22.3	914.6±583.8	165±32.2
Mahakanadarawa	A3	144.3±33.7	797.2±553.7	165.2±41.2
Mamaduwa	V2	130.3±56	418.8±81.1	96.5±33.9

Note: * Significantly preferred environmental conditions at least one time.

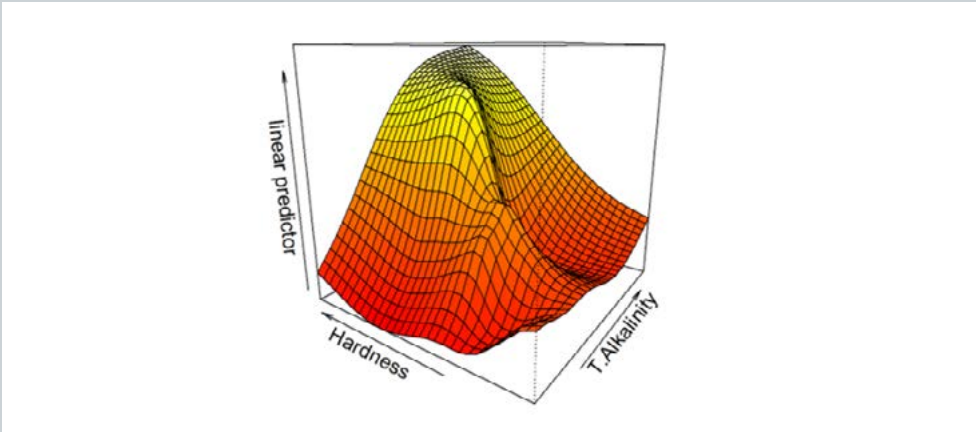


Figure 2.7.11: Multivariate generalised additive significant model showing the tilapia harvest as linear predictor with the interaction term of hardness and total alkalinity (variance explained = 56%)

Catla fish harvest

According to the decision tree model, stocking of catla fingerling was the most significant factor ($R^2 = 0.68$) instead of limnological parameters. While the analysis suggests that a stocking density above $\sim 1,300$ fingerlings ha^{-1} can lead to significantly higher production ($p < 0.05$), only 6 out of 74 samples support this finding. Furthermore, GAM showed that the maximum harvest can be obtained using $\sim 1,800$ fingerlings ha^{-1} as the stocking density, and increasing beyond that is unnecessary. Therefore, excluding stocking, total alkalinity is the most important factor, followed by tank elevation as the second most important. Catla production

tends to be significantly higher ($p < 0.001$) when total alkalinity exceeds 106 mg L^{-1} , with tank elevation less than 145 ft (Figure 2.7.12 and Figure 2.7.13). Additionally, lower elevations ($< 145 \text{ ft}$) result in significantly higher production ($p < 0.001$). Reservoirs within the limit of significant environmental parameters are shown in Table 2.7.4. According to the decision tree model, Iranamadu tank, Vavunikulam, Muthiyankaddu, Vadamunai, Pudumurippu kulam, Karavita wewa, Unnichchai and Akkarayankulam are expected to result in significantly lower yield of catla harvests.

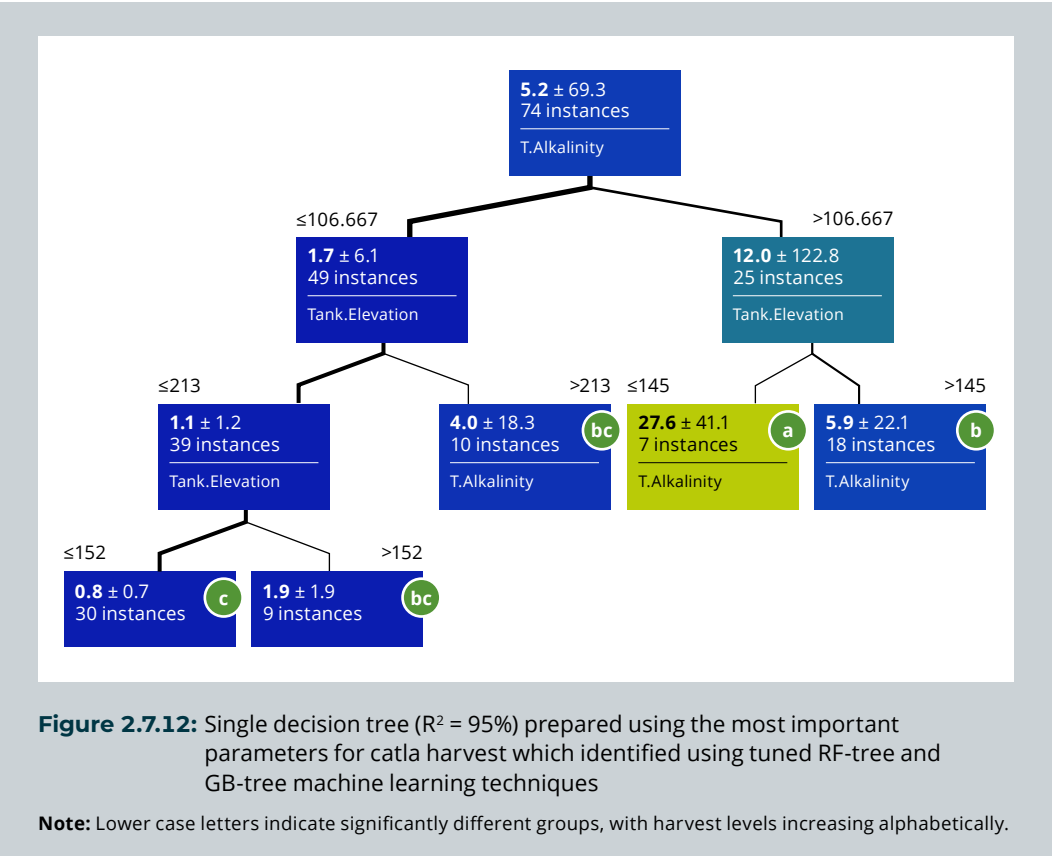


Figure 2.7.12: Single decision tree ($R^2 = 95\%$) prepared using the most important parameters for catla harvest which identified using tuned RF-tree and GB-tree machine learning techniques

Note: Lower case letters indicate significantly different groups, with harvest levels increasing alphabetically.

Table 2.7.4: List of reservoirs within the limit of significant environmental parameters (mean±SD) for expected higher catla harvests based on the decision tree model

Name	Code	T Alkalinity (mg L ⁻¹)	Elevation (ft)
Tabbowa*	P4	157.9±36	66
Devalahandiya	P1	100.6±17.7	53
Kottukachchiya	P6	112.4±25.3	123
Vijayakatupotha	P5	99.5±28.1	53
Ridiyagama*	H1	140.5±21.5	59
Wanela	T4	130.2±42.2	72
Weerawila Wewa	H2	162±54.3	73
Urusita_wewa*	Mo5	141.6±42.9	145

Note: * Significantly preferred environmental conditions in all the samples.

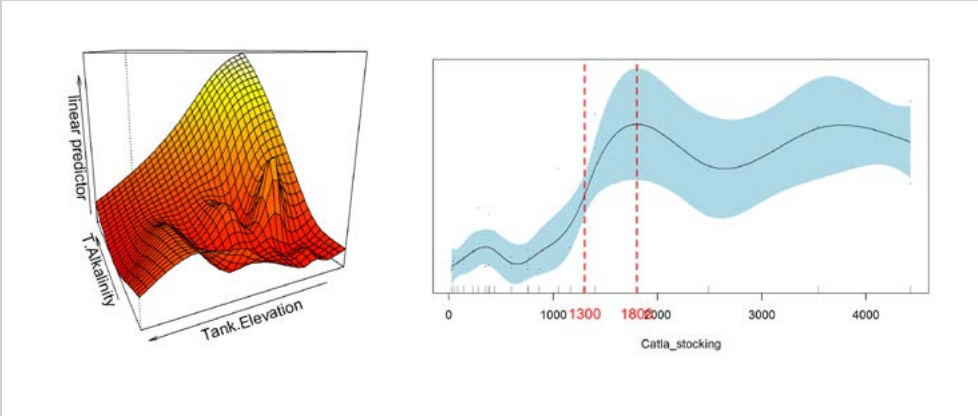


Figure 2.7.13: Multivariate GAM illustrating catla harvest as a linear predictor

Note: The left panel shows the interaction between total alkalinity and tank elevation, while the right panel depicts the variation of catla harvest with stocking density. The model explains 99.8% of the variance with stocking density included and 90.9% without it.

Rohu harvest

According to the decision tree models (Figure 2.7.14), stocking of rohu fingerlings is the most significant factor ($R^2 = 0.84$) instead of limnological parameters. While the analysis suggests that a stocking density above $\sim 1,800$ fingerlings ha^{-1} can lead to significantly higher production ($p < 0.05$), only 11 out of 68 samples support this finding. According to the GAM (Figure 2.7.15), total alkalinity and stocking is significant and production had peaked around 5,200 fingerlings ha^{-1} . However, excluding stocking, total alkalinity is the most influential factor among all parameters. Indicating a positive relationship at multiple nodes in the

decision tree, rohu harvest is significantly higher when total alkalinity exceeds 106 mg L^{-1} ($p < 0.01$).

Significantly higher rohu harvest was observed, where:

- rohu fingerling stocking is between 1,800 and 5,200 fingerlings ha^{-1}
- total alkalinity is higher than 107 mg L^{-1} , with tank elevation lower than 145 ft.

It was a significantly lower harvest when:

- total alkalinity is lower than 107 mg L^{-1} .

According to the decision tree model, Ridiyagama, Tabbowa, Urusita Wewa, Weerawila Wewa, Dewalahandiya Wewa and Wanela are expected to yield higher rohu harvests.

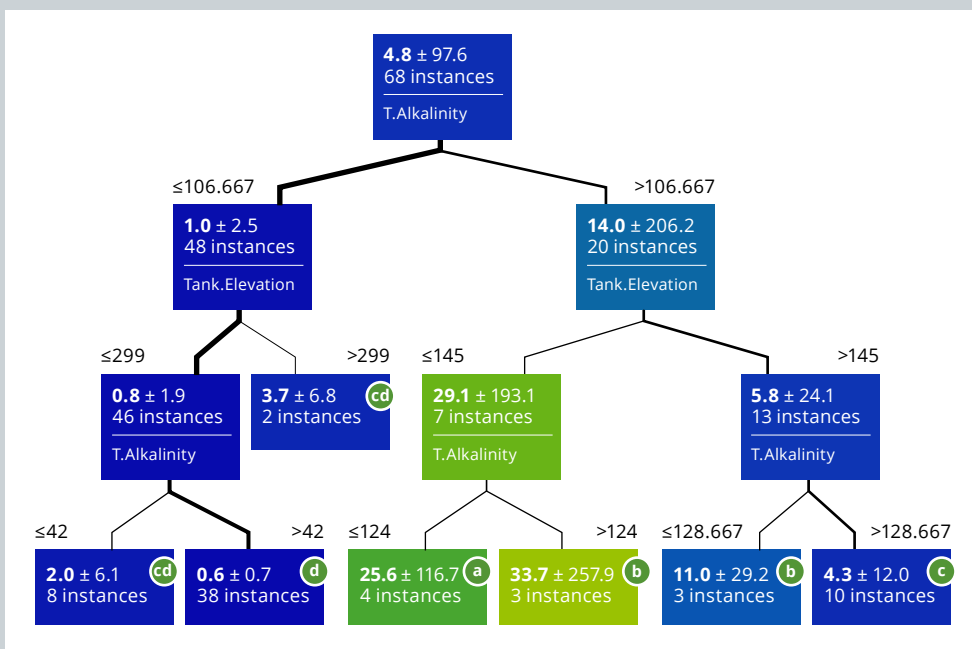


Figure 2.7.14: Single decision tree ($R^2 = 77\%$) prepared using the most important parameters for rohu harvest which were identified using tuned RF-tree and GB-tree machine learning techniques

Note: Lower case letters indicate significantly different groups, with harvest levels increasing alphabetically.

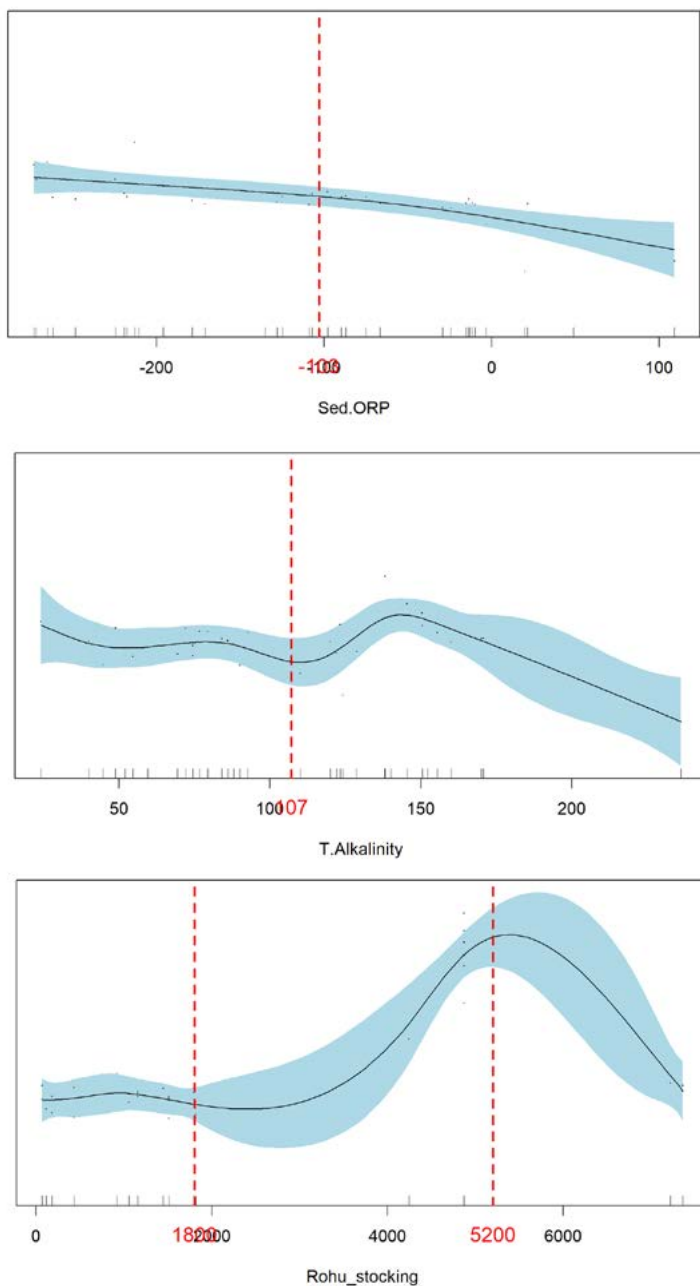
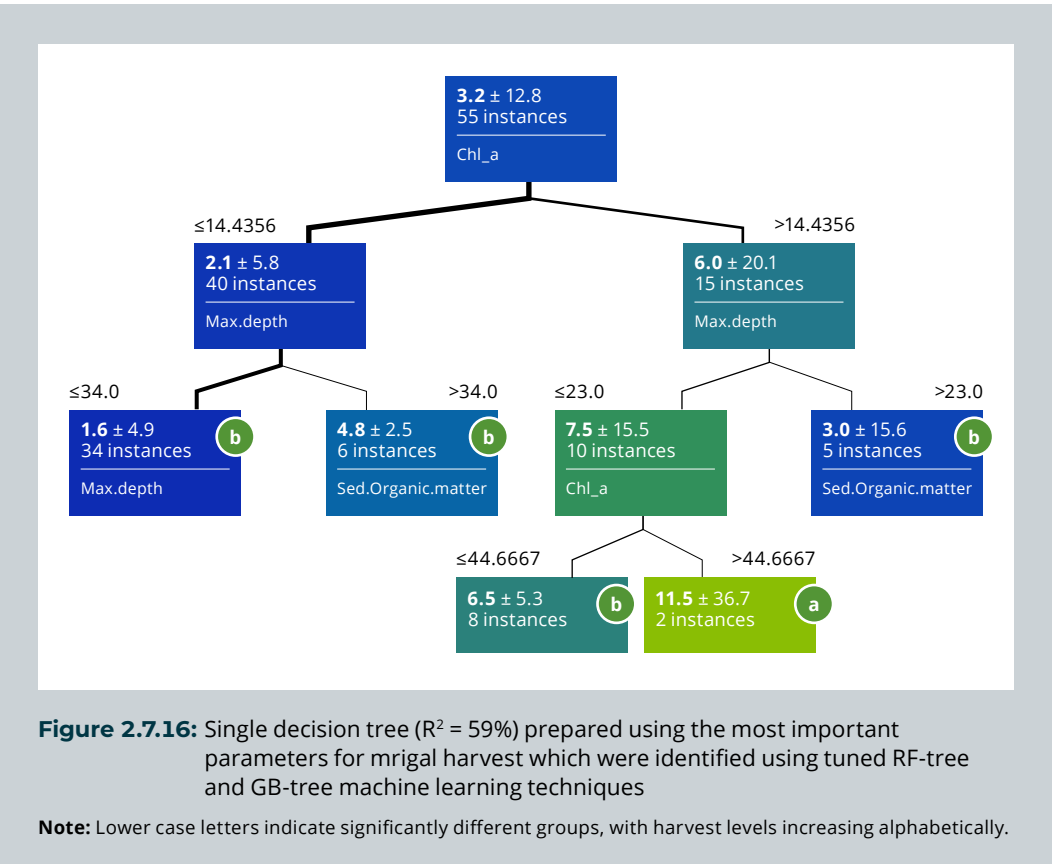


Figure 2.7.15: Multivariate GAM showing the rohu harvest variation in y axis with error in its smooth term and selected major factors in x axis with its original scale values (explained variation was 81%)

Mrigal harvest

RF suggests that the stocking density of mrigal fingerlings as the most important factor instead of limnological parameters. However, only 54% of the variance has been explained, and the divided samples were not significant. Figure 2.7.16 considers only the limnological conditions since GAM (Figure 2.7.17) also is not detecting the stocking density as a significant predictor. Therefore, excluding stocking density, chlorophyll-a is the most important

factor. Mrigal production is significantly higher ($p<0.05$) when chlorophyll-a concentration exceeds $14.4\text{ }\mu\text{g L}^{-1}$ and the reservoir's maximum depth is less than 23 ft; otherwise, it is significantly lower (Figure 2.7.16). Reservoirs within the limits of significant environmental parameters are shown in Table 2.7.5. Nachchaduwa, Ranawa, Weerawila wewa, Muthukandiya. Maha Andarawewa and Kalmadu reservoirs did not fall within the optimal range of limnological parameters.



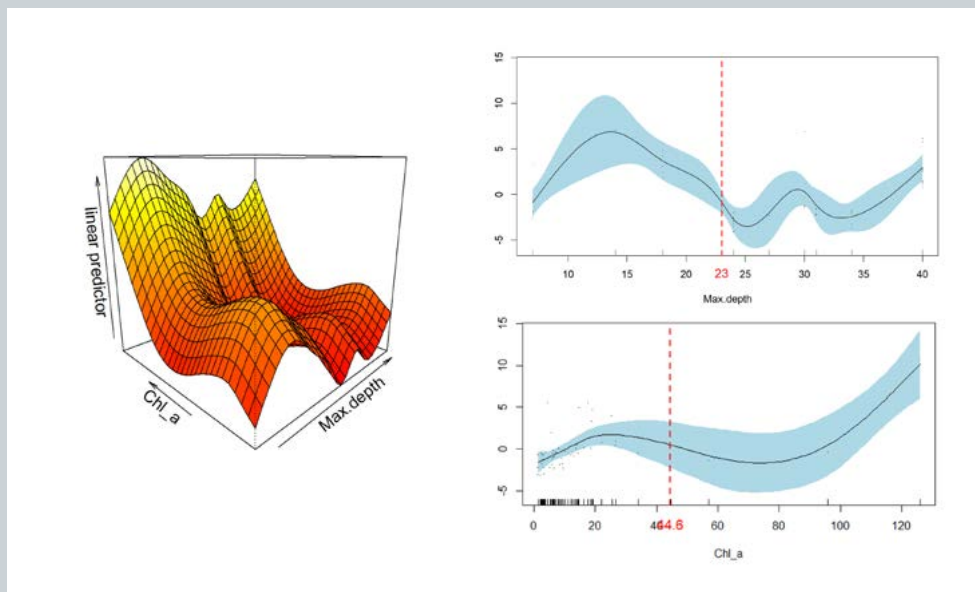


Figure 2.7.17: Multivariate GAM illustrating mrigal harvest as a linear predictor

Note: The left panel shows a 3d surface of maximum depth and chlorophyll-a, while the right panel depicts the variation in the mrigal harvest with each parameter. The model explained 78.9% of the variance without stocking density.

Table 2.7.5: List of reservoirs within the limit of significant environmental parameters (mean±SD) for expected higher mrigal harvests based on the decision tree model

Name	Code	Chlorophyll-a ($\mu\text{g L}^{-1}$)	Max depth (ft)	Sed. organic matter %
Aluthdiulwewa	A5	17.1±15.5	20	18.7±2.7
Vadamunai	B3	28.8±16.2	20	16.8±3.5
Maha Aluthgam ara	H3	20.2±27.5	12	13.4±9.3
Kimbulwanaoya	Ku3	18.2±16.5	17	13.8±5.2
Maeliya	Ku4	27.4±17.7	18	19.8±3.9
Siyambalangamuwa	Ku5	32.6±31.4	18	17.9±4.2
Hambegamuwa	Mo1	42.1±41.5	18	16.1±2.6

Considering all the important parameters for CBF species, the mean values of total alkalinity, tank elevation, sediment TP, organic matter percentage, hardness and chlorophyll-a are spatially represented using the two-dimensional GAM model in Figure 2.7.18.

Discussion

The present study revealed substantial limnological variations among reservoirs across the main classes of variables, including reservoir morphometry, nutrients, primary production, DO and dissolved

ions in water during 2 major monsoon periods. The measured limnological factors correlated and displayed distinct gradients and seasonal fluctuations. Additionally, reservoir elevation and several other limnological factors were identified as being correlated with reported GFP and species-wise finfish harvest variations.

Heavy rains associated with the north-east monsoon contribute to increased nutrient input from run-off, which is deposited in the sediments at reservoir bottoms, and increasing water inflow increases the water volume in reservoirs. Concurrently, rising

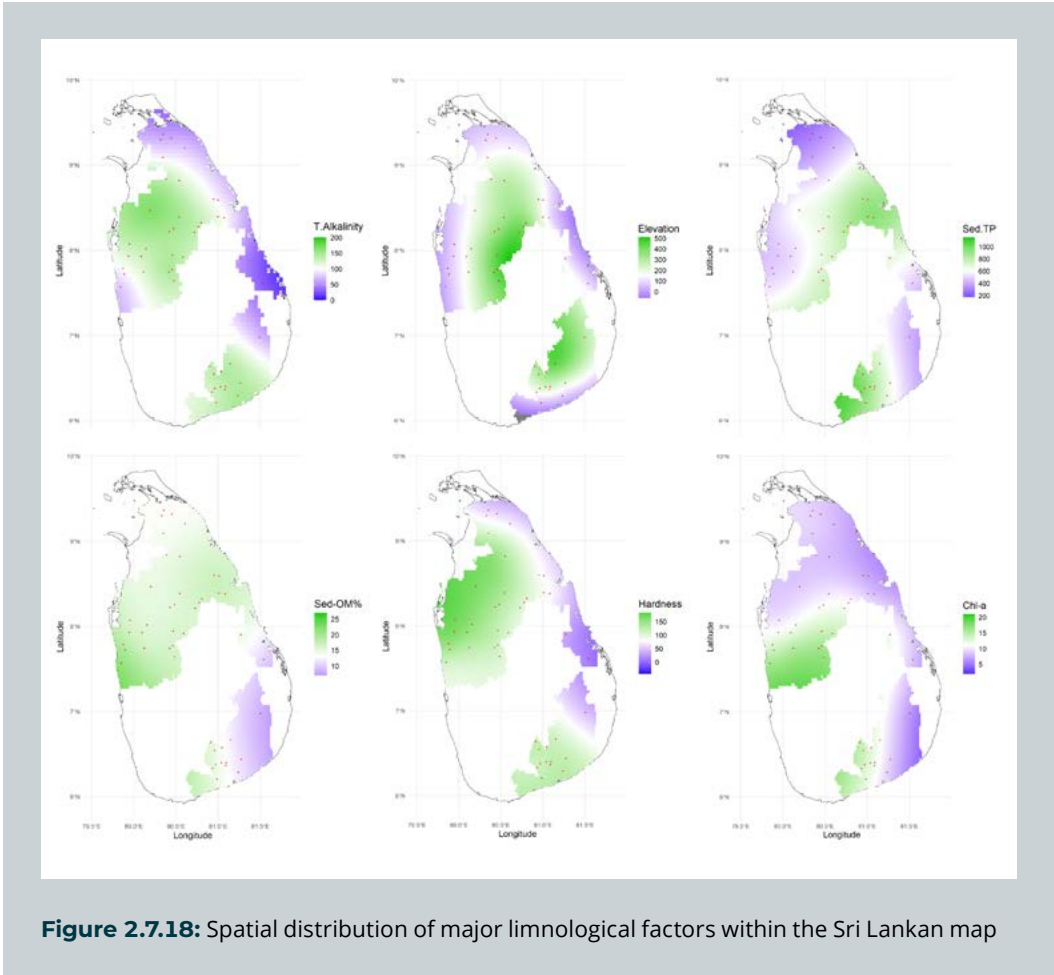


Figure 2.7.18: Spatial distribution of major limnological factors within the Sri Lankan map



water levels result in a dilution effect that reduces dissolved ion concentrations in the water column, whereas enhanced mixing increases DO levels. As the monsoon transitions into the south-west phase, rainfall intensity decreases, leading to a gradual increase in dissolved ions, including hardness, conductivity, salinity and nutrients. Nutrients previously deposited during run-off events are progressively released into the water column, fostering increased primary production. This process is evidenced by reduced sediment nutrient levels, increased dissolved nutrient levels, and chlorophyll-a in the water.

Another interesting pattern was observed because of the variations in rainfall intensity during the monsoon seasons. During the dry season, a phosphorus balance between the water and sediment phases was observed; the TP concentration in water gradually increased, while it decreased in the sediment. This may be mainly due to the release of phosphorus from the sediment into the water. Wang et al. (2019) indicated that the sediment can act as a phosphorus source during summer by transforming phosphorus from sediment to water. Iron can trap phosphate under oxygen-rich conditions and release it back into the water under anoxic conditions (Bakker et al. 2016). Furthermore, the increased evaporation of water may have concentrated phosphate in water. During the rainy season, nutrient-rich storm flow conditions may replenish the sediment TP. Water TP further decreased with spillover and deposition in the sediment phase during the north-east monsoon. Similarly, Mihiranga et al. (2025) indicated that organic phosphorus is transported to reservoirs via surface and soil water run-off, mainly as dissolved organic phosphates, during wet seasons. Furthermore, Wang et

al. (2019) found that sediment can act as a sink during the winter and spring.

TN in the water may decrease primarily due to assimilation by phytoplankton, which is driven by the spiked primary production during the dry season. This indicates that the reduction in nitrogen is more influenced by biological processes than spillover, which is in contrast to the behaviour of TP in the same period. According to Han et al. (2014), under anaerobic conditions, sediment can produce ammonia through the mineralisation of organic matter. Because nitrification is suppressed by the unavailability of oxygen, ammonia nitrogen can be concentrated within the water. Therefore, sediments can act as a nitrogen source during the dry season. Theoretically, primary producers can assimilate more nitrogen than phosphorus (Karpowicz et al. 2019) and the typical Carbon:Nitrogen:Phosphorus ratio is 106:16:1 according to the Redfield ratio (Tyrrell 2001).

Interestingly, stocking was not identified as a significant parameter in the tree-based regression model, suggesting that environmental conditions, rather than stocking density, primarily drive the GFP harvest. This finding implies that increasing stocking efforts may not yield better harvests unless the optimal limnological conditions are met.

According to both univariate GAM and regression tree-based models, reservoirs with elevations below 243 m may provide more favourable environmental conditions for GFP productivity, possibly because of their inherent biological instinct to adapt to environmental conditions closer to the ocean as suitable for their reproductive migration behaviour. According to FAO (2009), GFP naturally found in 'tropical and subtropical freshwater environments

influenced by adjacent brackish water areas' because they spend their larval stage in brackish water, and post larvae migrate to freshwater for growth. Next, mating occurs in freshwater, and egg-bearing females migrate to brackish water areas where egg hatching and larval development occur. According to this life cycle, they may require lower elevations for better survival and growth. Most of the sampled reservoirs were not directly connected with each other through a perennial cascade system; therefore, it is not possible to assume that GFP migrated through the sluice-released water into the reservoirs at lower elevations.

Alkalinity in water is important for buffering pH levels, mainly during the rainy season. Raindrops can dissolve more carbon dioxide while travelling through the air from clouds to the ground (Radha et al. 2022; Silva and Manuweera 2004). Dissolving CO₂ can produce carbonic acid, which drives sudden pH changes in natural water, leading to respiratory failure with ionic imbalances between the water and gills of fish (Chen et al. 2023). This impact can be reduced if ionic compounds or complexes are available within the water to buffer incoming foreign acids or bases. Furthermore, the calcareous outer shell of GFP can be dissolved because of the low pH, where alkalinity has lower values; hence, there is no control over pH changes. According to the results, the alkalinity higher than 110 mg L⁻¹ (as CaCO₃) was significantly better. However, increasing it to more than 150 mg L⁻¹ resulted in a slight reduction in harvest but with a higher standard error. This suggests that alkalinity levels between 110–150 mg L⁻¹ (as CaCO₃) in reservoirs are beneficial for GFP production. Similarly, Adhikari et al. (2007) found that 100 mg L⁻¹ was associated with the highest survival rate and growth.

Lower sediment total, which is associated with higher production, may be explained by bioturbation. GFP is a benthic feeder that can disturb benthic sediments by releasing phosphorus into the water column. Therefore, a phosphorus content below 443 mg kg⁻¹ in sediment can be an indicator of a higher abundance of GFP in the reservoir.

Reddish colour in sediment calculated as CIE Lab color value a* can mainly occur due to iron oxides in sediment (Wang et al. 2022). The iron in water, mainly Fe³⁺, can reduce the amount of bioavailable phosphate by forming complexes with phosphorus in the presence of oxygen (Bakker et al. 2016). Hence, primary production can be retarded, resulting in a cascade of effects on the entire food web of the reservoir. Eventually, a decrease in the growth of omnivorous GFP may have occurred. In addition, higher ferric concentrations can affect the survival of GFP because these particulate iron oxides can clog the gills and cause irritation in the gills due to their highly oxidative nature. However, lower levels of iron can increase primary production (Keller et al. 2012). Hence, lower levels of red colour in the sediment seem to be beneficial for GFP harvest.

The finfish harvest results suggest that a simple increase in stocking density may not yield better harvests unless the optimal limnological conditions are met. Tilapia is a self-recruiting species which can reproduce in Sri Lankan reservoirs (Athauda 2010). Hardness and total alkalinity have been identified as the major limnological factors that influence tilapia production. The hardness was calculated using the total ion concentrations of magnesium and calcium in water. While magnesium is mainly important for primary production because it is the central atom in chlorophyll-a,



calcium is crucial for osmoregulation in aquatic animals and is a constituent of the exoskeleton and bones (Wurts and Durborow 1992).

Although tilapia do not possess any calcareous outer layers such as GFP to be dissolved under low pH conditions, their gill tissues are susceptible to sudden pH changes (Wurts and Durborow 1992). According to the results, the combination of alkalinity and hardness performed well, rather than as individual factors. An alkalinity higher than 90 mg L⁻¹ and hardness higher than 140 mg L⁻¹ yielded better results. However, the highest hardness value recorded in this study was 202.7 mg L⁻¹; therefore, configuring an upper limit was not possible here. According to Cavalcante et al. (2014), the alkalinity:hardness ratio is important, and a 1:1 ratio has a significant influence on production. Tilapia (2025) reported that a hardness between 50–150 mg L⁻¹ is preferred for the culture of tilapia and most other finfish species.

Although stocking densities between 1,300 and 1,800 fingerlings ha⁻¹ are suggested for significantly higher catla production, the limited number of samples makes this recommendation uncertain. The model may have been overfitted. However, stocking in reservoirs where alkalinity is higher than 106 mg L⁻¹ and elevation is lower than 145 ft will lead to a significantly higher harvest. According to Jena (2009), 25–32 °C is the preferred temperature for *C. catla*. Lower elevations are often associated with higher water temperature and biodiversity (Vijverberg et al. 2012). This can increase the metabolic activity of fish, allowing them to grow faster.

The rohu yield suggests that stocking density should be maintained between 1,800–5,200 fingerlings ha⁻¹ to obtain the

maximum yield. Other than the stocking density, a total alkalinity higher than 106.6 mg L⁻¹, lower tank elevation less than 145 ft and sediment oxidation reduction potential (ORP) less than -103 mV can result a significantly higher harvest. As discussed before, alkalinity is important for pH buffering to reduce damage to fish, and a lower elevation will increase the metabolic rate of fish, enabling faster growth. Lower and negative sediment ORP are associated with reducing or anoxic conditions in the sediment (Godoi et al. 2012). If the sediment is anoxic, the lower water column might also be anoxic, causing fish to move into the upper layers, where oxygen is sufficient for their survival. Eventually, they can be entangled by passive gillnets deployed in the upper water column to increase the harvest. Alternatively, as discussed before, anoxic conditions can release trapped phosphorus into the water column, making it bioavailable to phytoplankton for assimilation. Since rohu mainly depends on phytoplankton as their main meal, this will also drive rohu fish into the euphotic zone, where preferred light intensities are available for higher abundance of phytoplankton.

Stocking density is not significant for mrigal harvest, although chlorophyll-a and maximum depth of the reservoir are considered major influential factors. The maximum depth was less than 23 ft, and chlorophyll-a was higher than 44.6 µg L⁻¹, which resulted in higher yields compared to other environmental conditions. Chhanda et al. (2019) have reported that mrigal fish prefer up to 9 ft of water depth, however in that study, they did not increase the depth beyond 9 ft to check the survival rate of fish. As shown by this study, 23 ft might be a possible maximum depth to survive because Towers (2009) stated that adult mrigal fish are bottom dwellers, and their

main diet consists of detritus and decayed vegetation supplemented by phytoplankton and zooplankton. For such a variety of diets, mrigal should move frequently from the surface to the bottom. Accordingly, higher chlorophyll-a levels can increase the growth and harvest of mrigal fish. When they are attracted to abundant planktonic communities in the upper water layers, they can become entangled in the gillnets.

Conclusion

This study highlights significant limnological variations among reservoirs across different monsoon seasons, emphasising the influence of hydrological and physicochemical changes on nutrient dynamics, primary production and fish productivity. Seasonal fluctuations in nutrient concentrations, particularly phosphorus and nitrogen, were evident, with sediment playing a crucial role as both a sink and source of nutrients. The observed shifts in nutrient availability and primary production underscore the importance of seasonal hydrological processes in shaping reservoir productivity.

Fish production was strongly influenced by limnological factors rather than stocking density alone, suggesting that environmental conditions play a significant role in shaping harvest outcomes. GFP productivity was linked to reservoir elevation, alkalinity levels and sediment phosphorus content, indicating the significance of both water chemistry and sediment characteristics in supporting optimal growth conditions. Finfish harvest, particularly for GIFT tilapia, catla, mrigal and rohu, was driven by key water quality parameters such as alkalinity, hardness and chlorophyll-a levels. These findings underscore the importance of maintaining a balanced water chemistry and reservoir morphometry to sustain optimal fish yields.

Overall, this research emphasises that successful fisheries management in reservoirs requires a comprehensive understanding of the seasonal limnological dynamics. Strategies focusing on water quality variations, nutrient balance and ecosystem stability can enhance fish productivity and ensure sustainable CBF in irrigational reservoirs. Future studies should further explore the long-term implications of climate variability and anthropogenic influences on reservoir productivity to refine management practices.

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2.8 Potential accumulation of selected pollutants in dry zone reservoirs utilised for inland fisheries

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Abstract

Sri Lanka's dry zone reservoirs are one of the oldest historically recorded systems in the world. They are critical sources for water storage, irrigation and inland fisheries, and there is potential to be influenced by anthropogenic pollutants. This study examines the dynamics of the criteria water pollutants, selected pesticides and heavy metals and microplastics in 7 reservoirs utilised for inland fisheries practices. Results indicate significant variations in pH levels, TSS, biochemical oxygen demand (BOD), nutrient concentrations and microbial contamination, driven by anthropogenic activities and natural hydrodynamic conditions. The presence of oil and grease, lead and pesticide residues highlights pollutant retention mechanisms, with Urusita wewa and Wan ela exhibiting notable contamination trends. Microplastic accumulation, particularly in Vijayakatupotha reservoir, suggests site-specific pollution sources and sediment deposition dynamics. Despite localised pollution concerns, most reservoirs maintain water quality parameters within permissible limits, ensuring fisheries sustainability. However, the absence of regulatory thresholds for fecal coliform contamination underscores the need for enhanced water quality monitoring. Understanding pollutant interactions, bioaccumulation risks and environmental retention patterns is vital for sustainable reservoir management and fisheries conservation. This study emphasises the importance of adaptive pollution control strategies, community engagement and policy interventions to mitigate contamination risks and maintain long-term aquatic ecosystem health.

Keywords: *heavy metals, pesticide residues, microplastics, culture-based fisheries, agrarian reservoirs*

Introduction

With globalisation and industrial development, aquatic pollution due to various types of pollutant accumulation in water, sediments and organisms therein, has become an emerging threat that can increase the potential risk for human health. Aquatic pollution occurs when harmful substances, such as chemical contaminants or pathogenic microorganisms enter aquatic systems, including streams, rivers, lakes, oceans and aquifers. This intrusion alters the physical, chemical or biological properties of the water, leading to a deterioration in its quality. As a result, contaminated water can be hazardous for human consumption, aquatic life and the surrounding ecosystem.

Amongst the water resources in Sri Lanka, agrarian reservoirs are significant due to their high number. It has been estimated to have more than 30,000 reservoirs and anicuts throughout the island especially in the dry zone (DAS 2000). This is similar to have about 3 ha of reservoir area for every km² of the island, probably the highest density of reservoirs in the world (De Silva 1988; Piet 1996). Most of those reservoirs have been constructed to store rainwater to support paddy culture in the dry zone. That means there is a high potential to receive pesticide residues to these waterbodies from the surrounding paddy lands. With the addition of synthetic fertilisers, heavy metal accumulation in these agricultural areas can also be high (Rajapaksha et al. 2023). Since these reservoirs are popular sources of inland fish production (Amarasinghe 1998), associated health risk to humans through the aquatic food web will be a major concern.

The term 'heavy metal' generally refers to elements with a density exceeding 4 g/cm³, including metals and metalloids

like arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb) and mercury (Hg), according to Duffus (2002), which can contaminate the environment at concentrations above natural levels. Heavy metal pollution primarily arises from industrial discharge, agricultural run-off and urbanisation, leading to contamination of water, air and soil. These metals are toxic even in low concentrations, capable of bioaccumulating in living organisms and disrupting biological systems when ingested through contaminated food or water, potentially causing neurological disorders, kidney damage and cardiovascular issues in humans. In aquatic ecosystems, heavy metals degrade water quality and accumulate in freshwater species like prawns and finfish (Bhakta 2010), posing risks to human health, particularly in countries like Sri Lanka, where such species are vital for consumption and export. Similarly, pesticides which are chemical compounds used in agriculture to manage pests (US EPA 2013) can infiltrate water bodies via run-off, leaching or spray drift, persisting in the environment and accumulating in the food chain. Their presence in freshwater organisms such as prawns and fish (Nayem et al. 2011; Sultana et al. 2012) can lead to chronic human health issues, including hormonal imbalances, cancer and immune suppression, posing challenges to public health and aquaculture in Sri Lanka due to potential contamination of irrigational reservoirs.

Additionally, microplastics (MP), defined as particles smaller than 5 mm (Thompson et al. 2004, 2024), originating from the breakdown of larger plastics, industrial processes and personal care products, have emerged as pollutants in aquatic environments. These particles are ingested by aquatic organisms like fish

and crustaceans, entering the human diet (Pinheiro et al. 2017), while their ability to adsorb heavy metals enhances their toxicity (Khalid et al. 2021). Although extensively studied in marine systems, MP impacts in freshwater ecosystems remain less understood, highlighting the need for research in Sri Lanka's dry-zone reservoirs, where diverse environmental conditions and ecosystem sizes may affect their occurrence and consequences.

This study aims to explore the extent of heavy metal, pesticide and MP pollution in selected dry-zone irrigational reservoirs in Sri Lanka. These reservoirs are not only key sources of freshwater but also critical habitats for aquaculture, particularly for species like *M. rosenbergii* (GFP), tilapia, mrigal and rohu. This research will examine water and sediment samples to identify pollutant levels and investigate contaminant levels of these pollutants in different tissue types of aquatic organisms. Additionally, the research will extend to studying the occurrence of MP in freshwater systems, addressing gaps in existing literature.

Materials and methods

Study area

The study was conducted within 7 dry zone reservoirs selected from Southern Province, Uva Province, North Western Province, North Central Province and Eastern Province in Sri Lanka (Figure 2.8.1).

Urusita (6°19'54"N; 80°56'02"E) and Handapanagala (6°39'40"N; 81°09'09"06"E) reservoirs in Monaragala district, Weerawila reservoir (6°17'13"N; 81°14'19"E) in Hambanthota district, Tabbowa (8°04'26"N; 79°57'17"E) and Vijayakatupotha (7°43'09"N; 79°53'36"E) reservoirs in Puttalam district, Maha Siyabalangamuwa reservoir (7°56'34"N; 80°27'58"E) in

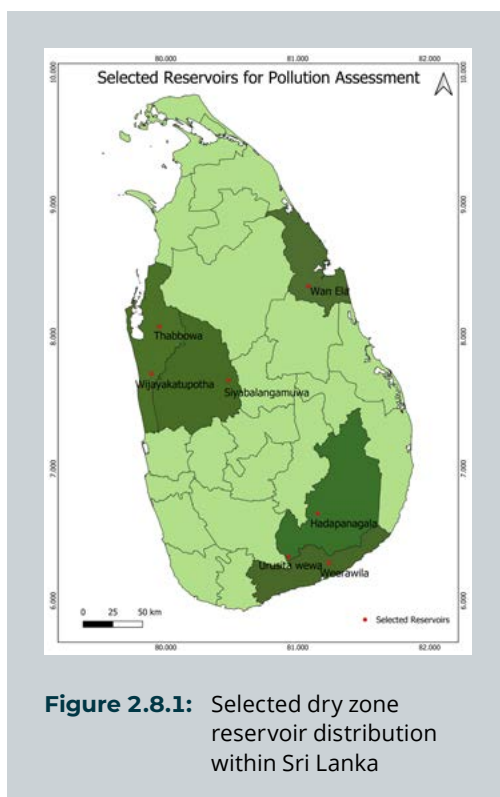


Figure 2.8.1: Selected dry zone reservoir distribution within Sri Lanka

Kurunegala district and Wan Ela (8°22'55"N; 81°04'50"E) in Trincomalee district were selected and background analysis was carried out from October 2022 to March 2023 to select appropriate sites for the sample collection based on their location and size, main inlets and outlets, fish catch information and surrounding/catchment area.

Sample collection and preservation

Sampling was carried out bimonthly from March 2023 to February 2024. Sample preservation and storage techniques were varied according to the selected parameters (Table 2.8.1). Water samples were obtained using a Ruttner sampler for laboratory tests except for MP analysis. Obtained water samples were subdivided into 4 portions as (A), (B), (C) and (D) for different analyses. Where necessary, samples were preserved and stored according to standard methods mentioned in Baird et al. (2017).

Table 2.8.1: List of tested parameters for assessing the reservoir pollution status

Category		Parameters
Criteria water pollutants (in water)		pH
		Nutrients (nitrate and phosphate)
		Total suspended solids (TSS)
		Biochemical oxygen demand (BOD ₅)
		Oil and grease
		Pathogenic organisms (Ex: fecal coliform)
Priority toxic pollutants	Heavy metals (in water, sediment and fish tissue)	Lead (Pb), Cadmium (Cd), Chromium (Cr), Arsenic (As)
	Pesticides (in water, sediment and fish tissue)	Azardirachtin A, chlorpyrifos, diazinon, emamectin benzoate, fipronil, MCPA, profenofos, thiamethoxam, fenoxaprop-p-ethyl, etofenprox
	Microplastics (in water and sediment)	Quantitatively analysed for morphometric parameters such as shape and size

Portion (A) of the obtained water sample was collected into 2 reagent bottles and one bottle was preserved with Winkler A and Winkler B while the other one was covered with a black polythene until further analysis for BOD.

The second portion (B) was filtered through a pre-weighted GF/C filter paper using a plastic filter setup connected to a vacuum pump. Filtrate was used to analyse dissolved heavy metals in water after preserving with concentrated nitric acid while filter paper was used to analyse TSS.

The third portion (C) was collected into a glass bottle and preserved with concentrated sulfuric acid to determine nutrient levels, and oil and grease levels.

The fourth portion (D) was collected into a sterilised glass bottle which was used to determine pesticide residues and fecal coliform level. All the collected and preserved water samples, as schematically mentioned in Figure 2.8.2, were stored under 4 °C until transferred to the laboratory.

A metal sieving device coupled with a water pump (Figure 2.8.3) was specifically prepared to collect MP according to their size. Sieves used in this device were completely made of stainless steel to reduce the potential contamination of MP from the sampling devices. Sieves containing MP were covered with aluminium foil papers and stored in 4 °C until transfer for further analysis.

Sediment samples were obtained using an Ekman grab sampler, and the samples were stored in polythene zip lock bags until transferred to the laboratory for heavy metal and pesticide analyses. The sediment samples for MP analysis were grabbed from near shorelines and fish landing sites, and they were stored in glass jars. All the sediment samples were stored in 4 °C until further analysis.

Fish and GFP samples were collected from fishers and stored in a freezer at -20 °C until further analysis.

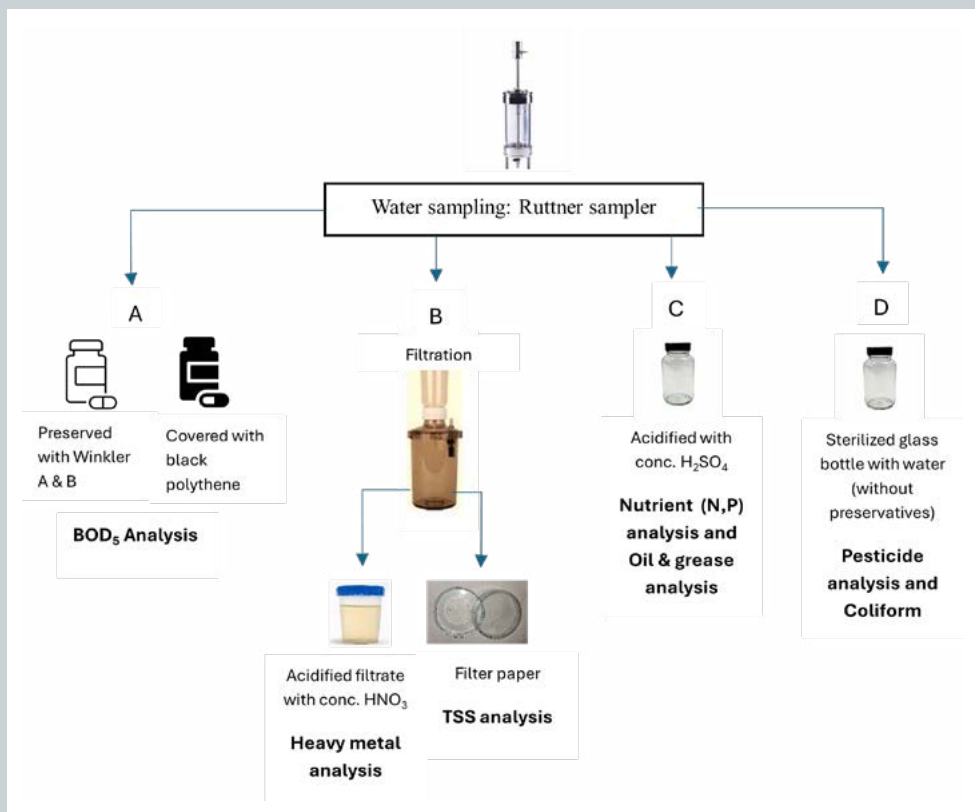


Figure 2.8.2: Schematic diagram of water sampling, and sub-sampling and preservation techniques used in the field



Figure 2.8.3: Sieving device used to sample water for microplastic analysis

Priority toxic pollutant analysis

Physicochemical properties such as temperature, DO and pH were measured on site using a portable water quality meter (HANNA®). Water samples were further analysed for BOD₅, TSS, nutrients, oil and grease, and fecal coliform to evaluate the criteria water pollutants.

Iodometric test (Azide modification) was followed to determine BOD₅ in reservoir water (Baird et al. 2017). TSS was determined on site by using a portable spectrophotometer (Hach® DR1900) and the obtained values were confirmed following the gravimetric method (Baird et al. 2017).

TP and TN levels were determined using colorimetric methods as described by Gross and Boyd (1998) and Baird et al. (2017). Acidified water samples with concentrated sulfuric acid (H₂SO₄) were digested using potassium persulfate (K₂S₂O₈). TP was determined via the ascorbic acid method, while TN was quantified using the sodium salicylate method. Absorbance measurements were taken using a portable spectrophotometer (Hach® DR1900).

Oil and grease levels were analysed by following the liquid-liquid partition gravimetric method using N-hexane extraction (Baird et al. 2017). Fecal coliform was determined using the multiple tube fermentation technique with Most Probable Number (MPN) statistical method (Baird et al. 2017).

Pesticide analysis

The water samples were pipetted into sample bottles without adding any preservation chemicals and kept under 4 °C until further analysis using High Performance Liquid Chromatography (HPLC). The sediment samples were prepared for HPLC analysis according to a

modified method adapted to our specific conditions by referring to Badawi et al. (2016) and Bollmann and Badawi (2020). Samples were air-dried on paper over several weeks and then sieved through a 0.5 mm sieve. A 500 g sample was weighed before and after drying at 105 °C until a constant mass was achieved, typically over 5–8 hours. The dried sample was stored in a desiccator, cooled to room temperature and reweighed to calculate water content. The samples were then ground using mortar and pestle, and approximately 2 g of the ground material was weighed into 50 mL centrifuge tubes. Subsequently, 10 mL of 0.01 M CaCl₂ solution (using either bi-distilled or distilled water) and 10 µL of internal pesticide standard were added. The mixture was briefly shaken and placed in an overhead shaker at high speed for 24 hours, followed by 20 minutes in an ultrasonic bath filled with water. The samples were then centrifuged at 4,600 RPM for 90 minutes, after which the clear supernatant was pipetted into a sample bottle, and the sediment tube was either discarded or washed. Sample bottles with extracted solutions were kept under 4 °C until further analysis using HPLC.

The dissected tissue samples were homogenised thoroughly for uniformity, and an appropriate amount of sample was weighed into clean centrifuge tubes. Acetonitrile, buffered with salts provided in the test kits (BEKOlut® QuEChERS kit), was added as the extraction solvent. The mixture was shaken vigorously and centrifuged to separate the organic phase containing the analytes. Dispersive solid-phase extraction was performed using pre-filled tubes with sorbents tailored for clean-up, followed by further shaking and centrifugation to remove unwanted co-extractives. The tissue digestion process was conducted according to a modified



method based on specific requirements for our research (*BEKOLut*® *QuEChERS KITS: Instructions for Use* n.d.; Souza et al. 2016). The cleaned extract was transferred to vials for analysis using LC-MS/MS technique (Agilent 6495b) which was equipped with a reverse-phase C-18 column (Phenomenex Synergi 4 µm Hydro-RP 80 Å, LC Column 150 × 3 mm).

Heavy metal analysis

All the water samples were filtered through GF/C filter papers and acidified on site, and they were transferred into polypropylene plastic containers for the determination of dissolved portions of heavy metals in water. Samples were stored under 4 °C until further analysis by Atomic Absorption Spectroscopy (AAS) (Baird et al. 2017).

All the sediment samples were defrosted and spread over pre-cleaned petri dishes for 24 hours to let them air dry in a clean laboratory environment. Air dried samples were ground using a ceramic mortar and pestle. Ground samples were sieved through a 1 mm strainer and subject to acid digestion. Digestion procedure was carried out according to the EPA 3050B method using nitric acid and hydrogen peroxide (US EPA 1996). Final extractions were filtered through GF/C filter papers and diluted up to 50 mL in volumetric flasks.

The fish samples were defrosted, and excess water was swabbed by clean, dry blotting papers. Sample preparation and digestion procedures were carried out following to a modified method (Mohammed et al. 2017). Dissected tissues were dispersed on petri dishes separately. They were kept in an oven at 80 °C for 24 hours. Oven dried samples, after letting them cool to room temperature, were crushed using a pre-cleaned ceramic mortar and pestle. Crushed samples were put into pre-cleaned polythene bags until

acid digestion to avoid contamination. Acid digestion for lead was conducted according to the wet digestion method using conc. HNO₃ acid. DOLT 2 reference was used as the certified reference material (CRM) for tissue analysis and exactly similar digestion procedure was followed to digest the reference. All the digested solutions were stored in polypropylene plastic containers and stored in a refrigerator until metal analysis was conducted using the direct flame method in fast sequential atomic absorption spectrometer (SpctraAA 220©/ VARIAN®).

Microplastics analysis

Water sampling and digestion procedures were carried out by referring to Prata et al. (2019) and Razeghi et al. (2022) with slight modifications. Reservoir water was pumped and filtered using the prepared filter device (Figure 2.8.4) onsite. The filter device was composed of a series of stainless steel filters arranged in descending order of pore size. From top to bottom, the filters consisted with pore sizes of 3 mm, 1 mm, 500 µm, 100 µm and 30 µm, respectively. This configuration ensures a sequential filtration process, effectively capturing particles of varying sizes at each stage.

After the filtration process, the stainless steel filters were backwashed using distilled water, and the washed water was passed through a GF/C filter paper to collect MPs on it. In cases where the turbidity of the reservoir was high, the stainless steel filters were backwashed using a sodium chloride solution and the resulting washed water was collected in a sediment microplastic isolation unit (SMI unit) (Figure 2.8.4). After allowing the samples to settle for 24 hours, the floating particles were separated by filtering them onto a GF/C filter paper. This step ensured that any remaining suspended particles were effectively removed from the sample.

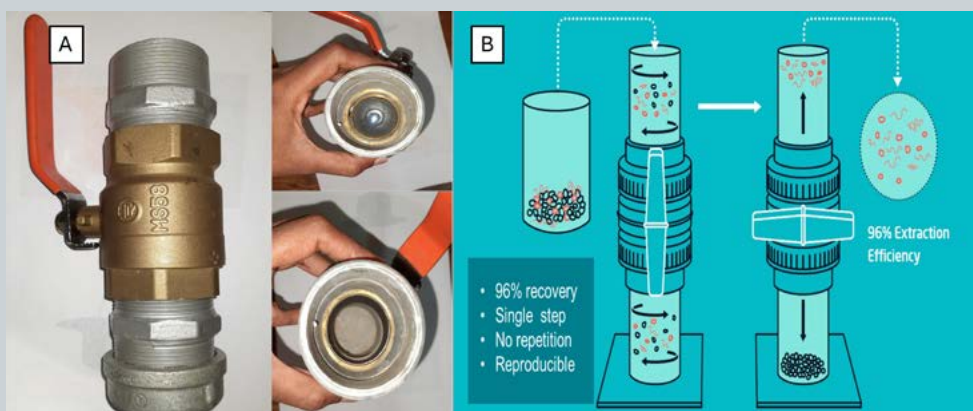


Figure 2.8.4: Sediment microplastic isolation unit; (A) newly prepared device and (B) schematic diagram from Cole n.d.

Sediment samples were subject to pre-treatment and extraction processes prior to isolating MP from sediments after a clear review of literature (Lakchani et al. 2025; Prata et al. 2019; Razeghi et al. 2022; Schrank et al. 2022). Each sediment sample was homogenised, and a known weight was stirred with sodium chloride in a beaker followed by ultrasonication for 10–20 minutes at room temperature. The resulting solution was transferred into the SMI unit for density-dependent separation as described above.

Isolated MPs on GF/C filters were stained by Nile red dye and observed under a dissecting microscope coupled with fluorescence light. This ensured the easy quantification of MP particles into different morphological categories such as fibre, fragments, foams and films.

Data analysis

The dataset obtained was systematically processed and analysed using Microsoft® Office Excel 365 version and IBM® SPSS Statistics 25 software allowing for a

comprehensive examination of trends, correlations and key findings relevant to the study objectives. Graphical presentations were used to visualise the distribution of data within 7 reservoirs throughout the one-year sampling period. Pollutant distribution across 7 reservoirs was compared using one-way ANOVA tests. The one-sample t-test was used to determine whether the pollutant levels in reservoirs are within the standard permissible levels. The assessment of water quality in the reservoirs was conducted in accordance with the Maximum Permissible Levels (MPL) outlined in the National Environmental (Ambient Water Quality) Regulations, No. 01 of 2019.

Results

Criteria water pollutants

The concentration levels of criteria water pollutants across 7 selected dry zone reservoirs are represented in Figure 2.8.5, highlighting differences in contamination severity throughout the one-year period from March 2023 to January 2024.

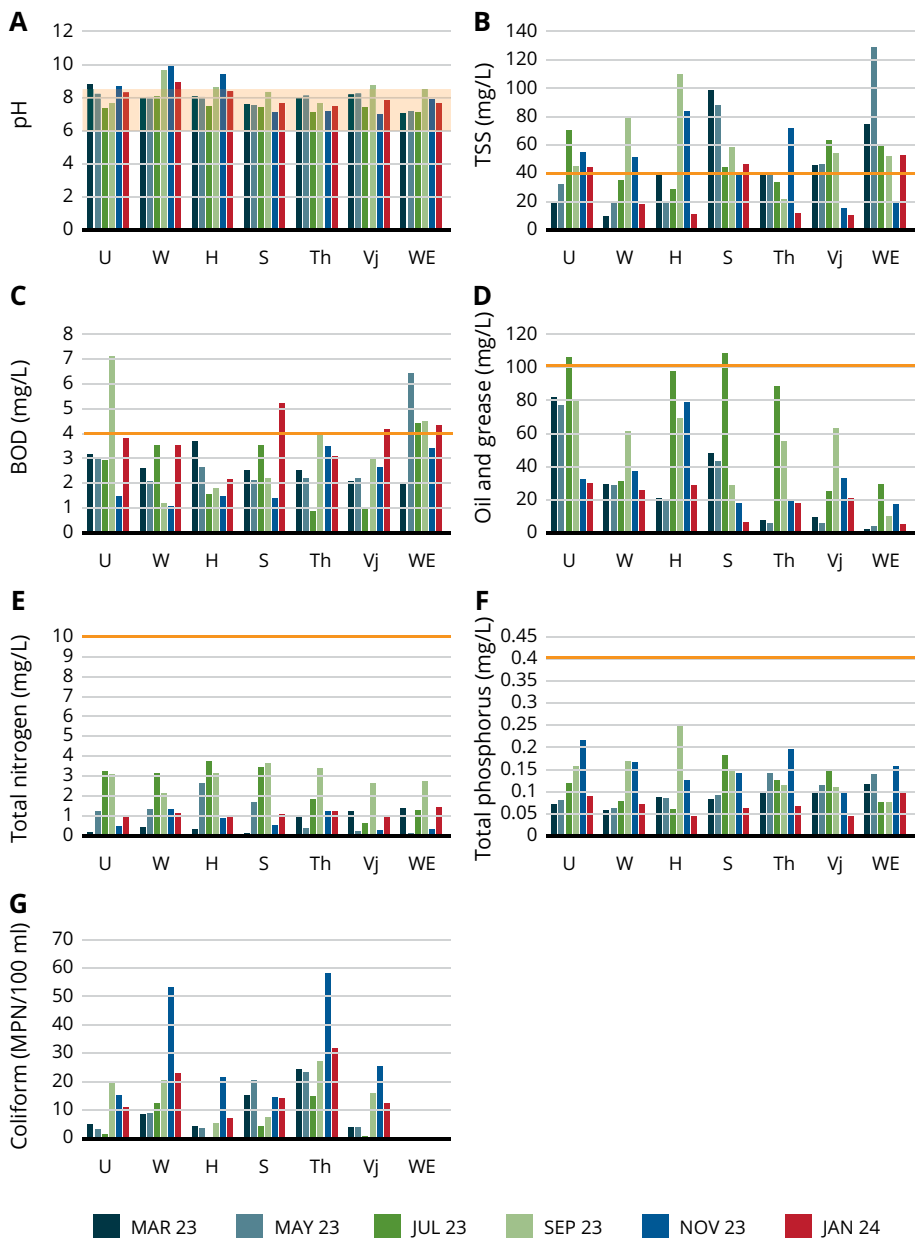


Figure 2.8.5: Graphical presentation of criteria water pollutants

Notes: (A) pH, (B) TSS, (C) BOD, (D) Oil and grease, (E) TN, (F) TP and (G) Fecal coliform, distribution within 7 reservoirs (U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela). Maximum permissible levels are indicated by an orange line for each parameter.

The distribution of pH (Graph A) within the reservoirs exhibits a statistically significant variation ($p < 0.05$). The highest mean pH was observed in Weerawila reservoir (8.75 ± 0.83), indicating relatively alkaline conditions, whereas the lowest mean pH was indicated in Wan Ela (7.51 ± 0.54). When assessing the MPL of pH for aquatic life (6.0–8.5), Weerawila reservoir and Handapanagala reservoir exhibited statistically similar values ($p > 0.05$) when compared to the established test value of 8.5. However, both reservoirs recorded pH values exceeding the standard range, indicating potential alkalinity concerns.

The TSS distribution within reservoirs (Graph B) reveals a statistically significant variation ($p < 0.05$). Among the reservoirs examined, Wan Ela exhibited the highest mean TSS concentration (67.67 ± 36.73 mg/L), indicating elevated particulate matter levels, while Weerawila recorded the lowest mean TSS (33.65 ± 26.75 mg/L), suggesting relatively clearer water conditions. The evaluation of TSS against the MPL for aquatic life (40 mg/L) revealed higher significant deviations in Siyambalangamuwa reservoir and Wan Ela, both exhibiting statistically significant variations ($p < 0.05$) from the established standard. In contrast, the remaining reservoirs recorded considerably lower TSS values, indicating relatively stable sediment concentrations within permissible limits.

The BOD distribution within the reservoirs (Graph C) indicates no statistically significant variation ($p > 0.05$) across the different water bodies. Among them, Wan Ela exhibited the highest mean BOD value (4.08 ± 3.81 mg/L), suggesting relatively higher organic matter presence and potential microbial activity, while Handapanagala recorded the lowest mean BOD concentration (2.31 ± 1.37 mg/L),

indicating comparatively lower organic pollution levels. The evaluation of BOD in Urusita and Wan Ela reservoirs against the MPL reveals no statistically significant difference ($p > 0.05$) from the established standard (4 mg/L). However, both reservoirs exhibit BOD values exceeding the permissible limit, suggesting elevated organic matter decomposition and microbial activity.

The analysis of oil and grease distribution across reservoirs, as depicted in Graph D, reveals a statistically significant variation ($p < 0.05$), indicating remarkable differences in contamination levels among water bodies. Urusita Wewa recorded the highest mean oil and grease concentration (66.75 ± 38.87 mg/L), suggesting greater pollutant input or retention in this reservoir, potentially due to anthropogenic activities, industrial run-off or hydrodynamic conditions. Conversely, Wan Ela exhibited the lowest mean concentration (9.91 ± 11.48 mg/L), indicating lower contamination levels in comparison to other reservoirs.

The nitrogen distribution within the reservoirs (Graph E) reveals no statistically significant variation ($p > 0.05$) among the different water bodies. Handapanagala reservoir recorded the highest mean nitrogen concentration (1.930 ± 1.66 mg/L), suggesting increased nitrogen inputs, potentially from agricultural run-off or organic matter decomposition. In contrast, Vijayakatupotha reservoir exhibited the lowest mean nitrogen value (1.002 ± 0.84 mg/L), indicating comparatively lower nitrogen pollution levels. Nitrogen concentrations against the MPL reveals a statistically significant variation ($p < 0.05$) from the established test value (10 mg/L). This indicates notable differences in lower nitrogen levels across the reservoirs.



The analysis of phosphorus distribution within the reservoirs (Graph F) indicates statistically significant variation ($p < 0.05$) across the different water bodies. Thabbowa reservoir recorded the highest mean phosphorus concentration (0.122 ± 0.06 mg/L), suggesting elevated phosphorus inputs, potentially from agricultural run-off or other external sources. In contrast, Weerawila reservoir exhibited the lowest mean phosphorus value (0.089 ± 0.06 mg/L), indicating comparatively lower phosphorus pollution levels. Phosphorus concentrations in all the 7 reservoirs revealed a statistically significant difference ($p < 0.05$) from the established standard (0.4 mg/L). This suggests notable lower concentrations of phosphorus levels from the MPL, indicating no present phosphorus pollution in reservoirs.

The distribution of fecal coliform within the reservoirs (Graph G) exhibits a statistically significant difference ($p < 0.05$). Among the reservoirs analysed, Thabbowa recorded the highest fecal coliform levels (28.81 ± 24.30 MPN/100 mL), indicating potential contamination sources, whereas Wan Ela showed no detectable coliform presence throughout the sampling period. Notably, no MPL has been established for fecal coliform concentrations in water designated for aquatic life under the National Environmental (Ambient Water Quality) Regulations, No. 01 of 2019.

Pesticides

The distribution of selected pesticides across the 7 reservoirs reveals distinct variation patterns as shown in Figure 2.8.6. Among the 10 selected pesticides, 5 (MCPA, Azadirachtin A, Emamectin Benzoate, Thiamethoxam and Fipronil) were detected in water samples, while the remaining 5 (Chlorpyrifos, Diazinon, Etofenprox,

Fenoxaprop-P-Ethyl and Profenofos) were not present. Azadirachtin A and Emamectin Benzoate exhibit statistically similar distributions ($p > 0.05$), indicating relatively uniform presence across all reservoirs. However, due to a technical error, peaks of Azadirachtin were found to be incorrectly identified by the HPLC machine; therefore, those detections are not reliable. Though Azadirachtin values are shown in result graphs, it will not be considered for discussion in this report.

In contrast, Fipronil, Thiamethoxam and MCPA show significant differences ($p < 0.05$) among reservoirs, suggesting potential localised contamination sources or differential environmental transport mechanisms. The analysis identified MCPA as the most highly contaminated pesticide, with an average concentration of 0.075 ± 0.017 μ g/L in the reservoir water. The statistical analysis confirms ($p < 0.05$) that pesticide concentrations in water remain within the standard permissible limits (5 μ g/L) established by the World Health Organization (WHO) and FAO, as regulated by the Central Environmental Authority (CEA) of Sri Lanka under the National Environmental (Protection and Quality) Regulations, No. 1 of 2008.

In sediment samples, only 2 pesticides (MCPA and Emamectin Benzoate) were identified, indicating selective retention within the sediment matrix. The analysis of pesticide concentrations in sediment samples (Figure 2.8.7) indicates statistically similar distribution across all reservoirs, with no significant variation ($p > 0.05$). This uniformity suggests that sediment-bound pesticides are relatively stable across different water bodies, likely influenced by consistent environmental factors such as sediment composition, deposition rates and limited external contamination sources.

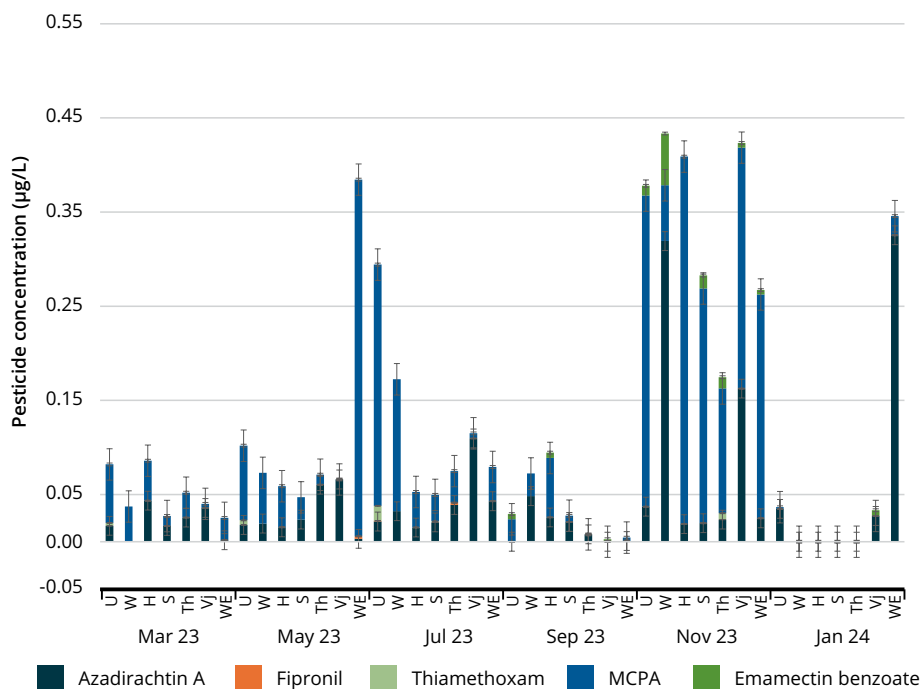


Figure 2.8.6: Temporal variation of pesticide distribution in reservoir water over a one-year sampling period

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

Pesticide residue analyses in fish tissue samples are still being carried out; therefore, the results are not included in this report.

Heavy metals

This study is still ongoing, and by the time of drafting this manuscript, only the lead (Pb) analysis was complete. The distribution of lead across reservoir water and sediment reveals distinct spatial patterns. In water samples, lead concentrations exhibit a statistically significant variation ($p < 0.05$) among reservoirs, suggesting differences in contamination sources, hydrodynamic factors or water chemistry influencing its

mobility. In contrast, lead distribution in sediment is statistically similar ($p > 0.05$) across all reservoirs, indicating consistent sediment deposition and retention processes.

The lead concentrations in reservoir water (Figure 2.8.8) reveal notable variations among locations. The highest recorded concentration was observed in the Urusita reservoir, with an average of 0.012 ± 0.005 mg/L, suggesting potential localised contamination sources or differing hydrodynamic conditions. In contrast, the lowest concentration was detected in the Vijayakatupotha reservoir, averaging

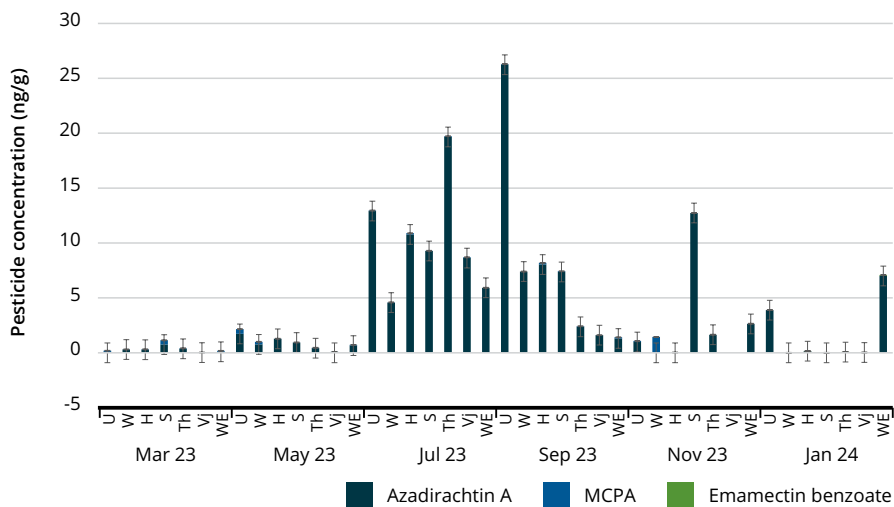


Figure 2.8.7: Temporal variation of pesticide distribution in reservoir sediment over a one-year sampling period

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

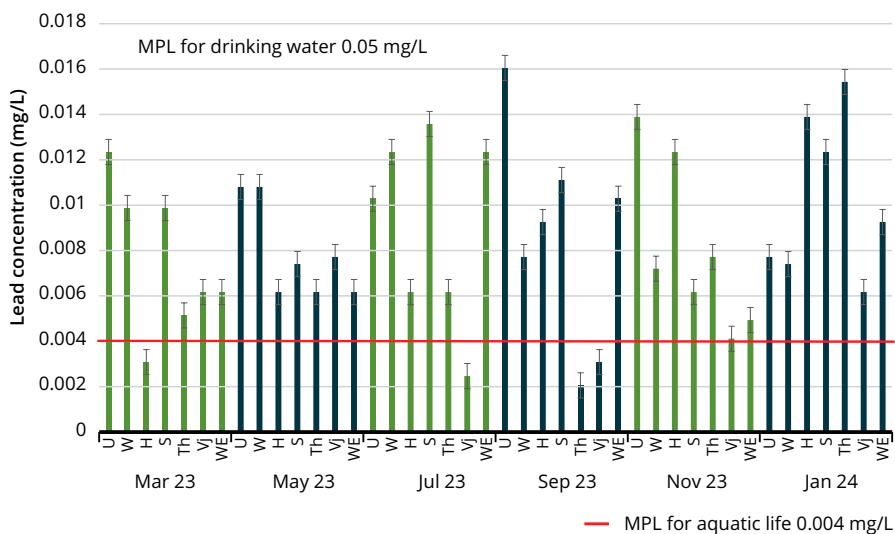


Figure 2.8.8: Temporal variation of lead (Pb) concentration in reservoir water over a one-year period

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

0.005±0.005 mg/L, indicating a relatively lower impact of lead contamination on this site. The analysis of lead concentrations in reservoir water, compared against established MPLs, indicates notable variations in suitability for aquatic life and drinking water. The National Environmental (Ambient Water Quality) Regulations, No. 01 of 2019, suggests an MPL of 0.004 mg/L for aquatic life, while the 0.05 mg/L as the limit for drinking water after simple treatment. Only Vijayakatupotha reservoir meets the MPL standard for aquatic life ($p>0.05$), implying minimal risk for aquatic organisms. All the reservoirs are suitable for drinking water consumption after simple treatment, as their lead concentrations fall within the MPL guideline (0.05 mg/L).

The lead concentrations in reservoir sediment (Figure 2.8.9) revealed Vijayakatupotha as the site with the highest recorded average lead levels (15.081±11.32 mg/L), indicating possible localised contamination sources or sediment retention mechanisms. In contrast, Tabbowa exhibited the lowest average lead concentration (8.742±7.04 mg/L), suggesting reduced lead deposition or external influence in that area. The Pb concentrations in sediment reveals that the recorded levels fall below the range (35.8 mg/kg – 128 mg/kg; dry weight) suggested by Sediment Quality Guidelines (SQGs) as US EPA (2006); Recommended Guidelines for Evaluating Contaminant Concentrations in Freshwater Sediments and the Potential for Those Contaminants to Adversely Affect Aquatic Biota (2016). This indicates that lead contamination in sediment does not exceed the thresholds typically associated with significant ecological risks. Correlation analysis between lead concentrations in reservoir water and sediment showed no statistically significant association.

The lead analysis for tissue samples was conducted by comparing fish muscle tissues and GFP muscle and exoskeleton tissues to assess differences in metal accumulation patterns between fish and GFP (muscle and exoskeleton) (Figure 2.8.10). Pb levels in fish tissue samples indicate significant variation among samples from different reservoirs ($p<0.05$). Accumulation of lead into GFP muscles and exoskeleton indicates a similar distribution ($p>0.05$) among the samples from reservoirs. According to the world heavy metals regulations, the maximum permissible limit for lead in fishery products is 0.2 mg/kg of fresh weight, and for crustaceans, an increased limit of 0.4 mg/kg is considered (FAO 2003). Lead accumulation in fish and GFP muscle tissues indicates that levels remain within permissible limits for 6 reservoirs out of 7, ensuring compliance with established safety standards. However, Wan Ela exceeds these thresholds, suggesting potential contamination risks. Lead accumulation in exoskeleton tissues from all reservoirs is significantly higher than muscle tissues, suggesting that consuming these parts may pose health risks due to potential heavy metal toxicity.

Microplastics

MP contamination was detected in both water and sediment samples across all surveyed locations, with varying concentrations observed among sites. MP concentrations in sediment were generally higher than in water, suggesting a tendency for accumulation and deposition over time. Statistical analysis revealed significant variation in MP abundance, with certain sites exhibiting markedly higher concentrations, possibly due to anthropogenic influence. Figure 2.8.11 illustrates the particle size distribution of microplastics across reservoir water, revealing a high concentration within

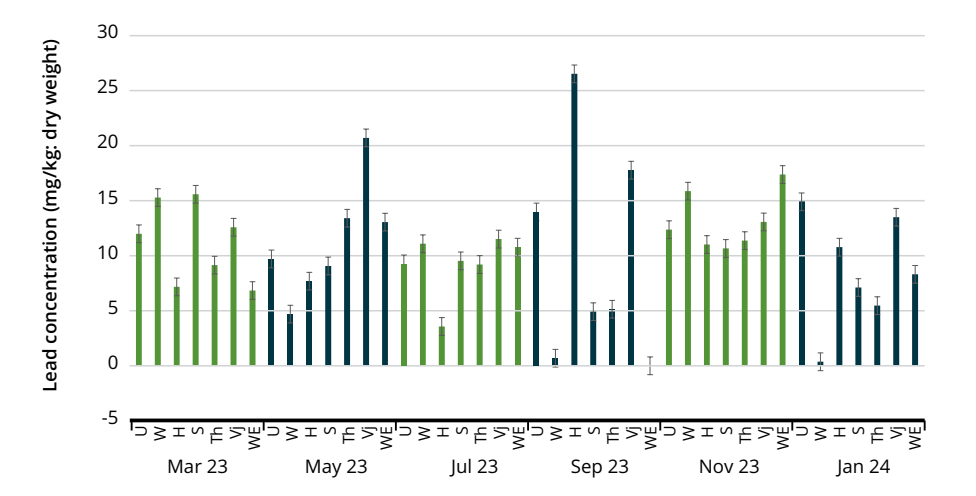


Figure 2.8.9: Temporal variation of lead (Pb) concentration in reservoir sediment over a one-year sampling period

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

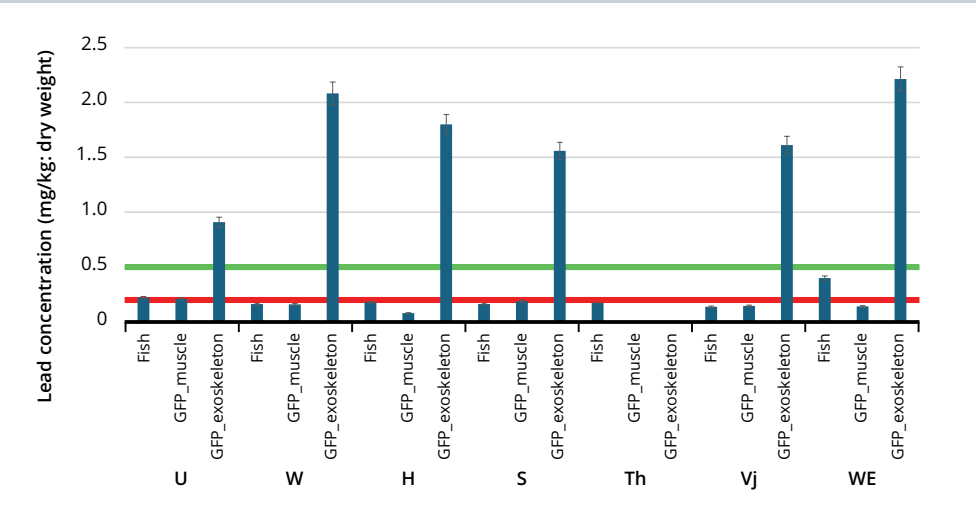


Figure 2.8.10: A comparative graphical representation lead (Pb) accumulation in fish and prawn tissues: muscle versus exoskeleton distribution

Note: Red line: mean total lead content for fish_0.2 mg/kg, green line: mean of total lead content for crustaceans_0.5 mg/kg; U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

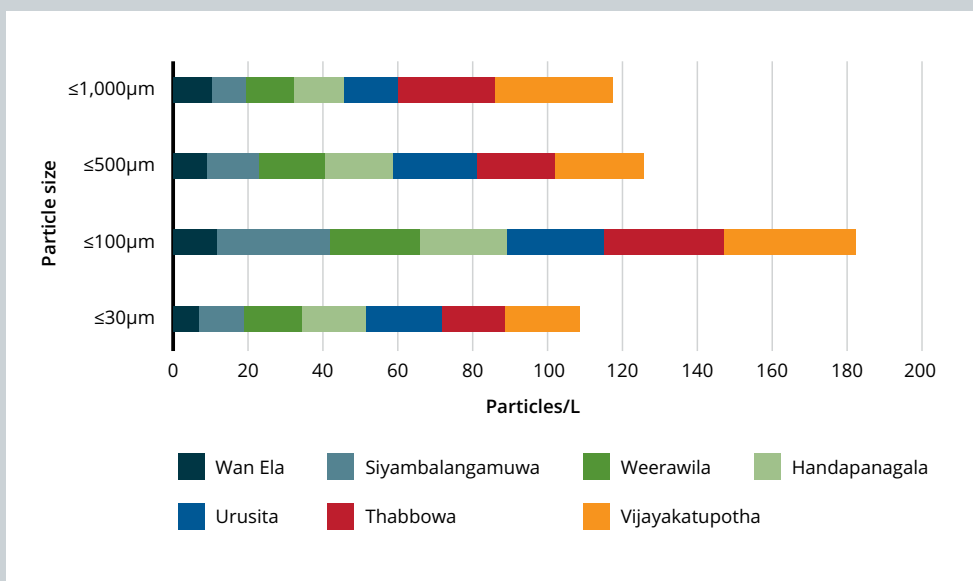


Figure 2.8.11: Microplastic size distribution across reservoirs selected for the study

the 100–30 µm size range. The MP concentration was observed in particles below 30 µm, indicating a lesser abundance of extremely fine microplastic fragments in reservoir samples.

As shown in Figure 2.8.12, fragments are the most abundant MP shape accumulating within reservoirs, indicating a prevalence of plastic degradation and fragmentation processes in these aquatic environments. Additionally, Vijayakatupotha reservoir exhibits a high concentration of MP in water, suggesting potential anthropogenic influence, surface run-off or direct plastic pollution sources contributing to elevated MP levels. Statistical analysis confirms that MP size distribution and particle shape distribution in water differ significantly across reservoirs ($p < 0.05$), highlighting site-specific contamination patterns. Figure 2.8.13 represents the particle size distribution of MP in reservoir sediment, showing a high concentration within the

100–30 µm size range, whereas the lowest MP portion is observed below 30 µm.

Figure 2.8.14 illustrates that fragments are the most prevalent MP shape accumulating within reservoir sediments, highlighting the dominance of plastic degradation and fragmentation processes in these environments. Furthermore, Vijayakatupotha reservoir displays a notably high concentration of MP in sediment. MP size distribution and MP particle shape distribution in sediment exhibit significant variations across reservoirs ($p < 0.05$), suggesting that environmental factors, pollution sources and sediment retention dynamics influence MP accumulation uniquely at each location.

There is a strong positive correlation between MP accumulation in water and sediment, suggesting that MP contamination is closely linked across these matrices, regardless of the particle

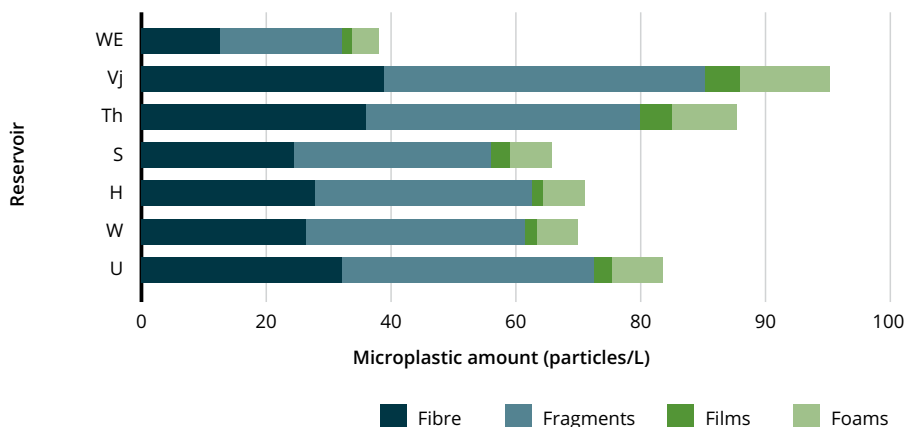


Figure 2.8.12: Shapes of microplastic distribution across the 7 reservoirs

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

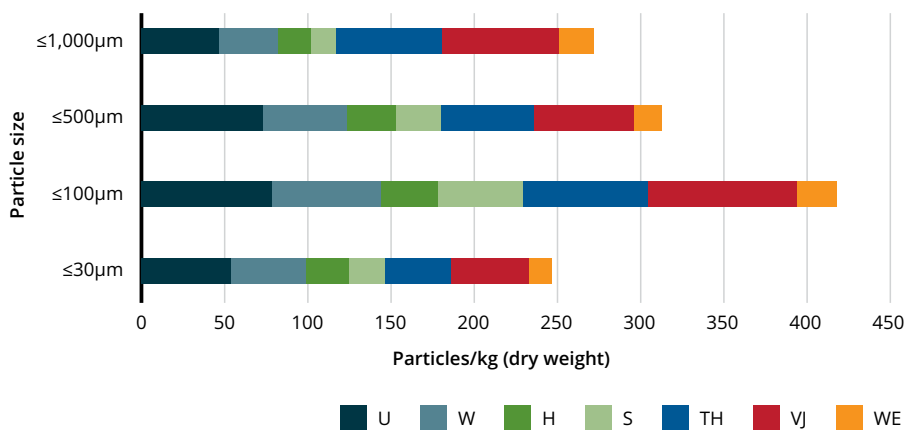


Figure 2.8.13: Microplastic size distribution across sediments from reservoirs selected for the study

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

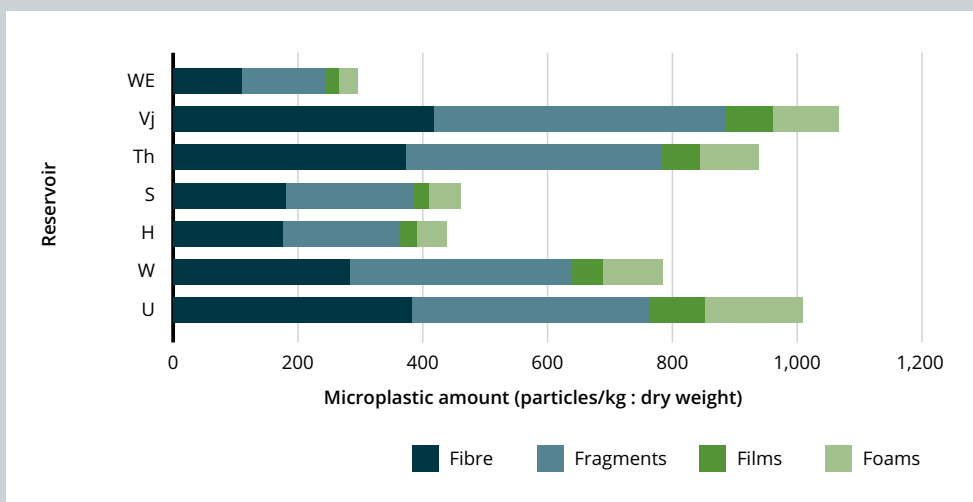


Figure 2.8.14: Shapes of microplastic distribution across the sediments from 7 reservoirs

Note: U:Urusita, W:Weerawila, H:Handapanagala, S:Siyambalangamuwa, Th:Tabbowa, Vj:Vijayakatupotha and WE:Wan ela.

size (Pearson correlation: 0.916) or shape (Pearson correlation: 0.932). This relationship implies that waterborne MP eventually settle into sediment, contributing to long-term environmental deposition and potential ecological impacts. In the analysis, MP sizes and shapes (Figure 2.8.15) were identified as morphometric characteristics, allowing for classification based on their physical dimensions and structural forms.

Discussion

Sri Lanka's dry zone reservoirs play a crucial role in water storage, irrigation and inland fisheries, but they are increasingly affected by various pollutants. Understanding the impact of conventional water pollutants, heavy metals, pesticides and MPs is essential for ensuring sustainable fisheries and ecosystem health.

The pH distribution across reservoirs reveals significant variations suggesting distinct water chemistry conditions influenced by environmental and anthropogenic factors such as geological variations, water source and anthropogenic activities affecting each reservoir. Elevated pH levels can influence nutrient availability, aquatic species composition and metabolic functions, potentially affecting ecosystem stability (Muniz 1990; Nolan 2024). The pH levels in Weerawila and Handapanagala reservoirs surpass the ideal threshold for sustaining aquatic organisms, indicating alkaline conditions that may impact ecosystem stability. Some species, like tilapia (*O. mossambicus*), exhibit greater tolerance to pH fluctuations, making them more suitable for such reservoirs (Russell et al. 2012).

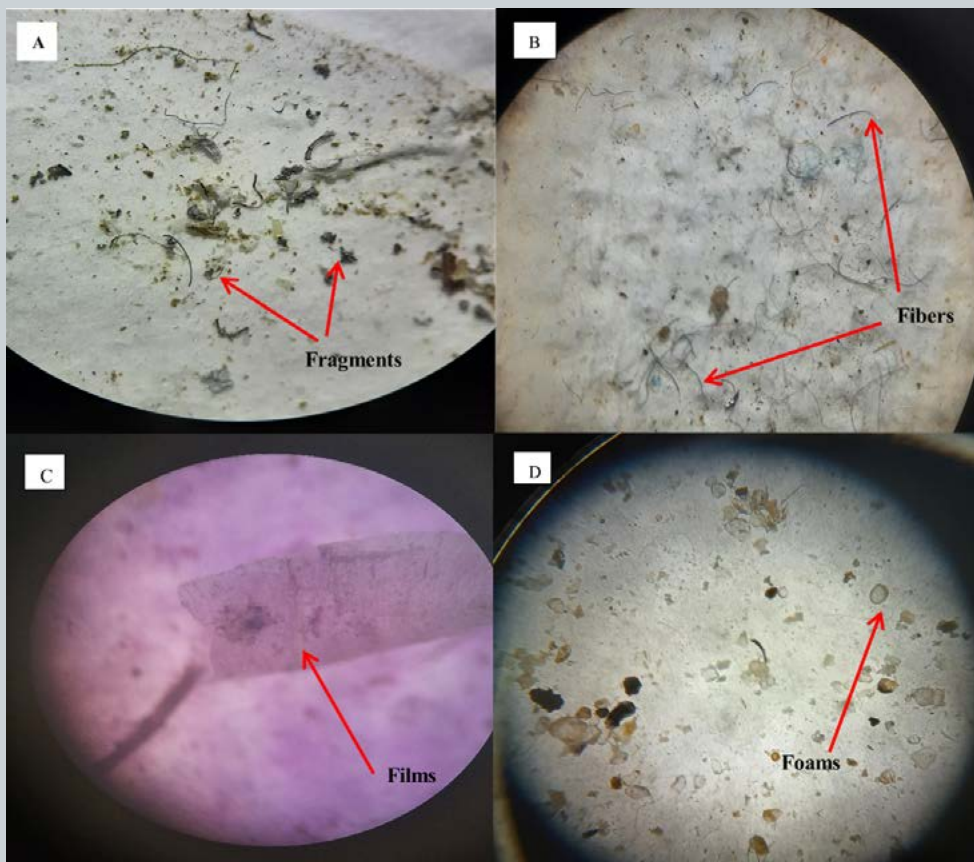


Figure 2.8.15: Dissection microscope images showing different microplastic shapes

Note: (A) Fragments under $\times 4$ (B) Fibres under $\times 4$ (C) Films under $\times 10$ (D) Foams under $\times 4$.

TSS in dry zone reservoirs play an important role in shaping aquatic ecosystems and fisheries productivity. Fluctuating water levels and sediment dynamics within these reservoirs due to seasonal rainfall patterns support TSS level variations in reservoirs impacting fish populations, water quality and overall reservoir ecology. Reservoirs with high TSS concentrations, such as Wan Ela, tend to have reduced light penetration, affecting primary productivity (Buana et al. 2021) and fish feeding behaviour (Kjelland et al.

2015). Conversely, reservoirs with lower TSS levels, like Weerawila, provide clearer water conditions, potentially benefiting visual predators (Turesson and Brönmark 2007) and enhancing fish growth rates (Bunnell et al. 2021; Engström-Öst and Mattila 2008). In reservoirs like Siyambalangamuwa and Wan Ela, when TSS levels exceed the MPL for aquatic life (40 mg/L), fish populations may experience stress due to reduced oxygen levels and clogged gills (Cavanagh et al. 2014; Montoya 2024).

BOD serves as a key indicator of organic pollution and microbial activity, influencing fish productivity and overall reservoir health. Reservoirs with higher BOD levels, such as Wan Ela, indicate increased organic matter decomposition, leading to oxygen depletion. Oxygen scarcity can stress fish populations, particularly species which require well-oxygenated waters for survival and growth. Elevated BOD values suggest heightened microbial activity, which can accelerate nutrient cycling but also contribute to eutrophication and excessive microbial decomposition (Aziz et al. 2024; Svobodová et al. 1993) that may lead to algal blooms, reducing DO levels and negatively impacting fish health.

The presence of oil and grease pollutants in certain reservoirs suggests a higher pollutant retention, potentially affecting aquatic ecosystems and fish productivity. Oil and grease pollutants can coat fish gills, impairing oxygen absorption and leading to stress or mortality (Svobodová et al. 1993). Therefore, Urusita Wewa, with the highest mean oil and grease concentration, may experience reduced oxygen levels, affecting fish respiration and overall health. But the reservoirs' water flow and mixing patterns may help disperse oil pollutants, preventing excessive accumulation in critical fish habitats. Despite oil contamination, nutrient cycling may still support plankton growth, ensuring a stable food supply for fish populations. If organic matter decomposition is well balanced, fish productivity may remain unaffected (Aziz et al. 2024) as Urusita wewa has relatively high BOD concentration levels.

Moderate nitrogen and phosphorus levels support plankton growth, ensuring a stable food source for fish populations. But excessive nutrient loading can lead to eutrophication, causing algal blooms which may deplete oxygen levels and

stress fish. Therein nutrient levels in a reservoir are playing a major role in shaping aquatic ecosystems and inland fisheries productivity. Handapanagala reservoir exhibited the highest concentration of nitrogen, maybe due to agricultural run-off and organic matter decomposition, while Vijayakatupotha recorded the lowest. Despite these variations, nitrogen levels remain well below the MPL of 10 mg/L, suggesting no excessive nitrogen pollution. In contrast, Thabbowa reservoir recorded the highest mean phosphorus concentration, likely due to external nutrient inputs, while Weerawila reservoir showed the lowest. However, all reservoirs maintain phosphorus levels below the MPL of 0.4 mg/L, indicating no excessive phosphorus pollution. Balanced nutrient concentrations contribute to healthy aquatic ecosystems, promoting optimal fish growth and reproduction.

The presence of fecal coliform in selected dry zone reservoirs exhibits a statistically significant variation, with Thabbowa reservoir showing the highest contamination levels, likely due to anthropogenic activities such as untreated sewage discharge or agricultural run-off, while Wan Ela recorded no detectable coliform presence throughout the study. The presence of fecal coliform in reservoirs could impact inland fisheries by introducing pathogens that may threaten fish health, alter microbial activity and potentially reduce oxygen levels due to increased organic matter decomposition (Wu et al. 2021). The absence of significant fecal contamination in certain reservoirs suggests varied pollution sources and differences in watershed management practices. Although fecal coliform contamination poses potential risks to water quality and aquatic health, no MPL has been established for fecal coliform in water designated for aquatic life by national



regulations, highlighting a regulatory gap in microbial water quality assessment for aquaculture applications. This underscores the need for additional monitoring and evaluation to ensure optimal water conditions for sustaining aquatic ecosystems.

The presence of pesticide residues in reservoirs highlights the influence of agricultural run-off, chemical persistence and environmental transport mechanisms on water quality and fisheries sustainability (Mitra et al. 2024; Rashad et al. 2025). The study reveals differential contamination patterns across water, sediment and biological tissue, with MCPA, Emamectin Benzoate, Thiamethoxam and Fipronil detected in water samples, while Chlorpyrifos, Diazinon, Etofenprox, Fenoxaprop-p-ethyl, and Profenofos were absent. Emamectin Benzoate exhibit uniform distribution within reservoir water, while Fipronil, Thiamethoxam and MCPA show localised contamination, indicating site-specific pollution sources. However, MCPA, identified as the most highly contaminated pesticide, remains steady within permissible limits (5 µg/L), ensuring regulated environmental exposure.

In sediment samples, MCPA and Emamectin Benzoate were selectively retained, indicating chemical persistence within the sediment matrix. The presence of these detected pesticides suggests potential contamination sources, primarily linked to agricultural run-off and pesticide application practices in the surrounding catchment areas. Factors such as hydrophobicity (K_{ow} : n-Octanol/Water Partition Coefficient values), sediment composition and pesticide application sources may influence their distribution across these matrices (Mitra et al. 2024; Nendza et al. 2025).

The analysis of fish tissue samples revealed no detectable pesticide residues, suggesting limited bioaccumulation within the examined aquatic organisms, minimising concerns for human consumption. Out of the 5 detected pesticides, 2 have relatively high log K_{ow} values (Fipronil: 3.75, Emamectin benzoate: 5.0) (University of Hertfordshire n.d.) but low concentrations in water and sediment. In contrast, highly observed pesticides in both matrices have low log K_{ow} values (Thiamethoxam: -0.13 and MCPA: -0.81) indicating a higher affinity for the aqueous phase rather than accumulation in biological tissues (University of Hertfordshire n.d.). These findings highlight the potential mobility and persistence of such pesticides in the aquatic environment while minimising direct incorporation into the food chain.

The study reveals considerable variations in lead concentrations across water, sediment and biological tissues, with Urusita reservoir recording the highest lead levels in water while Vijayakatupotha reservoir exhibited the lowest. Only Vijayakatupotha reservoir exceeds the MPL for aquatic life (0.004 mg/L), implying minimal risk for aquatic organisms, whereas all reservoirs remain suitable for drinking water consumption after simple treatment (0.05 mg/L) according to National Environmental (Ambient Water Quality) Regulations, No. 01 of 2019. Elevated lead levels in Wan Ela reservoir exceeding the MPL (0.2 mg/kg for fish, 0.4 mg/kg for crustaceans) for fishery products based on heavy metal regulations legal notice No 666/2003 (FAO 2003), suggest bioaccumulation risks, potentially affecting fish metabolism and reproduction. Lead accumulation in GFP exoskeleton tissues is significantly high, suggesting that consuming these parts may pose

health risks such as neurological disorders, cardiovascular diseases, kidney dysfunction and reproductive complications, due to heavy metal toxicity (Collin et al. 2022). The negative correlation between lead concentrations in GFP muscle and exoskeleton tissues suggests differential metal retention mechanisms.

The presence of MPs, with fragments being the most abundant form, indicates plastic degradation and fragmentation processes. The 100–30 µm size range dominates both water and sediment samples, while larger particles and smallest particles are less abundant. This trend suggests that fragmentation processes primarily break plastics down into mid-sized particles, while smaller MPs may be more susceptible to further degradation or dispersion, making them harder to detect (Sutkar et al. 2023). High MP concentrations in Vijayakatupotha reservoir suggest anthropogenic influence, surface run-off or direct plastic pollution sources, potentially affecting fish respiration and digestion. MP can be ingested by fish, leading to digestive blockages, reduced nutrient absorption and potential toxic exposure (Jo et al. 2025; Yin et al. 2021). The strong positive correlation between MP accumulation in water and sediment indicates that waterborne MPs eventually settle into sediment, contributing to long-term environmental deposition. This MP retention in sediment may alter benthic habitats, affecting bottom-dwelling organisms and food chain stability (Silva et al. 2022). Their persistence highlights the need for effective pollution management strategies to reduce plastic waste and minimise contamination in reservoirs. The standardised guidelines for MP contamination are still evolving, with no globally accepted levels for their presence in water bodies, sediments or aquatic organisms. While regulatory bodies

such as the WHO, FAO and the United Nations Environment Programme (UNEP) have highlighted the risks associated with MP pollution (Gamarro and Costanzo 2022; Lusher et al. 2017; Marsden et al. 2019; Zehel 2023), specific threshold limits for MP concentrations in aquatic environments and seafood have yet to be established.

Conclusion

This study highlights the complex interactions between conventional pollutants, heavy metals, pesticides and MPs, demonstrating site-specific contamination patterns that influence water quality and fishery sustainability. While most reservoirs maintain water parameters within permissible limits, concerns such as MP accumulation, lead retention and fecal coliform presence emphasise the need for enhanced monitoring and pollution management strategies. The variability in pH, nutrient levels and suspended solids further underscores the dynamic nature of these ecosystems, necessitating adaptive reservoir management approaches. To ensure long-term sustainability, efforts must focus on strengthening regulatory frameworks, implementing wastewater treatment measures and promoting community-driven conservation initiatives. Addressing pollutant retention mechanisms, bioaccumulation risks and hydrodynamic influences will help optimise water quality management and support resilient fish populations. By integrating scientific research with policy interventions, Sri Lanka can foster sustainable inland fisheries while preserving the ecological integrity of its dry zone reservoirs. Continued environmental assessments and stakeholder engagement will be pivotal in mitigating contamination risks and safeguarding aquatic ecosystems for future generations.

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2.9 Post-harvest quality loss in giant freshwater prawns: effects of storage conditions and duration

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Abstract

The GFP (*M. rosenbergii*) is a commercially valuable species in Sri Lanka; however, post-harvest quality deterioration presents a significant challenge. This study aimed to assess post-harvest losses, identify critical control points and evaluate storage methods to enhance the quality of GFP products. A structured questionnaire survey was conducted among 286 stakeholders in the GFP market chain, supplemented by focus group discussions and verification of export data. Freshly harvested GFP samples were subjected to various storage conditions: chilled (ice storage), frozen at -20 °C, and blast-frozen at -35 °C for 21 days, with periodic assessments of colour, texture and sensory attributes. Instrumental analyses included CIELAB colour measurements, total colour change (ΔE), texture profiling, and sensory evaluation by trained panelists. Results indicated substantial post-harvest losses, with an average of 31.9% lost before reaching the exporter, primarily due to physical damage. Additionally, predation and soft-shell occurrences at the fisher level contributed to both harvest and quality losses. Colour, texture and sensory assessments demonstrated that ice storage effectively preserved GFP quality for up to 9 days, outperforming frozen GFP, which exhibited significant deterioration before this period. In contrast, both freezing and blast-freezing initially induced rapid colour changes that later stabilised, with no significant differences between these 2 methods. Texture parameters varied among storage conditions, with both freezing and blast-freezing effectively maintaining sensory attributes over prolonged storage. However, while blast-freezing preserved product quality for an extended period, it did not retain the original organoleptic characteristics as effectively as ice storage during the initial 9 days. Based on these findings, ice storage is recommended for short-term market distribution, whereas blast-freezing remains the preferred method for long-term storage, particularly for the export market.

Keywords: *storing duration, ice, freeze, blast-freeze, texture parameters, instrumental measurements, export market*

Introduction

Fisheries and aquaculture sectors are increasingly recognised for their vital role in global food and nutrition security in the 21st century (FAO 2022). In 2020, global fisheries and aquaculture production reached 214 mt, with 122.6 mt valued at USD281.5 billion, derived primarily from aquaculture. Global inland aquaculture production accounts for 44.4% of total aquaculture production, totalling 54.4 mt. The major aquaculture commodities that account for nearly 99% of inland aquaculture production include Indian and Chinese carp, tilapia, catfish, shrimp, crawfish, crabs and prawns (FAO 2022). The GFP, *M. rosenbergii*, plays a significant role in the growth of global freshwater prawn production, contributing up to 2.6% of total aquaculture crustacean production in 2020 (FAO 2022). In Sri Lanka, GFP production, an indigenous species, is primarily obtained through CBF in reservoirs of the dry zone. The introduction of GFP to inland reservoirs has increased rural income, enhancing the overall economic and social wellbeing of rural fisher communities engaged in CBF in Sri Lanka (Jones et al. 2021; Amarasinghe et al. 2022; Digamadulla et al. 2023). Among the commodities utilised in CBF in Sri Lanka, GFP offers immense export potential and significant market value, making it essential to boost production while maintaining quality and safety standards to meet consumer expectations and achieve global competitiveness.

The quality of GFP is assessed through various parameters, including colour, texture and sensory characteristics, which are essential attributes that significantly influence consumer preferences and product valuation (Ottestad et al. 2011; Chéret et al. 2007). The quality of GFP products directly affects consumer

preferences and acceptability, with freshness, texture and appearance being key factors that consumers consider when purchasing aquatic foods (Verbeke and Vackier 2005). Therefore, preserving original qualities throughout the supply chain ensures consumer satisfaction and marketability. As a highly valued product in international markets, the demand for GFP hinges on its ability to meet consumer expectations for quality. This research evaluates the post-harvest quality of GFP in Sri Lanka, focusing on changes in physical parameters (colour and texture) and sensory evaluation. It aims to propose solutions for improving quality by optimising storage conditions and duration. Understanding the factors that influence post-harvest losses and implementing best practices can enhance marketability and economic returns. The findings will contribute to the sustainable development of Sri Lanka's CBF, ensuring food security and economic benefits for stakeholders in the supply chain.

Materials and methods

Post-harvest quality loss through market chain

A questionnaire was developed to identify stakeholders in the GFP market chain and gather insights into harvesting and post-harvest practices. Interviews were conducted with fishers, collectors, factory agents, exporters and aquaculture extension officers using a snowball sampling technique (Biernacki and Waldorf 1981; Deepananda et al. 2015; Naderifar et al. 2017). A total of 286 questionnaires were administered across 7 stakeholder groups. The collected data focused on GFP collection, grading, icing, packing, storage, pricing and transportation. Additional information was gathered through focus group discussions and key informant

interviews. Export data was obtained from Sri Lanka Customs, and the accuracy of the data was verified through further assessments when discrepancies arose.

Fresh GFP was collected from the Ridiyagama reservoir in Sri Lanka (440±38 g), immersed in a chilling water bath at 5 °C for 30 minutes, and then transported in Styrofoam containers with flake ice to the laboratory within one hour. After washing with cold distilled water, the samples were processed by dividing them into 3 groups:

1. chilled in Styrofoam boxes with a 1:1 GFP-to-ice ratio
2. directly frozen at -20 °C
3. blast-frozen at -35 °C for 4 hours before being stored at -20 °C.

Storage was maintained for 21 days, and analyses were conducted at regular intervals. Frozen samples were thawed at 4±0.5 °C prior to assessment.

Instrumental analysis

Colour measurements were conducted at the midline of the carapace, across all 6 abdominal segments, the telson, and the flesh of the second abdominal segment of GFP stored under different conditions on days 0, 3, 6, 9, 12, 15, 18 and 21. A chromometer (Model CR-400, HunterLab, Miniscan XE Plus, Osaka, Japan) was used to assess colour based on the CIE colour space, measuring L* (lightness), a* (red/green chromaticity) and b* (yellow/blue chromaticity).

Total colour change (ΔE) was calculated as:

$$\Delta E = \sqrt{((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)} \text{ (Wright 1971)}$$

Texture measurements followed the method established by Sigurgisladottir et al. (1999). Fresh GFP from 3 experimental groups was analysed before storage (day 0) and reassessed on days

3, 6, 9, 12, 15, 18 and 21 under various storage conditions. The second abdominal segment was chosen for texture profile analysis, which involved 2 compression cycles using a TA.XT Plus texture analyser (Brookfield, UK) with a TA3/100 probe. Hardness, springiness, chewiness and cohesiveness were evaluated in 10 replicates and analysed using Texture Expert software (version 1.22, Stable Micro Systems, UK).

Sensory evaluation

A trained panel of 10 individuals (5 males and 5 females, aged 23–26) was employed to conduct sensory assessments of GFP quality. Panelists were selected based on health criteria, ensuring that they had no sensory impairments. Evaluations were performed separately for raw and cooked GFP samples stored under different conditions. Initially, raw samples were assessed for colour, appearance, texture and odour and then cooked at 175 °C for 15 minutes with 1% salt, after which they were evaluated for odour, flavour and texture. Panelists rinsed their mouths with water and refreshed their sense of smell with coffee between samples.

The Modified Quality Index Method (QIM), based on the approaches of Khodanazary (2019) and Begum et al. (2011), was employed to evaluate quality by assigning demerit scores ranging from 0 (indicating the best quality) to 3 for raw samples or 5 for cooked samples, depending on the observed changes. Sensory tests were carried out in individual evaluation booths.

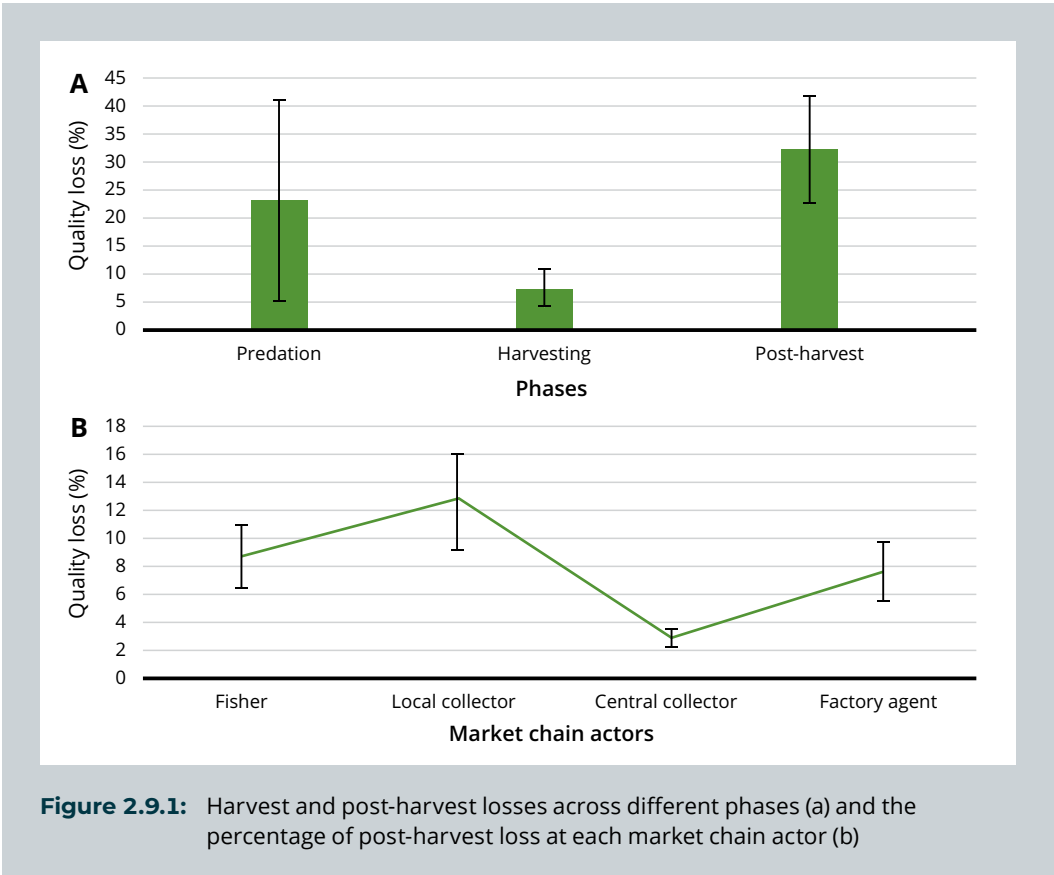
Results

Post-harvest quality loss

The export-oriented GFP market chain consists of 4 major actors, spanning from the producer (fisher) to the consumer: local collector, central collector, factory agent

and exporter. One significant source of loss occurs at the fisher level, where an average of 22.9% of the total harvest was lost due to predation while GFP remained entangled in gillnets. Key predators include eels, tortoises and spiny eels (*Mastacembelus armatus*). Then, from the rest of the harvest, an average of 7.1% consists of soft-shelled GFP, which are categorised as low-quality at the fisher level. Physical damage, particularly head detachment (head loose) and appendage breakage, was a major contributor to the loss of GFP quality, resulting in post-harvest losses across the market chain. These physical quality attributes are critical factors in determining the suitability of GFP for export. Along the market chain, notable post-harvest losses

occur at various stages, with an average total loss of 31.9% by the time the harvest reaches the exporter. These post-harvest losses are distributed among different actors in the market chain. Fishers account for 8.7% of the total loss, while local collectors are responsible for the highest proportion at 12.7%, and central collectors contribute the lowest at 2.9%. As a result of these cumulative post-harvest losses, only 61.1% of the total GFP harvested from reservoirs is classified as good quality and deemed suitable for export. The distribution of GFP harvest and associated post-harvest losses across different phases (a) and the proportional contribution of each market actor to the total post-harvest loss (b) is presented in Figure 2.9.1.



Instrumental analysis (colour, texture)

The external shell and flesh color of GFP act as primary indicators of its quality, which is closely linked to freshness. The CIELAB colour parameters (L^* , a^* and b^* values) measured across different body segments (carapace, abdominal segments 1–6 and tail) exhibited significant variations ($p < 0.05$). The carapace demonstrated the highest positive a^* (reddish) and b^* (yellowish) values. In contrast, the abdominal segments displayed considerably lower a^* and b^* values compared to the carapace, revealing near-zero or negative a^* values, indicating a shift from reddish to greenish tones. Lower b^* values also suggested a trend toward bluish tones. The L^* values, representing lightness, progressively decreased along the abdominal segments and tail, indicating a reduction in brightness, with the lowest CIELAB values documented at the tail (L^* : 22.96; a^* : -0.17; b^* : 4.3). In terms of colour visualisation, a distinct contrast was observed between the carapace and the rest of the body, while minimal colour

variation was noted among the abdominal segments and tail. Lab* colour changes across different body segments of GFP (i) and the corresponding visual colour representation based on Lab* values (ii) are shown in Figure 2.9.2.

The colour difference (ΔE) between the outer shell and flesh of GFP stored in ice was relatively lower compared to that of frozen GFP during the initial storage period. However, ΔE in ice-stored GFP increased rapidly, with noticeable changes in the outer shell and flesh after days 12 and 6, respectively. In contrast, the total colour change ΔE in the outer shell and flesh of freeze-stored and blast-freeze GFP did not show a significant difference ($p > 0.05$). Nevertheless, a significant difference was observed between frozen and ice-stored GFP in terms of outer shell and flesh colour changes. The outer shell and flesh of frozen GFP exhibited a rapid increase in ΔE within the first 3 days of storage, followed by a decline and stabilisation after day 9. The total colour change (ΔE) in the outer shell

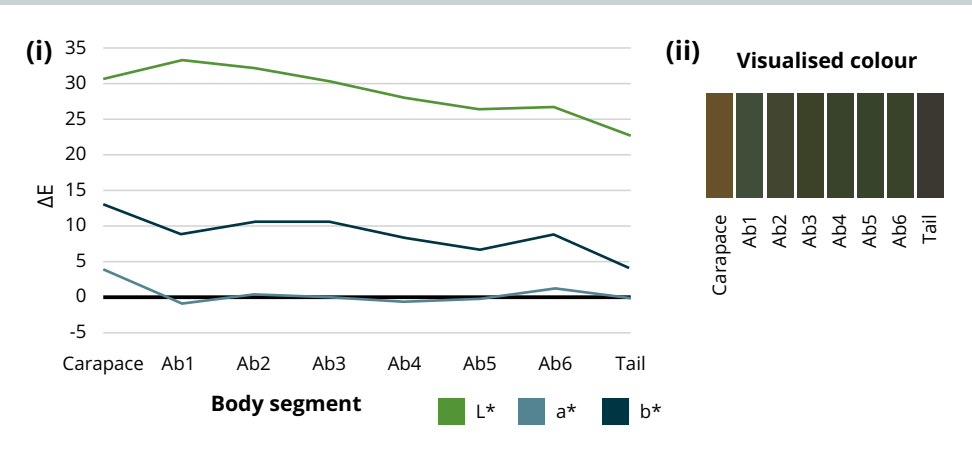


Figure 2.9.2: Lab* colour changes across different body segments of GFP (i) and corresponding visualised colour representation based on Lab* values (ii)

of the GFP body segments (carapace and abdomen) and the flesh of the second abdominal segment over the storage period under ice and frozen conditions is shown in Figure 2.9.3.

Texture

Throughout the storage period, the hardness, springiness, cohesiveness and chewiness of fresh GFP underwent significant changes, differing based on the storage conditions. During iced storage, the texture parameters remained relatively stable for the first 6 days, followed by a sharp decline over the next 15 days. In frozen storage, however, a rapid decrease was observed within the initial 6 days, after which the rate of decline stabilised for the remainder of the storage period. In both freezing methods, these texture parameters declined sharply during the early storage days, followed by a slower rate of change. In contrast, GFP

stored under chilled conditions exhibited a continuous decline throughout the storage period. Notably, frozen samples experienced the most significant texture alterations during the early storage phase, whereas ice-stored GFP exhibited pronounced changes in the later stages. Among the storage methods, blast-frozen GFP showed the least variation in texture parameters, while ice-stored GFP exhibited the most substantial deterioration by the end of storage. The changes in instrumental texture parameters of GFP muscles over the storage time and conditions are presented in Table 2.9.1.

Sensory evaluation of GFP stored under ice, freezing and blast-freezing conditions revealed significant differences ($p<0.05$) in odour, texture, colour and flavour across the various storage methods and durations. Ice-stored raw GFP experienced progressive deterioration, with the fresh

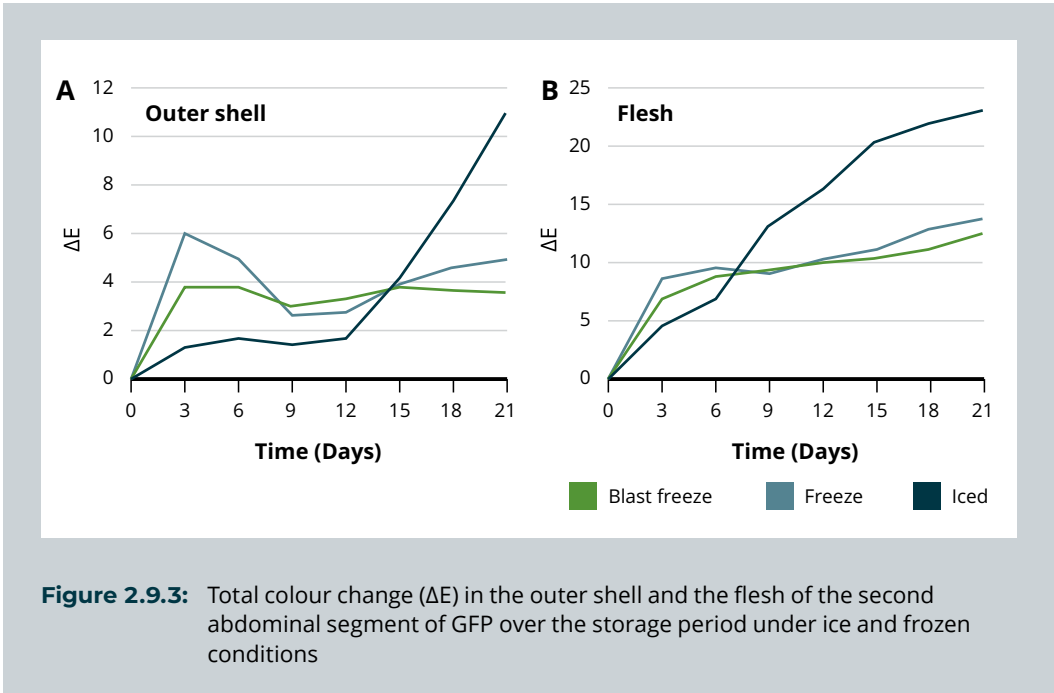


Table 2.9.1: The changes in instrumental texture parameters of GFP muscles over the storing time and condition

Textural parameters	Storing condition	Storage duration (days)									
		0	3	6	9	12	15	18	21		
Hardness (g)	Ice	99.02±3.68	93.12±4.23	86.14±3.22	77.48±3.81	66.55±2.03	53.19±1.98	38.87±3.67	21.71±3.2		
	Freeze	99.02±3.68	88.30±3.77	85.32±1.58	78.65±1.65	73.42±2.40	69.34±2.33	66.36±4.38	61.81±4.3		
	Blast-freeze	99.02±3.68	93.04±4.56	89.64±2.98	86.51±2.67	80.94±4.11	79.11±2.76	78.27±5.90	76.33±3.9		
Springiness (mm)	Ice	0.98±0.01	0.94±0.03	0.87±0.07	0.78±0.01	0.64±0.03	0.50±0.07	0.39±0.06	0.24±0.03		
	Freeze	0.98±0.01	0.82±0.02	0.74±0.03	0.69±0.05	0.64±0.06	0.63±0.04	0.61±0.05	0.57±0.06		
	Blast-freeze	0.98±0.01	0.92±0.04	0.89±0.02	0.86±0.07	0.84±0.03	0.83±0.01	0.81±0.04	0.80±0.09		
Cohesiveness	Ice	0.70±0.01	0.66±0.04	0.62±0.01	0.55±0.03	0.48±0.01	0.40±0.03	0.32±0.01	0.25±0.03		
	Freeze	0.70±0.01	0.67±0.06	0.62±0.02	0.59±0.02	0.54±0.02	0.51±0.02	0.49±0.02	0.47±0.02		
	Blast-freeze	0.70±0.01	0.68±0.02	0.64±0.02	0.62±0.03	0.62±0.01	0.59±0.03	0.58±0.04	0.57±0.03		
Chewiness (g)	Ice	67.91±2.70	57.08±3.10	46.39±1.54	33.03±2.65	20.27±1.99	10.6±2.61	4.74±1.44	1.26±2.13		
	Freeze	67.91±2.70	48.35±2.44	44.99±2.08	39.75±2.56	38.23±3.01	32.17±1.40	30.73±2.10	29.34±2.56		
	Blast-freeze	67.91±2.70	58.18±1.54	57.69±1.97	52.79±2.12	49.14±2.43	49.34±1.80	48.82±2.91	46.46±3.20		

odour transitioning to neutral by day 3, weak ammonia by day 12, and putrid by day 18. In contrast, freeze- and blast-freeze GFP maintained a neutral odour throughout the storage period. Texture changes were also pronounced in ice-stored samples, which softened progressively from slightly firm and elastic by day 3 to soft and watery by day 15. Frozen samples stabilised after initial softening, while blast-frozen samples retained their firm, chewy texture. Additionally, the colour of ice-stored GFP dulled over time, with the flesh turning yellowish, whereas frozen and blast-frozen samples maintained a stable lime hue. The head-abdomen attachment weakened significantly in ice-stored GFP after 12 days, while frozen samples showed moderate detachment, and blast-frozen samples maintained a firm attachment. The sensory attributes of cooked GFP underwent noticeable changes during the storage period, depending on the preservation method used. In ice-stored samples, the initial 'milky sweet' flavour progressively deteriorated into a sour, bitter taste by day 21. In contrast, frozen samples retained a slightly sweet, greasy flavour, whereas blast-frozen GFP preserved its original 'milky sweet', creamy and meaty taste throughout the storage period. The odour of cooked GFP also evolved; fresh samples initially exhibited a milky, boiled milk or mushroom-like odour by day 3, which gradually changed to a boiled vegetable odour by day 12, a musty odour by day 15, and an ammoniacal odour by day 18. Both frozen and blast-frozen samples maintained a milky, boiled milk or mushroom-like odour throughout the entire storage period. Texture analysis revealed further quality changes as well; the initially firm and chewy texture of cooked GFP softened over time, becoming very soft and pulpy by day 15 in ice-stored samples. Frozen samples developed a lumpy texture

from day 6 onward, while blast-frozen samples consistently maintained their firm and chewy texture throughout the storage period. The sensory evaluation of raw and cooked GFP stored under ice, freeze and blast-freeze conditions over a 21-day storage period is summarised in Table 2.9.2.

Discussion

The key actors in the export-oriented GFP market chain play a crucial role in determining product quality and minimising post-harvest losses. These essential players in this market chain hold pivotal positions, with the number of intermediaries varying based on harvesting quantities, reservoir-to-trader distances and transportation availability. Understanding these distinct market channels provides valuable insights into the GFP flow from fishers to consumers, helping to reduce post-harvest losses, enhance competitiveness and optimise marketing systems.

Predation during the harvesting phase significantly contributes to losses because the high abundance of predatory species in Sri Lankan reservoirs poses a considerable threat to GFP harvests. This issue is exacerbated by the practice of setting fishing nets overnight, which increases both post-harvest quality loss and predatory pressure. Implementing innovative strategies to mitigate predation is essential for reducing harvesting losses. Additionally, GFP undergoes periodic molting, shedding its exoskeleton and leaving soft-shelled prawns vulnerable to damage. Soft-shelled GFP is often rejected in export markets, leading to economic losses throughout the supply chain.

Harvest losses occur in fisheries worldwide, affecting every stage from production to consumption. Post-harvest losses can be classified into several key types, including

Table 2.9.2: Sensory evaluation of raw and cooked GFP stored under ice, freeze and blast-freeze storage conditions over the 21 days

GFP product	Sensory modality	Storage method																	
		Ice									Freeze								
		Storing duration (days)									Storing duration (days)								
		0	3	6	9	12	15	18	21	0	3	6	9	12	15	18	21		
Raw GFP	Colour	Carapace	0	1	1	3	3	3	3	0	2	2	2	2	2	2	2	2	
		Abdomen	0	1	1	2	3	3	3	0	2	2	2	2	2	2	2	2	
		Tail	0	1	1	2	2	3	3	0	2	2	2	2	2	2	2	2	
		Flesh	0	1	1	2	2	3	3	0	1	1	1	1	1	1	1	1	
	Appearance	0	1	1	1	2	2	3	3	0	0	1	1	1	1	1	1	1	
Cooked GFP	Texture	0	1	1	2	3	4	4	4	0	1	1	1	2	2	2	2	2	
	Odour	0	1	1	1	2	2	3	3	0	1	1	1	1	1	1	1	1	
	Total Score	0	7	7	13	17	19	22	22	0	9	10	10	11	11	11	11	11	
Total Score	Odour	0	1	1	1	2	3	4	4	0	1	1	1	1	1	1	1	1	
	Flavour	0	1	1	2	3	4	4	5	0	1	2	2	2	2	2	2	2	
	Texture	0	0	1	2	2	3	3	3	0	0	1	1	1	1	1	1	1	
	Total Score	0	2	3	5	7	10	11	12	0	2	4	4	4	4	4	4	4	

Note: Raw GFP: Colour (outer): 0- Fresh, bright, shining greenish blue, 1- Slightly loss of brightness, 2- Loss of brightness, 3- Dull in colour, Colour(flesh): 0- Translucent and shiny, 1- Lime colour, 2- Slightly yellowish, Light yellow, Appearance: 0- Shape intact & head firmly attached to the abdomen, 1- Shape intact & head slightly loose from the abdomen, 2- Flesh loosely attached to the shell & head loosely attached to the abdomen, 3- Flesh loosely attached to the shell & head very loosely attached to the abdomen, Texture: 0- Hard & elastic, 1- Slightly hard & elastic texture, 2- Slightly soft & slightly elastic texture, 3- Moderately soft & loss of elastic texture, 4- Soft and watery texture, Odour: 0- Fresh, 1- Neutral, 2- Weak ammonia, 3- Putrid.

Cooked GFP: Odour: 0- Fresh, 1- Milky/Boiled milk /mushroom shed, 2- Boiled vegetables, 3- Musty, 4- Ammonical, Flavour: 0- Milky sweet, 1- Milky sweet, creamy meaty, 2- Slightly sweet, sweet greasy/fatty aftertaste, 3- Slightly sour & very slight sweetness, 4- Sour/bland/ fishy, 5- Soapy, bitter, Texture: 0- Firm, chewy, 1- Lumpy, breaking into firm segments easily, 2- Lumpy, but the segments are softer than the above, 3- Very soft/ pulpy.

physical loss, quality deterioration, nutritional decline and losses driven by market forces (Cheke and Ward 1998). These losses occur throughout the GFP market chain, with physical damage to appendages often resulting from improper handling, storage and transportation practices. The issue of 'head looseness' significantly affects export quality, while mishandling prawns during gillnet retrieval further contributes to quality degradation. In the studied reservoirs, most fishers deliver live GFP to landing sites and allow them to die while waiting for collectors, which further deteriorates quality. The 'chill-killing' method, which involves submerging live prawns in an ice-water slurry, is recommended to enhance product quality (D'Abramo et al. 2009). However, its adoption remains limited due to fishers' reluctance to exert additional effort beyond harvesting.

Contrary to the global trend, which indicates that the highest losses occur at the producer level (Acharjee et al. 2021), local collectors are identified as hotspots of post-harvest losses, primarily due to prolonged storage without sufficient ice, improper packing and suboptimal transportation techniques. These collectors, often fishers or nearby villagers, lack access to adequate ice supplies and depend on buyers for ice delivery, which is often insufficient. In some instances, GFP is stored in freezers instead of ice, further accelerating quality deterioration. In contrast, central collectors experience the least quality loss due to improved handling practices, while factory agents encounter unexpected quality losses, despite better packing and grading, which may be attributed to mechanical damage during transportation and unloading. This issue may stem from factory agents receiving fixed salaries with additional

commissions, which can lead to a lack of motivation to maintain product quality. Enhancing transportation infrastructure and road systems can significantly reduce post-harvest losses, as extended transport times from rural reservoirs to central collectors negatively impact quality. Raising awareness among market-chain actors about proper handling and quality maintenance directly decreases post-harvest loss, highlighting the need to close the knowledge gap across all stages of the market chain.

The colour of fish is primarily influenced by the protein-water binding properties and pigments present in the skin or surface of the flesh (Xie et al. 2023). In prawns, colour changes have been linked to lipid oxidation, which leads to the degradation of the carotenoid pigment astaxanthin (Cruz-Romero et al. 2007). Lab* values serve as indicators of colour, protein-water binding capacity, pigments in the outer shell or meat surface, lipid oxidation rates, and variations in astaxanthin content across different GFP body segments. These factors may contribute individually or collectively to the notable differences in Lab* values observed among GFP segments. Additionally, the shifts in a* values in GFP segments could be linked to reactions between phenol oxidase and deoxy phenylalanine, which trigger melanin production (Savagaon and Sreenivasan 1978).

The colour of food plays a crucial role in shaping consumers' perceptions of quality, significantly influencing their purchasing decisions (Sun et al. 2019). In prawns, colour changes are key indicators of quality deterioration, driven by enzymatic and bacterial activities during storage that lead to discolouration as well as various biological and physicochemical alterations (Yu et al. 2018). Research by Tsironi et al.



(2009) and Jin et al. (2018) has shown that colour degradation occurs more rapidly at higher freezing temperatures. Similarly, the present study found that fresh colour degradation in GFP was more noticeable and pronounced during frozen storage compared to ice storage, particularly in the initial storage period. The initial low bacterial count may be attributed to the inability of mesophilic bacteria present in fresh prawns to survive prolonged exposure to low temperatures, as noted by Rodrigues et al. (2000). However, after a lag phase in the GFP body and flesh, psychrophilic bacteria that were initially present are likely to multiply, contributing to the rapid changes in ΔE values observed during the later stages of ice storage. In contrast, frozen storage resulted in more rapid colour changes early on, potentially due to physical and biochemical alterations caused by sudden exposure to freezing temperatures and temporary freeze burns. Over time, these colour changes appeared to stabilise, possibly due to the disruption of various molecular bonds in native protein structures during freezing and frozen storage, as protein denaturation tends to occur more prominently at the onset of the freezing process. This structural alteration may weaken the connection between the outer shell and the prawn's meat, leading to visible colour differences compared to fresh GFP. Lower storage temperatures may slow the deterioration of quality, maintaining more stable colour changes over the 21-day storage period. The hepatopancreas, a central metabolic organ and primary lipid storage site (Liu et al. 2021), likely contributes to the faster quality degradation observed in the carapace region due to its higher nutrient content compared to the abdomen and tail. Furthermore, variations in nutrient availability and pigment concentrations across different body segments may

influence the rate of colour changes. Although the factors affecting colour change might initially impact all body segments, differing rates of degradation over time could be attributed to a combination of external environmental conditions and internal physiological factors.

Texture is a key quality parameter for assessing the flesh of prawns and fish in aquaculture industries (Bjørnevik et al. 2002). In the present study, the texture parameters of GFP remained relatively stable during the first 6 days of ice storage, after which a noticeable decline was observed. This pattern aligns with findings by Jain et al. (2007), who reported significant texture loss in fish muscles beginning around day 6 of ice storage. Similar trends have also been noted by Love (1983) and Rhee et al. (1984), further supporting these observations. Under freezing conditions, the formation of ice crystals and protein denaturation play crucial roles in altering texture, driven by endogenous enzymes and microbial activity (Ocaño-Higuera et al. 2011; Badii and Howell 2002). In the early stages of frozen storage, a rapid decline in texture parameters may be attributed to tissue damage caused by ice crystal formation during freezing and blast-freezing. In contrast, GFP stored in ice exhibited a more gradual decline in texture throughout the storage period, consistent with the findings of Jain et al. (2007), who reported a similar decrease in stiffness for raw Nile tilapia fillets stored at ice temperature. Interestingly, blast-frozen GFP experienced minimal texture changes, while ice-stored samples showed the most pronounced deterioration by the end of the storage period. This aligns with Ninan (2021), who identified texture changes as a reliable indicator of spoilage, closely linked to storage temperature due

to the temperature-dependent nature of enzymatic and microbial activities. Additionally, the composition of fat and collagen influences fish texture, as microbiological processes and autolysis after death lead to the degradation of myofibrillar proteins, resulting in muscle softening (Li et al. 2012, 2013). The combined effects of temperature fluctuations, enzymatic activity and microbial processes throughout the 21-day storage period contributed to the texture changes observed in this study.

Sensory evaluations conducted on both raw and cooked GFP covered multiple modalities, including appearance, texture, odour and flavour, following the methods used by Khodanazary (2019) and Azam et al. (2013). GFP stored on ice maintained 'very good' quality for up to 6 days, consistent with Begum et al. (2011), but contrasting with Haider et al. (2011), who observed this quality only for 3 days. GFP remained commercially acceptable for up to 9 days, likely due to effective post-harvest handling, which included chill-killing and suitable ice-to-GFP ratios. These findings diverge from reports of quality deterioration by day 9 (Khodanazary 2019; Rahman et al. 2001), with the variability attributed to differences in species, chemical composition and storage practices (Saidi et al. 2023; Cantillo et al. 2020). Additionally, GFP stored under freezing and blast-freezing conditions preserved its organoleptic quality for up to 21 days, aligning with the results of Azam et al. (2013), who reported similar findings for GFP stored at -20 °C for up to 56 days. The methodology of employing sensory modalities and a structured scoring system provides an accurate and species-specific framework for evaluating the quality of export-oriented GFP, which is essential for maintaining high export standards. These findings underscore the

significance of improving post-harvest handling practices to minimise quality loss. Strategies such as training fishers in proper handling techniques, using appropriate ice-to-product ratios and adopting chill-killing practices can significantly reduce post-harvest losses and extend the shelf life of GFP, benefiting the export market and ensuring higher quality standards.

Conclusion

The current study revealed that harvesting losses of soft-shelled GFP are unavoidable for fishers, with additional physical and quality losses occurring throughout the market chain, peaking at the final intermediate stage. Predation during harvesting further reduces yields, particularly in reservoirs with an abundance of predators. Local collectors experience the highest post-harvest quality losses due to poor handling and storage practices. Contributing factors include inadequate infrastructure, limited technical resources, suboptimal packaging, disorganised transport and insufficient cooling facilities. These losses diminish income at every stage and impact the food and income security of rural fishing communities. The study found that ice storage effectively preserved the colour, texture and organoleptic qualities of GFP for up to 9 days, after which significant deterioration occurred. In contrast, both freezing and blast-freezing initially caused rapid colour changes that later stabilised, with no notable differences between the 2 methods. Texture properties varied among storage conditions, with ice-stored GFP showing noticeable changes in the later stages compared to frozen samples. While ice storage maintained superior organoleptic qualities and consumer preference in the short term, it proved inadequate for long-term preservation after 9 days. Conversely, freezing and



blast-freezing effectively sustained organoleptic properties over extended periods, with blast-freezing emerging as the most suitable method for preserving sensory quality and maintaining consumer preference. Based on these findings, ice storage is recommended for short-term market chains, whereas blast-freezing is the preferred method for long-term storage, particularly for the export market.

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3 Culture-based fisheries value chain



Members of the fisheries society in Bulankulama Reservoir in Anuradhapura, Sri Lanka harvest culture-based fisheries. Photo: Dr Kelum Wijenayake.

3.1 Value chain considerations of culture-based fisheries in Sri Lankan reservoirs

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Abstract

Sri Lanka's culture-based fisheries (CBF) provide significant livelihoods and food security for villagers in proximity to the country's dense network of reservoirs. In this paper, we summarise the value chain findings of ACIAR project FIS/2018/157, 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.

We describe 3 types of finfish and giant freshwater prawn (GFP) domestic value chains, depending on whether products are consumed locally or in urban areas, and the number of agents in the chain. We also describe 2 types of GFP export value chains – one where export companies are not involved in activities along the value chain, and the second where export companies partner with reservoir fishery organisations to stock, cultivate, harvest and market their products. We show that CBF are profitable, with low risk to fishers. Price received by GFP fishers are lower when export companies are involved in all aspects of the marketing chain than when they are not, but these companies bear a significant burden of the costs such that the profitability of fishers is similar for both types of value chains. However, where export companies are involved throughout the chain, they bear most of the risk.

The division of labour within the value chains of CBF is traditional, with men performing physically intense and skill-requiring activities, females assisting in less demanding tasks and children providing occasional support. Providing training for various members of the value chains, especially to convert informal activities into commercial economic activities, is likely to enhance economic and social benefits within fishing households, as well as within the fisheries sector.

We present a SWOT analysis of Sri Lankan CBF, considering all aspects of the value chain. Many of the weaknesses and threats are common across similar fisheries in other countries, such as poor availability and supply of seed stock, poor harvesting technologies, lack of common GFP grading methods at landing sites, poor storage and transportation facilities, asymmetries in price transmission along the chain, poor access to bank loans and governance issues. However, Sri Lanka has advantages that are not experienced in other countries, such as the profitability of the fishing enterprise due to low costs and low risks, and the established export market for GFP.

There are significant opportunities for improving the efficiency of production, institutions and markets of GFP and finfish CBF value chains in Sri Lanka. To exploit opportunities and transform activities throughout the value chain, we recommend Sri Lanka develops a comprehensive sector-wide strategy, with extensive consultation and buy-in from all stakeholders, that includes a vision, strategic objectives, implementation plan, resourcing strategy, and monitoring and evaluation plan.

Introduction

Sri Lanka is home to a dense network of reservoirs constructed for the purpose of irrigation, hydroelectric generation and drinking. These reservoirs provide year-round food supply for local communities as well as livelihoods that include small-scale irrigation of agricultural crops (predominantly paddy rice), fishing, and associated agribusiness services such as marketing and transportation services. Many of these reservoirs are very large. Irrigation authorities in Sri Lanka classify them by size as major (>800 ha), medium (200–800 ha) and minor (<200 ha).

These reservoirs support a wide range of native and exotic fish species as well as GFP. Although indigenous cyprinid species are abundant, they are largely unexploited due to poor consumer preference. Fish production is dominated by 2 exotic cichlid species: *Oreochromis mossambicus* and *O. niloticus* (commonly known as Mozambique tilapia and Nile tilapia, respectively).

The productivity of reservoir fisheries has been enhanced through the stocking of post larvae (PL) seed. This type of fishery enhancement is called ‘culture-based fisheries’ (CBF) and is practiced in many inland water bodies across the world. Sri Lanka’s National Aquaculture Development Authority (NAQDA) produces PLs in hatcheries and partners with local fishing communities to stock the PLs into the reservoirs. There are some private hatcheries run largely by export companies.

Fish production from CBF is largely sold into local, regional or urban markets. On the other hand, GFP is largely sold to high-end restaurants or hotels in Sri Lankan cities, or exported. GFP is a high-value species, with the average harvest price being about double that of finfish, and consumer prices can be 20 times or more higher in foreign markets.

Value chain analysis in fisheries refers to a systematic examination of all the steps involved in producing and delivering a fish product from the initial input stage (such as PL stocking) to the final consumer, identifying areas where value can be added or inefficiencies minimised at each stage to optimise the overall profitability of the fish product. Stages in the value chain include input supply, production (fish harvesting), processing, marketing and distribution. Key actors in the chain include input suppliers, fishers, processors, traders, exporters, wholesalers, retailers and consumers.

Value chain 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 project’s value chain analysis is to ensure post-harvest and supply practices meet market requirements and that both male and female actors in the supply chain gain maximum benefits. The purpose of this paper is to summarise the project’s value chain 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 Paranamana (2025), Paranamana et al. (2024) and Paranamana et al. (2025).

Project findings

Understanding the value chain

There is significant variation across GFP and finfish value chains in Sri Lanka. Value chain analysis was conducted for case studies of 5 reservoirs of different sizes and locations across Sri Lanka in late 2023. Three different types of value chains were identified for finfish and GFP sold into local markets, as shown in simplified schematics in Figure 3.1.1. Type 1 value chains describe marketing channels where Reservoir Fishery Organisations (RFOs) sell product direct to local retailers who sell to local consumers. Types 2 and 3 value chains describe marketing channels where the product is sold to consumers in urban markets. Type 2 value chains include urban wholesalers and retailers. Type 3 value chains exclude urban wholesalers; RFOs sell direct to urban retailers.

Very little finfish but most GFP is exported. Two different types of value chains were identified for exports of GFP – Case 1 and Case 2 – plus variations within these types. Figure 3.1.2 provides a simplified schematic for these different cases.

In Case 1, the export company is not involved in activities further down the chain. Production and collection are conducted independently and RFOs, primary collectors and secondary collectors have the freedom to sell their products to any collectors and exporters. In Case 2, a private export company is involved in all nodes of the value chain. The export company is involved in input supply by

breeding PLs and providing this seed stock to RFOs so they can stock their reservoirs. The RFOs must then sell to primary and secondary collectors that are engaged by the export company. Generally, farm-gate prices are higher in Case 1 value chains than Case 2 (Table 3.1.1).

Table 3.1.1: Average farm-gate price of GFP for Case 1 and Case 2 export value chains (LKR/kg)

	Case 1	Case 2
Quality 1	1,700 – 2,000	900 – 1,500
Quality 2	1,000 – 2,000	900 – 1,000

Case 2 value chains are generally less complex than those of Case 1. We identify 3 types of variations in Case 1 value chains (Case 1A, 1B and 1C). Case 1A is a linear value chain, with one primary collector, one secondary collector selling to one export company. Case 1B involves several primary collectors who sell straight to the exporter. Fishers have the freedom to sell to any primary collector, although they often negotiate long-term agreements with single buyers. Case 1C involves several primary collectors, one secondary collector and one exporter. Negotiated prices in Case 1B are generally higher than those received from Case 1A and Case 1C as they avoid the need of a secondary collector (Table 3.1.2).

Table 3.1.2: Average farm-gate price of GFP for Cases 1A, 1B and 1C export value chains (LKR/kg)

	Case 1A	Case 1B	Case 1C
Ungraded	2,000	1,700	
Quality 1		2,000	2,000
Quality 2		1,500	1,000

If grading is conducted at the landing site, it is generally based on whether the GFP are damaged. In some rare cases, the prawns are graded on weight as to whether they are higher or lower than 250 g/individual.

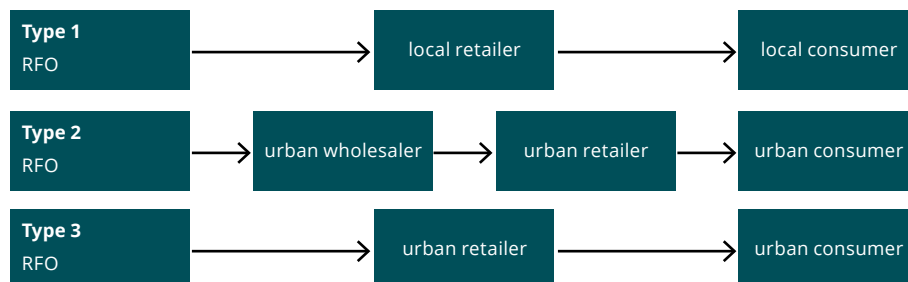


Figure 3.1.1: Simplified schematic of 3 different types of finfish and GFP value chains for local markets of CBF in Sri Lanka

Note: RFO = Reservoir Fishing Organisation

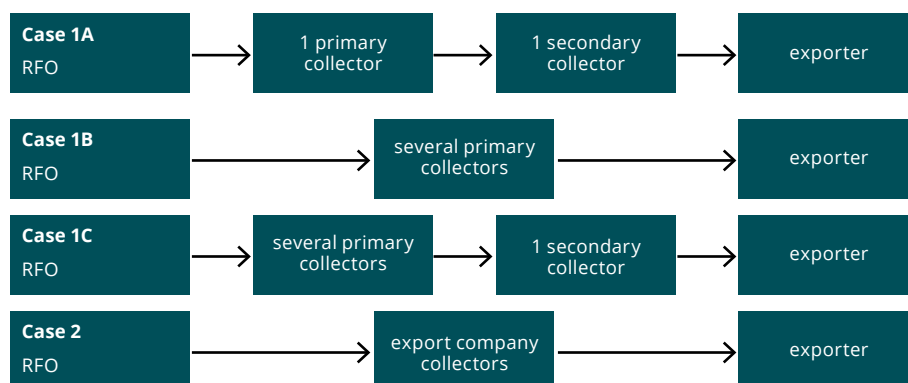


Figure 3.1.2: Simplified schematic of 2 different types of GFP export value chains (Case 1 and Case 2), showing variations within Case 1

Note: RFO = Reservoir Fishing Organisation

Table 3.1.3: Consumer prices of cooked GFP (LKR/individual)

Size	Price in foreign markets	Price in local markets	
		5-star hotels	Other hotel retailers
150 – 200 g	5,900	4,500	1,900
200 – 250 g	6,200	5,400	2,200
250 – 300 g	8,100	6,000	2,400
300 – 400 g	10,000	7,600	3,000
400 – 500 g	12,000	9,100	
>500 g	14,800	10,600	

However, significant grading occurs along the value chain, generally by the exporter, providing significant value adding.

If GFP are rejected due to damage or other quality issues, they are sold into local markets. Those GFP of a standard that satisfies international consumers are graded by weight and exported. Consumer prices differ for different sized prawns, with larger prawns receiving higher prices, as shown in Table 3.1.3.

We focus on the Sri Lankan segments of the value chain. Price build-up along the chain between the RFO and the exporter for Case 1 and Case 2 value chains is shown in Figure 3.1.3. Fishers and secondary collectors get a higher proportion of the price in Case 2 where exporters are involved throughout the chain, compared with Case 1 where exporters are not involved throughout the chain. However, the overall price is lower for Case 2 than Case 1 (see Table 3.1.1).

The total revenue (price multiplied by production) in Case 1 is higher for RFOs and primary collectors compared with Case 2 (Figure 3.1.4 A). However, their variable

costs¹ are also higher, as export companies are paying most of the RFO and primary collector costs in Case 2 (Figure 3.1.4 B). Gross margins are almost the same for both cases (Figure 3.1.4 C): slightly lower when the export company is involved in the chain (Case 2) than when they are not (Case 1). However, as export companies are paying a larger proportion of the costs in Case 2, they are bearing significant risks, more than offsetting the small difference in gross margin. This risk borne by exporters is reflected in gross margin per unit costs shown in Figure 3.1.4 D.

Fisher costs are dominated by fish net replacement, boat repairs and maintenance, and labour. Primary and secondary collector costs are dominated by GFP purchases, with some fuel, and vehicle repair and maintenance costs.

1 We focus on the collection of variable costs (such as labour, nets and fuel) rather than total costs (variable costs plus fixed costs (such as buildings and vehicles)) for practical reasons, and also because fixed cost items are often used for purposes other than fishing. As variable costs fluctuate with production volume, they provide an accurate picture of how much profit is generated per unit sold.

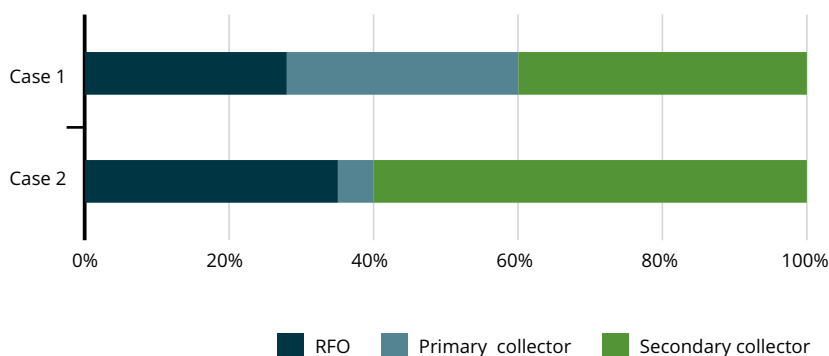


Figure 3.1.3: Price build-up between RFO and exporter for Case 1 (no exporter involvement in the chain) compared with Case 2 (exporter involvement along the chain) value chains

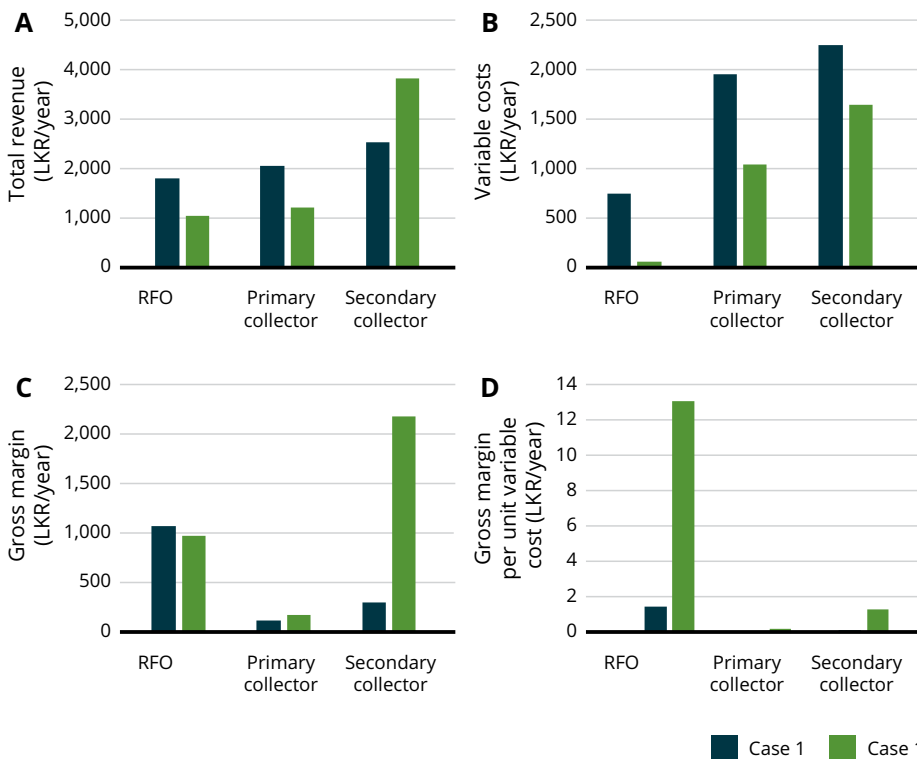


Figure 3.1.4: Total revenue (A), variable costs (B), gross margin (C) and gross margin per unit variable cost (D) for RFOs, primary collectors and secondary collectors for Case 1 (export companies are not involved in the value chain) and Case 2 (the export company is involved in the value chain)

Inclusivity of value chains

There is both female and male participation in all nodes of value chains, with the exception of finfish wholesaling, which is exclusively a male activity (Figure 3.1.5 and Figure 3.1.6). Male participation dominates female participation in all value-chain activities with the exception of finfish processing (largely fish drying). RFO, fisher and collector activities conducted by men, women, boys and girls are listed

in Table 3.1.4. The division of labour is traditional, with men performing physically intense and skill-requiring activities, females assisting in less demanding tasks and children provide occasional support. Providing training for various members of the GFP and finfish value chains, especially to convert informal activities into commercial economic activities, will enhance economic and social benefits within fishing households, as well as within the fisheries sector.

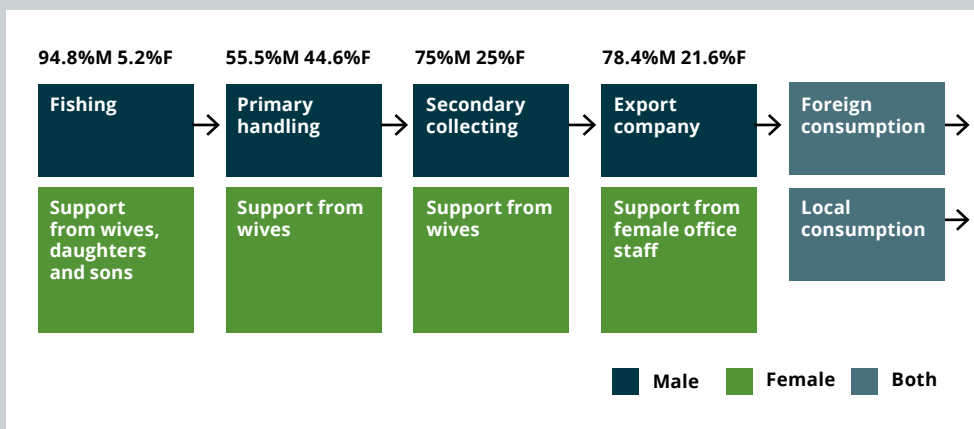


Figure 3.1.5: Female and male participation in value chain for GFP

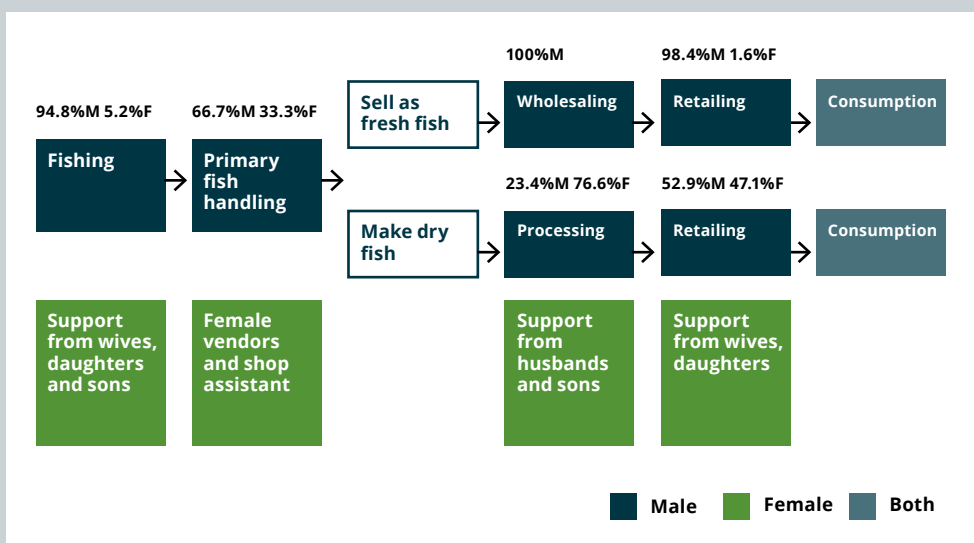


Figure 3.1.6: Female and male participation in value chain for finfish

Table 3.1.4: Activities conducted by men, women, boys and girls with RFOs, fishers and collectors

	RFO	Fishers	Collectors
Men	• Registration and legal documentation • Appointing society officers • Participating in society meetings and workshops • Hiring labour • Reporting financial transactions • Arranging refreshments for visitors • Making society-related decisions • Hatchery management • Transporting of PLs and fingerlings • Stocking • Purchasing fishing equipment • Safeguarding boats • Protecting the reservoir from illegal fishing • Searching for prices for other reservoirs • Negotiating with buyers • Conducting sales • Serving as shop assistants	• Harvesting from the village reservoir • Scaling • Grading • Cleaning • Transporting boats	• Decision-making • Engaging with RFOs • Collecting from village reservoirs • Handling and grading GFP • Keeping the product on ice
Women	• Reporting financial transactions • Participating in meetings with moderate contribution • Labour hiring • Society decisions • Arrangement of refreshments • Cleaning and documenting maintenance activities in the hatchery • Documentation of stocking	• Cleaning fishing gear • Scaling • Grading	• Handling and grading GFP • Cleaning
Boys		• Cleaning boats	• Supporting fish handling and collecting
Girls	• Arrangement of refreshments	• Cleaning fishing gear	• Supporting fish handling and collecting



SWOT analysis of Sri Lankan value chains of GFP and finfish

The strengths, weaknesses, opportunities and threats apparent in Sri Lankan value chains of GFP and finfish are listed in the following SWOT analysis.

Strengths

Market-related strengths include:

- strong demand, especially locally for fish and internationally for high-value GFP
- strong demand for dry fish in local markets
- most activities along finfish and GFP value chains have low costs and low risk
- fishing contributes significantly to sustainable livelihoods for villagers, providing an additional income-earning source that in some cases is more profitable than agricultural activities (such as paddy rice cultivation)
- finfish prices are affordable for villagers
- finfish production contributes to food security in local villages.

Institutional strengths include:

- experienced fishers
- strong local institutions in RFOs, who are effectively managing fishing intensity
- engagement of villagers along the value chain
- an established export market for GFP
- fishing activities generate agribusiness job opportunities through support services such as input supply, marketing and transport
- vertical integration of value chain activities in some regions, which injects much-needed finances into fish and GFP production, increasing the availability of seed stock and bears some risk for fishers.

Product strengths include:

- organic production
- large size of GFP and diverse range of finfish species
- natural nutrition in reservoirs means that supplementary feeding is not needed.

Weaknesses

Market-related weaknesses include:

- daily harvest per fisher is low and uncertain
- lack of local demand for GFP and dependence on fluctuations in international markets
- export markets underdeveloped for finfish
- lack of competition along the value chain (in some regions, there is only one primary collector)
- lack of comprehensive grading for quality or size by fishers and collectors – most grading is conducted by exporters – price signals for quality and size are not transferred down the value chain, potentially leading to price asymmetry and market control in the chain
- lack of information and poor coordination between and across actors in the value chain.

Institutional weaknesses include:

- subsistence nature of fishing (fishers often only catch enough to fulfil daily requirements)
- GFP is considered a by-catch of fishing
- fishers financially depend on export companies for GFP sales
- difficulties accessing loans and insurance from banks as fishing is considered an informal activity
- high interest rates.

Product weaknesses include:

- poor availability of good quality seed for stocking reservoirs; there is especially a lack of quality wild broodstock
- the production of seed requires significant scientific knowledge, technical capacity and financial support, and is risky
- poor understanding of the economically optimum stocking density and fishing intensity across reservoirs and fish species
- harvesting is labour intensive and time consuming
- lack of technically efficient harvest technology for GFP – a high proportion of GFP are damaged in gillnets, and the GFP damage the gillnets which affects fishing activities
- perishable nature of GFP and finfish – local and international buyers prefer live or fresh products
- poor storage practices along the chain, especially for GFP, and a lack of understanding of optimal ways to store and transport GFP.

Opportunities

Market-related opportunities include:

- there are no close substitutes at the reservoir level for GFPs
- GFP have strong international demand and are a high-price commodity
- the international market for GFP is large
- significant potential to improve the quality of marketing in local and international markets
- potential to expand international markets through the introduction of certification, branding (as quality and organic) and traceability
- economic benefits to fisheries through improved grading of GFP and finfish by

species, size and quality at landing sites to reflect consumer preferences.

Institutional opportunities include:

- significant opportunity to transform traditional informal fishing activities into formal enterprises through innovation and commercialisation of activities
- potential to improve inclusivity and equity through training to improve skills in various activities across the value chain, especially for women
- possibilities for pursuing profit-sharing, employment mechanisms and volunteer support in adjacent and downstream villages to manage conflicts and to lower incentives for illegal fishing
- capacity to improve understanding of optimal stocking densities and fishing intensity within RFOs and NAQDA, and pursue strong community-based governance arrangements
- implementing advanced water management systems such as pumps, rainfall pattern monitoring and improved forecasting before stocking PLs to reduce mortality associated with low- and high-rainfall events.

Product opportunities include:

- private and private-public partnerships to improve broodstock, hatchery techniques and availability of high-quality seed
- consideration of quarterly or gradual stocking, rather than annual stocking
- implementing GFP-specific harvesting equipment such as traps
- cultivation of GFP through fencing off sections of reservoirs, stocking PL prawn into these areas away from predation, and minimising the likelihood of prawns getting damaged by, and damaging, fish gillnets

- potential to improve understanding of optimal marketable size, growth rate and growth periods
- improving knowledge and understanding of storage requirements along the value chain for freshness
- encouraging value-added processing for diversified products.

Threats

Market-related threats include:

- new entrants into fishery, leading to reduced harvests for all licence holders and causing conflict among the villagers
- substitution between finfish species
- strong bargaining power of export companies involved in activities along the value chain
- high product quality requirements of international markets
- traders and collectors bear high risk
- GFP exporters are price-takers; prices are dependent on international market conditions.

Institutional threats include:

- multiple use conflicts between agriculture and fishing activities over water allocation in the dry season; fishing is secondary to agricultural uses in terms of determining water allocation
- illegal catching
- insufficient technical capacity and financial constraints of fishers, especially for stocking.

Product threats include:

- predator damage from birds and other aquatic predators (tortoises, crocodiles and predator fish species) resulting in harvest loss and reduced quality
- uncertainty of harvest due to seasonal variability

- limited water circulation in reservoirs leading to the spread of disease and fungal infestations
- pollution from agricultural run-off containing pesticides and fertiliser which contaminate resource and negatively impact fish health
- some reservoir areas have limited natural nutrition.

Comparative data from other countries and fisheries

Value chain analysis is a growing field of research within the agricultural and fisheries sector. Literature on this topic suggests that the general areas of sector improvement that are highlighted in value chain analyses include:

1. improving the planning, legal and regulatory framework for sustainable management of the resources
2. increasing the quantity and improving the regularity and continuity of production
3. improving the quality and safety of products
4. improving the mechanisms for cooperation among the value chain actors
5. reducing the time needed to reach the customer
6. minimising transactional costs
7. improving the capacity of chain actors to follow and assimilate technology and market developments (Parke 2013).

Value chain analysis is useful for identifying actors in the value chain, estimating the profit share of each actor in the chain, and identifying constraints and opportunities along the chain.

Many of the value chain weaknesses and threats we have identified in this paper are common to fisheries in other

countries. Such weaknesses and threats in production include lack of modern knowledge, poor harvesting technologies, poor storage facilities, illegal fishing and weak governance. Market-related threats include price fluctuations, poor quality supply, asymmetry in price transmission, insufficient value-added, seasonality of demand, and food loss and food waste. These constraints are experienced across the world, especially in low to middle-income countries in Africa (for example, Aziz et al. 2023 and Kamaylo et al. 2021) and Asia (for example, Kamaylo et al. 2021 and Navy and Sophea 2012).

With respect to prawns, value-chain analysis conducted in other countries has highlighted similar weaknesses and threats as those presented in this paper. This is especially true for poor access to high-quality PLs during stocking periods, high mortality of PLs, poor access to bank loans so cash advances are given by traders and local investors as an informal loan system, difficulties paying back these cash advances, lack of processing, lack of grading at farm-gate and associated low prices, poor profitability for fishers, limited investment, poor information flows and underdeveloped organisation of the value chain (Joffre and Aung 2012; González-Figueroa 2024).

Upon comparing data from other countries and fisheries, it is apparent that Sri Lanka has advantages that are not experienced in other countries. This includes profitability of fishing due to low costs, low risk associated with fishing activities and the established export market for GFP.

Specific recommendations from value-chain analyses in other countries have been made in terms of stricter regulation on size limits of harvest, seasonal closures, improvements of monitoring schemes, introduction of certification processes,

development of post-harvest facilities, increased capacity for effective extension services, creating access to formal credit facilities and habitat protection (Acharjee et al. 2023; Awel et al. 2018; Kamaylo et al. 2021; Navy and Sophea 2012; Rosales 2017). Most studies make recommendations for changes in individual aspects of the value chain but do not go on to developing a comprehensive strategy for the transformation of activities throughout the value chain.

Applying project findings for the enhancement of Sri Lankan CBF

There is great potential for reducing inefficiencies and capitalising on opportunities to expand livelihoods and improve food security of villagers in proximity to Sri Lanka's CBF (Abeyrathne et al. 2020). Sri Lanka's CBF have significant advantages over similar fisheries in other countries; especially the profitability of fishing due to low costs and low risks, and the established export market of GFP. Our earlier SWOT analysis outlines significant opportunities that can be exploited through:

- 1. production efficiencies** (private and private-public partnerships for improving availability and quality of seed stock, implementing GFP-specific harvesting equipment, fencing off GFP culture areas, improving storage and transportation facilities, and encouraging value add)
- 2. institutional arrangements** (such as improving capacity and skills for improved inclusivity and equity, innovative governance arrangements to manage conflicts and lower illegal fishing, and implementing advanced water management systems and seasonal forecasting)

3. improved marketing (such as introducing grading at landing sites, certification, branding and traceability).

To comprehensively exploit these opportunities requires a sector-wide development strategy. Fishing strategies have been developed in other parts of the world, generally to achieve one or a few aims within the fishing sector, such as combatting illegal, unreported and unregulated fishing, promoting sustainable fishing², and supporting coastal communities through community-based management³. Few strategies have a sector-wide perspective across the length and breadth of the value chain.

Though sector-wide strategies are rare, they have the potential to create significant transformation of value chains. ACIAR has co-funded 2 such sector-wide strategies – The *Myanmar Pulses Sector Development Strategy* (2017) and Pakistan's *Pulses Industry Development Strategy* (2023). The development of both these strategies is having enormous benefit in these countries, creating cooperation across stakeholders in the value chain, and transforming livelihoods and food security in the agricultural sector.

Development of a sector-wide strategy for Sri Lanka's CBF will require extensive and comprehensive stakeholder engagement with fishers, RFOs, villagers, collectors, processors, exporters, agribusiness, academia, non-government organisations (NGOs) and all levels of government. It could be led by government – perhaps NAQDA or directly by the Ministry of Fisheries and Aquatic Resources.

2 For example, Australia's 'Combating IUU Fishing and Promoting Sustainable Fisheries in Southeast Asia Program, available at <https://www.agriculture.gov.au/>.

3 For example, Asia-Pacific Economic Cooperation's Road Map on small-scale fisheries and aquaculture, available at <https://www.apec.org/>.

To be effective, the strategy should include:

1. A broad vision. For example, an inclusive, regionally and globally competitive, sustainable and adaptable culture-based fisheries sector contributing to the socioeconomic wellbeing of all members of the value chain and contributing to the development of Sri Lanka's national economy.
2. Carefully crafted objectives.
3. An implementation plan.
4. A resourcing strategy for all parts of the implementation plan (including private and public funding, and investment from aid and overseas development assistance).
5. A monitoring and evaluation plan.

We suggest that Sri Lanka pursue developing a CBF development strategy, so that opportunities along all parts of the value chain can be exploited for improved wellbeing of all stakeholders of CBF in Sri Lanka.

Acknowledgements

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3.2 Benefit sharing among actors in the culture-based fisheries sector in Sri Lanka: an analysis of giant freshwater prawn and finfish value chains

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Abstract

Establishing an efficient market mechanism is important to empower the rural fishery community economically. It is fundamental for the reduction of the inequality gaps among actors within fisheries value chains. Rural fishing communities are centred around reservoirs, and they engage in CBF activities in addition to farming. This industry has received less government attention than marine fisheries, but it is highly significant in improving the livelihoods of rural communities. Therefore, understanding the characteristics of value chains in the CBF sector is important. This study was carried out in 5 locations in 3 districts in Sri Lanka via 5 case studies within the CBF sector. The objectives of this study were to identify existing value chains in the CBF sector and how its benefits are shared among the value-chain actors. Data were collected through field surveys. This study found that there are 2 main products in CBF: GFP and finfish. The main destination for GFP is the export market, while the finfish is mainly a target for the local market, especially within and outside village boundaries. Several value-chain nodes function in markets such as fishing, primary collecting, secondary collecting, wholesaling, retailing and consuming. In the fishery value chain, fishers received the highest price percentage when selling finfish as fresh. When finfish go to the dry fish market, fish receive the lowest price percentage. Within the GFP value chain, fishers who handle larger-sized prawns tend to capture lower value shares, whereas secondary collectors obtain the highest proportion of the end-market price. Upstream actors of value chains received lower benefits among the value-chain nodes. Thus, ensuring fair pricing methods and improving fishers' bargaining power through strategically managing harvest is recommended in this study.

Keywords: *culture-based fisheries, finfish, giant freshwater prawns, value chain*

Introduction

Equitable benefit sharing is one of the sustainable development goals in any country. When considering the term 'benefits', it is known as gain from a particular thing. It can be a kind of product, economic activity or financial return. The benefit from fishery products to the human is diverse and may be computed differently. In general, benefits are calculated as the output of the commodity based on their weight and quantity. Hence, fishery output can be divided further into capture and culture fisheries (Lackey 2005). Capture fisheries are conducted on a large scale and mainly target profitability. Additionally, capture fisheries have a longer value chain, creating more business and employment opportunities than culture fisheries (Martinez 1997). Although, culture fisheries have low input and output relationships (Martinez 1997; Edwards 1999). Culture fisheries significantly contribute to ensuring food security, generating income, strengthening livelihood patterns and alleviating poverty. However, its value creation process is shorter than capture fisheries (Martinez, 1997).

Benefit sharing among fishery activities is commonly measured based on the economic value of the commodity output through the wholesaler or retailer (Lackey 2005). Calculating benefits is easy for commercial or capture fisheries as the fishery products are mainly market oriented. But in culture fisheries or small-scale fisheries, product quality is very important. The measurement carries out the weight of the fish or fish quantity. Here, the economic value measures the benefits provided to fishers or society. Even in commercial or CBF, substantial benefits may be associated with cultural or religious aspects beyond the national

boundaries (De Silva 2011). Although some researchers pointed out that small-scale fisheries are crucial for rural development, some researchers found that small-scale fishers and fish farmers receive minimal economic benefits for their products, while processors and retail markets receive a larger share of the value chain's benefits (Bjorndal et al. 2014). Consequently, it is essential to examine how benefit sharing works among the value-chain actors in the CBF sector in Sri Lanka.

Although measuring values and benefits is difficult in CBF (De Silva 2011), it is essential to assess the need for this sector to be enhanced sustainably. Therefore, this study aims to identify the existing value chains in the CBF sector, types of benefits from value-chain participation, and how benefits might be shared among actors in both GFP and finfish value chains.

Methodology

The case study research method was used for this study. The case study approach to research provides in-depth, multidimensional knowledge about complex issues in reality. It includes a wide range of disciplines, especially social science (Crowe et al. 2011). The case study method is appropriate for capturing explanatory information for the research questions 'how', 'what' and 'why'. In addition, it is useful to understand casual links and patterns. Thus, this method helps to find the existing flow of the value chains and gaps in existing mechanisms (Yin 2009). Five reservoirs in 3 districts were examined for the value-chain analysis in this study. Value-chain mapping, as well as estimating revenue, cost and marketing margins along these chains were used to identify benefit sharing among the chain actors. Data were collected from individual, semi-structured interviews with value chain actors and

secondary sources such as fisheries society records books. Data were gathered from June to December 2023. This paper summarises the findings of the study on value chains, as a component of the comprehensive studies conducted under the ACIAR project.

Reservoirs selected for the present study are indicated in Figure 3.2.2. Case A: Urusita wewa (Mo5) in Monaragala district; Case B: Vijayakadupotha wewa (P5) and Case C: Tabbowa wewa (P4) in Puttalam district; Case D: Iranamadu wewa (Ki2) and Case E: Pudumurippu wewa (Ki3) in Kilinochchi district. The criteria for selection of reservoirs were based on geographical location.

Results and discussion

Four sub-themes were identified for analysis under the main theme of assessing existing supply chains in the CBF sector: the number of value chains, chain nodes and their relationship; market proportion; nature of the price determination; and operating cost, profit and market margins of the industry.

Market proportions – controls by the value chain actors

Market destination is an important component of the value-chain analysis. Three major market destinations were identified: local/village, national/urban and foreign/export markets. The village/local demand for GFP is a relatively low proportion of the value chains. Fishers bring GFP home for consumption when the harvested GFP does not reach export quality or when there is small physical damage due to predator attacks, or damage to the head or malting. In such cases, GFP are rejected and used for subsistence. The percentage of rejection due to damage is close to around 3%. The proportion

distributed for local sales, especially in restaurant 5-star hotels as well as other local hotels is around 23%. Occasionally, villagers came to the landing site to purchase GFP on special occasions or due to personal interest. The largest proportion of the GFP harvest – around 74% – is exported (Figure 3.2.1).

There are 3 major markets for fresh and dried finfish as well: local/village, surrounding small town and national/urban markets. Urban wholesalers hold the largest share (35%) of the finfish market. This could mean wholesalers play a crucial role in bulk distribution before products reach retailers (especially in Case D). Therefore, urban wholesalers might play a dominant role in the finfish market. Local retailers (30%) also have a substantial share, indicating a strong demand for direct-to-consumer sales (Case E) (Figure 3.2.3). It appears that many customers prefer buying from local/village retailers rather than the urban market as the fish sold by local retailers is fresher than that sold by urban retailers, who generally sell frozen

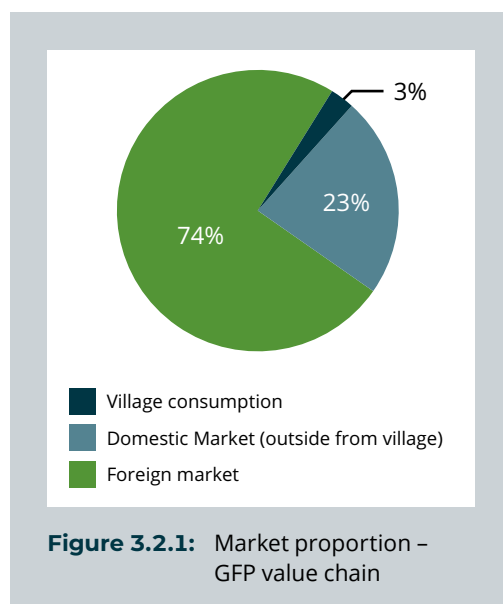


Figure 3.2.1: Market proportion – GFP value chain

fish. Urban retailers have a lower market share than local retailers and wholesalers. This might imply that urban markets are more competitive or consumers prefer local markets over urban ones when purchasing inland finfish. The lower percentages used for processing finfish suggest that dried finfish has less market demand compared to other categories. This could indicate seasonal demand. However, finfish has no export market contribution with all of the catch reaching rural and urban consumers in Sri Lanka.

Types of value chain actors and relationship

Five channels were identified within the GFP value chain (Figure 3.2.4) based on the product movement of GFPs from fishers through different intermediaries before reaching the end market. Chain 1 represents the movement from fishers, followed by the primary handlers, secondary handlers, company handlers and export companies (Case A, D, and E). Chain 2 represents the direct movement of fishers and primary collectors to the secondary

handler and from there to the export market (Case C and some chain from Case B). Chain 3 moves from the fisher, primary handler and company handler to the export company. Chain 4 contacts the primary handler directly to access the domestic market. Finally, Chain 5 consists of direct sales from fishers to local consumers.

When assessing the finfish market, 6 value chains were identified (Figure 3.2.5). The supply in Chain 1 flows is from fishers to the fisheries society, which manages the catch and distributes it. The society sells part of the catch to urban wholesalers (Case D) from whom it reaches urban retailers, followed by village retailers and urban consumers. Chain 2 is determined by the value added from fishers to the fisheries society and directly links with the wholesaler, who meets with village retailers. Chain 3 moves from the fisheries society to the urban retailer, who purchases fresh fish from the society for sale to the urban consumer through village retailers. In Chain 4, village retailers meet directly with the fisheries society to purchase finfish, and this is then sold to village consumers. Chain 5 constitutes village consumers purchasing fresh fish directly from the fishery society, identified as Chain 6.

When examining the gender division of labour within the value chains of both the GFP and the finfish market, it is evident that men dominate most sectors. In the GFP chain, approximately 45% of primary handling is performed by women. In contrast, in the dried finfish value chain, women account for 77% of processing activities and 47% of local retailing.

The nature of price determination and quantity

There was price variation in GFP trading across different locations. In Cases D and E, fishers received a lower price

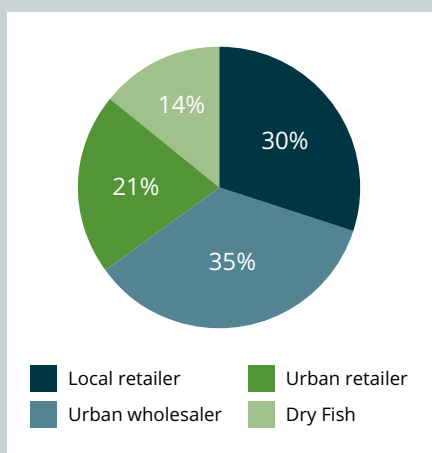


Figure 3.2.3: Market proportion - finfish value chain

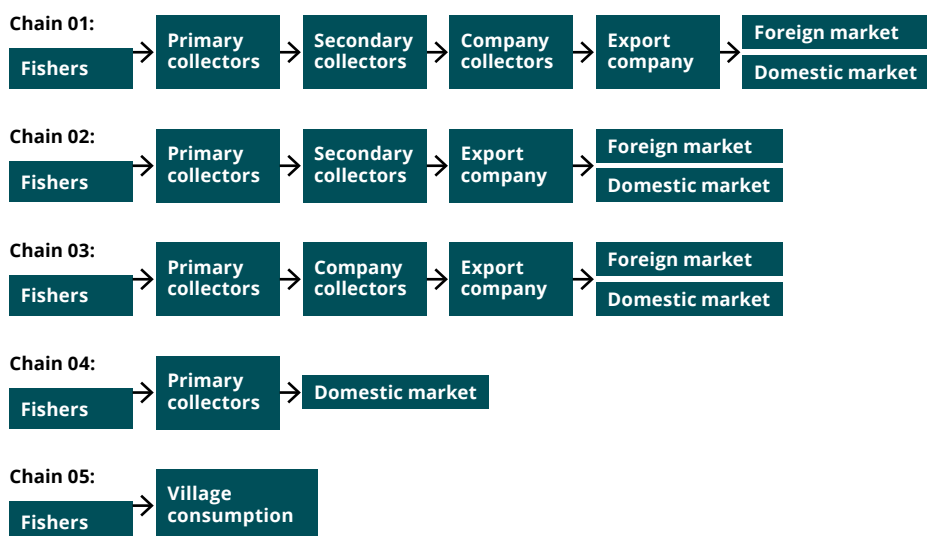


Figure 3.2.4: Types of value chain – GFP

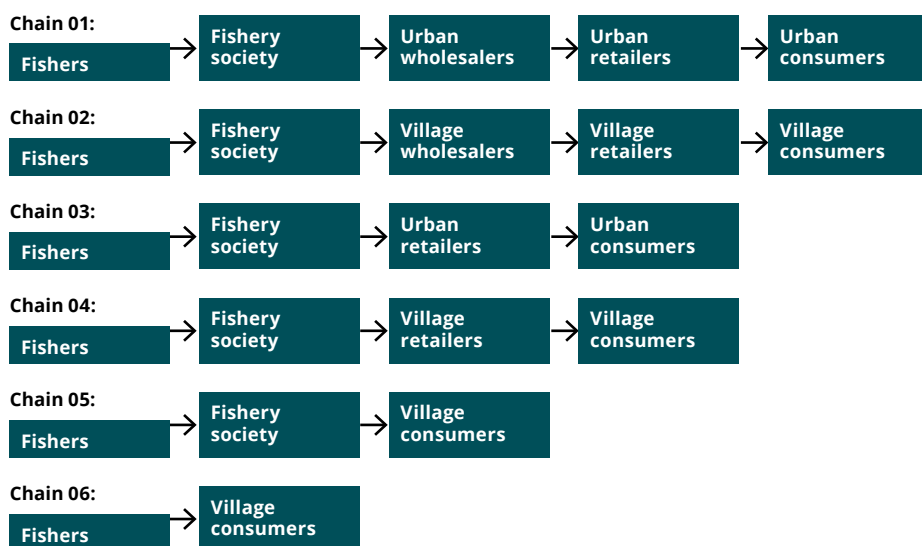


Figure 3.2.5: Types of value chain – finfish



(LKR900–1,500/kg), whereas in Cases A, B and C, prices were determined at a higher level (LKR1,500–2,000/kg). In this value chain, primary GFP handlers categorise the prawns based on physical appearance based on overall size, leg size, damage to carapace or other parts of the body (Case B, C, D and E). The primary collector decides the price based on the quality. In some cases, as in A, there is no price variance, and any type of GFP is bought at the same price. Therefore, it is clear that price is determined by the collector according to their criteria. There is no common pricing method at the landing site.

When the GFP harvest reaches the export company, it is categorised according to the weight of individual GFP. Exporters export GFP according to a weight categorisation above 500 g, 400–500 g, 300–400 g, 250–300 g, 200–250 g and 150–200 g. Fishers received the highest proportion of the total price when GFP are sold for village consumption. As the GFP increase in size from 150–200 g to above 500 g, the proportionate share received by fishers decreases to less than 60% to 40% of the total price across all nodes of the supply chain. Thus, as the weight of the GFP increases, the percentage of the price that fishers receive decreases. This pattern is also apparent for primary collectors, who receive the least proportion of the overall price. However, as the GFP weight increases gradually, the percentage of the price accruing to secondary collectors increases markedly from 30% to 60%, thus providing them with greater benefits when GFP reach a larger size.

Local retailers and village consumers pay the highest price range (LKR500–575/kg) for all categories of finfish. Local retailers sell fish directly to village consumers, often in smaller quantities. The higher price reflects smaller-scale distribution costs,

transportation expenses and margins compared to bulk purchases. Consumers in villages may have limited access to alternative fresh finfish sources, leading to slightly higher prices. Wholesalers purchase fish in bulk, leading to a lower price compared to that paid by retailers. The price variation (LKR440–500/kg) could be due to seasonal availability, quality differences (different species) or supplier negotiations. Wholesalers serve as intermediaries, distributing fish to urban retailers or local markets.

Urban retailers buy from wholesalers and sell with a mark-up to urban consumers. The price range for finfish sold by urban retailers is slightly lower than that of local retailers, possibly because of higher competition in urban markets with marine fish. Transportation costs influence the pricing. The significantly lower price for fish sold to make dried fish (LKR125/kg) suggests that lower-quality or excess fish are used for this process. Fresh fish fetches higher prices, while fish used for drying is often cheaper. Dry fish processing adds value but reduces weight, leading to different pricing structures in the market.

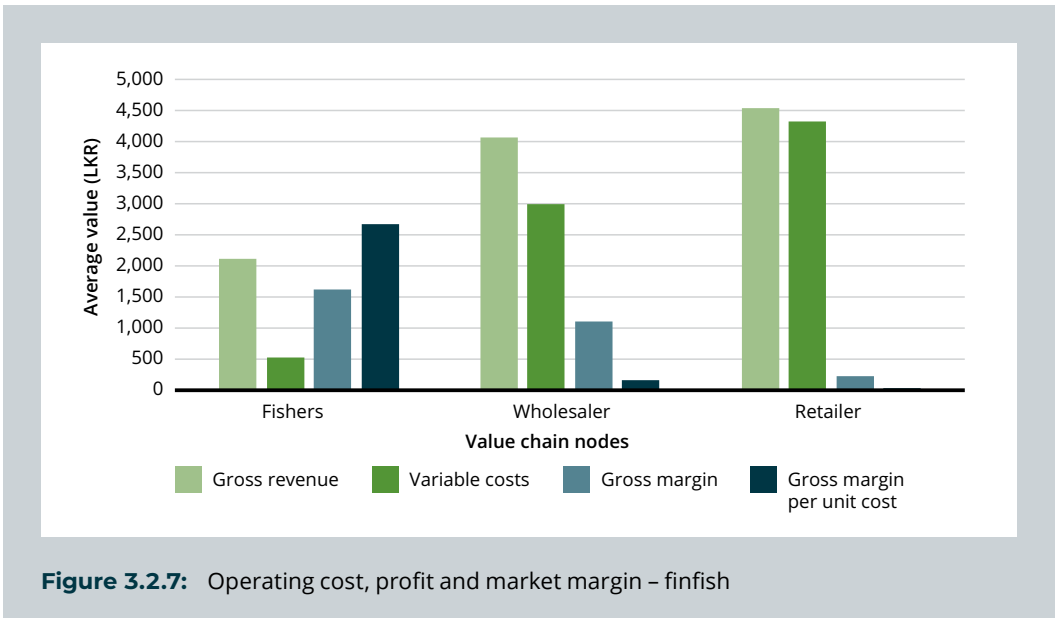
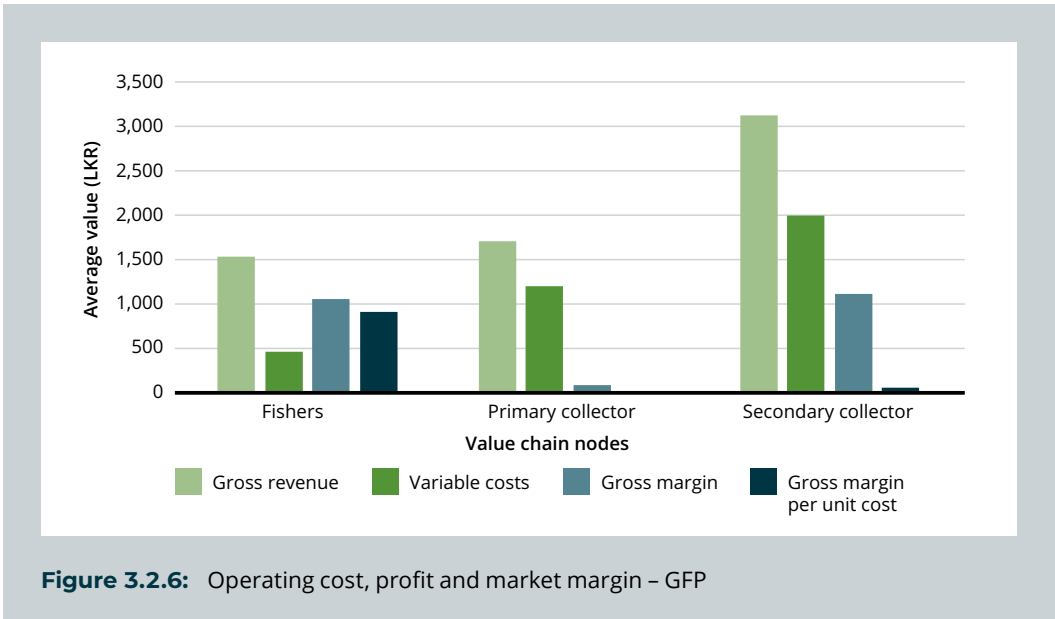
Retail prices are the highest within value chains, with local retailers having the highest range. Wholesalers get the lowest rates, benefiting from bulk purchases. Urban retailers fall between wholesalers and local retailers, reflecting a competitive urban market. Dry fish is the least expensive raw material as it is often made from lower-grade or excess fish.

Operating cost, profit and market margin

Gross revenue is lowest for fishers, followed by primary handlers in the GFP market. In contrast, the highest gross revenue is received by secondary collectors – nearly twice as high as fishers. Considering

variable costs, fishers have the lowest costs, while the secondary collector has the highest variable costs with the primary collector bearing moderate variable cost (Figure 3.2.6).

Fishers incur several types of costs when producing GFP. In some cases (such as Case A) fishers experience the highest cost for PL stocking for the next production cycle, accounting for 23% of their total costs. This is because fishers invest their





money in re-stocking. In addition to PL stocking, the other significant costs include labour, boat and fish net repair. Labour costs are primarily incurred to maintain the fisheries society premises and clean the reservoir area by removing aquatic plants from the water's surface. Due to GFP fisheries, damage to fish nets has increased, resulting in additional costs for net replacement or repair, which represents 15% of their total expenses.

To understand the distribution of costs and value captured along the GFP value chain, it is essential to examine the roles and responsibilities of key intermediaries involved in post-harvest handling. Among these actors, the primary and secondary GFP handlers play a critical role in aggregating, transporting and preparing the product for subsequent market channels.

Primary GFP handler (primary collector):

This individual is responsible for handling GFP and bears the costs related to purchasing inputs and fuel. The input purchasing cost is the payment made to the fisher for their GFP harvest, which accounts for 99% of the total expenses.

Secondary GFP handler (secondary collector): The individual who purchases GFP from the primary handler is known as the secondary collector. This person typically covers 98% of the total cost associated with acquiring GFP. This total includes expenses related to fuel, transport vehicle repairs and maintenance, labour and ice. However, these additional costs are relatively insignificant compared to the high cost of purchasing GFP. Therefore, the input buying cost is also considerable for the secondary GFP handler.

In terms of gross margins in GFP value chains, primary collectors have the lowest

margins (LKR9.72/kg), followed by fishers. The highest gross margin is accrued by secondary GFP collectors (LKR38/kg). Additionally, the gross margin per unit of variable cost is highest for fishers followed by secondary collectors. Primary collectors have the least gross margin per unit of variable cost.

Variable costs serve as an indicator of the risk taken by each agent in the value chain. The primary collector receives the lowest gross revenue among all agents in the chain. In comparison to other supply chain actors, secondary collectors receive the second-highest gross revenue, but they also bear the highest risk. On the other hand, fishers enjoy the least gross revenue while facing the lowest risk. Primary collectors received the lowest market margin (14%), while the secondary collectors received the highest market margin (37%) among the value-chain nodes. The secondary collectors' market margin is approximately 3 times higher than the primary collectors'.

In the finfish market, retailers received the highest gross revenue, followed by wholesalers and fishers (Figure 3.2.7). Retailers faced the highest variable costs and therefore assumed the greatest risk. Wholesalers incurred the second largest variable costs, while fishers had the lowest variable costs. This indicates that wholesalers experienced moderate risk, while fishers encountered the least level of risk.

Additionally, fishers achieved the highest gross margin among the finfish value chain nodes, whereas retailers had the lowest gross margin. This difference is primarily because retailers face intense market competition from substitute products.

Market margin distribution shows that wholesalers receive a higher market margin (LKR180.1/kg) than retailers (LKR86.1/kg)

and fishers. Wholesalers purchase a large quantity of finfish and sell to retailers while covering their transportation costs. In contrast, retailers purchase smaller quantities of finfish, which prevents them from achieving the same level of market margin as wholesalers.

In terms of gendered benefits from value chains, women are located in nodes that accrue the lowest returns. In the GFP value chains, they are engaged in the primary handler node. Within the finfish value chains, they are mostly confined to the dried finfish chain, where their main participation is in the processing and local retailing nodes. Thus, while their variable costs are low, so are their gross margins.

Discussion

Fishing, fish farming, wholesaling, retailing and processing are the main nodes in GFP and finfish value chains. Several marketing nodes are evident, along with unequal benefit sharing among the value-chain actors, which were investigated in this study (Sinh et al. 2014).

The GFP value chain is different from the finfish value chain as the finfish market chain is mainly targeted at considering fulfilling village/local fish consumption requirements. In contrast, the GFP value chain is mainly focused on the export market targeted at foreign consumers (Abeyrathne et. al. 2020; Jones et.al 2021). Therefore, the largest proportion of the GFP harvest is delivered out of the village.

The gendered value chain in the fishing industry reveals that fishing, primary handling, wholesaling and retail selling are predominantly male-dominated activities. In contrast, the production of dried fish is primarily a female-dominated task. Although women participate in retail selling, they do not typically engage in wholesale

selling. In the aquaculture sector, women represent a significant portion of the labour supply (Song 1997). Their contributions are particularly notable in fish processing, marketing, fry collection, fish feeding and net mending, as evidenced by cases in other developing countries (Bueno 1997; Locicero 1997; Virulhakul 1997; Murray et al. 1998; Kusakabe 2003; Paranamana et al. 2024).

Fishers received the lowest percentage of the final price while the secondary collectors received the highest percentage within this value chain. As the weight of GFP increases, the percentage of the price received by fishers becomes a lower price percentage. A considerable proportion of the market margin centres around the secondary collectors (for GFPs) and wholesalers (for finfish).

Conclusion and recommendation

Both GFP and finfish are important for CBF communities and the rural economy. While finfish is essential for food security, GFP offers a high earning potential for households engaged in culture-based fishing. Therefore, the value chains for both products need to be improved.

To maximise benefit-sharing among value-chain actors, the information asymmetry regarding price determination must be minimised. The pricing methods used at the farm-gate and by exporting companies should be aligned. Currently, fishers are unaware of the premium value associated with GFP due to hidden information within the value chain. If collectors pay fishers based on the weight of the GFP, the fishers will be incentivised to harvest larger, premium-sized GFP instead of smaller ones.

Additionally, market access must be improved for upstream value-chain actors, including fishers, processors and primary handlers/collectors, to reduce existing

benefit-sharing gaps. It is also crucial to strengthen the bargaining power of these upstream actors by increasing their market nodes, production volumes and/or the quality of their products.

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3.3 Nature, extent and causes of post-harvest losses in export-oriented giant freshwater prawn (*Macrobrachium rosenbergii*) market chain in Sri Lanka

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Abstract

The GFP (*M. rosenbergii*) industry in Sri Lanka is vital to rural livelihoods and the national export economy. However, substantial post-harvest losses occur throughout the market chain, from harvest to export. We assessed the extent and causes of these losses for fishers and evaluated handling, grading, storage and transportation practices at each key actor stage of the market chain. GFP is primarily harvested as bycatch in gillnet fisheries that target finfish. Substantial post-harvest losses occur at the producers due to predation, physical damage, molting and delayed retrieval. Predation rates vary widely among reservoirs, reaching as high as 60.1%. Molting rates also contribute to losses, with up to 15.2% recorded at some reservoirs. Post-harvest handling practices are inconsistent; fishers generally did not grade or ice the harvests, while only 50% of local collectors employ adequate icing (with a GFP-to-ice ratio of 2:1 to 3:1), though one-third of them use minimal quantities. Central collectors and factory agents adopt better practices by implementing improved grading systems and lowering GFP-to-ice ratios to 1:1. Most of the key actors utilise insulated containers such as Styrofoam or fibre-reinforced plastic (FRP) boxes. Transportation durations range from 5 minutes to 6 hours, with rural infrastructure challenges leading to delays, which increases the susceptibility to spoilage. Exporters grade GFP based on weight and quality, primarily for chilled (60%) and frozen products. Poor handling, inadequate icing, prolonged storage and infrastructure limitations contribute to quality degradation and economic loss. This study emphasises the need for improved post-harvest management practices, including standardised grading, proper icing, infrastructure development and capacity development of key market-chain actors to minimise losses and enhance export competitiveness.

Keywords: *market chain, quality management, export market, grading, icing practices*



Introduction

The GFP (*M. rosenbergii*) industry is vital to the Sri Lankan inland fisheries sector, supporting rural livelihoods, national food security and export earnings (Jones et al. 2021; Amarasinghe et al. 2022; Digamadulla et al. 2023). However, marketing and distribution systems for GFP face several challenges, such as product quality deterioration, physical damage and logistical delays. Post-harvest loss refers to the decline in a product's quality and quantity following harvest, which impacts its marketability, shelf life and economic value. Factors such as the time elapsed post-harvest and temperature management throughout the supply chain are critical in determining the final product quality (Olafsdóttir et al. 1997; Olafsdóttir et al. 2004). Studies have identified significant post-harvest losses of GFP at various handling stages, with severe quality degradation frequently occurring during transportation (Kamal et al. 2000). Moreover, delays in handling after harvest have been shown to impact product quality negatively (Rahman et al. 2001), and notable quality losses have been documented under different storage conditions. As international markets increasingly demand traceable, high-quality seafood products that meet rigorous food safety and environmental standards, it is crucial to minimise post-harvest losses and improve handling efficiency throughout the export-oriented GFP market chain in Sri Lanka (Martinsdóttir et al. 2001; Paul 2014). Understanding the critical control points and loss mechanisms is vital for developing targeted interventions that enhance value retention and sustainability in the industry. Therefore, this study aims to investigate the extent and causes of post-harvest losses in Sri Lanka's GFP industry, from harvesting at reservoirs to

final export. By examining practices related to handling, storage, transport and marketing, this research provides insights and practical recommendations to reduce losses, enhance product quality, and improve the global competitiveness of the Sri Lankan freshwater prawn industry.

Materials and methods

The present study, conducted from May 2022 to May 2023, examined fisher communities fishing in 22 dry zone perennial reservoirs across 9 administrative districts of Sri Lanka (Table 3.3.1). A structured questionnaire, developed and refined through preliminary surveys, was administered in data collection, carried out through interviews, focus group discussions and key informant interviews, for which interviewees were selected employing the snowballing sampling technique (Biernacki and Waldorf 1981; Deepananda et al. 2015; Naderifar et al. 2017). Consequently, stakeholders in the GFP market chain, including fishers, collectors, factory agents, exporters and aquaculture extension officers, were identified and interviewed. The study administered a total of 286 questionnaires to assess aspects including harvesting, post-harvest handling, pricing, transportation and market challenges. The accuracy of the collected data was validated through additional assessments and interviews with the key informants. Moreover, primary in-situ data concerning harvesting methods, post-harvest losses, storing, and export procedures were collected from key informants selected at each node of the market chain. The data collected were analysed, and the outcome was aptly presented to elucidate the post-harvest losses at each node of the GFP market chain. In this context, the currency conversions were made based on the conversion rate in February 2023, when USD1 was approximately LKR362.7.

Table 3.3.1: Details of the dry zone perennial reservoirs of Sri Lanka used for the present comprehensive study

District	Reservoir name	Reservoir category	Area at FSL (ha)	Effective area (ha)	GPS coordinates	
					Lat	Long
Anuradhapura	Nachchaduwa	Major	1,781	891	8° 25'25.47"	80° 48'11.58"
Hambantota	Ridiyagama	Major	871	436	6° 20'68.02"	80° 98'63.33"
	Weerawila Wewa	Medium	567	284	6° 28'74.36"	81° 23'82.85"
	Mahagalwewa	Minor	140	70	6° 39'53.97"	81° 03'76.10"
Kilinochchi	Iranamadu	Major	2,927	1,464	9° 31'76.75"	80° 44'97.85"
	Akkarayankulam	Major	809	405	9° 29'73.48"	80° 32'76.40"
	Puthumurippu	Minor	151	76	9° 36'17.11"	80° 35'43.26"
Kurunegala	Siyambalangamuwa	Medium	210	105	8° 06'27.04"	80° 31'78.40"
Monaragala	Muthukandiya	Medium	560	280	6° 97'97.02"	81° 50'32.15"
	Kiriibban wewa	Medium	375	188	6° 37'57.99"	80° 97'00.30"
	Urusita wewa	Medium	262	131	6° 33'26.15"	80° 93'36.58"
	Handapanagala	Medium	226	113	6° 66'55.47"	81° 15'16.60"
	Hambegamuwa	Medium	210	105	6° 54'19.86"	80° 95'65.25"
Mullaithivu	Vavunikulam	Major	1,275	638	9° 08'99.70"	80° 35'13.69"
	Muthiyankaddu	Major	1,255	628	9° 20'15.21"	80° 60'75.41"
Puttalam	Tabbowa	Medium	607	304	8° 07'25.54"	79° 95'54.42"
	Devalahandiya	Medium	257	129	7° 78'74.86"	79° 87'92.12"
	Karavitagaraya	Medium	256	128	7° 56'80.43"	79° 84'85.60"
	Vijayakatupotha	Medium	243	122	7° 72'00.39"	79° 89'51.42"
Trincomalee	Mahadiulwewa	Medium	543	272	8° 60'70.43"	80° 95'35.57"
	Wendrasanwewa	Medium	410	205	8° 39'19.00"	81° 00'87.70"
Vavuniya	Bogaswewa	Medium	472	236	8° 88'66.60"	80° 65'81.77"

FSL = Full Supply Level



Results

Harvesting practices and handling loss

GFP was primarily harvested using gillnets with a mesh size of 3.5 inches and above as bycatch from finfish fishing operations. Harvesting typically began in the evening, between 2 pm and 4.30 pm, when gillnets were set, and the catch was retrieved the following morning, between 8 am and 10 am. Harvest losses were attributed to predation, physical damage, molting and delays in retrieval. The leading causes of these losses were predation and quality deterioration, including head loss and broken appendages. Among the total GFP entangled in gillnets, the highest predation rate (60.1%) was documented at the Dewalahandiya reservoir, while the lowest (2.8%) was reported at the Ridiyagama reservoir. The percentage of GFP with head loss ranged from 0.7% (Dewalahandiya) to 5.6% (Ridiyagama), whereas appendage damage varied from 1.2% (Mahadivul Wewa) to 7.9% (Kiri Ibban Wewa) at the producer level. The proportion of molted GFP in the harvest ranged from 1.2% at Mahadivul Wewa to 15.2% at Mahagal Wewa reservoirs (Figure 3.3.1).

Market-chain structure and pricing

The post-harvest handling and marketing of GFP in Sri Lanka involved various stakeholders, including fishers, collectors, factory agents, exporters, consumers, input suppliers, support staff and regulatory authorities. As the producers, fishers sold their harvest mainly to local collectors, while smaller quantities were sold directly to central collectors or factory agents. Local collectors were crucial intermediaries between fishers and central collectors, who supplied GFP to the factory agents. Central collectors sold their stock directly to factory agents, facilitating transactions between intermediaries and exporters.

Exporters, the final node in the Sri Lankan market chain, obtained GFP exclusively from designated factory agents without direct engagement with other stakeholders. Input suppliers in the GFP market chain included providers of nets and boats, as well as repair and financial services. Additionally, suppliers offered materials such as Styrofoam and FRP boxes, ice, transportation and fuel. Support staff were vital in ensuring product quality, safety and financial operations.

GFP pricing was determined by quality. Collectors purchased high-grade GFP from fishers at an average price of LKR1,800/kg (≈USD5), while lower-grade GFP was acquired at an average of LKR850/kg (≈USD 2). Higher-level market-chain actors acquired GFP from local collectors at prices ranging from LKR1,150/kg (≈USD3) for low-grade to LKR2,550/kg (≈USD7) for high-grade. Exporters obtained GFP from factory agents at LKR2,000–4,000/kg (≈USD6–11) and sold it internationally at an average price of LKR4,533–8,160/kg (≈USD12.5–22.5).

Post-harvest handling and quality management

Grading

GFP was not graded by fishers before sale. Local collectors, except those from Ridiyagama, Hambegamuwa, Karawitagala and Urusitawewa, graded GFP at purchase. They classified GFP into grading categories: Ga (male and others), Gb (soft-shelled and others), Gc (200 g and below, soft-shelled, head-loose), and Gd (less than 100 g and soft-shelled). Central collectors, except in Karawitagala and Mahadivulwewa, graded GFP before purchase and regraded purchased GFP into grading categories such as male, female, head-loose and soft-shelled. Most factory agents classified GFP based on weight (100 g and above

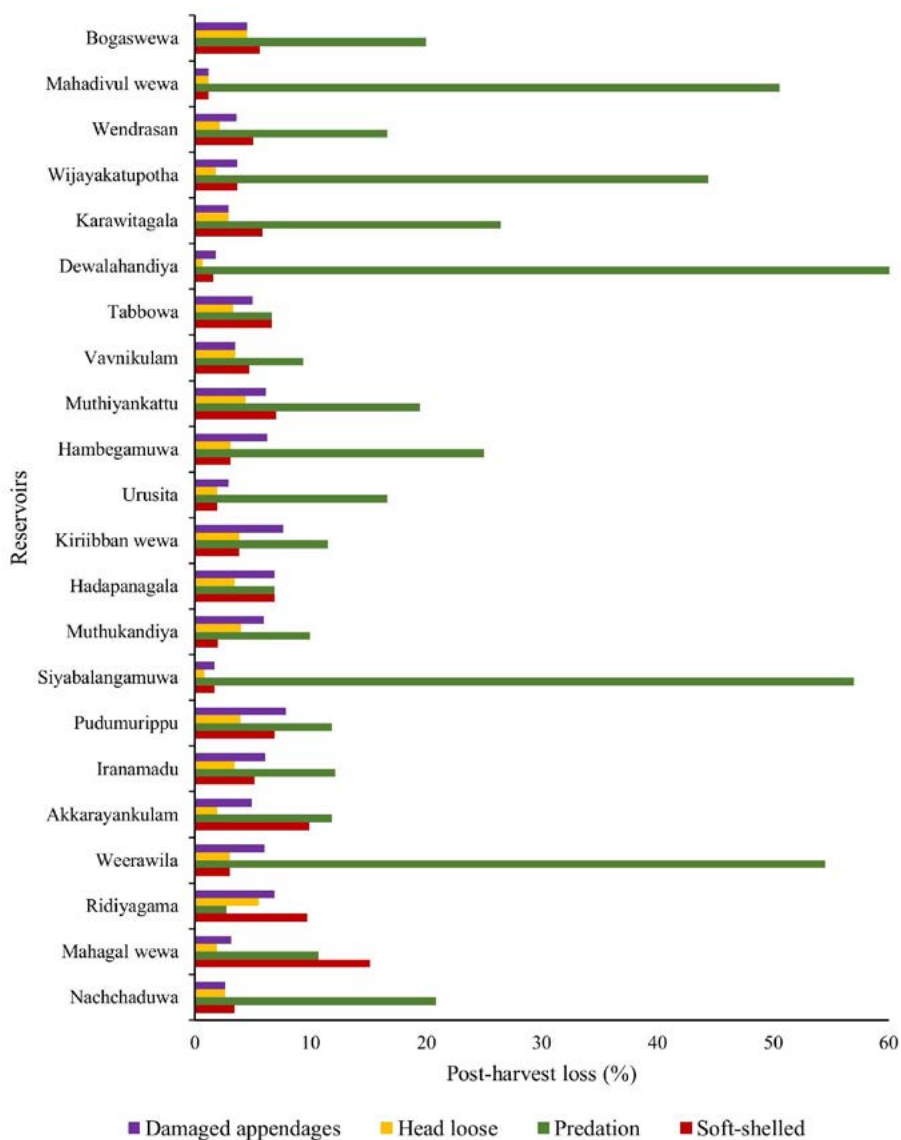


Figure 3.3.1: Harvesting and post-harvest handling losses observed in producers (fishers) at each study reservoir



or 450 g and above), while others at the Nachchaduwa, Wendrasan and Muthukandiya reservoirs employed sex (male and female) and condition-based grading (head-loose and soft-shelled). Final grading was performed by exporters within factory premises before processing, using weight and quality as the primary criteria.

Storing

Fishers did not store their harvest, but the other key actors in the market chain stored GFP before selling. The duration of storage varied from one actor to other, and some local collectors, such as those at Ridiyagama and Tabbowa reservoirs, sold their stock within one to 2 hours, while others in reservoirs like Vavnikulam, Muthiyankattu and Iranamadu kept the GFP until the next day. At Nachchaduwa and Karawitagala, the storage duration was 2 to 3 days. Central collectors typically stored GFP for up to 2 days, while the factory agent at Dewalahandiya kept stock for up to 2 days. Exporters stored fresh (chilled) GFP for a maximum of one day, ensuring that the export process was completed on the same day as unloading. In contrast, frozen GFP was stored for up to a year until orders were received.

Local collectors primarily used a 3:1 GFP-to-ice ratio, central collectors employed a 2:1 ratio, and factory agents utilised a 1:1 ratio. Washing was conducted solely at the exporter level, where freshwater was applied for chilled products, and a chlorine bath (70 g Cl/1,000 L at 4 °C) was employed for frozen items. Local collectors predominantly stored GFP in FRP containers, with some opting for freezers or ice-filled non-functional freezers. Frozen GFP was maintained at -18 °C at export facilities, while chilled products were kept in FRP containers.

Transporting

The shortest transport time, ranging from 5 minutes to 3 hours, was recorded between fishers and local collectors, while the longest transport time of 3 to 6 hours was observed from factory agents to exporters. Local collectors dwelling near reservoirs who reach their homes within 5 to 30 minutes use motorcycles or walk as a mode of transportation. GFP was transported by central collectors using lorries within 2 to 3 hours, while factory agents at Mahagalwewa and Dewalahandiya used lorries which took 3 to 5 hours to reach the destination. The transport time between local collectors and the next node varies from 20 minutes to 6 hours, where lorries serve as the primary mode of transport. Factory agents transported GFP to exporters using lorries within 3 to 6 hours. Among the factory agents, 40.91% received salaries with commissions, while others operated independently. Most local collectors relied on Styrofoam boxes for GFP transportation. Central collectors and factory agents utilised FRP boxes for both transport and storage. The exporters packaged chilled products in Styrofoam boxes and frozen products in cardboard boxes. Table 3.3.2 summarises details on grading, storage and transportation at each node of the GFP market chain. The input and product flow, along with the extent and causes of post-harvest losses at each key actor, are depicted in Figure 3.3.2, which provides a detailed overview of the GFP market chain in Sri Lanka.

Table 3.3.2: Post-harvest handling (grading, storing and transportation) by the key actors of the export-oriented GFP market chain in Sri Lanka

Reservoir	Fishers			Local collectors			Central collectors			Factory agents			Exporters				
	Grading	Storing time (day)		Grading		Storing time (day)	Transportation to next node		Grading	Storing time (day)	Transportation to next node		Storing	Time Mode (-hr)	Transportation to next node		
		Time (-min)	Mode	Storing time (day)	Time Mode (-hr)		Time Mode (-hr)	Time Mode (-hr)									
Nachchaduwa Mahagal wewa Ridiyagama Weerawila Akkarayankulam Iranamadu Pudumurippu Siyabalangamuwa Muthukandiya Hadapanagala Kiriibban wewa Urusita Hambegamuwa Muthiyankattu Vavnikulam Tabbowa Dewalahandiya Karawitagala Wijayakatupotha Wendrasan Mahadivul wewa Bogaswewa	On-site selling; No storing																
	5	F	Ga	2	2-4	L	x	x	x	Gf	0-1	3-4	L	Frozen: up to 1 year; Fresh: 0-1 day		Based on destination and product type Frozen: Air freight; Frozen: Sea freight	
	180-300	L	x	x	x	x	x	x	Ge	0-1	4-6	L	Soft-shelled or quality and weight based				
	15	B	No	No	1/3	B	Gf	0-2	1-2	L	Ge	0-1	4-6	L			
	15-20	B	Ga	1-2	2-4	L	x	x	x	Ge	0-1	4-6	L				
	20-30	B	Ga	0-1	4-6	L	x	x	x	Ge	0-1	3-4	L				
	15-20	B	Ga	0-1	4-6	L	x	x	x	Ge	0-1	3-4	L				
	10-15	B	Ga	0-1	4-6	L	x	x	x	Ge	0-1	3-4	L				
	15	B	Gc	2	6	L	x	x	x	Ge	0-1	6	L				
	15	B	Gc	2	3-5	L	x	x	x	Gf	0-1	4	L				
	10	B	Ga	2	3-5	L	x	x	x	Ge	0-1	4-6	L				
	60	B	x	x	x	x	Gf	0-1	1-3	L	Ge	0-1	4-6	L			
	150	B	No	2	2	B	Gf	0-2	1-3	L	Ge	0-1	4-6	L			
	10-20	B	No	0-1	2-3	L	x	x	x	Ge	0-1	4-6	L				
	15-20	B	Ga	0-1	4-6	L	x	x	x	Ge	0-1	3-4	L				
	15-20	B	Ga	0-1	4-6	L	x	x	x	Ge	0-1	3-4	L				
	30	B	Gb	No	1/3	L	Gf	0-1	1-1.5	L	Ge	0-1	3-4	L			
	5-10	B	x	x	x	x	x	x	x	Ge	2	3-4	L				
	5-10	F	No	2-3	1-2	L	No	0-1	2-3	L	Ge	0-1	3	L			
	30	B	Gd	2	1-3	L	x	x	x	Ge	0-1	2-4	L				
	20	B	Gb	1-2	3	L	x	x	x	Gf	0-1	4-5	L				
	120-180	L	x	x	x	No	0-2	1-3	L	Ge	0-1	5	L				
	10	B	Ga	1-2	2-4	L	x	x	x	Ge	0-1	3-4	L				

Notes: Ga - male and other (female, head loose, soft-shelled); Gb - soft-shelled (molted) and other (male, female, head loose); Gc - 200 g (male/female and 200 g, soft-shelled, head loose); Gd - 100 g and soft-shelled; Ge - based on quality and weight; Gf - male/female, head loose, soft-shelled; B - bike; L - lorry; F - by foot).

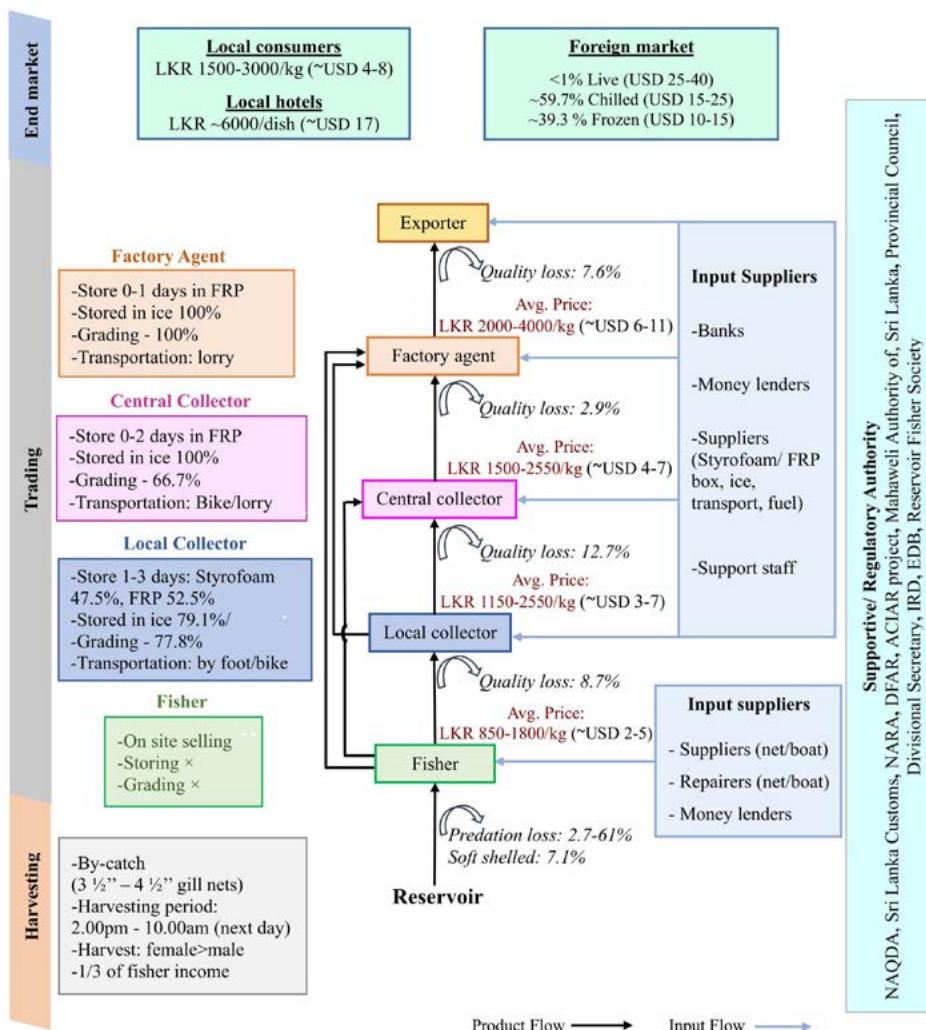


Figure 3.3.2: A detailed overview of the input and product flow, as well as post-harvest losses, at each key actor in the GFP market chain in Sri Lanka

Note: NAQDA – National Aquaculture Development Authority; NARA – National Aquatic Resources Research and Development Agency; ACIAR – Australian Centre for International Agricultural Research; IRD – Inland Revenue Department; EDB – Sri Lanka Export Development Board.

Export market trends

Sri Lanka exports GFP mainly in fresh (chilled) and frozen forms. Chilled GFP makes up nearly 60% of exports, primarily to Southeast Asia. Frozen products underwent blast-freezing and were shipped to Europe and other markets. Strict quality standards, including grading based on weight and appearance, determined export viability.

Discussion

Sri Lankan reservoir fisheries operate under community-based, self-governing systems, where local fisher communities establish and enforce fishing practices to ensure the social wellbeing of the fisher communities. Although it is not a primary target species, the GFP (*M. rosenbergii*) is frequently caught as bycatch in gillnets deployed overnight. This is mainly due to GFP nocturnal and benthic behaviour, which increases its vulnerability to passive fishing gear, gillnets (Brown et al. 2010) and significantly contributes to fishers' income. The growth of GFP depends on molting, which is influenced by inhabiting environmental conditions (Aiken 1980; Boyd 1990; Dall et al. 1990). The high molting rates observed in the Mahagalwewa reservoir indicate favourable conditions for GFP growth. However, molted prawns are considered unsuitable for the export market, leading to economic losses. Conspicuously, predation and improper handling during harvesting further diminish the yield and quality of GFP. Addressing these challenges necessitates strategies to reduce predatory pressure on GFP entangled in gillnets and enhance the fisher awareness for proper post-harvest handling.

The structure of the Sri Lankan GFP market chain varies by district/reservoirs, with different numbers of intermediaries in

the market chain connecting fishers to exporters. GFP is consistently supplied to exporters through factory agents, and 4 leading export-oriented market chains have been identified (authors' unpublished data). Field observations and stakeholder interviews have identified 4 primary market channels in the GFP value chain, including:

1. direct sale from fisher to factory agent
2. fisher to collector to factory agent
3. fisher to local trader to factory agent
4. fisher to local market, bypassing the export chain.

The prevalence of each channel is influenced by factors such as daily harvest quantity, the distance between the reservoir and the trader or processor, the availability of insulated transportation, and local infrastructure facilities and conditions. The study confirms that intermediaries play a crucial role in pricing and market access, while regulatory bodies ensure compliance with quality and safety standards, ensuring continued production in the long run. Furthermore, analysing these market channels offers insights into GFP distribution and stakeholder interactions. Thus, the study affirms that optimising these systems can enhance market efficiency and competitiveness and reduce post-harvest losses.

The export value of GFP in Sri Lanka demonstrates notable fluctuations over time, influenced by a combination of intrinsic biological factors and extrinsic market dynamics. A significant challenge within the GFP value chain is the dominant role played by market intermediaries, particularly collectors who represent the higher nodes of the market chain and exert substantial influence over pricing mechanisms. Fishers typically accept prices set by collectors, which



reduces their earnings. However, the study reveals that direct sales through fisher cooperatives would enhance fisher income and minimise post-harvest losses. The GFP is generally categorised into 2 primary quality grades: high and low, based on physical appearance, integrity and freshness. Quality categorisation is heavily influenced by handling procedures during harvest, packing and transportation. Poor practices such as delayed retrieval from nets, exposure to sunlight and inadequate chilling lead to physical damage, including broken appendages, soft shells from recent molting and head detachment. These conditions downgrade the product to a lower quality category, resulting in a substantial price reduction in the next node of the market chain. The resulting price gap between high- and low-quality GFP can be substantial, translating into financial losses for fishers and downstream stakeholders, including collectors and exporters. Furthermore, the diminished volume of high-grade prawns constrains the competitiveness of Sri Lankan GFP in premium international markets, where product appearance and quality are critical. As GFP is a lucrative commodity, these post-harvest losses negatively impact food security, income stability and the development of inland fisheries.

Grading responsibilities generally begin at the collector level. Local collectors, who purchase GFP directly from fishers, commonly classify GFP into 2 broad categories. The high grade consists of high-quality, hard-shelled, intact prawns, typically male individuals weighing over 100 g. These prawns are favoured by exporters for their superior appearance, meat content and durability during transport. The low grade (quality) includes prawns with detached heads (head-loose), soft shells from recent molting,

broken appendages, and females, which are considered less valuable due to their fragility and reduced meat yield. Central collectors at selected reservoirs employ a more detailed grading system based on sex, head condition and molting, as mandated by factory agents. Factory agents assess GFP by quality and weight, while exporters apply their standards before sorting based on international market demand. Our findings confirm that robust grading practices from the fisher level onward through the market chain can enhance market segmentation, reduce spoilage and increase the income of each actor in the market chain. Training fishers in post-harvest handling and on-site grading can help them supply more consistent, high-quality GFP and strengthen their role in the GFP market chain.

The quantity of GFP collected daily by local and central collectors is often minimal, discouraging central collectors and factory agents from frequent reservoir visits. Consequently, local and central collectors must store GFP within their limited storage facilities for up to 3 days until a substantial collection is received. Extended storage time at this node may result in more significant post-harvest quality loss. In some cases, factory agents and exporters store GFP for at least one day due to transportation delays. Ahmed et al. (2009) have observed that GFP traders supply their prawns directly or through agents to exporters within one to 2 days of purchase. In contrast, the present study indicates that GFP purchased by local collectors reaches exporters within zero to 6 days (excluding transportation time).

The use of ice is critical in preserving the post-harvest quality and extending the shelf life of GFP throughout the supply chain. Effective chilling through icing slows down microbial growth and enzymatic

activity, which are key contributors to spoilage in aquatic products (Tsironi et al. 2009; Wachirasiri et al. 2016). Studies have shown that maintaining an optimal ice-to-product ratio, typically between 1:1 and 1:3, can preserve sensory and microbiological quality of GFP for up to 5 days under ambient tropical conditions (Paul 2014). Although icing is commonly practiced along the supply chain, it is often overlooked at the producer level (Hassan et al. 2012). Our study reveals that only half of local collectors use sufficient ice, while a significant portion use very little. A similar scenario has been reported in Bangladesh, where many collectors utilised minimal ice during transport (Alam 2010). Proper icing dramatically influences the quality indicators, as demonstrated by Martinsdottir et al. (2001) and Paul (2014). Improving icing practices at the GFP supply chain, especially at the fisher and local collector levels, is essential for reducing post-harvest losses, maintaining product quality and meeting export market standards.

Fishers sell GFP at landing sites, while local collectors transport them using various methods, often challenged by poor rural roads. In contrast, urban-based factory agents benefit from superior transport infrastructure. The study identifies that thermal insulation is crucial for maintaining the quality of GFP during storage and transportation. Thus, most stakeholders now use Styrofoam or FRP containers, which provide better temperature control than older materials such as wood or aluminium (Quang 2005; Vyncke 1965; FAO 2003; Hassan et al. 2012).

Market fluctuations, infrastructure limitations and regulatory compliance issues impact Sri Lanka's competitiveness in global GFP markets. Improving processing techniques like individual quick freezing

(IQF) and developing value-added products would enhance export potential. International buyers prioritise reliable supply, stringent quality standards, and food safety and sustainability certifications. The ability of Sri Lankan entrepreneurs to meet these demands is crucial for their competitiveness in global seafood markets. To improve its position, Sri Lanka must strengthen regulatory frameworks, enhance traceability systems and adopt environmentally sustainable practices. By focusing on certification and sustainability, Sri Lanka can improve market access and build buyer confidence, ensuring the long-term growth of the GFP industry.

Conclusion

Post-harvest loss in the Sri Lankan GFP industry is a multifaceted issue that affects the entire value chain, from harvest to export. Significant losses arise from poor handling during harvesting, inadequate icing, suboptimal storage, delayed transportation and inconsistent grading practices. Predation, physical damage, molting and the lack of immediate icing led to significant quality deterioration at the producer level. Although some storage container use and storage infrastructure improvements have been made, challenges persist, particularly in rural areas with limited road access and insufficient cold chain facilities. Furthermore, fishers have limited bargaining power and frequently rely on intermediaries, diminishing their income and undermining quality control at the source. The complex market chain, which consists of multiple intermediaries such as collectors, factory agents and exporters, introduces variability in quality management and pricing. Inconsistent grading, infrequent collection due to low daily harvest volumes, and extended storage times further deteriorate the

harvest. Although exporters maintain better quality standards, downstream inefficiencies often affect them. These cumulative losses impact not only economic returns but also food security, the sustainability of inland fisheries and the global competitiveness of the Sri Lankan GFP industry.

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3.4 Carapace length and exoskeleton weight help predict chitin yield of giant freshwater prawn (*Macrobrachium rosenbergii*) cultured in perennial reservoirs across different agroecological zones in Sri Lanka

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Abstract

Chitin, the second most abundant polysaccharide, is found in the exoskeletons of crustaceans, including the GFP (*M. rosenbergii*), which is an important commodity in CBF in Sri Lanka. We examine the chitin yield of GFP inhabiting perennial reservoirs (n=25) scattered across different agroecological zones (n=6) in Sri Lanka, as well as the relationships between chitin biomass from GFP exuviae and morphometric characteristics (GFP length) and yield characteristics (exoskeleton weight) of GFP collected from various agroecological zones. The discarded inedible exoskeletons of GFP are used to extract chitin through a process that includes preconditioning, demineralisation and deproteinisation. The chitin yields significantly differ ($p < 0.05$) among GFP-inhabiting reservoirs across agroecological zones. The highest biometric characteristics of GFP are observed in reservoirs with annual rainfall of 900 mm or less, which may enhance the production of GFP through CBF in Sri Lanka. The highest chitin yield ($18.30 \pm 5.24\%$) was obtained from GFP exoskeletons inhabiting reservoirs with 900 mm of annual rainfall. Strong correlations were observed between chitin yields and carapace length, as well as the shell weight of GFP inhabiting reservoirs across the 3 derived agroecological zones. The results support the hypothesis that the agroecological status of reservoirs influences the quantity of chitin extracted from the exoskeletons of GFP. Thus, the study concludes that the chitin yield of GFP can be predicted using either carapace length or exoskeleton weight, which could assist in establishing a small-scale chitin production industry in Sri Lanka.

Keywords: culture-based fisheries, agroecological zones, relationship, predicting, chitin

Introduction

Sri Lanka is blessed with large, perennial and small, seasonal reservoirs (Chandrasoma et al. 2015). As of 2019, a total of 1,398 perennial reservoirs, including 43 major perennial reservoirs, 92 medium perennial reservoirs and 1,263 minor perennial reservoirs, were scattered across 25 administrative districts of Sri Lanka (Anon 2022). Additionally, numerous small tanks are dispersed throughout the dry zone, and local scientists have found that developing CBF in these seasonal, small reservoirs is more effective for boosting inland fish supply (Amarasinghe and Wijenayake 2015; Silva et al. 2006). Although the perennial reservoirs are mainly impounded for agricultural use, hydroelectricity generation and drinking water supply, they are rarely utilised for fishery development (De Silva and Amarasinghe 1996; Nissanka and Amarasinghe 2000). The reservoirs in Sri Lanka are scattered across various agroecological zones. Agroecological zoning (AEZ), as outlined in studies by the Food and Agriculture Organisation of the United Nations (FAO 1996), defines different zones based on combinations of soil, landform and climatic characteristics. The specific parameters used in this definition emphasise climatic and edaphic requirements of crops and the management systems under which they are cultivated. Each zone presents a similar combination of constraints and opportunities for land use, offering a foundation for targeted recommendations to enhance the existing land use situation, either by increasing production or mitigating land degradation (FAO 1996). Annual rainfall is the primary factor influencing the division of agroecological zones in Sri Lanka (Premarathne and Pushpakumara 2025).

From the earliest recorded history, inland fisheries have played a key role in supporting the subsistence economy of Sri Lanka (Jones et al. 2021). The large-scale development of inland fisheries began only in the early 1950s with the introduction of tilapia, as well as Indian and Chinese carp, into the dry zone reservoirs of Sri Lanka. CBF in Sri Lanka began in the 1960s by stocking Mozambique tilapia in some reservoirs. CBF, which involves direct stocking and recapturing strategies, significantly increases yields in both perennial and non-perennial reservoirs. Introducing CBF in village reservoirs is the most important strategy for enhancing inland fisheries (Amarasinghe and Wijenayake 2015). Exotic tilapia, Chinese and Indian major carps, along with indigenous GFP (*M. rosenbergii*), are the primary commodities utilised for CBF in both perennial and seasonal reservoirs across Sri Lanka (Deepananda et al. 2014). In 2019, the annual fish production in Sri Lanka's aquaculture sector was 10,710 mt, with 1,195 mt attributed to GFP catch (Ministry of Fisheries and Aquatic Resources Development 2022). The GFP culture is gaining popularity among crustacean farming due to several key factors, including its profitability, which is a source of income for rural families. It enables inland farming on both small and large scales (not limited to coastal areas) and supports polyculture with carp, tilapia and barbs. Additionally, GFP culture has lower feed costs, as these organisms are omnivorous and have a wide availability of food resources in the reservoirs, while reducing input costs. It also reduces expenses for pesticides and herbicides, as GFP feeds on fish parasites and weed seeds in paddy fields while enhancing soil fertility (Chowdhury et al. 1993).



Chitin is a vital compound in insect cuticles and the cell walls of fungi, which account for about 500–5,000 kg/ha of chitin in the soil (Pillai et al. 2009). Consequently, large amounts of chitin are synthesised naturally (Einbu 2007). Chitin, which is composed of N-acetyl-glucosamine (GlcNAc), is the second most ubiquitous naturally abundant mucopolysaccharide after cellulose on Earth (Dutta et al. 2002). The chitin is hard and inelastic (Subasinghe 1999), and the colour of the chitin flakes or powder is either white or yellowish. Crustaceans lack a backbone; they typically possess a hard exoskeleton that protects their soft internal bodies from predators and various diseases. The cuticle of crustaceans is composed of 4 distinct layers. From outermost to innermost, these layers include the epicuticle, exocuticle, endocuticle and a membranous layer (Simkiss and Wilbur 1989). The outermost epicuticle is a barrier against the external environment due to its waterproof properties, with a thickness ranging from 1 to 5 µm. The exocuticle accounts for one-fifth of the cuticle and contains unevenly distributed calcium carbonate within canals of pores and chitin-protein fibrils. Before molting, these 2 layers are formed, and mineralisation occurs afterwards. In the endocuticle, chitin aligns with protein fibres in a specific arrangement of lamellae (Lowenstam and Weiner 1989). Consequently, 3 significant components can be identified in the cuticle: chitin, protein and calcium carbonate. The relative proportions of these components can vary even within a single individual (Cribb et al. 2009). Chitin in crustaceans appears as a protein-polysaccharide complex, and several different proteins can bind to it to form a chitin/protein complex (Cribb et al. 2009). Following ecdysis, most crustaceans consume exuviae to meet their chitin requirements (Luo 2019). The value addition

of GFP at processing factories usually removes the exoskeleton. Also, scientists have identified the importance of chitin for biomedical purposes. Considering the importance of extracting chitin from GFP, which is a significant biomass of the GFP exoskeleton, the present study examines the influence of the agroecological status on the quantity of chitin biomass in the GFP exuviae obtained from agroecologically different reservoirs in Sri Lanka.

Materials and methods

The present study involved extracting chitin biopolymers from the exoskeletons of male and female GFP, collected from a total of 25 reservoirs across 4 administrative districts in the North Central, North Western, Southern and Uva provinces of Sri Lanka: Anuradhapura, Puttalam, Hambantota and Monaragala. The study reservoirs were assigned to different agroecological zones based on the criteria used by FAO (1996), which helps categorise Sri Lanka into 46 agroecological zones (Table 3.4.1). Consequently, 5 reservoirs in the Hambantota district belong to the lowest annual rainfall zone, DL5, while the other 2, H3 (Muruthawela) and H6 (Udukiriwala), are in the IL1b zone. The Anuradhapura and Puttalam district reservoirs, along with 4 others in Monaragala district, M2 (Kiriibbanwewa), M3 (Urusita), M7 (Habaralu) and M8 (Mahawwewa), belong to the DL1b zone. The remaining 3 reservoirs (M4 – Handapanagala, M5 – Hambegamuwa, M6 – Buduruwagala) are in DL1a. M9 (Sugaladevi) belongs to the DL2a zone, and M1 (Muthukandiya) is in the IL2 zone, representing the zone with the highest annual rainfall among the 6 agroecological zones in the present study. The distribution of study reservoirs across different agroecological zones is shown in Figure 3.4.1. In the present analysis,

Table 3.4.1: Agroecological zones of Sri Lanka and their annual rainfall

	Climate zone	Agroecological zone		Annual rainfall (mm)
1	WET ZONE	UP COUNTRY	WU1	3,100
2			WU2a	2,400
3			WU2b	2,200
4			WU3	1,800
5		MID COUNTRY	WM1a	3,300
6			WM1b	2,900
7			WM2a	2,200
8			WM2b	1,800
9			WM3a	1,600
10			WM3b	1,400
11		LOW COUNTRY	WL1a	3,200
12			WL1b	2,800
13			WL2a	2,400
14			WL2b	2,200
15			WL3	1,700
16	INTERMEDIATE ZONE	UP COUNTRY	IU1	2,400
17			IU2	2,100
18			IU3a	1,900
19			IU3b	1,700
20			IU3c	1,600
21			IU3d	1,300
22			IU3e	1,400
23		MID COUNTRY	IM1a	2,000
24			IM1b	2,000
25			IM1c	1,300
26			IM2a	1,800
27			IM2b	1,600
28			IM3a	1,400
29			IM3b	1,200
30			IM3c	1,100
31		LOW COUNTRY	IL1a	1,400
32			IL1b	1,100
33			IL1c	1,300
34			IL2	1,600
35			IL3	1,100
36	DRY ZONE	LOW COUNTRY	DL1a	1,100
37			DL1b	900
38			DL1c	900
39			DL1d	900
40			DL1e	900
41			DL1f	800
42			DL2a	1,300
43			DL2b	1,100
44			DL3	800
45			DL4	750
46			DL5	650

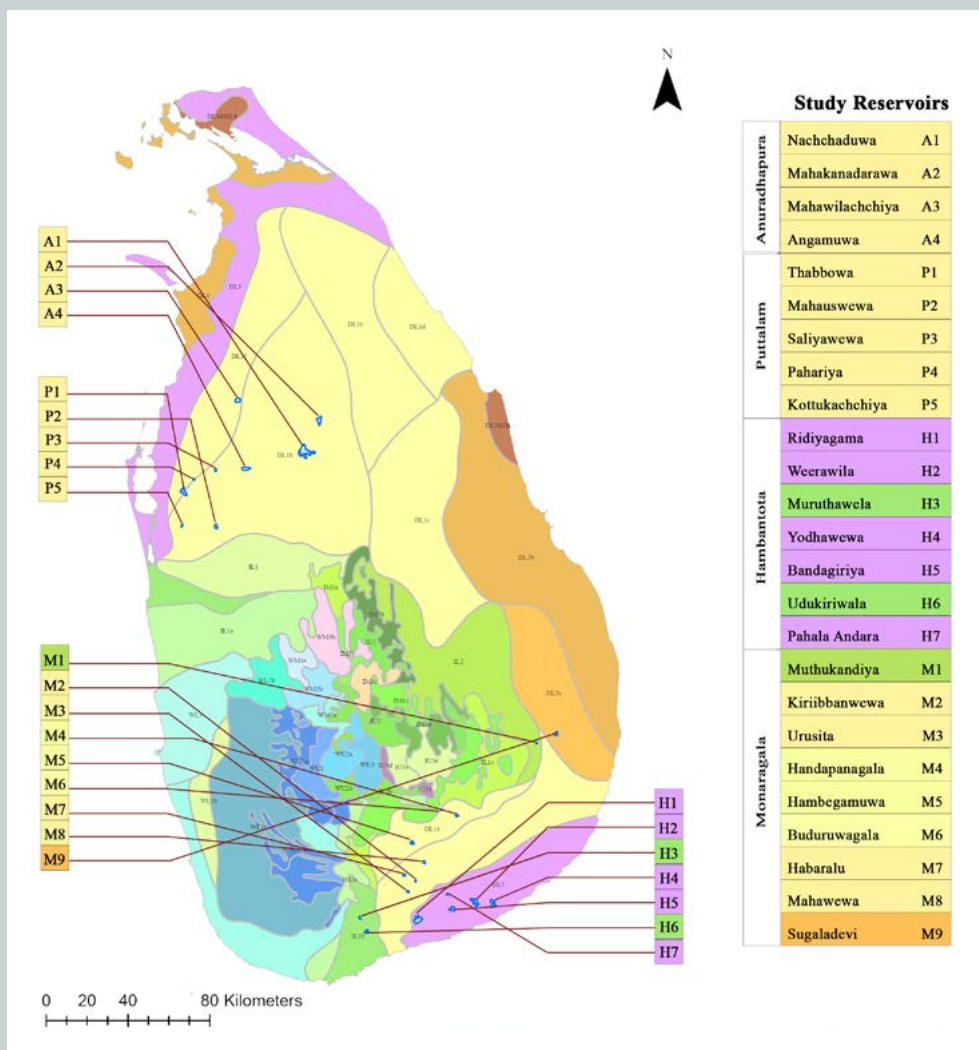


Figure 3.4.1: The map of Sri Lanka, showing the locations of study reservoirs across different agroecological zones in Sri Lanka

the study reservoirs scattered across 6 agroecological zones were grouped into 3 categories based on the annual rainfall (Table 3.4.2). Here, Category 1 represented the 5 reservoirs scattered in areas with <650 mm annual rainfall, and Category 2 included 13 reservoirs scattered in areas with annual rainfall of ≤900 mm. Category 3 consisted of 7 reservoirs with an annual rainfall of >900 mm.

A total of 12 intact (undamaged and no missing appendages) GFP – 6 males and 6 females – were purchased at the fish landing sites of each study reservoir from local fishers (n=25). Collected GFP were arranged in polystyrene boxes layered with ice to prevent damage and losses. Sex differentiation was achieved by identifying the ‘lump’, a spine-like structure located on the ventral side of the first abdominal somite, which is found only in male GFP. The GFP samples were transported to the Fish Post-Harvest Laboratory in the Department of Fisheries and Aquaculture, University of Ruhuna, to complete the experimentation. Total length (TL), taken as the length from the tip of the antennule’s plate to the end of the telson, and carapace length (CL), taken from the base of the eyestalk to the posterior end of the carapace for both sexes, were measured separately using a measuring board and a vernier caliper, respectively. The total body weight of the

respective GFP individuals was measured separately using a top-loading balance (Type 3600, Mettler, Switzerland). Then, the chitin extraction was made separately for male and female GFP at the laboratory, following the procedure outlined in Figure 3.4.2.

The normality of all collected data was assessed using the Shapiro-Wilk test ($p>0.05$). Mean separations were done using the one-way ANOVA and Tukey’s (HSD) studentised range tests at $\alpha=0.05$. Pearson’s product-moment correlation was performed to determine the relationship between the extracted chitin biomass and the carapace length and exoskeleton weight. Regression and correlation analyses were made with the combined sexes of the GFP. Minitab version 20 was used for all calculations and statistical comparisons.

Results

Morphometric and yield characteristics

Morphometric and yield characteristics of male GFP showed higher values than those of females. The highest values for TL, CL, body weight (BW), and exoskeletal/shell weight (SW) were recorded in GFP that inhabited reservoirs in DL1b agroecological zone receiving 900 mm of annual rainfall. The mean, minimum and maximum value ranges of morphometrics for blue-claw

Table 3.4.2: Distribution of study reservoirs in 6 different agroecological zones and categories of the reservoirs used for the present analysis

Reservoir category	Agroecological zone	Annual rainfall (mm)	Reservoir code (see Figure 3.4.1 for the reservoir name)
Category 1	DL5	<650	H1, H2, H4, H5, H7
Category 2	DL1b	≤900	A1, A2, A3, A4, P1, P2, P3, P4, P5, M2, M3, M7, M8
Category 3	DL1a	>1,100	M4, M5, M6
	DL2a	>1,300	M9
	IL1b	>1,100	H3, H6
	IL2	>1,600	M1

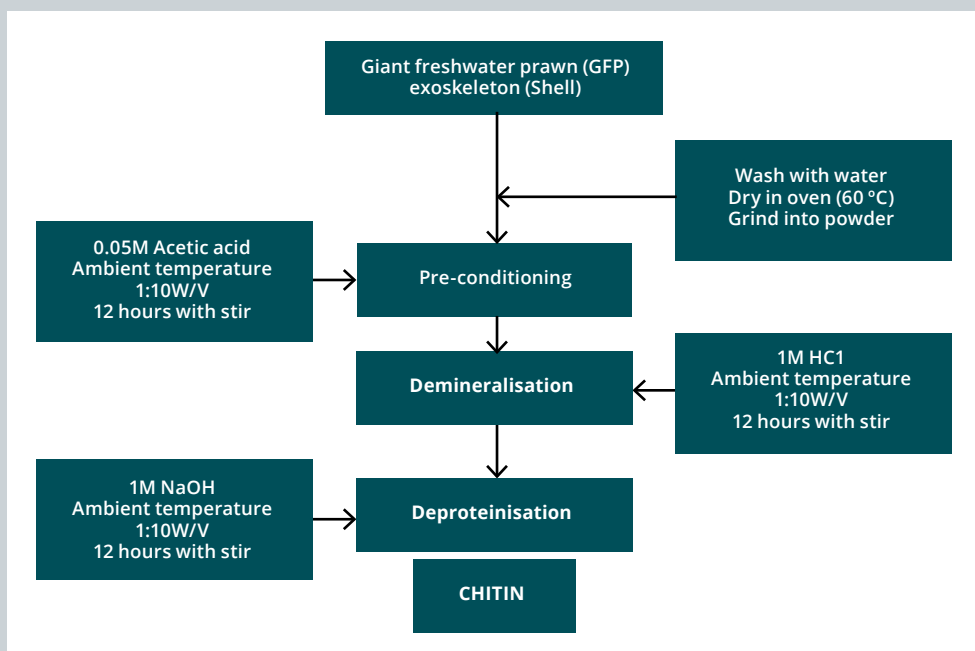


Figure 3.4.2: The flow chart, illustrating the procedure used in isolating chitin from the GFP shells

males (n=150) and females (n=150), and a total of 300 combined sexes GFP, are summarised in Table 3.4.3.

Variations in Chitin across agroecologically different reservoirs

The highest chitin weight and percentage of chitin per SW for male GFP were 9.90 ± 5.49 and 18.45 ± 5.16 , respectively, recorded from the reservoirs in the DL1b agroecological zone, which has an annual rainfall of 900 mm. Conversely, the lowest chitin weight and percentage of chitin per SW for female GFP were 2.31 ± 1.05 and 18.15 ± 5.34 , respectively, also recorded from the reservoirs in DL1b. Descriptive statistics of chitin weight (g) and chitin percentage per SW recorded from blue-claw males, females, and combined sexes of GFP are summarised in Table 3.4.4.

Chitin weight versus morphometric and yield characteristics

The simple linear regression analysis performed on males, females and combined sexes of GFP showed a significant correlation ($p < 0.05$) between the chitin yield and the morphometric (CL) and yield characters (SW). The strongest relationship between CL and chitin weight was reported from the Category 1 reservoirs, followed by Category 3 ($r = 0.80$) and Category 2 ($r = 0.78$) reservoirs, respectively. Also, the strongest to lowest relationship between shell and chitin weights was shown from Category 1 to Category 3 reservoirs, respectively. The correlation and simple linear regression results for combined sexes of the GFP are summarised in Table 3.4.5 and depicted in Figure 3.4.3.

Table 3.4.3: Reservoir category and TL, CL, BW and SW of male, female and combined sexes of GFP collected from agroecologically different reservoirs in Sri Lanka

Morphometric and yield characteristics	Reservoir category	Agro-ecological zone	Male			Female			Combined sexes		
			N	mean±SD	Min-max	N	mean±SD	min-max	N	mean±SD	min-max
Total length (cm)	C1	DL5	30	28.35±3.75 ^a	19.90–33.60	30	24.41±3.12 ^a	18.40–31.00	60	26.40±3.96 ^a	18.40–33.60
	C2	DL1b	78	28.38±3.15 ^a	20.20–35.40	78	24.80±2.95 ^a	17.60–33.10	156	26.58±3.53 ^a	17.60–35.40
	C3	DL1a, DL2a, IL1b, IL1b2	42	26.48±2.31 ^b	18.60–31.00	42	22.57±2.37 ^b	18.40–28.50	84	24.52±3.05 ^b	18.40–31.00
Carapace length (cm)	C1	DL5	30	7.74±1.29 ^{ab}	4.95–9.40	30	6.01±0.88 ^{ab}	4.17–7.58	60	6.88±1.40 ^{ab}	4.17–9.40
	C2	DL1b	78	8.18±1.10 ^a	4.70–10.50	78	6.22±1.03 ^a	4.20–10.50	156	7.20±1.45 ^a	4.20–10.50
	C3	DL1a, DL2a, IL1b, IL2	42	7.21±0.84 ^b	4.26–8.50	42	5.72±0.77 ^b	4.17–8.00	84	6.46±1.09 ^b	4.17–8.50
Body weight (g)	C1	DL5	30	285.30±129.50 ^a	70.00–499.90	30	138.51±52.73 ^{ab}	45.91–263.50	60	211.90±122.80 ^a	45.90–499.90
	C2	DL1b	78	308.00±95.70 ^a	67.40–553.70	78	152.77±67.87 ^a	55.80–519.00	156	230.37±113.57 ^a	55.80–553.68
	C3	DL1a, DL2a, IL1b, IL2	42	222.60±68.60 ^b	55.70–369.00	42	121.88±46.39 ^b	45.91–256.00	84	172.25±77.18 ^b	45.91–369.00
Exoskeleton weight (g)	C1	DL5	30	46.34±24.73 ^{ab}	9.03–98.35	30	18.94±7.99 ^{ab}	6.39–39.16	60	32.64±22.87 ^{ab}	6.39–98.35
	C2	DL1b	78	47.26±26.43 ^a	7.84–120.02	78	26.17±24.19 ^a	6.10–176.78	156	36.72±27.38 ^a	6.10–176.78
	C3	DL1a, DL2a, IL1b, IL2	42	36.07±13.54 ^b	5.49–61.08	42	14.95±4.84 ^b	6.39–24.46	84	25.51±14.66 ^b	5.49–61.08

Note: Superscript letters indicate statistically significant differences between groups. Values that share the same superscript do not differ significantly from one another, whereas values with different superscripts differ significantly based on post-hoc comparisons (p<0.05).

Table 3.4.4: Chitin weight and chitin percentage per SW for male, female, and combined sexes of GFP inhabiting agroecologically different reservoirs

Chitin yield	Agroecological zone	Male			Female			Combined sexes		
		N	mean±SD	min-max	N	mean±SD	min-max	N	mean±SD	min-max
Chitin (g)	DL5	30	7.47±4.03 ^{ab}	1.04-16.09	30	2.57±1.33 ^{ab}	0.74-6.40	60	5.02±3.87 ^{ab}	0.74-16.09
	DL1b	78	9.90±5.49 ^a	0.88-25.41	78	3.35±2.46 ^a	0.85-17.83	156	6.62±5.37 ^a	0.85-25.41
	DL1a, DL2a, IL1b, IL2	41	5.63±2.58 ^b	0.78-14.35	42	2.31±1.0 ^b	0.74-6.70	84	4.01±2.61 ^b	0.74-14.35
Chitin (%)	DL5	30	16.19±2.86 ^{ab}	11.53-28.43	30	13.59±3.38 ^b	4.81-20.18	60	14.89±3.37 ^b	4.81-28.43
	DL1b	78	18.45±5.16 ^a	3.78-34.04	78	18.15±5.34 ^a	6.91-38.79	156	18.30±5.24 ^a	3.78-38.79
	DL1a, DL2a, IL1b, IL2	41	15.79±3.46 ^b	7.80-28.43	42	15.02±3.13 ^b	11.06-29.70	84	15.43±3.29 ^b	7.80-29.70

Note: Superscript letters indicate statistically significant differences between groups. Values that share the same superscript do not differ significantly from one another, whereas values with different superscripts differ significantly based on post-hoc comparisons (p<0.05).

Table 3.4.5: Correlations between extracted chitin weight and morphometric characters, as well as yield characteristics of GFP inhabiting agroecologically different reservoirs in Sri Lanka

Variable 1	Variable 2	Category 1			Category 2			Category 3		
		r	p value	r	p value	r	p value	r	p value	
In carapace length (CL)	In chitin weight	0.89	<0.001	0.78	<0.001	0.80	<0.001			
In shell weight (SW)		0.95	<0.001	0.82	<0.001	0.94	<0.001			

r: correlation coefficient

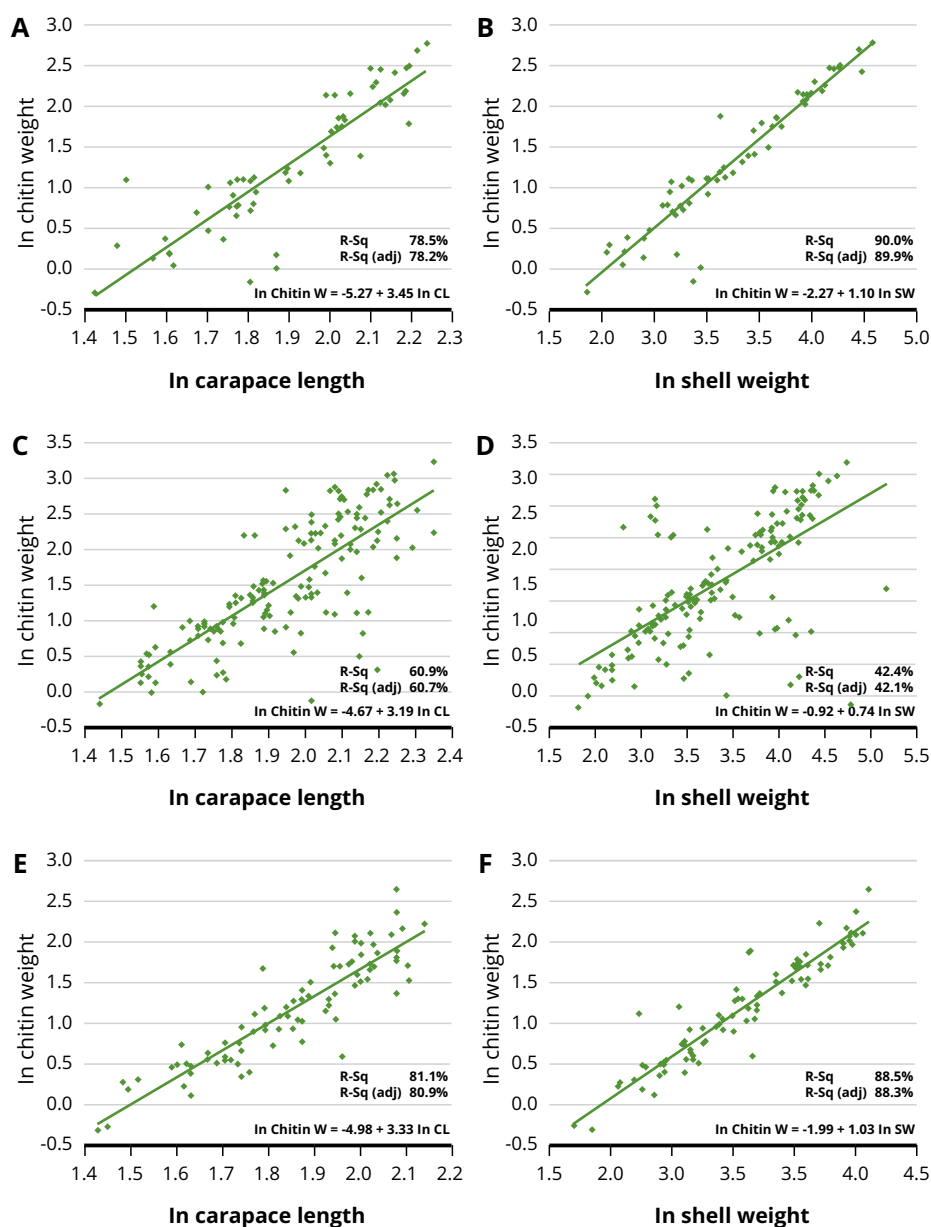


Figure 3.4.3: Simple linear regression between chitin weight and CL and SW of GFP captured from agroecologically different reservoirs in Sri Lanka

Note: a & b for Category 1 reservoirs; c & d for Category 2 reservoirs; and e & f for Category 3 reservoirs.

Discussion

The present findings reveal that the exoskeletons of GFP are an important source of chitin, which is considered a precursor to chitosan, regarded as the wonder drug of the 21st century. Aligning with morphometric and yield characteristics, the highest chitin yield was obtained from male GFP due to their higher SW compared to females. Concerning the biometric characteristics, the higher SW has been reported from males, dwelling in reservoirs in the DL1b agroecological zone, which receives an annual rainfall of 900 mm. The overall outcome of this study indicates that reservoirs located in DL1b agroecological zone with an annual rainfall of 900 mm provide suitable habitats for GFP, an important species in CBF, not only as a food commodity but also as a source for extracting high-quality biopolymer chitin from their exoskeletons. Strong correlations have been observed between chitin weight and CL, as well as with SW in GFP, inhabiting the reservoirs across the 3 categories of agroecological zones. Thus, the present study demonstrates that the chitin yield of GFP can be predicted using either CL or SW.

Sexual dimorphism in the growth of male GFP compared to females has been documented in several studies (Nagamine and Knight 1980; Thanh et al. 2009; Lalrinsanga et al. 2012; Indarjo et al. 2021). The findings align with those studies, showing that the length and weight are significantly higher in male GFP than in females. This reveals that perennial reservoirs of Sri Lanka are ideal for GFP CBF, which yield higher harvest biomass through cultivating larger prawns that attract the export market. Literature confirms that most studies based on agroecological zoning in Sri Lanka have

aimed to address resource management, agricultural production and land-use planning, making it an essential tool for sustainable development (Premarathne and Pushpakumara 2025). Although the present study deviates from conventional techniques, it assists in building a novel approach between agroecological zones and CBF in Sri Lanka. Chitin extraction is a common practice that utilises a large quantity of exoskeletons from crustaceans, internal skeletons of cephalopods (cuttle bones and squid pens/gladius), molluscan shells and fish scales. However, the extraction of this polymer from individual GFP exoskeletons has received less attention in scientific studies. Therefore, for the first time in Sri Lanka, this study has assessed the effects of the agroecological status of GFP residing in dry zone reservoirs and the sexual dimorphism of GFP on the chitin biomass extracted from their exoskeletons. Our findings reveal that male GFP exoskeletons can be used to extract a higher percentage of this polymer than female GFP. The percentage of chitin yield recorded in this study ($18.30 \pm 5.24\%$) aligns with the findings on chitin from shrimp shell waste by Samar et al. (2013), chitin from *P. monodon* shell by Islam et al. (2016), and chitin extracted from deep-sea mud shrimp by Rasweefali et al. (2021). Lobster shells have been reported to yield low biomass, although crabs yield higher biomass. The relatively low chitin yield may be attributed to de-polymerisation and loss of chitin particles during washing (Sewvandi and Adikari 2002). This suggests that innovative methodologies are needed to extract high chitin biomass.

Additionally, the significant findings of this study indicate that the yield of chitin is higher in the GFP inhabiting reservoirs within agroecological zones with annual rainfall of 900 mm (Category 2) compared

to those with less or more than 900 mm (Categories 1 and 3, respectively). The most plausible explanation for this finding is the greater growth of GFP in reservoirs located in agroecological zones with 900 mm of annual rainfall (Category 2), which helps increase SW. According to prior research by Sanuja et al. (2024), most reservoirs in the agroecological zone with 900 mm of annual rainfall (Category 2) can be classified as eutrophic reservoirs, while others are categorised as mesotrophic reservoirs. Although mesotrophic reservoirs are considered healthy aquatic systems with moderate transparency, primary production, alkalinity, well-oxygenated water, and sediments containing moderate amounts of organic matter (Kim and Kim 2021), better results have been observed in eutrophic reservoirs, which are regarded as slightly unbalanced aquatic systems primarily due to anthropogenic nutrient inputs. The CL of GFP is considered the most convenient and accurate morphometric character that can be measured in the field. Therefore, establishing strong correlations and simple linear relationships helps predict the chitin yield of GFP. The present findings can address the lack of scientific research on CBF in agroecological zones in Sri Lanka.

Conclusion

The findings indicate that the amount of chitin extracted from GFP exuviae depends on the agroecological state of the reservoir they inhabit. The highest chitin yield is observed in reservoirs housing GFP, particularly in the agroecological zone DL1b, which experiences an annual rainfall of 900 mm. These findings support the proposed hypothesis that the agroecological status of the perennial reservoirs influences the quantity of chitin extracted from the exoskeletons of

M. rosenbergii and that the chitin yield of GFP can be predicted using either CL or SW. Furthermore, the empirical results recommend collecting GFP from other dry zone perennial reservoirs and expanding the study to include seasonal reservoirs (non-perennial) in Sri Lanka to compare the quantity of chitin extracted from GFP inhabiting these 3 types of reservoirs as well.

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4 Bioeconomics of culture-based fisheries



Canoes made of fibre-reinforced plastic beached during the daytime at Mahadivulwewa Reservoir, Sri Lanka. Photo: Professor Asanka D Jayasinghe.

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 than 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. rosenbergii*). 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 species, 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.

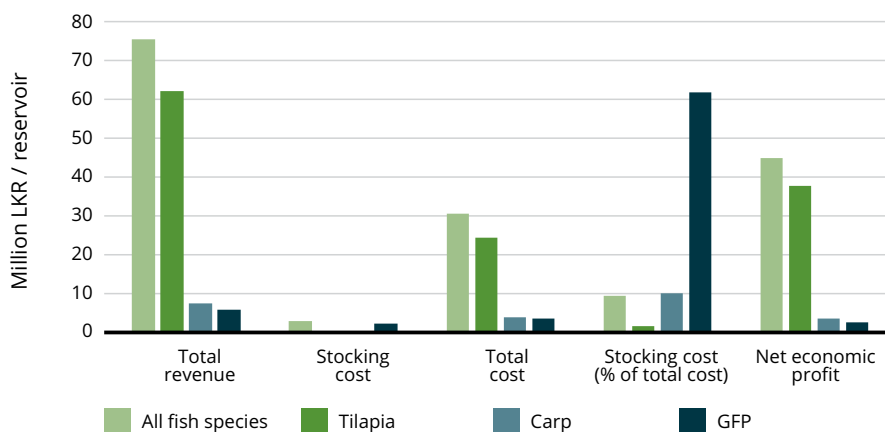


Figure 4.1.1: Economic statistics of CBF in Sri Lanka, 2019 and 2020

When considering the effect of reservoir size on profitability, generally the major reservoirs are more profitable than 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 species 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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4.2 Optimising stocking strategies in Sri Lankan reservoir culture-based fisheries: some bioeconomics and sustainability concerns

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Abstract

The sustainability of the CBF system depends on the balance between stocking and extension practices. This current study focused on selected 24 reservoirs' CBF practices and its economics. During the study we have identified that stocking is a prerequisite, which has been the source of CBF as well as the reservoir fishery of Sri Lanka. Here, the question of interest is whether the intensification of stocking is profitable and sustainable. Descriptive and preliminary bioeconomic analysis was conducted. Primary data were sourced from the logbooks of RFOs and the National Aquaculture Development Authority databases (2019–2020), while secondary data were obtained from RFO administrative and financial records. Stakeholder perception survey on CBF sustainability was included with 176 participants to supplement data. It is evident that the stocking has been conducted arbitrarily, which is obvious in the ad hoc production. The stocking efficiency per area (SEA) has been affected by both fishing intensity (FI) and stocking density (SD) at different rates across the reservoir types. The questionnaire outcomes concluded that intent to increase stocking are with expectation of higher income. From fisher opinions, it is understandable that the economic sustainability has the higher leverage compared to the environmental sustainability.

Keywords: *bioeconomics, culture-based fishery, reservoirs*

Introduction

Stocking strategies are recognised globally as a means to enhance fisheries, among them CBF being a notable environmentally sustainable method (De Silva 2003). CBF distinguishes itself by positioning it between aquaculture and capture fisheries (FAO 2015), resembling characteristics of aquaculture – incorporation of hatchery-reared juvenile fish into natural or semi-natural water bodies such as reservoirs and fisheries – practice of continuous partial harvesting by fishing gear. Additionally, CBF operates as a communal endeavour with somewhat defined ownership (Amarasinghe and De Silva 1999; Amarasinghe and Nguyen 2010). In fisheries and aquaculture

management, bioeconomic approaches are useful to identify optimal production measures in simple systems (Bjorndal 1988; Clark and Munro 1975) relating biological performance production to economic considerations. Further, inclusion of market prices, resource allocation and institutional constraints are also vital in complex system studies (Seijo et al. 1998). Consequently, various empirical methods have been proposed to evaluate the bioeconomic aspects of inland capture fisheries and aquaculture (Geethalakshmi et al. 2021). In addition to addressing food security and livelihoods, the economic sustainability of CBF must be prioritised within management frameworks. To enhance the

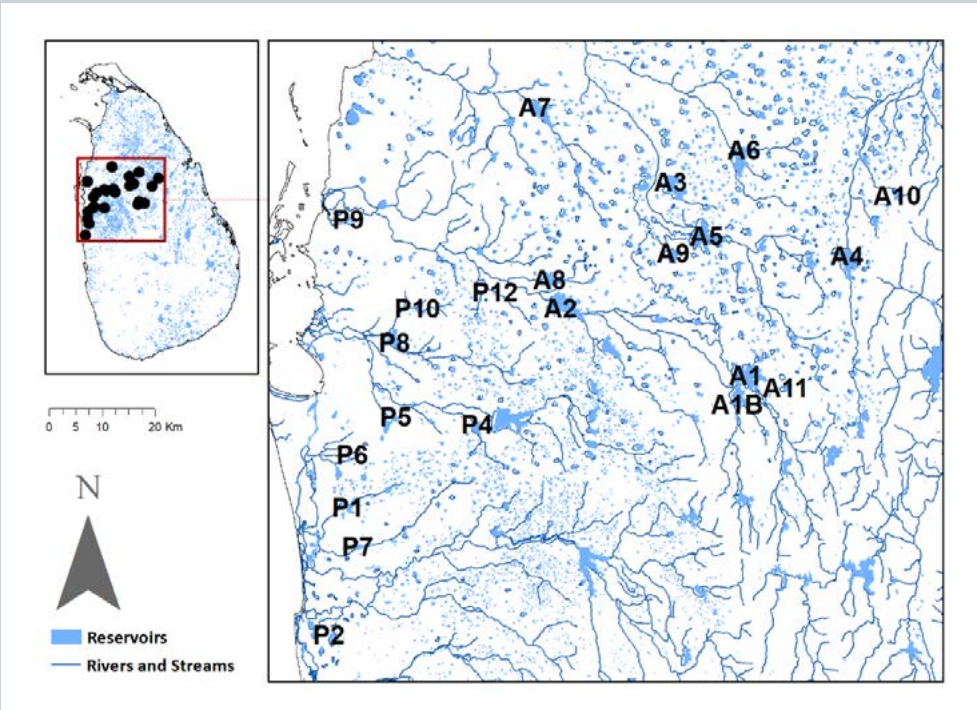


Figure 4.2.1: Locations of reservoirs selected for the study

Note: details of reservoir and the denoted codes are given in Table 4.2.1.



economic benefits of CBF, it is essential to focus on intensifying fishing effort and stocking practices. However, the economic implications of these initiatives should not be overlooked. The potential for increasing fishing effort in reservoir CBF (for instance, open access) is significantly limited due to stringent legal restrictions imposed by inland fisheries regulations in the country. The government, specifically NAQDA, provides substantial subsidies for stocking and extension services through RFOs, which offer certain incentives to CBF fishers operating in reservoirs.

Additionally, our understanding of the bioeconomic dimensions of CBF is limited, which significantly hinders the formulation of more effective strategies for the sustainable development of CBF. This paper, summarising results of the comprehensive study, aims to address 2 key aspects that could enhance CBF planning. We expect to set a foundation for the development of a rational CBF bioeconomic model and articulate implications that are practically viable for sustainable development.

Materials and methods

Twenty-four reservoirs, representing major (>800 ha), medium (200–800 ha) and minor (<200 ha) types, were selected (Figure 4.2.1 and Table 4.2.1). Primary data were sourced from RFO logbooks and NAQDA databases (2019–2020), while secondary data were obtained from RFO administrative and financial records, supplemented by information gathered using open-ended questionnaire field surveys. Bioeconomic variables were calculated using these data (Table 4.2.2), and prices of fish catch and stocking costs are summarised in Table 4.2.3.

Descriptive analysis of bioeconomic variables was conducted. A trend analysis using geomline function (trend of means) was conducted for SEA against both FI and SD, to study the variability. Net economic profit analysis based on the stocking cost categories was conducted. The categorisation was performed by considering species-specific stocking densities and reservoir types, and the details are given in Table 4.2.4.

Further, a preliminary stakeholder perception survey on CBF sustainability included 176 participant stakeholders – fishermen (95), collectors (14), exporters (4), fishmongers (10), villagers (33), extension officers (8), policymakers (3), academics (6) and researchers (3), to broaden data collection by interviews. Then the outcomes of the survey were summarised. Statistical analyses and visualisations were conducted using R software (RCoreTeam 2020).

Table 4.2.1: Details of studied inland reservoirs and RFOs

No.	Name	Recode	Type	Area (ha)	LS	BT	BO	FT	AF
1	Kala Wewa	A1	Major	1,440	5	125	95	130	125
2	Kiulekada	A10	Minor	283	1	10	10	23	10
3	Maha Elagamawa	A11	Minor	80	1	4	3	15	14
4	Balalu Wewa	A1B	Major	1,200	1	79	76	95	91
5	Rajanganaya	A2	Major	1,619	10	180	155	230	230
6	Nuwara Wewa	A3	Major	1,197	4	61	59	110	98
7	Hurulu Wewa	A4	Major	1,619	3	98	72	107	95
8	Nachchaduwa	A5	Major	1,781	4	55	55	107	107
9	Mahakanadarawa	A6	Major	1,457	4	81	65	122	108
10	Mahawilachchiya	A7	Major	971	7	120	114	157	114
11	Angamuwa	A8	Medium	445	4	80	80	120	120
12	Turuwila	A9	Medium	280	3	23	23	45	45
13	Devalahandiya	P1	Medium	257	1	25	16	52	18
14	Pahariya	P10	Minor	72	2	12	8	27	20
15	Saliyawewa	P11	Minor	20	1	10	8	23	10
16	Dangaswewa	P12	Minor	20	2	5	4	8	8
17	Karavitagaraya	P2	Medium	256	4	22	10	53	10
18	Mahauswewa	P3	Medium	212	1	26	24	32	25
19	Kachchimaduwa	P4	Minor	65	1	5	0	18	5
20	Kottukachchiya	P5	Minor	70	1	18	6	27	6
21	Viluka wewa	P6	Minor	65	1	4	1	18	8
22	Vijayakatupotha	P7	Medium	243	2	34	24	45	30
23	Tabbowa	P8	Medium	607	4	40	20	78	30
24	Eluwankulama	P9	Minor	65	1	5	0	18	5

Note: Recode: see Figure 4.2.1; Reservoir code: A – Anuradhapura district, P – Puttalam district, LS – Landing Sites, BT – Total number of boats (canoes), BO – Boats under operation, FT – Total fishers, AF – Active fishers.

Table 4.2.2: Variables and important equations used for calculations

Variables	Denotations and Equations	Description	Unit
Primary data			
Reservoir surface area (A)	A_i	Surface area at full supply level of reservoir in hectares.	ha
Catch (C)	C_{ids}	Species-wise catches in kilograms in a day.	kg
Stocking (S)	S_{is}	Species-wise individual counts of stocking stages in a year – FL or PL.	nos
Total of active fishers for entire fishing days (FO)	$FO_i = \sum_{d=0}^{d=D} F_d$	Total of fishers (F) operated in active days in the given reservoir.	F
Total of active days of entire fishing fishers (FD)	$FD_i = \sum_{f=0}^{f=F} D_f$	Total of active days (D) of fishers (F) in the given reservoir.	days
Secondary data			
Wage (W)	w_{im}	Average labour cost for fishing per month.	LKR
Maintenance cost (M)	M_{im}	Average maintenance cost for net-mending and canoe repairs per month.	LKR
Selling price of catch (SPC)	SPC_{is}	Price of fish catch per kilogram.	LKR kg ⁻¹
Purchasing price of stocking stages (PPS)	PPS_{is}	Price of stocking stages per count.	LKR nos ⁻¹
Stocking transport cost (TRC)	TRC_{is}	Transportation cost for each stocking event.	LKR
Variables calculated from primary and secondary data			
Production (P)	$P_{is} = \frac{\sum_{d=0}^{d=D} C_{ids}}{A_i}$	Per hectare biomass of fish caught in a reservoir in a year.	kg ha ⁻¹
Stocking density (SD)	$SD_{is} = \frac{S_{iys}}{A_i}$	Per hectare number of FL or PL stocked in a reservoir for a year.	nos ha ⁻¹
Fishing intensity (FI)	$FI_i = \frac{FO_i / FD_i}{A_i}$	Per hectare active fishers in a day for a year.	F day ⁻¹ ha ⁻¹
Stocking efficiency per area (SEA)	$SEA_{is} = \frac{P_{is} / SD_{is}}{A_i}$	Production per stocking unit for a unit area.	kg nos ⁻¹ ha ⁻¹

Variables	Denotations and Equations	Description	Unit
Revenue (RV)	$RV_{is} = \sum_{d=0}^{d=D} C_{ids} \times SPC_{is}$	Species-wise revenue from the fish catch in a reservoir.	LKR
Total revenue (TR)	$TR_i = \sum_{s=0}^{s=S} R_{is}$	Total revenue experience from the cumulative fish catch by a reservoir or RFO for a year.	LKR
Stocking cost (SC)	$SC_{is} = S_{is} \times PPS_{is}$	Cost for purchasing stocking stages.	LKR
Total stocking cost (TSC)	$TSC_i = \sum_{s=0}^{s=S} S_{is} \times PPS_{is} + \sum_{s=0}^{s=S} TRC_{is}$	Sum of stocking costs and transportation costs incurred in a reservoir or RFO for a given year.	LKR
Total cost (TC)	$TC_i = TSC_i + \left(\sum_{m=0}^{m=M} [W_{im} + M_{im}] \right)$	Sum of total stocking cost and opportunity costs of fishing incurred in a reservoir or RFO for given year.	LKR
Net economic profit (NEP)	$NEP_i = TR_i - TC_i$	Net revenue experienced by a reservoir or RFO in a given year.	LKR

Notes: Here, i – reservoir number; d – date, $d = 0, 1, 2, 3, \dots, D-1$; m – month number, $m = 0, 1, 2, 3, \dots, M-1$; s – species of interest; y – years; r – levy rates, $r = 1\%, 2.5\%, 5\%$ and 10% . In 2020, USD1 = LKR185.43.

Table 4.2.3: Details of selling prices of reservoir fish catch and purchasing prices of stocking stages

Species	Price in LKR			
	Mean	STD	Max	Min
Catch				
Tilapia	550	50	700	450
Catla	450	10	480	420
Other fishes	400	10	420	360
Giant freshwater prawn	900	100	1,500	500
>300 g	1,100	100	1,500	1,000
<300 g	600	30	700	500
Stocking				
Tilapia FLs	4.5	0.25	5	4
Giant freshwater prawn PL	2	0.25	2.5	1.5
Others FLs	4	0.15	4.5	3.5

Notes: STD – Standard deviation; Max – maximum; Min – minimum. FL – fingerlings; PL – post larvae. Here, the selling prices of catch per kg are at the reservoir or RFO and similarly purchase price of stocking materials are for a FL or PL at the hatchery. In 2020, USD1 = LKR185.43.

Table 4.2.4: Details of stocking cost categorisation according to type of catch and reservoirs type

Catch type	Stocking cost type	Reservoir type (nos ha ⁻¹)		
		Major	Medium	Minor
FISH	LSC	≤1,000	≤750	≤1,000
	MSC	1,000–2,000	>750	>1,000
	HSC	>2,000	N/A	N/A
FWP	LSC	≤2,000	≤1,200	≤400
	MSC	2,000–4,000	>1,200	>400
	HSC	>4,000	N/A	N/A
TOTAL	LSC	≤2,500	≤2,000	≤1,500
	MSC	2,500–5,000	>2,000	>1,500
	HSC	>5,000	N/A	N/A

Note: FISH – includes both tilapia and Indian major carps; FWP – Giant freshwater prawn; TOTAL – cumulative catch. The stocking cost types are LSC – low stocking cost, MSC – medium stocking cost, HSC – high stocking cost.

Results

During the current study, it was found that FI and SD were the main drivers of reservoir CBF development in Sri Lanka. Among the studied 24 reservoirs where extent ranged from 20–1,781 ha (mean, 609.1±89.7 ha), with the mean FI of 0.1331±0.0164 F day⁻¹ ha⁻¹ and mean of total SD of 3046±582 nos ha⁻¹, the mean total production has been reported as 265.5±40.4 kg ha⁻¹ (Table 4.2.5). Regarding CBF extension, the FWP has been stocked at a high density (2109±394 nos ha⁻¹) compared to both Indian major carps (IMC) (655±211 nos ha⁻¹) and tilapia (TIL) (281.5±80.9 nos ha⁻¹). Thus, the SEA of FWP (2.5×10⁻⁵±7×10⁻⁶ kg nos⁻¹ ha⁻¹) was higher than those of TIL (2.40×10⁻³±5.76×10⁻⁴ kg nos⁻¹ ha⁻¹) and IMC (8.20×10⁻⁴±3.4×10⁻⁴ kg nos⁻¹ ha⁻¹). Notably, due to higher price of FWP (>LKR500), even in general, at a low recovery rate (6.66±1.32%), there is a significant monetary contribution to TR of around 51.33% when it represents 31.65% of the total catch.

The trend analysis given in Figure 4.2.2 depicts the possible variance that may occur in the relationship of SEA with both FI and SD, as the reservoir types have been considered. It is clear that except major reservoirs, SEA increases with FI in both medium and minor reservoirs. Nonetheless, according to the findings, intensification of SD is effective only in minor reservoirs (Figure 4.2.2). Most of the major reservoirs have reported SEA below 0.5 X 10⁻³ kg nos⁻¹ ha⁻¹ and prominently it declined even though the stocking density increased. In minor reservoirs, increase of both FI and SD had a positive influence, where the SEA ranges up to 4.10 X 10⁻³ kg nos⁻¹ ha⁻¹. In contrast, the SEA in most medium reservoirs reported less than 0.4 X 10⁻³ kg nos⁻¹ ha⁻¹.

According to the results of net economic profit (NEP) analysis shown in Figure 4.2.3 and summary given in Table 4.2.6, NEP was significantly different for medium reservoirs (0.0421), where the NEP in medium stocking cost (LKR1.41±0.87 million) is positive with comparatively higher low stocking cost (LKR-0.51±0.35 million).

Table 4.2.5: Summary statistics of studied bioeconomics related variables in CBF of Sri Lanka during 2019 and 2020

Variable	Measurement	Mean	SE	Min	Max
Reservoir surface area (A)	ha	609.1	89.7	20.0	1,781.0
Fishing intensity (FI)	F day ⁻¹ ha ⁻¹	0.1331	0.0164	0.0353	0.5
Total stocking density (SD_T)	nos ha ⁻¹	3,046	582	0	21,621
Stocking density of TIL (SD_{TIL})	nos ha ⁻¹	281.5	80.9	0.0	3,085.0
Stocking density of IMC (SD_{IMC})	nos ha ⁻¹	655	211	0	8,871
Stocking density of FWP (SD_{FWP})	nos ha ⁻¹	2,109	394	0	12,750
Total production (P_T)	kg ha ⁻¹	265.5	40.4	0.0	1,393.2
Production of TIL (P_{TIL})	kg ha ⁻¹	181.1	21.2	0.0	531.6
Production of IMC (P_{IMC})	kg ha ⁻¹	74.6	29.6	0.0	1,094.3
Production of FWP (P_{FWP})	kg ha ⁻¹	9.72	1.78	0.00	51.39
Total stocking efficiency per area (SEA_T)	kg nos ⁻¹ ha ⁻¹	5.04×10^{-4}	1.16×10^{-4}	0.00	4.10×10^{-3}
Stocking efficiency per area of TIL (SEA_{TIL})	kg nos ⁻¹ ha ⁻¹	2.40×10^{-3}	5.76×10^{-4}	1.09×10^{-4}	1.36×10^{-2}
Stocking efficiency per area of IMC (SEA_{IMC})	kg nos ⁻¹ ha ⁻¹	8.20×10^{-4}	3.4×10^{-4}	0.00	1.09×10^{-2}
Stocking efficiency per area of FWP (SEA_{FWP})	kg nos ⁻¹ ha ⁻¹	2.5×10^{-5}	7×10^{-6}	0.00	2.46×10^{-4}
Total revenue (TR)	LKR	75,344,046.00	13,931,673.00	0	266,017,250.00
Revenue from TIL (R_{TIL})	LKR	62,063,800.00	11,775,062.00	0	229,420,000.00
Revenue from IMC (R_{IMC})	LKR	7,444,474.00	1,571,669.00	0	52,430,198.00
Revenue from FWP (R_{FWP})	LKR	5,835,772.00	1,738,620.00	0	66,595,500.00
Total stocking cost (STC)	LKR	2,871,617.00	386,796.00	0	10,048,000.00
Stocking cost for TIL (STC_{TIL})	LKR	388,677.00	80,230.00	0	2,148,100.00
Stocking cost for IMC (STC_{IMC})	LKR	427,940.00	61,927.00	0	1,772,500.00
Stocking cost for TIL (STC_{FWP})	LKR	2,055,000.00	349,266.00	0	8,640,000.00
Total cost (TC)	LKR	30,456,298.00	4,375,947.00	2,643,750.00	116,471,250.00
Total cost for TIL (TC_{TIL})	LKR	24,270,752.00	3,678,817.00	585,436.00	86,376,239.00
Total cost for IMC (TC_{IMC})	LKR	4,047,987.00	680,695.00	0	23,892,211.00

(Continues on next page)

Variable	Measurement	Mean	SE	Min	Max
Total cost for FWP (TC_{FWP})	LKR	3,373,673.00	475,973.00	0	11,918,439.00
Net economic profit (NEP)	LKR	44,887,748.00	10,556,184.00	-43,029,000.00	207,468,450.00
Percentage of TIL production (PP_{TIL})	%	73.30	3.31	12.20	99.36
Percentage of IMC production (PP_{IMC})	%	20.04	3.11	0.00	87.80
Percentage of FWP production (PP_{FWP})	%	6.66	1.32	0.00	31.65
Percentage of TIL revenue (RP_{TIL})	%	69.53	3.46	13.44	99.36
Percentage of IMC revenue (RP_{IMC})	%	17.92	2.87	0.00	86.56
Percentage of FWP revenue (RP_{FWP})	%	12.55	2.21	0.00	51.33
Percentage of cost for TIL (CP_{TIL})	%	15.98	3.58	0.00	100.00
Percentage of cost for IMC (CP_{IMC})	%	21.94	2.96	0.00	74.26
Percentage of cost for FWP (CP_{FWP})	%	62.09	4.26	0.00	100.00

Notes: SE – Standard error, Max – maximum, Min – minimum, TIL – tilapia (GIFT), IMC – Indian major carp, FWP – Giant freshwater prawn (*M. rosenbergii*). In 2020, USD1 = LKR185.43.

Table 4.2.6: Summary of NEP analysis based on a stocking cost categorisation across reservoir types

Subject	Reservoir type	Stocking cost types	n	Mean	SE	Max	Min	P value	Groups
NEP (LKR million)	Major	LSC	3	20.73	3.71	25.88	13.52	0.829	NS
		MSC	8	22.68	3.09	35.33	10.67		NS
		HSC	5	20.02	3.14	27.93	12.68		NS
	Medium	LSC	8	-0.51	0.35	0.63	-2.72	0.0421	b
		MSC	6	1.41	0.87	5.27	-0.33		a
	Minor	LSC	13	0.2	0.07	0.63	-0.17	0.891	NS
		MSC	4	0.22	0.12	0.52	-0.04		NS

Note: SE – standard error, Max – maximum, Min – minimum, LSC – low stocking cost, MSC – medium stocking cost, HSC – high stocking cost

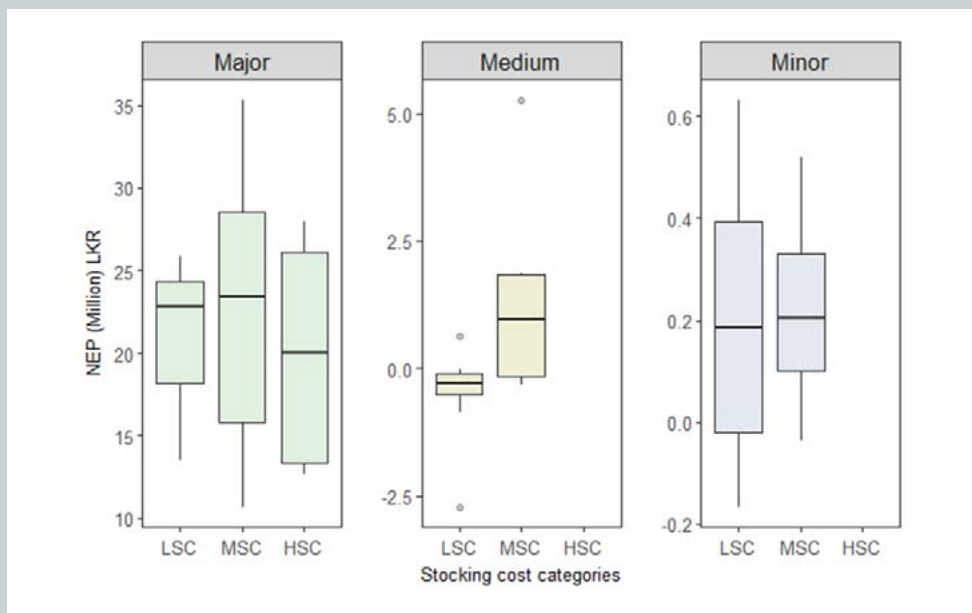


Figure 4.2.3: Visualisation of variability of NEP with stocking cost categories (as explained in Table 4.2.4) across the reservoir types

Note: LSC – low stocking cost, MSC – medium stocking cost, HSC – high stocking cost.

The preliminary questionnaire survey suggests that there is a clear perception difference among the CBF stakeholders. Further, the outcomes expected by increasing stocking is to achieve a higher income. From fisher opinions, it is understandable that the economic sustainability has the higher leverage compared to the environmental sustainability. Some of the highlighted stakeholder perceptions included:

- CBF requires continuous annual stocking to ensure the continuous fishery production in reservoirs (expressed by most fishers)
- tilapia stocking has to be reduced or controlled, since there is not much improvement in recent catch trends (to be taken care of by extension officers)
- Indian major carp stocking should be improved through continuous extension (responsibility of research and development organisations such as NAQDA)
- GFP stocking was appreciated due to monetary gain, since it was the high-value product among freshwater fishery species in Sri Lanka (expressed by almost all stakeholders)
- subsidised or free fish stocking negatively affects the fishers' motivation for self-sustained CBF in RFOs, while anticipating more government support (responsibilities of government and policymakers)
- self-sustained RFOs have better management mechanisms in collecting a commission fee or the levy on fish catch (some fishers and extension officers are responsible).

Discussion

Stocking practices varied significantly due to species composition, stakeholder preferences and financial constraints. The FWP has been stocked in higher densities by reckoning the higher early mortalities and/or low recovery rates through current harvesting strategies. Nevertheless, detailed study is needed to quantify the optimal stocking densities based on both biological attributes of the ecosystem and financial viability. Economic analyses suggest that NEP is a more reliable performance measure than TR, which is a more pragmatic incentive for fishing. Thus, the RFOs believe that reservoirs require higher SD for profitability, but it is evident from the current study that optimisation of profit is necessary by adjusting both FI and SD. Hence, this study should be extended for the search of optimal limits of FI and SDs. Species-specific stocking thresholds further influence profitability. Hence, the species-specific SEA and relative NEP should be taken into account. Further, low catchability of FWP necessitates technological interventions to improve recapture rates, such as the introduction of efficient capture methods.

From the insights of stakeholders, a reservoir-specific approach has to be executed at the managerial levels, whereby RFO executives should be educated and awakened about the process stipulated with a stocking calendar and fishing operations. Limiting enrolment in RFOs might mean fishers are compelled to adopt illegal fishing, so assigning fishing turns and considering fisher livelihood type – whether customary or subsistence – is pragmatic.

Overall, the study underscores the need for adaptive management strategies that integrate bioeconomic optimisation with stakeholder-driven governance. By

balancing fishing effort, SD and economic incentives, policymakers can improve the sustainability and profitability of CBF in Sri Lankan reservoirs. Future research should refine stocking models, enhance catchability rates for high-valued species, and develop institutional frameworks for equitable and efficient resource allocation.

Conclusion

CBF systems require a holistic approach for effective management, which should be viewed through the bioeconomic context. This study addressed key bioeconomic challenges and highlighted the importance of bioeconomics for sustainable development of CBF in Sri Lankan reservoirs. The current stocking densities and fishing intensities have to be revisited with bioeconomic performance of CBF in Sri Lankan reservoirs. Moreover, prioritising stakeholder perceptions is essential for sustainable CBF development and policymaking.

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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 $226 \text{ kg ha}^{-1} \text{ yr}^{-1}$ at an optimal fishing intensity of $55 \text{ boats ha}^{-1} \text{ yr}^{-1}$, having a maximum economic return (MER) of $\text{LKR}16,000 \text{ ha}^{-1} \text{ yr}^{-1}$ for $\text{LKR}2,600 \text{ ha}^{-1} \text{ yr}^{-1}$. 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 $\text{kg ha}^{-1} \text{ yr}^{-1}$, 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.

$$\text{VFY} = a \text{ CFI} - b \text{ CFI}^2 \quad (1)$$

$$\text{VFY} = c \text{ CSD} - d \text{ CSD}^2 \quad (2)$$

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 ($\text{kg ha}^{-1} \text{ yr}^{-1}$) 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 $226 \text{ kg ha}^{-1} \text{ yr}^{-1}$ at the optimal fishing intensity (FI_{MSY}) of $55 \text{ boat-days ha}^{-1} \text{ yr}^{-1}$.

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.

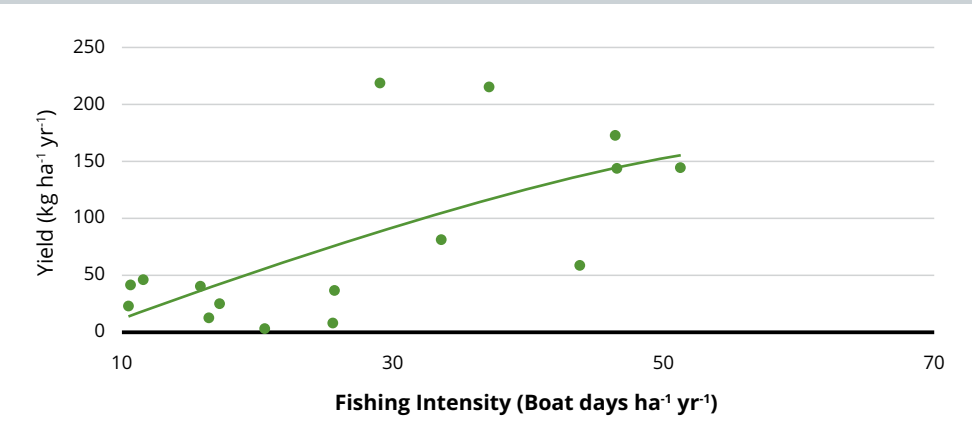


Figure 4.3.1: Relationship of fish yield and mean annual fishing intensity for carp species

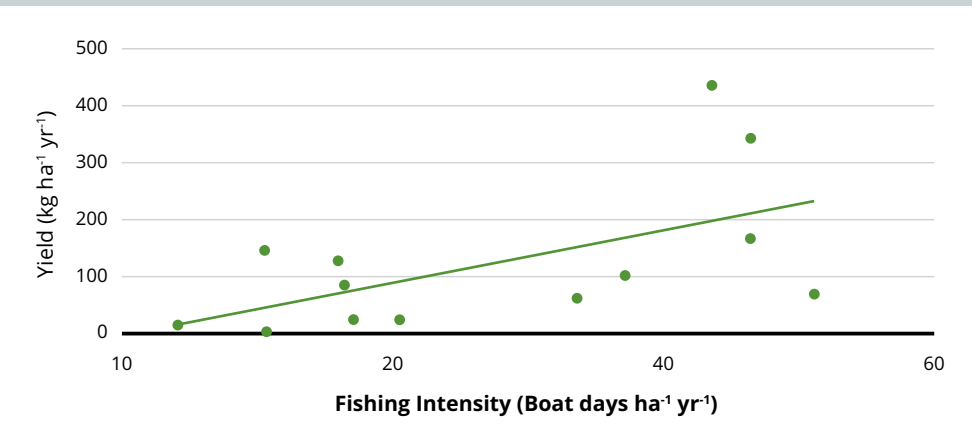


Figure 4.3.2: Relationship of fish yield and fishing intensity for tilapia species

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	<i>r</i>
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.

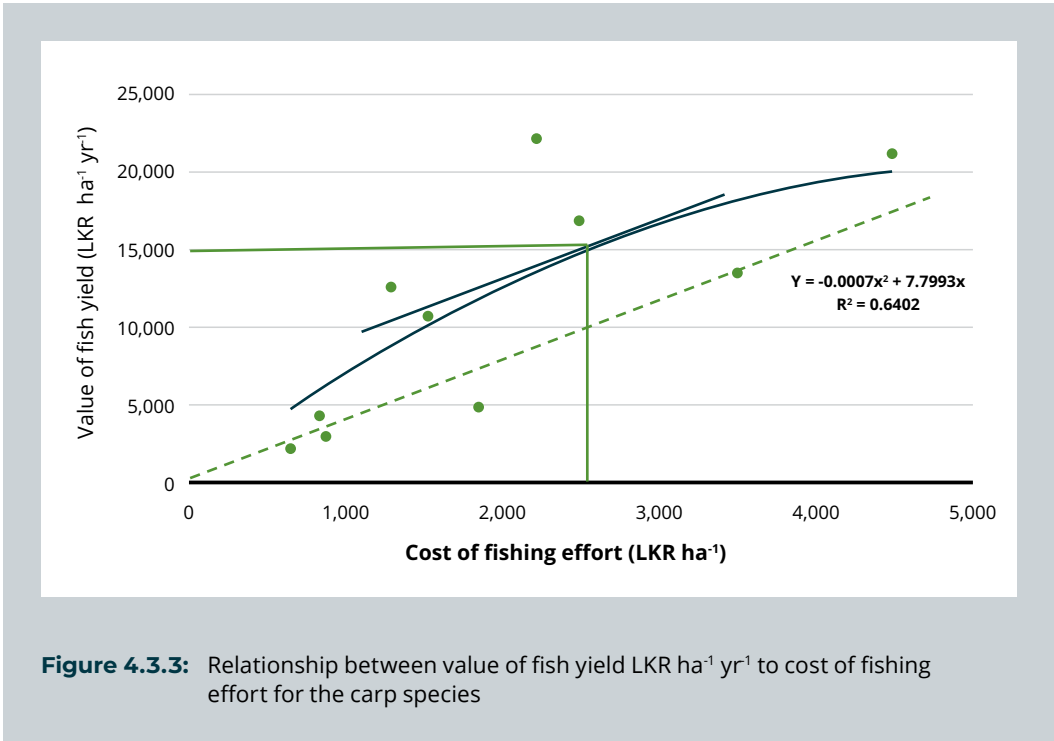
The MER for the carp species was observed at approximately LKR16,000 ha⁻¹ yr⁻¹, with a corresponding cost of fishing intensity of LKR2,600 ha⁻¹ yr⁻¹. The relationship between the stocking rate and carp yields also exhibited a quadratic relationship (Figure 4.3.5) having an optimal stocking density of 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



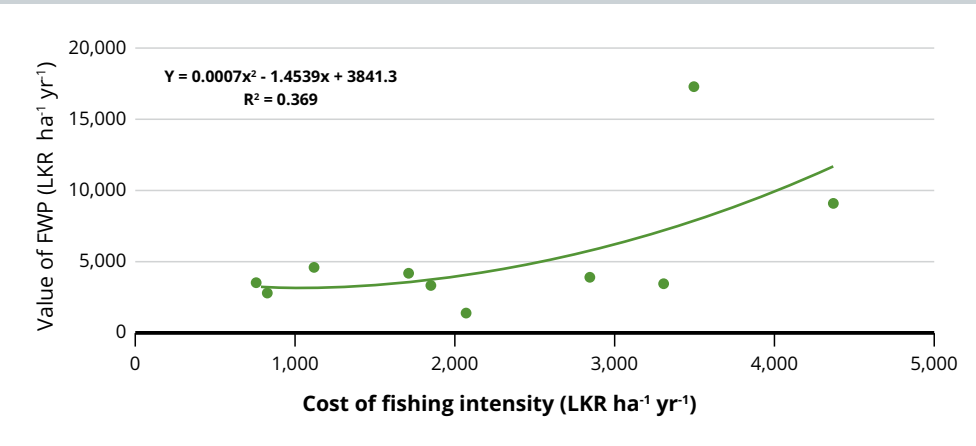


Figure 4.3.4: Relationship between value of fish yield to cost of fishing intensity for the FWP (*M. rosenbergii*)

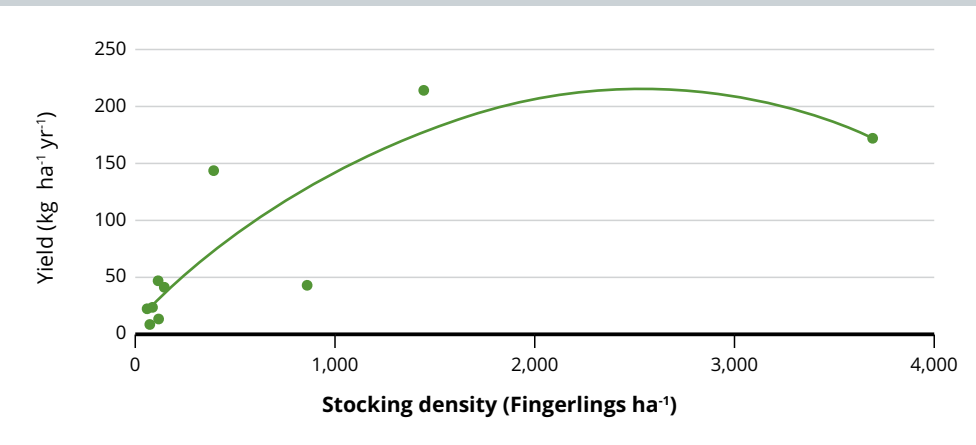


Figure 4.3.5: Relationship of carp yield (kg ha⁻¹ yr⁻¹) to stocking density (fingerlings ha⁻¹)

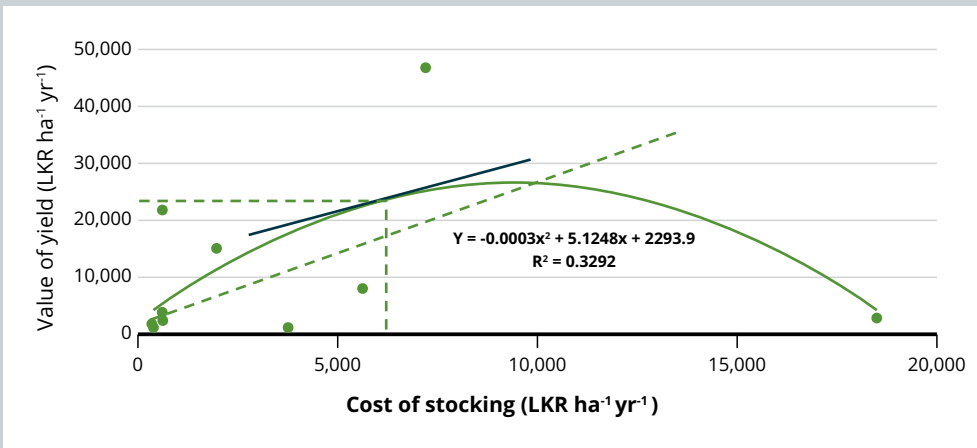


Figure 4.3.6: Relationship between value of carp species and cost of stocking

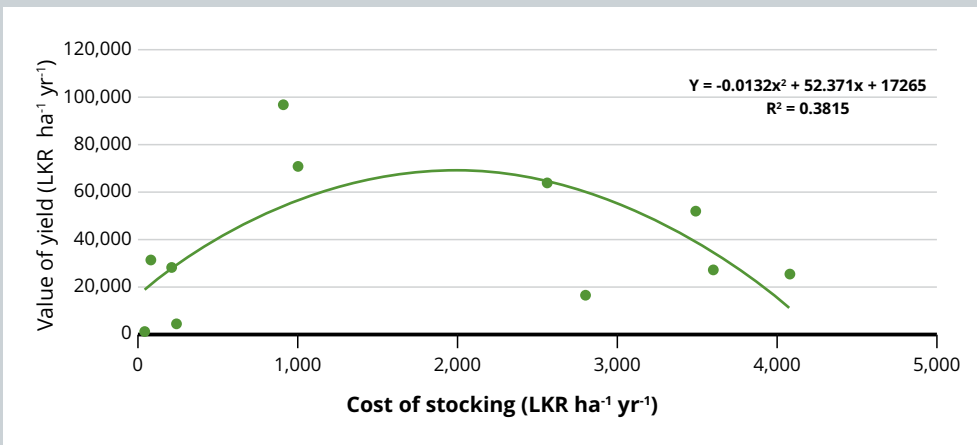


Figure 4.3.7: Relationship between value of yield and cost of stocking for tilapia species



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 $226.52 \text{ kg ha}^{-1} \text{ yr}^{-1}$ at a fishing intensity of $105.41 \text{ boat-days ha}^{-1} \text{ yr}^{-1}$. 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 $\text{LKR}5,000 \text{ ha}^{-1} \text{ yr}^{-1}$, while for tilapia, the MEY was $\text{LKR}43,000 \text{ ha}^{-1} \text{ yr}^{-1}$ with a cost of effort of $\text{LKR}2,600 \text{ ha}^{-1} \text{ yr}^{-1}$. 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

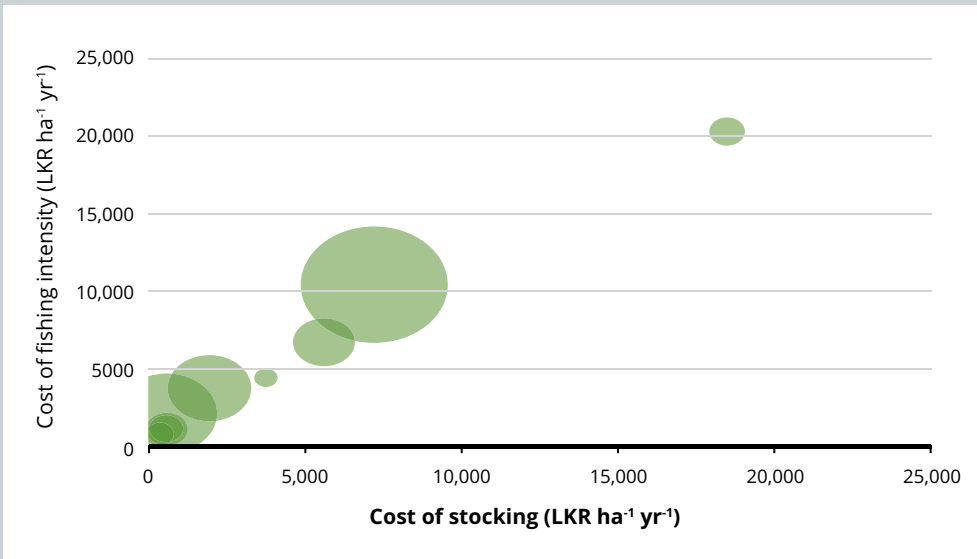


Figure 4.3.8: The relationship between cost of fishing stocking and cost of fishing intensity for carp species

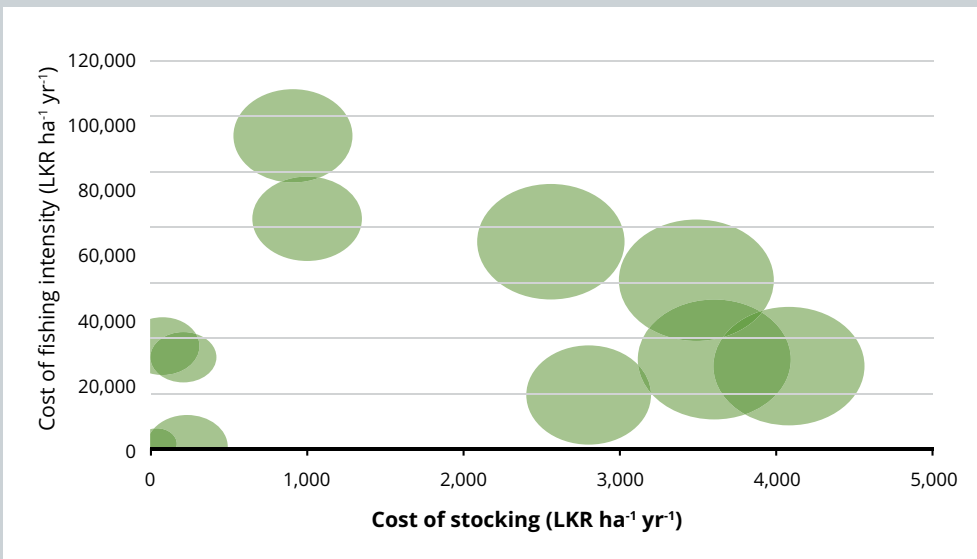


Figure 4.3.9: The relationship between cost of fishing stocking and cost of fishing intensity for tilapia species

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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5 Social science, livelihoods and gender



Men and women work together to clean their fishing nets after finishing a fishing round at the Iranamadu Reservoir in Sri Lanka. Photo: Ms Gayani P Paranamana.

5.1 Addressing gender equity and wellbeing in culture-based fisheries communities in Sri Lanka

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Abstract

Inland fisheries, of which culture-based fisheries (CBF) is a sub-sector, provide valuable aquatic products, important for sustaining rural livelihoods and food security. Women's engagement in inland fisheries value chains is estimated to be higher than in marine fisheries value chains globally, as well as in Asia. Within the context of gender issues in inland fisheries in Asia and a macro-level assessment of gender inequality in Sri Lanka, this paper focuses on addressing gender equity and wellbeing in CBF communities in Sri Lanka. The conceptual approaches of social relations, gender inclusive value chains analysis and social wellbeing are combined to explore gender roles and relations within the livelihood system of reservoir communities, the extent of participation of women in fishing-related activities and in fisheries governance, the gendered location and benefits of participating in CBF value chains, as well as wellbeing perceptions that underlie the motivations and outcomes of CBF livelihoods in Sri Lanka. This paper is based on a literature review, as well as primary data from fieldwork by Kanchana and Paranamana in 9 reservoir-based CBF communities, located in 5 districts in Sri Lanka. Qualitative methods, centred on in-depth, semi-structured interviews and focus group discussions (FGDs), were used by the researchers. The analysis reveals the predominant engagement of men in CBF value chains of finfish and giant freshwater prawn (GFP). Women are mostly confined to several nodes, such as dried fish processing and retailing in the finfish chain, and primary handling in the GFP chain – activities with low economic returns. In addressing gender equity and wellbeing within the CBF sector in Sri Lanka, we argue for a transformative approach that focuses on translating policy into action, as well as changes in institutional systems and gender norms to ensure higher returns to women through a participatory, consultative process.

Introduction

Global inland fisheries production, of which CBF is a sub-sector, was estimated to be around 1.3 mt annually (FAO 2024) with its economic value estimated at around USD26 billion (Funge-Smith 2018). An estimated 16.8–20.7 million people were engaged in harvesting in inland fisheries, with a ratio of 1 female fisher to 7.3 male fishers (Funge-Smith 2018). A further 8–38 million people were estimated to be employed in post-harvesting activities (processing and trading) in inland fisheries, of which 54% were estimated to be women (Funge-Smith 2018). As pointed out by Kusakabe (2003), it appears that women are not only involved in post-harvesting but also harvesting in inland fisheries in Asia, to a greater extent than in marine fisheries. In Southeast Asia, women are involved in gleaning or fishing in paddy/fish/shrimp pond systems, lakes and wetlands (Kusakabe 2003). Case studies from Kerala, India reveal that women accompany husbands on fishing trips to lakes and estuaries (Gopal et al. 2022). While women constitute a large proportion in post-harvesting activities in inland fisheries globally and in Asia, they tend to engage in small-scale processing and trading of fish varieties important to poor people's diets/food security, while men engage in larger-scale trading of high-value, export-oriented products with larger profit margins (Kusakabe 2003).

However, gender roles are not rigid as they can change with economic and environmental changes (Kusakabe 2003; Gopal et al. 2022). Women can get more involved in fisheries if water bodies expand – for example, dam construction in the Mekong, or when returns from agriculture decline. If climate change has negative impacts on agriculture (for example, the inundation of fields or unexpected

weather patterns), larger numbers of both women and men can move into fisheries. Conversely, climate change can also change fish availability in different locations; decline in fish catches can result in men or women moving out of fisheries-related livelihoods. As gender roles are different, women and men have different knowledge, experience and skills in relation to fisheries within their sociocultural contexts (Kusakabe 2003). Moreover, households are not necessarily monolithic: complementary roles, as well as conflictual interests and needs exist among household members (Kusakabe 2003), thus leading male and female members to negotiate trade-offs in their roles and interests. Constraints to women's involvement in inland fisheries include gender norms, family care needs, limited mobility and limited access to loans (Funge-Smith 2018). Benefits from women's engagement in inland fisheries range from a larger contribution to household income, access to small nutritious fish in household diets and flexibility in dealing with climate change, when it might affect agriculture or fisheries differently (Funge-Smith 2018).

The rationale for gender equity in CBF is based on an analysis that applies to the small-scale fisheries and aquaculture sector in general (Weeratunge et al. 2010). First, while both men and women are employed in the fisheries/aquaculture sector, women's work is often invisible, unrewarded and underestimated. Most fisheries and aquaculture development projects have targeted men as their primary beneficiaries. Second, labour productivity in these sectors remains low if women do not receive sufficient returns on their work. Gender disparities in fisheries can result in lower labour productivity within the sector and inefficient allocation of labour at household and national levels. Customary beliefs, norms, practices and



laws, and/or unfavourable regulatory structures of the state, reduce women's access to fisheries resources, assets and decision-making (FAO 2006; Porter 2006; Okali and Holvoet 2007), confining them to the lower end of supply chains, receiving lower returns, within a pervasive 'informal' sector in many developing countries. Third, aside from the economic rationale for gender inclusion, the violation of women's rights for social equality in the fisheries and aquaculture sector undermines the wellbeing of women, from a rights-based perspective. Women and men often have different access and tenure rights to water and land resources. Even when women use aquatic resources, they are often excluded from fisheries governance and rarely consulted in attempts to manage these resources. Fourth, the wellbeing of the entire fishing household and thereby society in general increases if inequalities between women and men are addressed. Even though women bear the brunt of the costs of gender inequities, these costs are distributed widely and are a cause of persistent poverty for all members of the society. Improving women's incomes and educational levels, as well as their access to information and decision-making processes, enhances human capabilities of the household, as well as society in general. Smith and Haddad (2000) found that women's education level and status within the household was the single most important factor for reducing child malnutrition in the world.

Development of CBF is considered as an environment friendly fisheries enhancement approach to utilising 12,000–15,000 inland reservoirs covering an estimated 206,000 ha in Sri Lanka for increasing fish production and food security (Wijenayake et al. 2021). In this paper, we address issues of gender equity

and wellbeing in CBF communities in Sri Lanka, within the overall small-scale inland fisheries context outlined above and based on the gender analysis emerging from the data of social science studies, conducted by Kanchana et al. (2025) and Paranamana et al. (2025) within the ACIAR project 'Improved productivity, efficiency and sustainability of the CBF for finfish and GFP in Sri Lanka'. Our conceptual approach incorporates the social relations perspective (Kabeer 1994; 1999), gender-inclusive value chain analysis (Mayoux and Mackie 2008; AgriProFocus 2012) and the social wellbeing perspective (McGregor 2008; White 2008). These perspectives are combined to understand the different roles and relations of women and men in fisheries production and value addition within CBF communities, gender gaps in benefits and costs accrued within CBF value chains, disparities in decision-making and governance, as well as differences in wellbeing outcomes from engaging in CBF. We hope this analysis will contribute fresh insights and address prevailing knowledge gaps on gendered engagement, decision-making and wellbeing within the small-scale fisheries literature in general, and the CBF literature in particular.

Conceptual approach

A range of gender and development (GAD) approaches/frameworks (March et al. 1999; Warren 2007) were developed since the 1980s to analyse and address inequities in women's and men's roles in economic and social development. While each of these frameworks has their strengths and weaknesses, the holistic social relations approach (Kabeer 1994; 1999), centred on gender relations between women and men, and combining equality with human wellbeing factors, has been used in this paper. This perspective focuses on

analysing gender norms and practices that shape activities of women and men, their access to resources, their agency and how power is negotiated within gender relations. As defined by Kabeer (1999, p 11), gender relations are social relations between women and men constituted of underlying 'rules, norms and practices by which resources are allocated, tasks and responsibilities are assigned, value is given and power is mobilised'. Gender relations intersect with other social relations, based on categories, such as class, race, ethnicity and religion, or what is conceptualised as intersectionality in current discourse. Within Kabeer's (1999) approach, gender relations operate within 4 interrelated institutions – family, community, market and state. Agency of women and men is a core concept in this approach and is delineated as an ability to make decisions, to define goals and act upon them (Kabeer 1999). Agency is enabled or constrained within the interrelated institutional framework and is critical to achieving wellbeing, empowerment and equality.

The social relations approach is useful to analyse the roles and relations within the gender division of labour in CBF communities, based on underlying norms and practices, which shape decision-making and engagement in livelihood activities, such as input purchasing, fishing/gleaning, processing and trading by household members. Moreover, the negotiation of power relations between women and men can also be assessed by looking at membership and decision-making in fisheries and other community organisations, bargaining power with suppliers and buyers, communication with fisheries/aquaculture extension officers, as well as the extent of their voices being taken into account in fisheries policies.

The social relations approach is combined here with gendered/gender inclusive value chain analysis (Mayoux and Mackie 2008; AgriProFocus 2012) to assess nodes where women and men are located, and relative benefits and costs to women and men of engaging in CBF value chains. Value chains are networks of actors whose activities enable the production and distribution of goods or services to consumers. In the case of fisheries value chains, actors use assets to transform inputs into goods or services (outputs), along 'upstream' (fishing), 'midstream' (processing, collecting, wholesaling) and 'downstream' (retailing) segments (Belton 2015). The term 'value chain' refers to the fact that value is added to preliminary products through the combination of other resources (ILO 2006).

Mayoux and Mackie (2008) have argued that gender analysis is often the 'weakest point' in most value-chain analyses and commonly disregarded in value-chain manuals. When included it is often incorporated as a separate activity that provides livelihood context, rather than being integral to the value-chain analysis process. They emphasise that identifying gender inequalities can be crucial to understanding the 'weakest links' within value chains to enable upgrading of these chains (Mayoux and Mackie 2008). Incorporating gender inclusive value-chain analysis helps to assess the gendered benefits and costs of small-scale fishers, fish processors and traders in being linked to market processes or being excluded from these processes; to explain why particular value chains are dominated by men or women; to identify circumstances where women have been able to participate successfully in value chains; and to assess how women can be supported to make a more effective economic contribution (Mayoux and Mackie 2008; AgriProFocus 2012).



The third conceptual orientation used in this analysis is the social wellbeing approach (McGregor 2008; White 2008), focused on what a person considers a 'good life' to be and what livelihood strategies s/he would pursue to achieve this 'good life'. This approach is actor-centred and considers the dynamics of change from the perspective of affected individuals and groups. Wellbeing within this perspective is both a process (pursuit) and an outcome (achievement) (Weeratunge et al. 2014). Social wellbeing is defined as: 'A state of being with others and the natural environment that arises where human needs are met, where individuals and groups can act meaningfully to pursue their goals, and where they are satisfied with their way of life' (Armitage et al. 2012, p 14). The social wellbeing approach is also known as the 3D wellbeing approach (White 2008) as it assesses wellbeing in terms of 3 interrelated dimensions – material, relational and subjective.

The material dimension of social wellbeing focuses on what resources (including the environment) to which a person has access and the extent to which the needs of the person are met. This includes livelihoods, income, assets, natural resource stocks, food, water, air quality, waste disposal, health, and bio-geo physical processes. The relational dimension considers the social relationships in which a person engages to pursue or achieve wellbeing. This includes relations with nature and other human beings, such as relations with animals and plants, access to and tenure of natural resources/land/coast/sea/reservoir, intra- and inter-household relations, gender and ethnic relations, community and extra-local relations which give access to resources and markets and shape behaviour through institutions/social structures. The subjective dimension takes

account of a person's skills and knowledge, feelings, level of satisfaction and sense of security with the quality or way of life he or she pursues or achieves. It includes feelings of autonomy, freedom, satisfaction, dissatisfaction, sadness, happiness, as well as aspirations for the future.

The 3 dimensions of wellbeing, although categorised separately for analytical purposes, are interrelated, and some elements of wellbeing, such as identity or health, can cut across 2 or 3 dimensions. In this paper, we look at perceptions of wellbeing that have emerged from men and women in CBF communities, and which dimensions of wellbeing are emphasised across gender, reservoir size and geographical location.

Methods

In addition to a literature review, this paper is based on primary data collected by Kanchana et al. (2025) and Paranamana et al. (2025), whose research methods are outlined in detail in their papers. Sample reservoir-based communities were selected from a total representative sample of 48 inland reservoirs, based primarily on size. In the gender-related studies, altogether 9 reservoir communities in 5 districts were selected between the 2 researchers based on criteria, such as geographical location, size of reservoir (minor, medium, major), sociocultural diversity (ethno-religious groups), and extent of involvement of women in CBF activities. Selection of respondents from households was based primarily on qualitative purposive sampling (Kanchana) and of actors along value chains was based on snowball sampling (Paranamana). Qualitative data collection methods included in-depth, semi-structured interviews with individual female and male research participants from reservoir-based households

(Kanchana) and with individual actors indicative of the different nodes along CBF value chains (Paranamana), as well as separate FGDs with women and men from CBF communities. Kanchana’s sample comprised 296 individual respondents (49.6% female, 50.4% male) and 12 FGDs with women and men, while Paranamana’s sample included 56 individual value-chain actors (71% male, 29% female).

Context: Gender inequality and implications for CBF in Sri Lanka

Sri Lanka was a pioneer among developing countries historically in achieving gender equity in social indicators, such as education (UNESCO 2018; World Bank 2019) and health (WHO 2019). However, this has not been matched with bridging gender gaps in economic and political participation. All national economic

indicators, such as the labour force participation rate, employed population by gender, economically active population in the rural sector and employed persons in the agricultural/forestry/fishing sector, show a wide gap between women and men (DCS 2024). Moreover, the representation of women in both parliament and local government is exceedingly low, among the lowest in South Asia and the world (IPU 2025; CLGF 2018) (Table 5.1.1).

Sri Lanka’s overall ranking in the Global Gender Gap Index (GGGI), based on 4 indicators (economy, politics, education and health), has decreased markedly from 13 in 2006 to 122 in 2024 (World Economic Forum 2006; 2015; 2024). The country’s performance in economic participation/opportunity and political empowerment has been poor over the last 2 decades and has been deteriorating (Table 5.1.2).

Table 5.1.1: Gender status in Sri Lanka – indicators

Dimension	Indicator	Female	Male
Economic	Labour force participation rate (2023)*	31.3%	68.6%
	Employed population by gender (2023)*	33.7%	66.3%
	Economically active population in rural sector (2023)*	34.5%	65.5%
	Employed persons in agriculture, forestry and fishing (2023)*	32.1%	67.9%
Political	Representation in Parliament (2024) **	9.8%	90.2%
	Representation in local authorities (2017–2018) ***	29.1%	70.91%
Social	Net secondary school enrolment rate (2018) #	92.3%	89.8%
	Life expectancy at birth (2019) ##	80 yrs	74 yrs
	Disease burden – Disability adjusted Life Years (DALY’s by 100,000 population) (2019) +	2,612.4	3,045.6

Sources: *DCS (2024): Sri Lanka Labour Force Survey Annual Report 2023; **Inter-parliamentary Union: Monthly ranking of women in national parliaments; ***CLGF 2018; #UNESCO 2019: Education and Literacy; ##World Bank 2019: Data Bank; + World Health Organization 2019.

Table 5.1.2: The Global Gender Gap Index (GGGI) – changing status of Sri Lanka

Year	Overall rank	Overall score	Economic participation and opportunity rank	Political empowerment rank	Educational attainment rank	Health and survival rank
2006	13 (total # 115)	0.7199	85	7	52	1
2015	84 (total # 145)	0.6860	120	59	57	1
2024	122 (total # 146)	0.6530	127	123	49	1

Sources: World Economic Forum (2006, 2015, 2024): Global Gender Gap Index.

Moreover, the global Social Institutions and Gender Index (SIGI) reveals increasing gender inequality in Sri Lanka between 2009 and 2023, across all its 4 indicators (restrictions within family, physical integrity, access to productive/financial resources and civil liberties), with the aggregated index value of inequality ranked as ‘very high’ (OECD 2023). Both indices show that Sri Lanka’s global rank in gender status has deteriorated relative to other countries, with the country underperforming in bridging gender gaps and inequality, even within South Asia. The primary reason for an increase in gender inequality in Sri Lanka appears to be the consequences of armed conflict, militarisation and authoritarian political regimes (Gamage 2024) of the last 20 years. Gender inequity issues have also been exacerbated by the COVID-19 pandemic and its consequences, including the economic crisis which began in 2022.

The disadvantaged position of women in Sri Lanka, however, has been fairly consistent for several centuries. Even though historical studies show a relatively positive gender status in the pre-colonial period (prior to the 16th century), this changed negatively during the colonial (1505–1948) and post-independence (1948–) periods. For example, traditional land tenure and inheritance laws (Kandyan law, Thesavalamai), which were favourable to women, were codified

in the colonial period to the benefit of men (Riseeuw 1988; Goonesekere 1990; Agarwal 1990), and the Land Development Ordinance introduced in 1935 continues to prioritise men in granting state land (Guneratne 2006; Fonseka and Raheem 2011). Relatively open sexual norms and practices among youth (Knox 1989), multiple forms of marriage and post-marital residence, some of which were favourable to women (Riseeuw 1988; Agarwal 1990), changed towards patrilocal marriage and residence due to imposition of Victorian norms in the colonial period, reinforced by Sri Lankan social and religious reformers (Riseeuw 1988; Ruwanpura 2006).

Thus, anthropological and sociological studies since the 1980s reveal that gender norms, roles and practices, as well as perceived differences in characteristics and behaviour of women and men are to the disadvantage of women. Thus, women’s engagement in livelihood activities, their mobility outside their home and village, and benefits derived from economic activities are negatively affected. Women’s wages tend to be lower than men’s, with an average pay gap of 27% (ILO 2024). This is based on cultural notions that women cannot do heavy work or women’s work is supplementary to that of men’s work as providers/breadwinners. Women’s primary roles are perceived as mother

and wife in the reproductive or private sphere (Schrijvers 1985) among all ethnic groups in Sri Lankan society. There is a reluctance to engage in paid work due to the household work burden and women often opt for flexible, household-based work (Gunatilaka 2013). Even though women perform many productive tasks, women are often perceived, by both men and women themselves, as not engaging in work as fishers or farmers in the productive/public sphere (Jayaweera 2015). Rather, the cultural perception is of helping (*udavukaranava*) the husband (Gunawardena 2016), despite long hours of work that women might put into agricultural or fish processing activities. Taboos restricting women from access to resources (boats, fishing nets) or entry into land or marine spaces exist in different parts of the country due to beliefs in impurity (*killā*) of women (Weeratunge et al. 2021). Moreover, women who are more closely associated with religious activities than men, are more likely to be subjected to the ambiguous perception towards fishing, as violating the Buddhist principle of refraining from taking life, a belief held within the Sinhala Buddhist ethnic group.

Gender-based violence and harassment, prevalent among all ethnic groups, compound the situation of gender inequality in Sri Lanka. Micro-level studies since the 1990s indicate a wide range of incidence – between 20% to 72% of women as subjected to domestic violence, depending on area and social group (Guruge et al. 2016). A large proportion of women express attitudes that indicate a level of tolerance towards violence. For example, the Demographic and Health Survey of 2006–2007 (DCS 2009) indicated that around 53% of women perceived that wife-beating was justified for one or more reasons, such as burning the

food, arguing with the husband, going out without telling the husband, neglecting the children, and refusing sexual intercourse. Harassment and violence against women in the workplace and public transport have been linked to the low female labour participation rate (UNDP 2021), while online abuse and violence against women entering the political sphere (Athukorala et al. 2021) is a factor identified for the unusually low female representation in politics.

The implication for CBF development within this overall context of gender inequality in Sri Lanka is that there is a critical need to increase women's economic participation in reservoir-based communities and benefits derived from CBF value-chain activities. Moreover, this needs to be accompanied by increasing women's representation in governance structures within CBF communities, such as membership and decision-making within fisheries societies. Such changes would lead to women's empowerment and wellbeing in CBF communities.

Knowledge gaps in gender issues within CBF in Sri Lanka

There is a lack of studies on CBF, based on systematic and rigorous gender analysis, in Sri Lanka, pointing to knowledge gaps that need to be addressed. The participation rate of women in inland fisheries (of which CBF is a component) at 5.53% in 2022 (MOF 2023), was lower than in the agricultural/fisheries/forestry sector as a whole, as indicated above. Women engaged in CBF include female heads of households, especially in post-war north and eastern parts of the country, and women from marginal communities in the dry zone, where most reservoirs are located. As women are often invisible in the fisheries sector in general, actual



engagement of women in CBF is likely to be higher. From available studies (De Silva et al. 2006; Amarasinghe et al. 2016) and field observations, the gender division of labour in CBF value chains pointed to men concentrated in fishing, trading (micro- and small-scale) and transport, women focused on processing, and to a small extent on gleaning and trading (micro-scale), and both involved in disentangling fish from nets and mending nets.

There have been few development projects that have addressed gender inclusion in CBF in Sri Lanka – however, the Asian Development Bank (ADB) Aquatic Resources Development and Quality Improvement project of 2003–2010 did involve a gender inclusion focus. Among its interventions to improve gender equity, women's membership in fisheries societies was increased to 10%, around 21% of loans were provided to women, and separate women's subcommittees were initiated in 35% of fisheries societies under the project (ADB 2010). Among other outputs were increased engagement of women in bookkeeping, collection of fisheries data within societies and handling the fish harvest in landing sites. The project also provided training in fish drying and salting, reservoir bund preparation, fingerling harvesting, as well as in non-fisheries supplementary income generating activities for women.

However, available studies and projects lack systematic data on gender roles and relations within CBF value chains, such as how women and men are differently located in value-chain nodes and engage in specific tasks/activities within these value-chain nodes; what benefits and costs accrue to women and men by participating in CBF value chains; and the gendered nature of governance within CBF communities. There is a need for an analysis of the gender norms and practices underlying

CBF value chains, the vulnerability context within which these chains operate, and perceptions of social wellbeing among women and men in CBF communities to understand the motivations for and outcomes from CBF engagement. These are some of the knowledge gaps that this paper seeks to address.

Gender insights from social science research of the ACIAR project

Two objectives of the ACIAR project were based primarily on social scientific data collection and analysis, and directly addressed gender concerns. These were:

- Objective 2: Conduct an inclusive, complete market-chain analysis from harvest to plate, to ensure post-harvest and supply practices meet market requirements and both male and female actors in the supply chain gain maximum benefits.
- Objective 4: Determine opportunities and constraints to achieving socially equitable livelihood benefits from CBF.

Gender inclusive value-chain analysis

In terms of Objective 2, gender-inclusive value-chain analysis (Paranamana et al. 2025) provided fresh insights on gender differences in the location of and engagement as actors in CBF value chains. In terms of the social relations approach outlined above, gender relations within the institutional context of the market emerged from this analysis. It revealed an overall predominance of men in all nodes within these value chains, with higher engagement of women in finfish value chains, relative to GFP chains. The highest participation of women was in dried finfish processing (76.5%) and in local, micro-scale retailing (47.1%) of dried finfish. The main engagement of women in the GFP value chain was in the primary handling node

(44.6%). The proportion of women engaged in fishing at 5.2% was lower than the global average for inland fisheries.

The data also showed differences in distribution of benefits and costs from value-chain participation across the 2 chain types (finfish and GFP), according to node actors and gender. Fishers (predominantly male) had higher returns in terms of market margins from the finfish value chain, relative to the GFP value chain. Fishers (predominantly male) had higher returns from the fresh finfish value chain relative to the dried finfish value chain. The highest returns in terms of market margin from GFP accrued to secondary collectors (predominantly male), followed by fishers. The lowest market margin accrued to primary collectors (both male and female). The highest returns in terms of market margin from fresh finfish value chains accrued to fishers, followed by wholesalers, with retailers receiving the lowest market margin.

Value-chain nodes in which women were predominant, such as dried fish processing, or had a relatively large share, such as primary handling in GFP, had lower returns than those in which men predominated. In the case of the dried fish value chain, the highest returns went to wholesalers (predominantly male). While actors who received higher returns generally bore higher risks and had higher variable costs, it is not clear whether the differences in benefits along value-chain actors can be explained entirely by the risks involved. This is indicated by the differences in bargaining power of and competition among node actors. In the GFP value chain, bargaining power was highest for secondary collectors/exporters and lowest for primary collectors with fishers in between. Competition also showed a similar pattern. In the finfish value chain, bargaining power was

highest for retailers and lowest for fishers/processors with wholesalers in between. Competition, on the other hand, was highest among retailers and lowest among wholesalers with fishers/processors in between.

Several gendered constraints to value-chain engagement emerged, such as women's activities in CBF not being recognised as work but as 'support' to men and thus not rewarded financially, women producers not possessing adequate bargaining power and women having less access to membership and decision-making in fisheries societies. Opportunities for women's participation identified were that women are generally considered as skillful in financial matters and in handling of GFP, which requires care to ensure that the carapace and claws are not damaged.

Gender roles and relations within CBF-related households

The main thrust of gender analysis under this project was incorporated within Objective 4 in the gender-focused study of Kanchana et al. (2025). This study is based on the social relations approach to identify gender roles and relations within the reservoir-based livelihood system, including women's inclusion in governance. Moreover, the social wellbeing approach was used to understand gender differences in motivations and outcomes in engaging in CBF-related livelihoods. The analysis addresses gender relations within the institutional spheres of household and community, and to some extent with the state, as community-based fisheries societies and extension services for CBF come under the purview of the state regulatory institution, National Aquaculture Development Authority of Sri Lanka (NAQDA).

Gender division of labour and relations

Research data (Kanchana et al. 2025; Kanchana 2025) revealed that men were predominant in most CBF-related activities in study households, ranging from 57% in retailing dried fish to 98% in collecting bait. Around 93% of fishers were men who fished alone, while 6% fished with female family members. Women were engaged in most tasks identified, apart from processing fresh fish for the market. Their participation was very low in collecting bait, as well as wholesaling and retailing of fresh finfish and GFP. Women's participation in fishing at 7% (1% who fished alone and 6% who fished with male family members) was slightly higher than indicated for inland fishing in national statistics but lower than the global average. Households reported substantial engagement of women in a range of CBF-related activities: 63% (19% alone, 44% jointly with men) in dried fish processing; 43% (24% alone, 19% jointly with men) in dried fish retailing (mostly at the local, micro-level); 29% (3% alone, 26% jointly with men) in mending nets; 16% (3% alone, 13% jointly with men) in purchasing fishing assets (canoes/boats, nets).

Both women and men participate in CBF mostly at household level with help from immediate family members. Women's CBF activities are perceived as 'supporting' men, while housework and childcare are seen as women's main tasks. The social norm that fishing is not women's work is strongly upheld by both men and women. However, in 4 of the 7 reservoirs – 2 located in the North Western (Puttalam district) and 2 in the North Eastern (Trincomalee and Mullaitivu districts) provinces – female respondents reported that more women had been involved in reservoir fishing in the past but stopped due to increased housework, migration overseas or decrease in fish stocks. The prevailing norm is

associated primarily with the perceived lack of fishing knowledge and skills by women and the prioritisation of housework, considered as a female task.

We can't go fishing. That's a male thing.
(Wife of fisher, Balahuruwa, Moneragala district)

Women are doing housework. They [the men] say that they are ashamed to take women for fishing activities. (Female farmer/wife of fisher, Mahadivulwewa, Trincomalee district)

Moreover, risks involved in fishing and the security of women in engaging in fishing on the reservoir at night were also mentioned as reasons for non-participation.

Only men deal with the risk [of fishing]. Women are not willing to go with them.
(Wife of fisher, Thabbowa, Puttalam district)

Women cannot go to the reservoir at night. There is no time to do anything else with housework. Women don't understand nets. (Male fisher, Kottukachchiya, Puttalam district)

The social norm that fishing is a male task has resulted in women's lack of access to fisheries assets, even though around a fifth of women were involved in decision-making around purchase of these assets within the household. The main constraint to participating in CBF identified by women related to their roles as wives and mothers, with housework and childcare perceived as their primary activity, based on underlying gender norms and practices. Other constraints were lack of fishing knowledge and skills, as well as religious concerns. In contrast, men indicated environment and tenure-related constraints, such as impact of climate uncertainty on fish stocks, access to the fisheries resource and illegal fishing. Men saw more opportunities than women

in increased incomes from harvesting GFP, as well as finfish, while women perceived potential for increasing dried fish production and retail, consistent with their customary gender division of labour.

Governance

Women's contribution to decision-making within the community in relation to CBF was extremely low (Kanchana et al. 2025; Kanchana 2025). Only 3 out of the 7 reservoir communities studied included female members in fisheries societies. Lack of access to membership was linked with non-engagement of women in fishing, as well as exclusion of women by male members or husbands.

As women are not involved in fishing activities, they are not members of the society. (Female farmer/wife of fisher, Kottukachchiya, Puttalam district)

There are no women in the fisheries society. Men don't want women to come. (Wife of fisher, Ridiyagama, Hambantota district)

Women's membership ranged from 16.6% in Urusitawewa, 25% in Tabbowa to 28% in Iranamadu fisheries society. The Iranamadu reservoir community, located in the north-eastern Mullaitivu district, is inhabited by war-affected Tamil households, with a larger proportion of female-headed households.

Becoming a member gives you the opportunity to fish and also provides you with the opportunity to strengthen your income. My husband's mother goes fishing in the reservoir. So, I go with them. Then I joined this society because I wanted to do fishing. (Female fisher, Iranamadu, Mullaitivu district)

The practice of women's involvement in fisheries activities has been higher in the North Western (Puttalam district) and North Eastern (Mullaitivu and Trincomalee

districts) provinces historically. Thus, in 2 fisheries societies (Mahadivulwewa in Trincomalee district and Tabbowa in Puttalam district), women indicated that they were involved in decision-making. However, men were twice more likely to be engaged in decision-making than women in Mahadivulwewa and 3 times as more in Tabbowa. Even though women are not members of the Mahadivulwewa fisheries society, they pointed out that they participated in place of their husbands, when the latter were otherwise engaged. Thus, it appears that they contribute to decision-making within the society without being members. Meanwhile, women members indicated their relatively active participation in the fisheries society in Iranamadu.

I talk when I need to talk. (Female fisher, Iranamadu, Mullaitivu district)

We talk about the price of fish and the time to dry fish. (Female fisher/processor, Iranamadu, Mullaitivu district)

However, despite voicing their concerns and issues in discussions, female members of the Iranamadu fisheries society did not affirm that they contributed to the decision-making of the society.

Social wellbeing

Notions of social wellbeing within CBF communities, based on Kanchana's (2025) fieldwork data, were wide-ranging, with the emphasis on one or more dimensions (material, relational and subjective), varying across reservoirs. Material wellbeing was most often articulated in terms of income, money, work, fishing, fish catch, farming, lack of debt, house, vehicle, food security and education. Notions of relational wellbeing that emerged were linked to strong family and community relations, living in harmony, helping



others, working together, not harming or troubling others and living without conflict. Subjective wellbeing notions that were frequently indicated related to living well, having a good life, happiness, freedom, independence, good health, religious practice, lack of suffering and a trouble-free life.

In both major reservoir communities (Iranamadu and Ridiyagama), the emphasis on the material wellbeing dimension was higher than on the other 2 dimensions. In one of the minor reservoir communities (Balahuruwa), relational wellbeing was emphasised over other dimensions, while in one of the medium reservoir communities (Tabbowa), the subjective wellbeing dimension was indicated as most important. In the other 3 reservoir communities, combinations of 2 wellbeing dimensions emerged as equally important – subjective/relational (Urusitawewa) and material/subjective (Mahadivulwewa) dimensions in 2 medium reservoir communities and relational/material dimensions in the minor reservoir community (Kottukachchiya). In general, these findings are consistent with Ekanayake's (2025) quantitative data, based on a randomised survey sample, on perceptions of social equity and livelihood benefits from CBF. These data revealed that while income was the most important motivation for CBF in major reservoirs, food security and independence were also factors of consideration in pursuing CBF in medium and minor reservoirs. Ekanayake's results also pointed to higher levels of poverty in medium and minor reservoir communities, compared to major reservoir communities, thus suggesting the importance of food security from inland fisheries production in the former types of reservoirs. In the relatively remote Moneragala district, the non-material

dimensions of wellbeing were emphasised in both the medium (Urusitawewa) and minor (Balahuruwa) reservoir communities. The medium reservoir community of Mahadivulwewa in Trincomalee district was noteworthy in that food security emerged as the most frequently indicated material aspect of wellbeing.

There were no marked gender difference in dimensions of wellbeing emphasised within most reservoir communities, pointing to shared notions between women and men. However, there was a slightly higher emphasis on material wellbeing by women in major and medium reservoir communities, and on relational wellbeing in minor reservoir communities. The overall focus on relational wellbeing by both women and men in minor reservoir communities suggest higher social cohesion within these communities.

Self-assessment of wellbeing and perceptions of satisfaction/dissatisfaction

The majority of research participants perceived that they had a good life, ranging from 50% of men in Kottukachchiya to 100% of women and men in Balahuruwa. The only exception was women from Ridiyagama, of whom only a minority of 33% thought that they had a good life. More women in Iranamadu, Urusitawewa and Kottukachchiya, and more men in Mahadivulawewa, perceived that they had a good life.

The majority of respondents (in 4 reservoir communities – Ridiyagama, Urusitawewa, Tabbowa and Mahadivulwewa) were satisfied with relational wellbeing aspects, with some differences among women and men within these communities. More men than women in Kottukachchiya were satisfied with material wellbeing aspects. In 2 reservoir communities

(Balahuruwa and Iranamadu), most research participants were satisfied with a combination of relational and material aspects of wellbeing. There was no gender difference in Iranamadu. However, more men than women were satisfied with material wellbeing in Balahuruwa, while the converse was true in the case of relational wellbeing.

The majority of respondents in 6 out of the 7 reservoir communities expressed most dissatisfaction with material wellbeing aspects, such as inadequate income or work, lack of a vehicle or house. Inadequate fish catches were indicated in Tabbowa and Mahadivulwewa medium reservoir communities. The only exception was Urusitawewa (medium), where respondents were dissatisfied with relational wellbeing aspects, expressed in terms of a negative influence exerted by people on the social environment due to alcoholism and drug abuse. A minority of research participants, both women and men, mentioned the ill effects of alcoholism and drug abuse in the 2 major reservoir communities (Iranamadu and Ridiyagama) and one other medium reservoir community (Tabbowa) as well.

Domestic violence and other issues facing women

Domestic violence, attributed to alcoholism and drug abuse, was reported by women and men from all reservoir communities. While women were more forthcoming with reporting domestic violence in the medium reservoir communities, a larger proportion of men reported its occurrence in the major and minor reservoir communities. The incidence or reporting of it was very low in Urusitawewa, although the majority of respondents there expressed dissatisfaction with the impacts of alcoholism. In addition to the physical and emotional harm caused

to women, domestic violence reveals underlying resource conflicts between women and men at household level, as violence was often related to the control of money for alcohol or drugs by men versus food and other household expenses by women. Other issues faced by women were harassment in the workplace and on roads, lack of transport, lack of freedom, childcare burden, lack of access to work, security concerns, kidnapping of minors and rape.

Foreseeing the future and aspirations for children

The majority of research participants (in 4 of the 7 reservoir communities) foresaw improvement in their material wellbeing in the future. A better economic situation, entailing higher incomes, better houses and vehicles, were frequently mentioned aspirations. Respondents in Iranamadu and Mahadivulwewa emphasised the subjective wellbeing dimension, in terms of a good life, happiness and freedom. A combination of subjective and material factors emerged in Tabbowa. In both Iranamadu and Tabbowa, the spiritual aspect of subjective wellbeing – the assistance of the gods and religious practice – was also mentioned. Moving out of fishing was envisaged by several respondents in Tabbowa and Kottukachchiya, both located in the Puttalam district. In contrast to the initial articulation of wellbeing notions, where women were more likely to emphasise material dimensions of wellbeing, men were more likely to focus on material wellbeing in anticipating the future, in most study communities.

In expressing aspirations for their children, the majority of respondents, both women and men (in 5 of the 7 reservoir communities) emphasised material wellbeing aspects, such as good education and good jobs. However, subjective



wellbeing factors, such as aspirations for a good life and happiness for children emerged as more important in Iranamadu and Balahuruwa reservoir communities. In all of the medium reservoir communities and in Kottikachchiya (minor) and Ridiyagama (major), a minority of research participants also articulated that being a good person, a good/productive citizen and contributing to society were aspirations for their children. In several reservoir communities (Ridiyagama, Tabbowa, Mahadivulwewa), aspirations for children to move out of the parental occupations of fishing or farming were expressed by both men and women.

Conclusion

Gender analysis in reservoir communities in Sri Lanka reveals predominant engagement of men along CBF value chains. Women's participation is considerably lower relative to that of men, with women confined to a few nodes, such as dried finfish processing and retailing, and primary handling of GFP, which bring lower returns than nodes in which men are engaged. Gender disparities in economic participation and benefits, as well as in governance, especially membership and decision-making in fisheries societies, reveal serious challenges in addressing gender gaps in CBF. In assessing social wellbeing, while women appear relatively satisfied with their lives, gender-based violence was reported from almost all reservoir-based communities studied. Within the context of growing gender inequality in Sri Lanka in the last 2 decades, addressing gender concerns within CBF communities and enhancing equitable opportunities for both women and men are critical. The implications of this analysis is that a gender transformative approach is needed to address inequities within the CBF sector.

Gender transformative approaches, from the 2000s, focus on the underlying causes of gender inequalities that limit the lives and livelihoods of women and men (McDougall et al. 2021). These constraints are structural, encompassing formal (policies), semi-formal (systems) and informal (norms) factors, which need to undergo change. Barriers to engage with, reduce or overcome structural constraints, from household, community, national to global levels need to be identified and transformed.

In terms of policies within the Sri Lankan context, the latest National Fisheries and Aquaculture Policy of 2018 (MFARD 2018) is committed to gender equality with provisions for promoting equal opportunities for women's participation, equal access to resources and benefits, gender mainstreaming in fisheries development strategies and women's contribution to finding joint solutions. However, it has no institutional mechanisms or action plan to implement this commitment, especially in the CBF sector. Thus, a gender transformative action plan for the CBF sector, based on institutional changes to redistribute power and resources with targets, timeframe and monitoring is needed. In considering institutional systems, data are currently collected on inland fish harvesting but women's activities remain invisible and under-counted, especially in gleaning and post-harvesting activities. Disaggregated data collection for all activities related to CBF needs to be done and extension services need to be provided for women, as well as men. The gender data and analysis, which has been generated by social science research under this ACIAR project, constitute an important contribution to this effort. In terms of the normative factor, it is a long-term process to change gender

norms and practices within households and communities. However, NAQDA and non-governmental organisations (NGOs) could work with communities to assess and value current women's work, increase their engagement in CBF value-chain nodes that bring adequate returns and promote their greater contribution to fisheries governance, as well as disseminate appropriate technology to enable more opportunities for women. Interventions need to address current disparities, and ensure that higher benefits from value chains accrue to women, based on a participatory, consultative process with women and men in CBF communities.

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5.2 Socially sustainable economy in culture-based fisheries in reservoirs of Sri Lanka and implications for sustainable livelihoods of rural communities

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Abstract

CBF can be used to achieve social and economic goals for reservoir-associated rural farming communities in Sri Lanka. The policy must be formulated for the integration of GFP production into Sri Lanka's reservoir CBF through scientific investigation. This paper examines social science aspects for the improvement of productivity, efficiency and sustainability of GFP and finfish, based on evidence from 48 minor, medium-sized and large irrigations in 10 administrative districts of Sri Lanka. The information was collected from fishers and non-fisher communities through the randomly selected sample surveys and case studies, using pretested questionnaires for face-to-face interviews to examine socioeconomic, cultural and local governance opportunities and constraints to maximise social equity and livelihood benefits, and inclusive, complete market-chain analysis from harvest to plate, to ensure both male and female actors in the supply chain gain maximum benefit for achieving equitable livelihood benefits for women and men. The 3 main analyses performed for each objective are sustainable livelihood framework, value chain analysis and the thematic analysis.

The research reveals that the socioeconomic conditions and the value-chain mechanism are more favourable for medium-sized reservoirs to develop CBF to achieve both social and economic goals of reservoir fisheries. CBF integration should focus on equity and resilience within fishing communities to ensure sustainable and effective CBF production. CBF has the potential to benefit both men and women. However, the economic benefits currently accrued to men are greater than those received by women, due to the predominance of men in most nodes of CBF value chains. The CBF sector can maximise the productive potential of both male and female members and their wellbeing by fostering an inclusive atmosphere, which will increase sustainability, economic development and food security.

However, challenges such as fingerling availability, water management, market fluctuations and the proper harvesting method must be addressed to ensure long-term sustainability. Therefore, we claim that the fisheries policy must be focused on the social equity of CBF to a more efficient, equitable and sustainable reservoir fishery system together with biological productivity.

Keywords: *social economic aspects, value chain, gender equity*

Introduction

ACIAR initiated a 5-year research project titled 'Improved productivity, efficiency and sustainability of the CBF for finfish and GFP in Sri Lankan reservoirs'. This project aimed to establish a robust, science-based and inclusive management regime for the CBF of GFP and finfish species in Sri Lankan reservoirs.

This initiative builds upon previous research, such as the project 'Assessing production of giant freshwater prawns in reservoirs in Sri Lanka', which aimed to improve yields and fisher community incomes through better stock and recapture strategies. By enhancing fish and prawn production, the current project seeks to contribute to the health and economic well-being of rural communities in Sri Lanka.

The project's objectives included:

- Investigating stocking, monitoring and harvesting practices to maximise fish and GFP production and product quality.
- Analysing the market chain to determine supply and post-harvest practices that meet market requirements and deliver maximum benefit for male and female fishers.
- Generating bioeconomic models as inputs to effective fisheries management.
- Determining opportunities and constraints to achieving gender-equitable livelihood benefits from CBF.

The productivity and efficient sustainable condition of GFP production is a collaborative effort of the natural science and social science component of the project. The latter is investigated mainly under the following 3 areas:

1. Socioeconomic, cultural and local governance opportunities and constraints to maximise social equity and livelihood benefits.
2. An inclusive, complete market-chain analysis from harvest to plate, to ensure both male and female actors in the supply chain gain maximum benefit.
3. Opportunities and constraints for achieving equitable livelihood benefits for women and men.

Economic importance of GFP production

The GFP (*Macrobrachium rosenbergii*) is a highly economically valued species in aquaculture due to its fast growth, high market demand and adaptability to freshwater environments. In countries like Sri Lanka, it plays a crucial role in CBF, where prawns are stocked in reservoirs and harvested to improve rural livelihoods. The economic impact of GFP is twofold. GFP production is an extension of ongoing CBF production. Therefore, its direct beneficiaries are rural farmer communities. Many rural fishers rely on CBF and GFP production as an alternative or supplementary income source to reduce economic vulnerability. This sector can be further improved to generate supplementary employment in hatcheries,

grow-out farms, processing and marketing. On the other hand, increased availability of GFP contributes to protein intake in local diets. However, now fishers' priority is to increase their income by selling GFP rather than increase their consumption as an alternative source of nutrition intake. Women's participation in post-harvest processing, value addition and marketing are ongoing normal fisheries activities around the world for enhancing household incomes. However, GFP has a vast future potential as a less time-consuming profitable fisheries activity for women that can be developed to maintain their household activities.

The national importance of GFP production is as a source of export revenue. GFP has a strong international market, boosting foreign exchange earnings. GFP has more international demand than the tilapia and carp species. The expansion of GFP farming reduces dependence on marine capture fisheries as well. Overall, the aquaculture sector, including GFP, strengthens the agriculture and fisheries sector of the economy. Evidence-based scientific management of culture-based prawn fisheries can enhance food security and economic resilience without over-exploiting natural resources.

Materials and methods

The research project covers 10 administrative districts in different ecological zones, and 48 reservoirs are investigated. Reservoirs are categorised based on their capacity and operational conditions, namely: large, medium and minor. CBF activities in large- and medium-sized reservoirs operate more than one fishery cooperative society, while small-scale reservoirs operate with one fishery cooperative society under respective farmer organisations. However, 3 different aspects of social sciences were investigated in a selected number of reservoirs, depending on their focus (Table 5.2.1).

The social science research was conducted in a subset of the 48 reservoirs as specified in Table 5.2.1. Data collection was performed using Participatory Rural Appraisal (PRA) and Rapid Rural Appraisal (RRA) tools for each objective. Mainly fisher households and fish vendors were interviewed using pre-test questionnaires individually. Also, researchers conducted focus group discussions where necessary. In particular, the case study research method was used for the value-chain study.

Table 5.2.1: Selected sample size for each objective of the social sciences studies

Social sciences research objectives	Number of reservoirs			Sample size
	Large	Medium	Minor	
1. Socioeconomic, cultural and local governance opportunities and constraints to maximise social equity and livelihood benefits.	01	04	08	272 households
2. An inclusive, complete market-chain analysis from harvest to plate, to ensure both male and female actors in the supply chain gain maximum benefit.	01	03	01	06 supply chain
3. Opportunities and constraints for achieving equitable livelihood benefits for women and men.	02	04	04	Fisher household 237 Non-fisher household 59

Data analysis

The primary objective of this activity was to identify opportunities and constraints in achieving socially equitable livelihood benefits from CBF. Data on Objective 1 of the social sciences study integrated into a sustainable livelihood framework SWOT analysis.

The value-chain analysis focuses on 3 main areas of the GFP market channel. One is market destination. Three major market destinations were identified: local/village, national/urban, and foreign/export markets. Sub-themes were identified for analysis under the main theme of assessing existing supply chains in the CBF sector: the number of value chains, chain nodes and their relationship, market proportion, nature of the price determination, operating cost, profit and market merger into the industry. The social relations of the fisheries community and the subsequent benefits and implications they can derive from the fisheries industry were analysed under division of labour: men may work in formal jobs, commercial farming or other income-generating endeavours, while women may handle childcare, home duties and subsistence farming. However, foreign/export markets analysis was not performed due to unavailability of reliable data and information. The second is access to resources. It is obvious that usually men have greater control over land, credit and technology, while women may have limited decision-making power in household and community matters. And the third analysis focuses on income generation. In most South Asian societies, men dominate formal employment and entrepreneurial activities, while women engage in informal or unpaid labour. Finally, decision-making power. Men often engage in household and community decision-making, while women's voices may be marginalised.

Thematic analysis was used to analyse qualitative data in Objective 3, the gender analysis of CBF. Descriptive statistics and analysis were used to calculate patterns and trends from the quantitative data generated by the study within the 3 dimensions: gender roles and relations, constraints and opportunities, and fisheries governance.

Although both gender groups participate, this inclusive perspective recognises that their roles, relations, opportunities, constraints and contribution to decision-making may differ within the 3 dimensions.

Results and discussion

Socioeconomic, cultural and local governance opportunities and constraints to maximise social equity and livelihood benefits

The general social perception of CBF in Sri Lankan reservoir fisheries is twofold. On one hand, CBF in reservoirs is considered a source of income, and on the other, it is a source of nutritional supply to the rural farming community. The income distribution among fishing communities varies across major, medium and minor reservoirs, reflecting different economic conditions. The community in the major- and medium-sized reservoirs belong to high average income groups (80% and 60%, respectively). However, the community of minor reservoirs had a relatively higher percentage (54%) of low-income households. These variations highlight the economic disparities among fishers, with minor reservoir communities experiencing higher levels of poverty compared to those in major and medium reservoirs. This implies that the community occupied in CBF in medium and minor reservoirs are involved in CBF to ensure their food security (Figure 5.2.1).

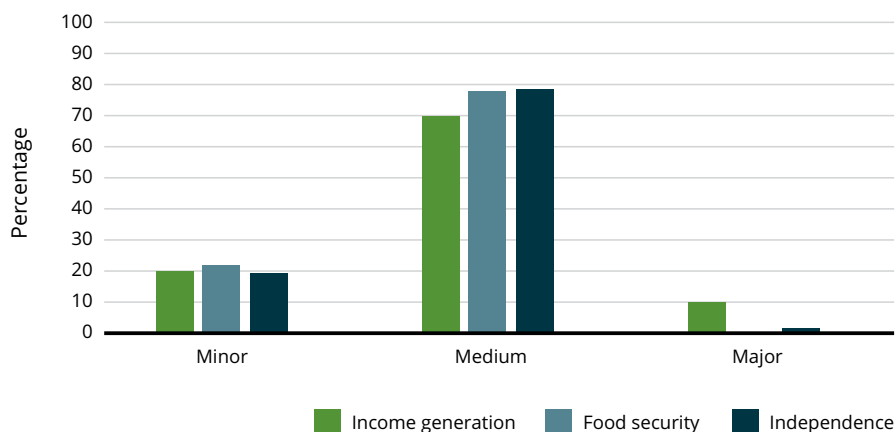


Figure 5.2.1: Perceptions of social equity and livelihood benefits in CBF

The medium-sized reservoirs are highlighted as types of reservoirs for the perceived benefits of reservoirs in a threefold consideration in the study. They considered CBF as a source of income generation, ensuring food security and independent economic activity. Farmer communities in the medium-sized reservoirs organise their agricultural practices under more than one farmer organisation, depending on the surface water distribution of the reservoirs. Furthermore, CBF in reservoirs was investigated under a sustainable livelihood framework.

The analysis of human capital in reservoir fishing communities was based on education, main occupation and training received for their main occupations. The results reveal significant differences in these 3 criteria across the 3 types of reservoirs. However, medium-sized reservoirs have the highest scores for the following 3 main factors: trained fishers in medium reservoirs (73%), followed by

minor reservoirs (20%), and lowest in major reservoirs (7%). These findings indicated that the medium reservoir fishers had the most access to training opportunities, while major and minor reservoir fishers had limited exposure to capacity-building programs.

The financial capital analysis shows that the highlight credit usage is reported from medium-sized reservoirs (65%). The minor reservoirs and major reservoirs credit usage is 23% and 12%, respectively. Similarly, the savings behaviour of the fishers of medium-sized reservoirs is comparatively higher (69%) than the other 2 types of reservoirs. Therefore, the medium-sized reservoirs reported the highest financial capital among the other reservoirs.

The communities of medium-sized reservoirs are on the frontier of natural capital assets. Access to drinking water and land ownership are the 2 major determinants included as natural capital assets in the study. The drinking water

access is 72%, and the land ownership of the fisher communities associated with the medium-sized reservoirs is 91%. However, land ownership is more evenly distributed based on the size of the plots (i.e. with 27% owning small plots, 30% medium-sized (41–100 perches) and 34% large plots (101–400 perches). The unequal distribution of land and water resources affects livelihoods and resilience of fishing communities.

Physical capital, including household assets and fishing equipment, has a direct impact on their productivity and the quality of life. Mobile phone ownership is widespread, with 100% of major reservoir fishers owning one, followed by 98% in medium and 94% in minor reservoirs. Electricity access is nearly 100% in major and minor reservoirs, and 99% in medium reservoirs. Ownership of fishing equipment availability also varies, with fibre boats being more common in major reservoirs (96%) compared to medium (83%) and minor (85%) reservoirs. Traditional rafts (Theppan) are used only in minor (17%) and medium (12%) reservoirs.

CBF is a group activity that is very much dependent on collective action and collective decision-making. Social capital plays a crucial role in shaping trust, cooperation and social relations within reservoir fishing communities, enhancing social cohesion. Trust in fisheries community leaders and fisheries society members is relatively high, indicating strong confidence in leadership and collective decision-making within fisheries societies. Trust in people within the fishing community is slightly lower but still significant, suggesting a sense of unity among fishers. Having a strong social capital is a prerequisite for the sustainable CBF activities as far as equity is concerned. Among the 3 types of reservoirs, medium-sized reservoirs are reported to be rather well equipped with social capital.

As depicted in Figure 5.2.2, medium-sized reservoirs have significant livelihood opportunities in the development of CBF, except for their low representation of physical capital (fishing gear and fibreglass boats), and mobile phone usage is comparatively low compared with the other reservoirs.

Contributing factors to social equity and livelihood benefits

Poor financial management is no exception in reservoir fisheries as a common issue in all sectors of fisheries. Wasteful or unproductive expenditure behaviours could be observed in the major reservoir communities more than the medium-sized and minor reservoir communities where the latter have notably poor financial management practices. One determinant for the quality of life is the expenditure on food. All 3 reservoir communities are spending a similar amount for their daily food necessities. Knowledge of the CBF process among communities associated with minor reservoirs is comparatively lower than that of communities associated with major reservoirs. Water allocation and benefit sharing issues related to conflict were very common in minor reservoirs rather than the other 2 types of reservoirs. The survey results show that these factors are considerable contributing factors for the inefficient socially equitable and livelihood benefit sharing among the CBF farming communities.

In addition, several constraints hinder the maximisation of social equity and livelihood benefits in reservoir fishing communities, particularly environmental, governance and economic challenges. Unauthorised fishing is a significant issue across all reservoirs, reported by 100% of major, 90% of medium and 67% of minor reservoir communities. Elephant threats are a major concern

Five livelihoods capitals of CBF in three types of reservoirs

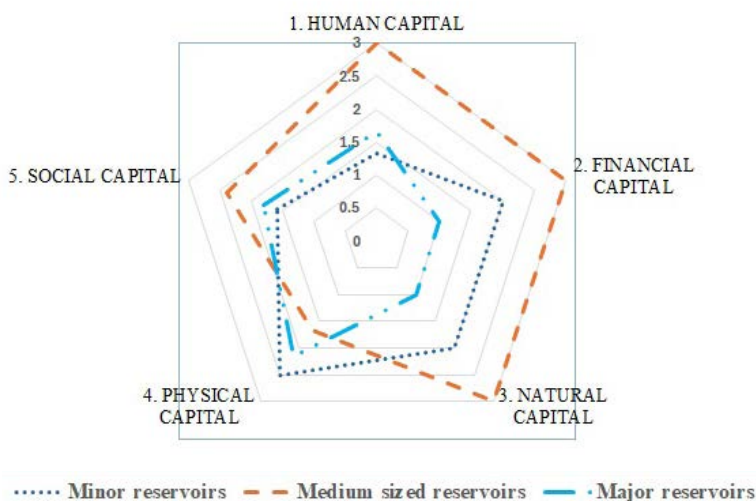


Figure 5.2.2: Estimated values of sustainable livelihoods assets of 3 reservoirs

in all reservoir types, affecting 100% of major and 59% of both medium and minor reservoirs. Furthermore, fishing activities being disrupted by governance issues, such as compliance with rules and regulations, are relatively low, with 4% in major, 11% in medium and 7% in minor reservoirs. Such threats can be minimised by introducing risk management mechanisms for medium reservoirs and introducing an insurance system. Furthermore, enhanced CBF activities in minor reservoirs need to be provided with subsidiary schemes. To ensure equitable fish consumption, establishing rural fish stalls is suggested.

An inclusive, complete market-chain analysis from harvest to plate, to ensure both male and female actors in the supply chain gain maximum benefit

Successful value chains should focus on 2 goals of CBF in reservoirs. The social goal

of CBF activities is to ensure food security and the economic goal is maximising profit (Figure 5.2.3). The main sources of the rural nutrition requirement are provided by the finfish supply in the rural market with excess demand. Therefore, the finfish supply in the reservoir fisheries has to be continued irrespective of the market price and the economic profit to maintain the social conflicts for sustainable CBF.

GFP in CBF is the main target for the export market due to the lucrative financial benefits. Local demand for GFP is still considerably low due to the market price. The local demand for GFP depends on the quantity of rejection from the export quality. Local market demanded 26% of GFP while export percentage is about 74%. Therefore, increased production of both finfish and GFP in reservoir fisheries can achieve both social and economic goals.

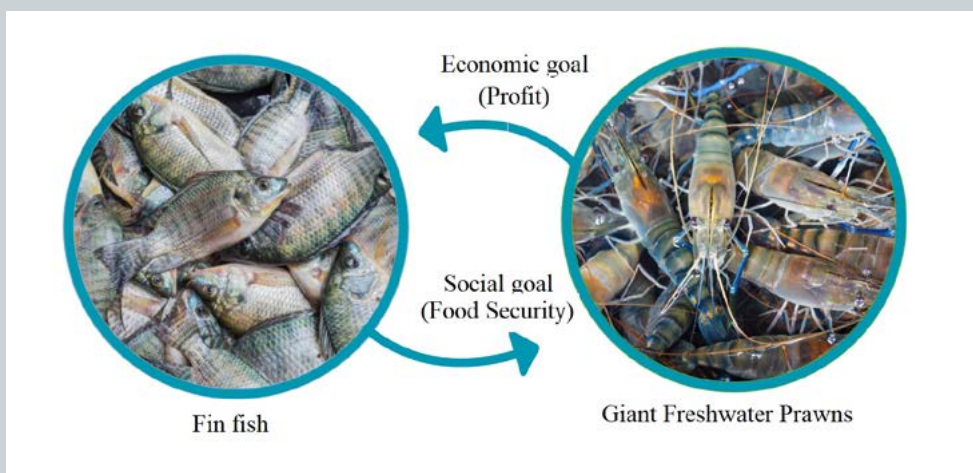


Figure 5.2.3: Social and economic goals of CBF in reservoir fisheries

Five channels were identified within the GFP value chain in the survey (Figure 5.2.4), and 6 channels were identified for the finfish market based on the product movement from fishers through different intermediaries before reaching the end market. The end users for the finfish market are dominated by the local consumers, and the foreign and local market are the end users of the GFP production. However, the noticeable factor is the large proportion of GFP sales exported to the foreign market as mentioned.

A large proportion of the market margin of the GFP market is received from the secondary collectors (in the local market), and the wholesaler receives it from the finfish market. The secondary collector of the GFP market receives such a big proportion for several reasons. There is an uncertainty of GFP production because fishers have no proper techniques (fishing gears) to harvest GFP. Ongoing harvesting methods damage the GFP and, therefore, considerably damage the GFP catch. The

damage to GFP is not of the accepted quality for the export market. When the final output is not predictable, the market price is not stable. This situation is aggravated with the scarcity of buyers that exist in the GFP market chain. There is no competitive market for GFP, therefore, fishers are price takers. Hence, the income of the fishers is unpredictable. Also, there is no proper grading or pricing method. In addition, poor fingerling supply is another drawback for sustainable GFP production.

Fishing, fish farming, wholesaling, retailing and processing are the main nodes in GFP and finfish value chains. Several marketing nodes are evident, along with unequal benefit sharing among the value-chain actors, which were investigated by Sinh et al. 2014. The gendered value chain in the fishing industry reveals that fishing, primary handling, wholesaling and retail selling are predominantly male-dominated activities. In contrast, the production of dried fish is primarily a female-dominated task. Although women participate in retail selling,

Types of Value Chain

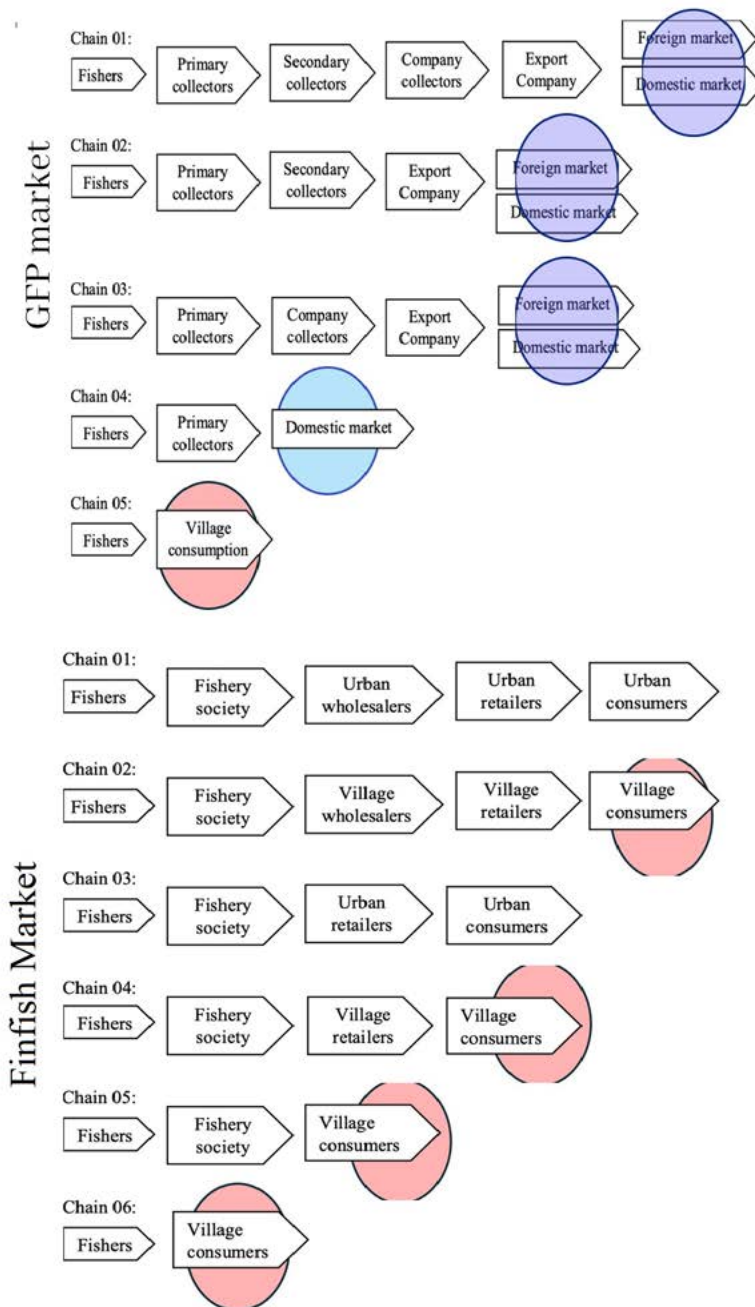


Figure 5.2.4: Value chain for finfish and GFP market of reservoir fisheries

they do not typically engage in wholesale selling. In the aquaculture sector, women represent a significant portion of the labour supply (FAO 2011). Their contributions are particularly notable in fish processing, marketing, fry collection, fish feeding and net mending, as evidenced by cases in other developing countries (Bueno 1997; Locicero 1997; Virulhakul 1997; Murray et al. 1998; Kusakabe 2003; Paranamana et al. 2024).

Opportunities and constraints for achieving equitable livelihood benefits for women and men

Gender roles and relations within the livelihood system of CBF communities reveal how men and women share responsibilities, access resources and engage in economic activities within households, which constitute the community. These roles and relations can differ across communities and societies due to cultural, social, economic and environmental factors. Gender roles define the expectations for men and women in economic, social and domestic spheres. These roles often dictate:

- Division of labour: Men often work in formal jobs, commercial farming and fishing, or other income-generating endeavours, while women handle childcare, housework and subsistence farming or fishing-related activities.
- Access to resources: Generally, men tend to have greater control over land, credit and technology, while women may have limited decision-making power in household and community matters.
- Income generation: In most societies, men dominate formal employment and entrepreneurial activities, while women engage in informal or unpaid labour.
- Decision-making power: Men often engage in household and community decision-making, while women's voices may be marginalised.

There are several opportunities and constraints for achieving equitable livelihood benefits for women and men. Naturally, CBF have excess supplies of labour in the reservoir fisheries. Therefore, the women's involvement in fisheries is yet to be debated. However, female fishers play a big role in support services in fishing. On the other hand, households' income in the rural farming community culture is inseparable (cannot be separated between female and male). However, the opportunity cost of female fishers' roles in households is not estimated. There is an opportunity for female involvement in north and east Sri Lanka due to the unemployed women-headed fisher households due to the past civil unrest. Therefore, as fisheries offer a less time-consuming livelihood, women can be more involved in CBF activities (especially GFP) without disturbing their day-to-day household commitments. In some cases, women are excluded from the fisheries activities because women's membership in fisheries cooperative societies is restricted.

Conclusion and recommendation

The socioeconomic conditions and the value-chain mechanism are more favourable for medium-sized reservoirs to develop CBF to achieve both social and economic goals. Due to water availability and the ongoing agreement in the farmer organisations, minor reservoirs are more suitable for finfish production in order to ensure rural fish consumption and enhance rural nutrition levels. CBF integration should focus on equity and resilience within fishing communities to ensure sustainable and effective CBF production. Policy must be focused on the social equity of CBF to a more equitable and sustainable reservoir fishery system. Both GFP and finfish are important for CBF communities and the



rural economy. While finfish is essential for food security, GFP offers a high earning potential for households engaged in CBF. Therefore, the value chains for both products need to be improved. To maximise benefit sharing among value-chain actors, the information asymmetry regarding price determination must be minimised. CBF has the potential to benefit both men and women. However, the economic benefits currently accrued to men are greater than those received by women, due to the predominance of men in most nodes of CBF value chains. The CBF sector can maximise the productive potential of both male and female members and their wellbeing by fostering an inclusive atmosphere, which will increase sustainability, economic development and food security.

GFP production can significantly uplift rural communities and contribute to Sri Lanka's national economy by investing in science-based management, efficient stocking practices and value-chain improvements. However, challenges such as fingerling availability, water management, market fluctuations and proper harvesting methods must be addressed to ensure long-term sustainability. The integration of GFP production into Sri Lanka's CBF has positively impacted the sustainable livelihoods of rural fishing communities. While challenges remain, particularly concerning market stability and resource management, the overall benefits underscore the potential of GFP cultivation as a viable livelihood strategy.

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5.3 Community perception issues and expectations on efficient culture-based fisheries production in irrigation reservoirs of Sri Lanka

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Abstract

This paper presents the results of a community awareness program for the fishing community associated with 48 irrigation reservoirs (13 small-scale irrigation reservoirs, 25 medium-scale irrigation reservoirs, and 10 large-scale irrigation reservoirs) in 10 districts. The introductory program examined the perceptions and expectations of the CBF farming communities on improving the productivity, efficiency and sustainability of finfish and GFP farming in the CBF in Sri Lankan irrigation reservoirs.

Common problems in GFP farming in all irrigation reservoirs include insufficient stocking of freshwater prawn larvae, predation by GFP, lack of formal methods for harvest of GFP, and predator damage. However, these issues can be different depending on the type of reservoir. Illegal fishing and trapping methods, and damage caused by wild elephants, are some of the other common problems that strongly affect the CBF.

Although freshwater production in Sri Lanka operates under the name of 'culture-based fishery industry', it is still not a competitive production industry or system aimed at maximising private profit, but rather fishing is perceived as a source of livelihood. Therefore, it is a production system that does not operate on a systematic business plan, nor does it implement small-scale guidelines that are accepted internationally. Policies should therefore be formulated based on experimental information on stocking, harvesting techniques and bioeconomic relationships to sustain GFP farming in CBF with the consideration of community perceptions and expectations.

Fish farmers expect continued government subsidies for fingerling supply. However, CBF can be developed as a profit-oriented industry rather than a source of livelihood, taking into account the rural protein requirement, the supply of fish, and GFP fingerlings finance through investment based on member funds, according to a business plan.



CBF can be sustained as an industry with the effective participation of the respective reservoir-based farmer–fisher cooperation for a more efficient district-level extension officer service, the understanding of problems and needs, participatory action research knowledge, and development of rural social and communication skills. The dependency of the fishing community on subsidies as well as the dependence of NAQDA for public finance can be gradually reduced. This consultation report suggests that NAQDA and the fishing community should make interdependent structural institutional reforms on an apolitical basis to make GFP farming a productive, efficient and sustainable ‘industry’.

Community perceptions and expectations play a decisive role in the efficiency and sustainability of CBF. Strategies that centre on participatory engagement, capacity building, equitable benefit distribution and responsive governance systems are essential to align CBF production goals with local realities.

Keywords: *perception, expectations, community participation, self-financing*

Introduction

CBF involve the enhancement of water bodies (like reservoirs, lakes and floodplains) through the release and recapture of cultured fish, allowing them to grow using natural productivity. CBF have been increasingly promoted for rural livelihood development, especially in Asia, Africa and some parts of Latin America, to enhance fish supply, food security and rural livelihoods (De Silva and Funge-Smith 2005). CBF is also considered a low-input, community-managed, semi-intensive form of aquaculture. However, the success of CBF depends heavily on the perceptions, expectations and participation of local communities. Understanding community dynamics is essential for enhancing production efficiency and long-term sustainability.

CBF systems differ from intensive aquaculture in that they rely on existing water bodies and natural productivity, often with community-level management (De Silva and Davy 2010). The objective is to augment fish yield while maintaining ecological balance.

Community perceptions and expectations

Community perception encompasses local beliefs, knowledge systems, attitudes and social norms, while expectations relate to perceived benefits such as income, food security, employment and ecological outcomes (Torell et al. 2010). Several studies highlight that low awareness and technical knowledge are major barriers to community participation. In Sri Lanka and Vietnam, De Silva et al. (2006) found that communities often lacked understanding of stocking density, species compatibility and harvesting strategies. Kaminski et al. (2018) found in Malawi that extension services were insufficient to bridge local knowledge gaps, affecting perceptions of CBF efficiency. The perception of fairness, transparency and leadership in community fishery committees is crucial. Studies in Cambodia and Laos (Chou 2009; De Silva 2016) noted that weak local institutions and elite capture erode community trust and reduce the willingness to cooperate in CBF initiatives. Furthermore, in Bangladesh, community-based organisations supported

by NGOs saw better management outcomes (Islam et al. 2011), increasing positive expectations. Community expectations often revolve around improved income and employment, and sources of nutrition. De Silva (2006) found that communities expected quick economic returns, which clashed with the seasonal nature of CBF in India. Nevertheless, expectations of equal profit sharing often do not match reality, especially when roles in management and labour are unequal (Haque and Dey 2017).

Experience in Indonesia and the Philippines shows that women's involvement in CBF was low despite their significant contribution to post-harvest and management activities (Weeratunge et al. 2010). Cultural norms sometimes prevent marginalised groups from accessing water bodies or participating in governance (Ratner and Allison 2012). CBF employ existing water bodies that are used for multiple purposes. Therefore, communities are sensitive to ecological changes linked to CBF, such as overstocking, introduction of exotic species or water pollution, which can lead to scepticism or resistance (Amarasinghe and Nguyen 2010).

Perception issues can be resolved through participatory planning and co-management. Evidence from Thailand and Bangladesh suggests that co-management frameworks enhance legitimacy and shared ownership (Pomeroy et al. 2001). Also, the inclusion of traditional knowledge and active dialogue is vital to align expectations. Lack of knowledge on CBF activities is another drawback for the development of CBF. Proper extension programs addressing both men and women can improve understanding and reduce misinformation (FAO 2024). For this purpose, mobile-based advisories and farmer-to-farmer learning have proven effective in parts of Southeast Asia. Equity-focused benefit sharing

is another issue for CBF development. Transparent systems for input allocation, labour contribution tracking and profit sharing are critical. Furthermore, institutional innovations such as fishery cooperatives with rotating leadership roles can help mitigate power imbalances (Sen and Nielsen 1996) and social conflicts.

Research methods

Using a participatory approach, a problem-tree analysis was conducted with the fishing communities that participated in the workshop to identify the causes, solutions and impacts of the problems of the sustainable development of the CBF industry. In addition, a focus group discussion was conducted with the participation of officials and members of the fishing groups using a set of open-ended questions to collect basic information related to the CBF industry.

Results and discussion

Rural farmer communities perceive some aspects of CBF based on their expectations. There are 2 main expectations on CBF production:

1. CBF should be a source of nutrition as a social goal.
2. CBF should be an income-generating activity as an economic goal.

The importance of aquaculture

The importance of aquaculture to livelihoods has been discussed in 3 ways. As presented in Table 5.3.1, overall, 100% of the fishers in all irrigation reservoirs consider it as an occupation for their livelihood. This statement is truest for full-time fishers, that is, active fishers who consider a higher percentage of their income contributes to their livelihood and they spend time on fisheries activities.

Table 5.3.1: Importance of CBF to 3 types of farmer communities (as a percentage)

Importance of CBF	Minor irrigation (%)	Medium irrigation (%)	Major irrigation (%)
As an occupation	100	100	100
As a source of nutrition	15	12	0
As an additional source of income	8	8	20

The common opinion of CBF as a source of rural nutrition suppliers is no longer true for large irrigation reservoirs, as shown in Table 5.3.1. However, about 15% and 12% of fishers in small and medium irrigation reservoirs, respectively, consider cultured fisheries as a source of nutrition. Fishers who have alternative sources of income but engage in fishing activities on a seasonal basis consider the CBF as an additional source of income. Expectation of quick returns often leads to over-harvesting or disagreement on harvest timing. Most communities expect CBF to provide a reliable, seasonal income stream, especially in dry or lean periods (Pant et al. 2014).

Rural fish consumption

Among the desired objectives of CBF is the improvement of rural nutrition. Although Sri Lanka is a country with a marine fishery around the island, the supply chain of marine fish production is not sufficiently organised. Therefore, the supply of marine fish available for rural consumption is limited and the market price for marine fish does not match the purchasing power of rural communities. On the other hand, although the accessibility and market price of freshwater fish are favourable for the rural consumer, there is still an excess demand. That means freshwater fish production has failed to meet the rural demand.

Fish production in small-scale irrigation reservoirs is a seasonal product and contributes significantly to rural fish

consumption. Of the total production, 64% is sold for rural consumption in minor irrigation reservoirs and it has been observed that the leading consumption choice is the tilapia species (Figure 5.3.1). The main criteria for such a choice are taste, market price, and the number of pieces that can be provided in one kilogram. On the other hand, fishers are inclined to stock carp species and GFP because of their weights and higher market prices, respectively.

However, rural consumers have less interest in carp species, and there is a low demand for GFP due to the high market price and low number of pieces that can be consumed per kilogram. There is a slight increase in rural consumption of GFP due to an increase of rejected harvest by purchasing agencies because of improper techniques of GFP catching. Rejected GFP is sold by fishers to the village consumers for low prices.

The fishing industry in small-scale irrigation reservoirs is influenced by farmer organisations, and rural consumer interest is a decisive factor for profitable fishing activities such as GFP. As a result, some small-scale irrigation reservoirs have had to stop stocking GFP. Some medium-sized irrigation reservoirs also have such influence from the farmer organisations and the rural communities but such influence is not seen in large-scale irrigation reservoirs. Many rural households anticipate increased fish availability for household consumption, not just market sales. Misalignment of project goals (for example, commercial focus) and community expectations can cause tension.

Reservoir-related common issues affecting CBF

Table 5.3.2 shows the common reservoir-related issues affecting CBF. Illegal net use and illegal fishing were identified as major issues common to all irrigation reservoirs and these issues are reported in 100% of the major irrigation reservoirs.

The implementation of legal measures by NAQDA officials is a legal requirement for controlling illegal fishing activities. However, the implementation of rules and regulations are an insufficient mechanism. Among the factors affecting this are the nature of resource ownership for proper implementation of the law,

the resources and technology available to law enforcement officers, and the socioeconomic and political context of the country. Furthermore, the restriction of fishing membership, the lack of a system for removing inactive members, the lack of alternative livelihood opportunities, and the high market price of GFP have contributed to the intensification of these illegal activities. Also, the dual nature of the duties of extension officers is an obstacle to the development of the GFP industry. That is, at one time, an officer may need to enforce the law and at another time, the same officer in the capacity of an extension service officer may implement welfare policies.

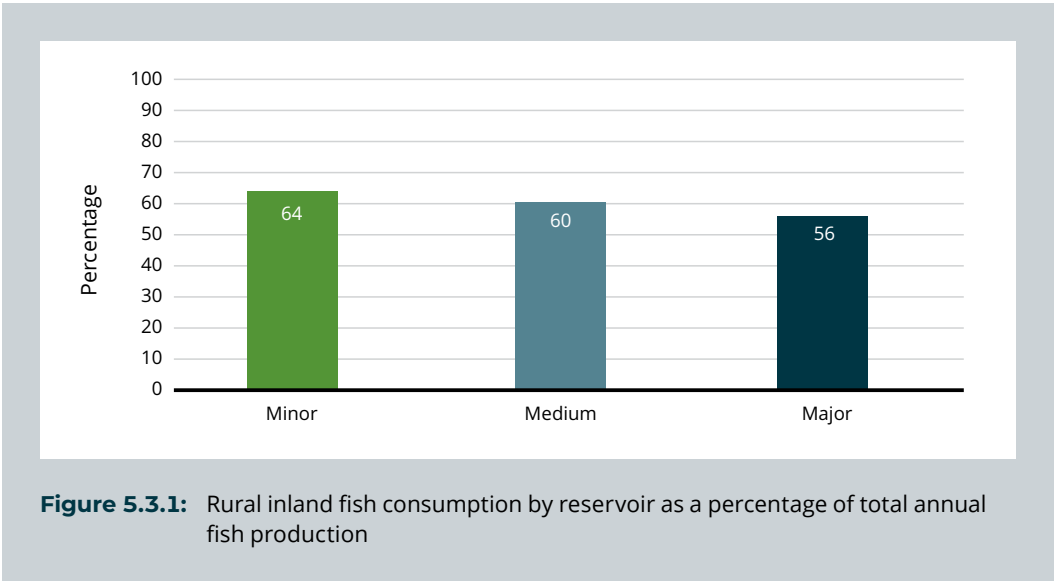


Table 5.3.2: Reservoir-related common issues affecting CBF (as a percentage)

Type of membership	Minor irrigation (%)	Medium irrigation (%)	Major irrigation (%)
Illegal fishing	85	84	100
Illegal net use	85	92	100
Elephant damage	77	60	80
Predator problems	31	8	20
Conflicts between fishers and farmers	31	24	10

In general, damage to nets by wild elephants is a common problem affecting many irrigation reservoirs and affects 80% of large irrigation reservoirs. Water management conflicts between fishers and farmers are often seen in small-scale irrigation reservoirs. Inter-sectoral water sharing (between paddy cultivation and fisheries), a problem in rain-fed small-scale irrigation systems, is strongly linked to farmer organisations. There is a lot of scope for solving this problem with good coordination between farmer organisations and fisheries committees in small-scale irrigation systems. Studies (for example, by Ahmed and Garnett 2011) highlight that CBF success depends on a strong sense of community ownership. Lack of clear tenure and benefit-sharing mechanisms often leads to low motivation and conflict. There is frequent concern about elite groups monopolising the benefits. This reduces trust among marginalised fishers and discourages their participation (Nunan 2006). Jentoft (2009) emphasises that perceptions of fairness in how benefits and responsibilities are shared play a central role in whether resource users participate in fisheries co-management. If communities feel benefits are inequitable, they may opt out or even sabotage the system. In Bangladesh and Sri Lanka, participatory studies found that women and small-scale fishers felt excluded from decision-making and harvest sharing (Crofton et al. 2024).

Religious practices associated with CBF

Compared to coastal fisheries, most inland fishers are Buddhist, with Hindu and Muslim also being identified in different regions. Agriculture and fishing have been part of the livelihood of Buddhist culture for a long time. This religious influence, which was strong during the era when fishing was limited to food only, has gradually eased with the expansion of commercial fishing. However, during the full moon days, Sri Lankan fishers generally refrain from fishing (both inland and at sea). However, there is no legal prohibition on fishing on those days; it is a religious consensus.

According to Table 5.3.3, 50% of the fishers in large irrigation reservoirs do not engage in fishing activities on full moon days and Fridays, while 85% and 96% in small and medium irrigation reservoirs do not engage in fishing activities on full moon days only. On the other hand, the very low rate of abstention from fishing activities on Fridays is reported because most of the fishers are not Muslim. The right to use water in small and medium irrigation reservoirs is linked to land ownership, and therefore, elderly landowners are often not interested in fishing activities for religious reasons. However, their young male adults participate in fishing activities. Nevertheless, in most cases, young adults are not members of farmer organisations. Therefore, the relationship between farmer organisations and Fisheries Cooperative Societies (FCS) is distant. The relationship between the farmer and the fishing group

Table 5.3.3: Religious practice associated with CBF (as a percentage)

Type of membership	Minor irrigation (%)	Medium irrigation (%)	Major irrigation (%)
Refrain from fishing on full moon days	85	96	50
Refrain from fishing on Fridays	15	4	50

is more important because the water management decisions in the irrigation reservoirs are linked to fishing activities. Cultural beliefs around fishing (for example, caste restrictions in South Asia) can limit participation. Bailey and Jentoft (1990) found cultural norms resistance to particular management interventions. Religious or local taboos on fish stocking practices (for example, releasing exotic species) may generate resistance.

Women's participation in CBF

Women's participation in the cultivated fisheries industry is notable for its greater focus on supply-chain activities in the southern regions of Sri Lanka, while the northern and eastern regions are more involved in harvesting activities. This may be largely due to the recent civil unrest in those regions.

Although participation by women in fishing activities is 41% in the medium and major irrigation reservoirs, low female participation is observed in the minor irrigation reservoirs due to the fact that they are engaged in agricultural and alternative employment, the seasonal nature of the fisheries activities and the high demand for finfish in rural areas (Figure 5.3.2). Women are also mainly involved in post-harvest fisheries activities such as drying and trading of dried fish. Women in the Northern, Eastern and North Western provinces are involved in fishing as members of fisheries societies.

The recruitment of new female members for fisheries societies is a bottleneck inherent in the recruitment process. This is due to membership restrictions, lack of evaluation or change of inactive, inefficient and illegal fishers of the society. In addition, there is a surplus of unemployed male labour due to the scarcity of alternative employment opportunities in rural areas.

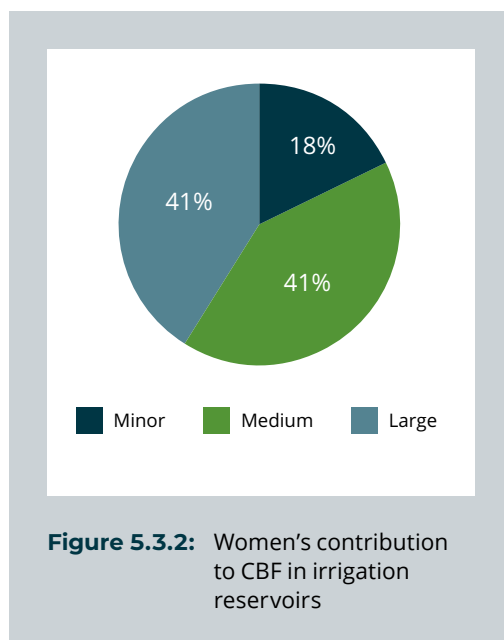


Figure 5.3.2: Women's contribution to CBF in irrigation reservoirs

GFP farming is more suitable for women because it is a potential supplementary source of income that can be occupied in a short period enabling them to add a significant portion of their family income in addition to their daily household chores. Women's roles in CBF are often limited to post-harvest activities. However, research (for example, Kruijssen et al. 2018) shows women want involvement in decision-making and guarding/harvesting. Gender-sensitive approaches are often lacking, despite growing evidence that inclusive governance increases project sustainability.

GFP farming in the CBF

GFP farming, which can be identified as a turning point in the CBF, has been rapidly expanding in the last decade. Although there is a strong attraction among fishers for GFP, which has high commercial and nutritional value, it was confirmed during community awareness workshops that the understanding of it is at a very low level.

Knowledge about GFP

Most people considered GFP to be a species of prawn introduced from another country, while only a handful knew that they are endemic to Sri Lanka.

As shown in Figure 5.3.3, about 70% of fishers in small-scale irrigation reservoirs do not know about GFP, while 60% of fishers in large irrigation reservoirs know about it. The factors considered in measuring knowledge were stocking of prawns, feeding patterns, harvesting, market chain and post-harvest handling. There is no evidence that the institutions that initially provided the fingerlings for stocking or NAQDA have conducted adequate awareness programs on GFP. However, with the commencement of the project on improving the productivity, efficiency and sustainability of finfish and GFP farming in Sri Lankan irrigation reservoirs, informal awareness sessions have been held by NAQDA and researchers involved in the

project. Many communities are unaware of the technical and ecological basis of CBF, leading to unrealistic expectations about fish yield and timelines (Kularatne et al. 2009). Misconceptions about overstocking or water pollution by cultured species can breed resistance.

Willingness of the aquaculture industry to cultivate shrimp

Irrigation reservoirs are aimed at supplying water for agriculture, and these reservoirs are the main water source for aquaculture. Similarly, GFP farming is a new approach to aquaculture. Accordingly, reservoir water use in agriculture, aquaculture and GFP farming are interrelated. The will of all stakeholders using irrigation reservoirs is a very important factor. Therefore, the perception of the rural consumer community, farmer organisations and fishery members as key stakeholders were sought for their willingness to cultivate GFP.

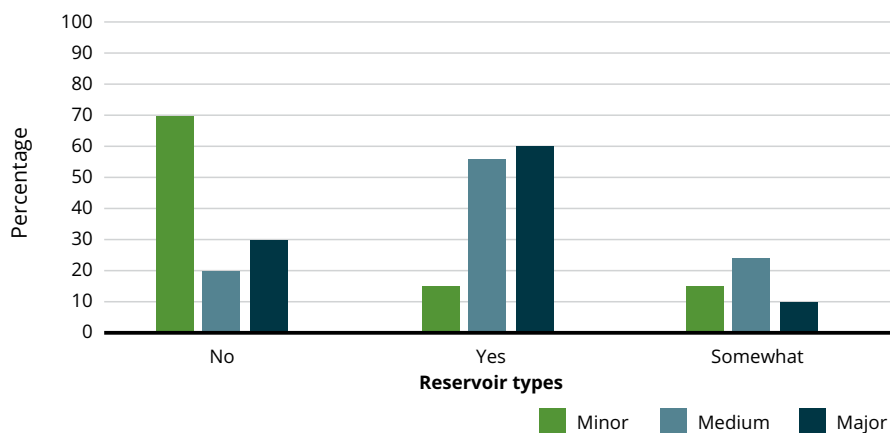


Figure 5.3.3: Fisher awareness of GFP by reservoir (as a percentage)

Perceptions of GFP farming in minor irrigation reservoirs

As per Figure 5.3.4, 69% and 77% of the consumer community and farmer organisations are somewhat in favour, respectively, while 69% of fishers expressed their preference for GFP farming in minor irrigation reservoirs.

The consumer community expects GFP reduces their dependence on finfish consumption. They do not fully agree with GFP due to agricultural water use, poor coordination and agreement between fishing groups and farmers organisations, and the low returns from aquaculture. While most fishers are more willing to do so due to its financial attractiveness, a small number of people expressed their disapproval due to concerns that GFP reduced the yield of other finfish species.

Perception for GFP farming in medium irrigation reservoirs

The reasons for the slight preference for GFP farming in medium irrigation reservoirs are similar to those for small irrigation reservoirs. Although the slight dislike is lower than for small irrigation reservoirs, 16% of the farmer organisations in these irrigation reservoirs are not fond of GFP (Figure 5.3.5). This is because in most cases, more than one farmer organisation is active in these irrigation reservoirs and the fishers do not have a direct connection with these organisations and do not receive direct benefits. In medium-sized irrigation reservoirs, farmer organisations and fisher groups operate separately.

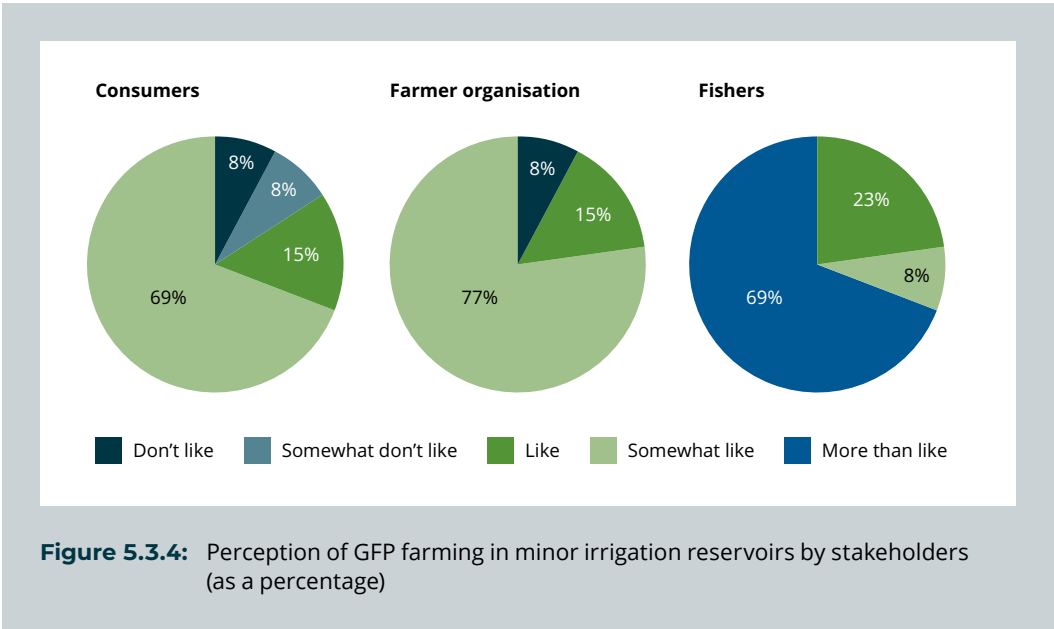


Figure 5.3.4: Perception of GFP farming in minor irrigation reservoirs by stakeholders (as a percentage)

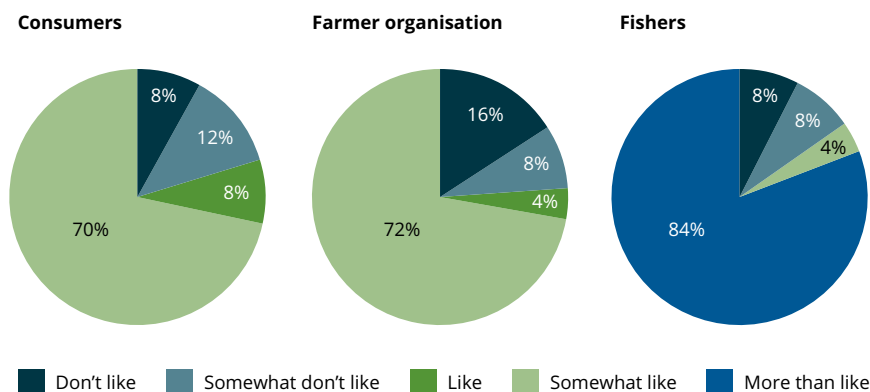


Figure 5.3.5: Perception of GFP farming in medium-sized irrigation reservoirs (as a percentage)

Perception for GFP farming in major irrigation reservoirs

The willingness of stakeholders in large irrigation reservoirs towards GFP farming is completely different from the situation in small and medium irrigation reservoirs. That is, no rural consumer or farmer organisation expressed any displeasure for GFP cultivation.

A high percentage of fishing groups (80%) are more interested in GFP farming while 20% of large irrigation reservoirs are somewhat interested because they suspect that GFP will reduce other finfish yields and may not receive the targeted harvest or income (Figure 5.3.6). The need for some financial or social benefit exchange between fisher societies and farmer organisations is important not as a payment but as social security for maintaining the fishing industry. Similarly, in the reservoir culture, such agrofisery integration is important as a tool that can be used to influence water management decisions and reduce social conflicts.

Key issues affecting GFP farming in freshwater irrigation reservoirs

One of the criteria considered in the selection of irrigation reservoirs at the beginning of the ACIAR project was to select irrigation reservoirs with the highest potential for the most efficient operation of the project. The key issues that are important in terms of their impact on GFP farming in such irrigation reservoirs are shown in Table 5.3.4.

Perceptions on major issues affecting GFP farming in the irrigation reservoirs

Although the issues common to the 48 irrigation reservoirs considered are presented in percentage terms, it is more important to identify the issues ranked according to impact. According to the fishers, the major issue affecting them is the insufficient number of GFP fry stocking into the irrigation reservoirs. This issue was clarified as one of the research areas of the project and accordingly, the density of fry stocking should be determined at the level of each reservoir and appropriate methods

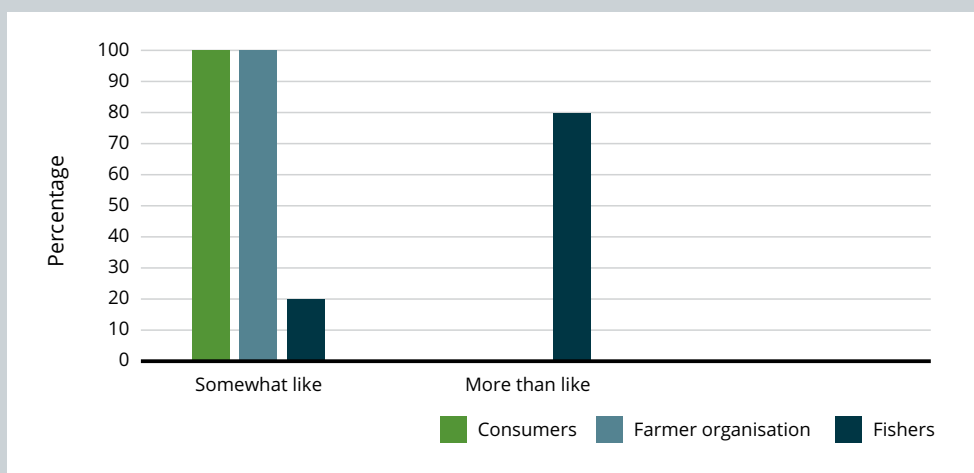


Figure 5.3.6: Perception of GFP farming in major irrigation reservoirs by stakeholders (as a percentage)

should be studied. The project proposal has been able to identify this issue as the first objective of the study.

Table 5.3.4: Major issues in terms of impact

Major issues affecting GFP farming	%
1. Insufficient stocking of GFP fry	31
2. GFP are predators of finfish fry	29
3. Lack of a formal method for GFP harvest	27
4. Predation of GFP by animals such as turtles, eels	21
5. GFP escape from sluices gates, spill and water access routes	17
6. Inactivity/disorganisation of fisheries cooperatives	17
7. Slow growth of GFP	8
8. Market-related issues	6
9. Issues regarding water sharing between sectors (fisheries-agriculture)	4

Among the main problems mentioned in Table 5.3.4, problems 1 to 3 and problem 8 are already being solved experimentally

by various research groups of the project, so appropriate recommendations will be made based on the results. In some irrigation reservoirs, catching eels is considered as an inappropriate fishing activity (for example, at Weerawila reservoir) and law prohibits catching turtles. However, a persistent pattern of catching only eels during a specific period can be observed. An experimental solution needs to be found to reduce the growth of GFP.

Fishers consider the lack of a formal method for GFP harvest as the main problem in GFP farming in small irrigation reservoirs. However, this problem is a third-order obstacle in other irrigation reservoirs. There are 4 main problems affecting GFP farming in medium irrigation reservoirs and large irrigation reservoirs. These are:

1. Insufficient stocking of GFP.
2. GFP are predators of finfish fry.
3. Lack of a formal method for GFP harvest.
4. GFP escape from sluices gates, spill and water access routes.



Initially, during the discussion on harvesting, it was mentioned that fishers catch shrimp. However, at the end of the awareness program, it was acknowledged that shrimp are caught as an untargeted harvest in nets used for catching finfish, and accordingly, it was acknowledged that fishers are not ‘shrimp catchers’ but ‘shrimp by-catchers’.

Among these basic problems, the escape of shrimp from the spills, sluice and water access routes can be identified as unorganised fishing groups that do not have a system in place to protect their stock as a common product. Also, since the stocking of fry in many irrigation reservoirs is based on subsidy schemes rather than full investment by the fishing groups, such problems have become ‘unsolvable’ problems due to the lack of significant attention to the risk of investment. Community perceptions are influenced by the presence (or lack) of strong local institutions such as fisheries committees or co-operatives (FAO 2024). Poor institutional transparency leads to suspicion and disengagement (Ratner et al. 2012).

Causes of the main problems in GFP shrimp farming by reservoir type

The causes of the main problems are specific to each reservoir. Accordingly, fishers in small irrigation reservoirs do not have sufficient knowledge about shrimp farming. Also, there is a risk of destroying immature shrimp fry due to the risk of balancing agricultural activities and CBF with a limited amount of water within a certain period. In addition, when small irrigation reservoirs are connected to large irrigation schemes, there may be a shortage of fish food due to the reduction in fish feeding areas (for example, at Van Ela small irrigation reservoir). The fact that the irrigation reservoirs remain full

of water throughout the year has led to a decrease in the number of cattle and other animals, and the lack of plant growth. Similarly, the inability to place shrimp in the right place due to difficulties in obtaining fry from the breeding grounds has led to the decline in shrimp farming. The weak participation of the societies and the lack of a business plan to organise a suitable program for fishing activities are also affecting to the unsustainability of GFP farming. Furthermore, since the majority of fishers are engaged in alternative sources of income (for example, at Ranawa Morowara reservoir), fishing activities are not seen to go beyond the level of mere subsistence.

Common reasons for central irrigation and large irrigation reservoirs are that fishers do not have the ability to breed, and the breeding centres that exist are few and far away. Due to this, the transportation costs to be borne are high. Accordingly, the opportunity to stock fingerlings at an appropriate time has been lost. Also, the spread of irrigation reservoirs over a large area and the number of landing sites is more than one, which reduces the risk management of production and fails to develop a systematic program to protect the harvest.

Proposed solutions to the problems of GFP farming by reservoir type

Based on the knowledge and experience of GFP fingerling stocking, several suggestions were presented for the existing problems as shown in Table 5.3.5. Considering their feasibility, they should be implemented without rejection, and before implementation, they should be actively tested through action research in collaboration with fisheries technicians.

Among the solutions proposed by the fishers, 3 common solutions can be identified for each reservoir. These are:

Table 5.3.5: Causes of major problems in GFP farming by reservoir type

Minor irrigation	Medium irrigation	Major irrigation
• Lack of knowledge • Destruction of fry • Reduction of fish feeding areas in irrigation reservoirs • Insufficient availability of shrimp at the right time • Inadequate water due to seasonal irrigation reservoirs • Alternative economic activities • Difficulty in obtaining from breeding grounds	• Fishers lack breeding capacity • Beliefs about catching eels • Risks of production and insecurity of harvest	• Reduction in breeding centres • Risk of production and insecurity of harvest • Inability to identify GFP and small shrimp • Failure to stock fry on time • Different prices from buyers

1. Stocking GFP fingerling at the right time and at the right density.
2. Government institutions should take action to breed shrimp fry and provide fishers with the necessary knowledge and equipment to grow immature fish fry.
3. Identifying suitable methods for catching GFP.
4. Creating a competitive market.

A closer look at these solutions reveals that the stock of fish fry is a primary factor of production in appropriate quantities at the right time. The uncertainty of fry supply and the dependence on fry suppliers and institutions, the reduction of the risk of spoilage through harvesting technology, and the competitive market have a strong impact on price and profit stability. In addition, the specific solutions proposed for each reservoir are presented in Table 5.3.6.

Among the proposed solutions, several of the most important solutions can be identified. Strengthening fisheries cooperatives for financial investment in fry, working together with farmer organisations

or all water users, providing fishers with the necessary knowledge and equipment for shrimp fry breeding or rearing, and adjusting the relative ratio of GFP and finfish fry, can be considered important solutions.

In addition, obtaining extension service support is a solution for medium irrigation reservoirs. However, a number of steps could be observed to make the existing extension service effective and efficient. Problems such as the inactivity/ disorganisation of fisheries associations and the sharing of water between sectors (fisheries–agriculture) can be solved by regularising extension services with the participation of all stakeholders using the irrigation reservoirs through business plans related to each reservoir.

Overall impact of major issues affecting GFP farming in freshwater irrigation reservoirs

As a result of uncertain production processes (such as irregular stocking of fry, technical weaknesses in harvesting,

Table 5.3.6: Suggested solutions

Minor irrigation reservoirs	Medium irrigation reservoirs	Major irrigation reservoirs
• Selection of a suitable location for GFP in the reservoir • Having a proper system for providing fry • Building unity and support within the community • Increasing the productivity and efficiency of the fishing industry • Enforcing the law against illegal fishers • Negotiating with the farmers' association • Placing fry in the prescribed quantity at the prescribed times • Providing training and equipment to fishers to breed shrimp fry • Placing grown shrimp fry • Not placing shrimp all at once • Scientific investigation into whether shrimp are predators	• Covering the pond and the outlet • Controlling predators and identifying markets • Strengthening fishing associations to invest financially in the hatchery • Regulating water use • Enlisting the support of fisheries extension officers • Building shrimp cages • Placing food-bearing rocks • Providing training and equipment to fishers to breed shrimp fry • Increasing productivity and efficiency of the fishing industry • Closing shrimp farming and exploring the growth of tilapia • Minimising intermediate trade • Joint efforts by all stakeholders related to the reservoir	• Stocking finfish at a level comparable to shrimp • Linking buyers • Creating markets • Controlling illegal fishing • Cultivating shrimp only in selected areas of the reservoir • Distinguishing between shrimp and fry • Providing food for shrimp • Predator control and marketing • Covering the hatchery and hatchery • Strengthening fishing associations to finance investments in fry • Replacing grown shrimp fry

incomplete knowledge of the biological process, and an increase in the proportion rejected by buyers from the total harvest), the supply of GFP is not stable due to the decrease in yield and price levels, especially in a monopolistic market situation, which inevitably leads to a reduction in income. Accordingly, savings decrease, and investment capacity decreases. Meanwhile, long-term input subsidies (through purchasing agencies or government programs) do not encourage investment, and the lack of a business plan due to the reliance on subsidies has been identified as the main impact, leading to a decline in income (Figure 5.3.7).

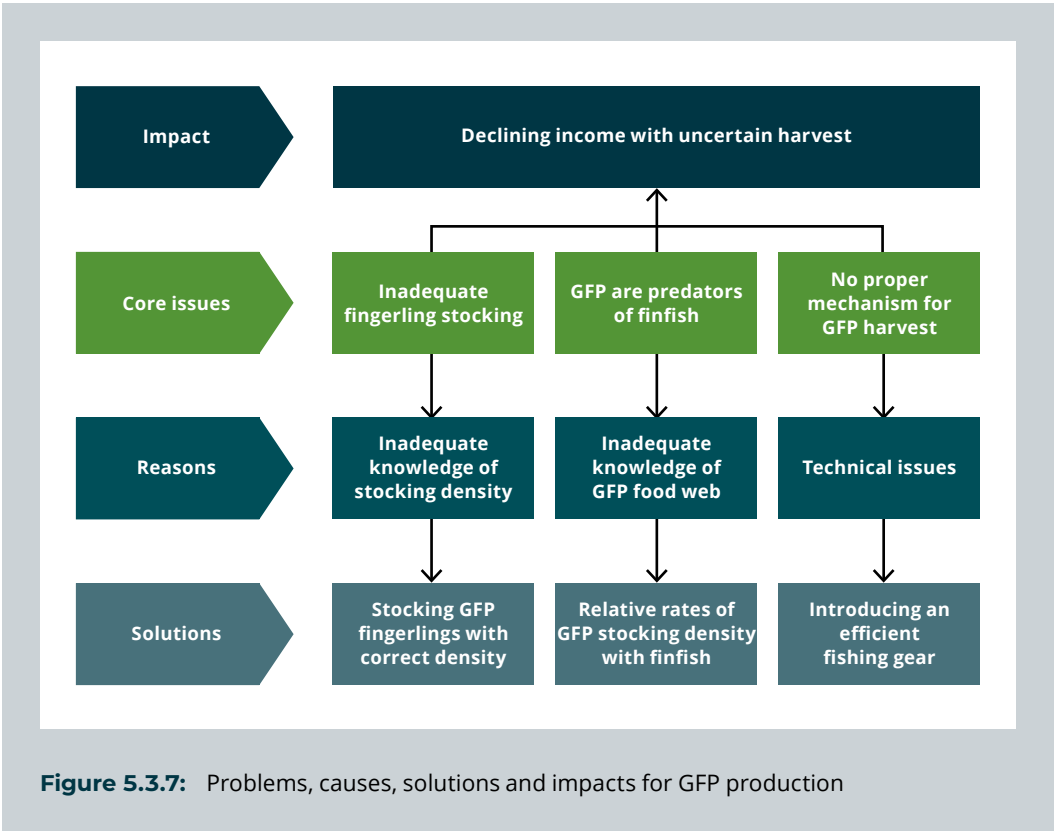
Conclusion

Although freshwater production in Sri Lanka operates under the name of the 'culture-based fisheries industry', it is still not a competitive production 'industry' or system aimed at maximising private profit, but rather a source of livelihood. CBF are considered a semi-industry with those who do not operate on a systematic business plan, depend on daily income, have more members engaged in fishing activities (in small and medium irrigation reservoirs) than regular members, do not have enough information to make sound savings and investment decisions, and have minimal

use of modern technology. In addition, there is no approach to implementing co-management methods or internationally accepted small-scale fisheries guidelines.

Considering the annual fish production, finfish and GFP production at all irrigation reservoirs are at a level that needs further improvement. Although CBF are not considered a source of nutrition, more than 50% of the annual fish production is sold for local fish consumption. Accordingly, finfish production is supported as a source of protein for the rural community and GFP production is directed to high-income consumers or export markets. Although there is a slight increase in rural demand for GFP consumption, mostly only GFP is marketed in rural areas and rejected by buying agencies or agents.

The use of illegal fishing gear and illegal fishing were identified as major problems in all irrigation reservoirs and these problems were reported in 100% of major irrigation reservoirs. Although the control of illegal fishing activities is the duty of extension officers – who are sometimes officers who implement the law while also implementing welfare policies. Therefore, the dual nature of the duties of the extension officers is a hindering factor to uplift CBF activities effectively. The relationship between farmers’ organisations and fisheries societies is distant. However, the relationship between farmers and fisher’s groups is more important because the water management decisions in the irrigation reservoirs are curtailing factors for CBF.





About 70% of fishers in minor irrigation reservoirs have no idea about GFP and 60% of fishers in large irrigation reservoirs understand GFP farming. Reservoir water use in agriculture, CBF and GFP farming are intertwined. Therefore, the rural consumer community, farmers' organisations and members of the fisheries groups are the key stakeholders in CBF and GFP production. Their interest in CBF and GFP farming is an important factor affecting the development of the industry. The need for some financial or social benefit exchange between fishing societies and farmers' organisations is important because it provides social protection for maintaining CBF farming. The agrofisheery integration can be used as a tool in the 'irrigation reservoir culture' and is important as a tool that can be used to reduce social conflict and influence water management decisions.

Proper road facilities, information and communication are more important for the rapid development of CBF production as a product that targets the market. Since GFP production mainly targets the export market, the availability of adequate road facilities can lead to rapid growth of this industry. In addition, the rehabilitation of irrigation reservoirs has affected the decline of fish growth at certain times.

In the marketing of finfish and GFP, the fisher is a 'price taker'. Although some established mechanisms can be seen in the sale of finfish in all the irrigation reservoirs, various uncertainties must be faced in the sale of GFP. Agreements where a specific company agrees to stock GFP fingerlings for irrigation reservoirs and sell its harvest to that agreed company can lead to a problematic situation in the GFP market and it can hinder the creation of a fully competitive market. However, the demand for freshwater fish still has an excess for local consumption. Therefore, there is a

good market potential for freshwater finfish production in the local market.

More important than enumerating the problems common to the 48 irrigation reservoirs was the identification of problems aligned by impact. Depending on the type of reservoir, the main problems of GFP farming are unique. Accordingly, fishers in minor irrigation reservoirs do not have enough knowledge about shrimp farming. The common reasons for medium irrigation and large irrigation reservoirs are the lack of breeding/stocking capacity for fishers, and the reduction of available breeding centres and the transport costs of fingerlings, as well as the missing opportunities to stock fingerlings at the right time. In addition, due to the spread of these irrigation reservoirs in a large area and the number of landing sites being more than one, the risk management of the production is minimal, and a systematic work plan has failed to protect the yield. Also, every fishing committee prepares a fund by saving some money from the commission tax but there is great reluctance to spend the money, especially for stocking GFP fingerlings in the face of uncertainty. The local consumption demands the tilapia species; therefore, tilapia production should be considered as an essential requirement at the reservoir level.

Based on the knowledge and experience of the fishers, many suggestions were made for the existing problems of GFP farming. Considering the usefulness of suggestions, these should be implemented as an active experimental exercise with the fishers before putting it into practice. Even so, it was possible to observe several steps to be taken to make the existing extension service effective and efficient. There is a possibility of finding solutions with the coalition of all the stakeholders using the irrigation reservoirs through the business plans related to the respective irrigation

reservoirs, by streamlining the extension services, and so on.

As a result of an uncertain production process, supply is unstable due to reduced yield and price levels, especially in a monopolistic market situation, which can inevitably lead to lower income. As a result, savings will decrease and investment power will decrease. Meanwhile, due to ongoing input subsidies, there is no incentive to invest and the lack of a business plan due to reliance on subsidies has been identified as the main impact of lower income. Community perceptions and expectations play a decisive role in the efficiency and sustainability of CBF. Strategies that centre on participatory engagement, capacity building, equitable benefit distribution and responsive governance systems are essential to align CBF production goals with local realities.

Recommendations

1. To improve the productivity, efficiency and sustainability of finfish and GFP farming in the CBF industry, the existing economic efficiency (technical and allocative) and productivity, and factors affecting these, should be studied.
2. Policies should be formulated based on empirical information on stocking, harvesting techniques and bioeconomic relationships to sustain CBF.
3. Maintain a program as an industry with investments based on member funds according to a business plan with the participation of the farmer and fisher groups related to the respective irrigation reservoirs. The need for rural protein should be prepared as a program that can be maintained as an industry with the participation of the respective reservoir-related farmer and fisher groups.
4. The following alternative methods are suggested to ensure a regular and efficient supply of finfish and GFP fingerlings:
 - 4.1 A hatchery centre of the NAQDA should be set up in each district extension area, whereby the fish fry at the initial stage should be bred and the responsibility of growing them to a size suitable for stocking should be assigned to the fishers of the medium irrigation reservoirs individually or collectively. Grown fish fingerlings should be sold from those irrigation reservoirs to fishers in minor irrigation reservoirs at a cost-based price. However, some financial return from the hatchery sales revenue is proposed to be paid as an incentive allowance to the employees and officers engaged in the work.
 - 4.2 Encouraging rural investment for private-sector breeding opportunities and improving the supply of fish fingerlings, thereby creating rural employment opportunities.
 - 4.3 Members (including women members) with capacity, access, and experience in irrigation reservoirs should guide the NAQDA with knowledge and facilities for fry to fingerling.
5. For a more efficient district-level extension officer service, an understanding of problems and needs, participatory action research knowledge and rural social and communication skills should be developed. In addition, the district-level extension officer service should be implemented in an insurance policy.

6. Agreements for a specific company to stock fingerlings for irrigation reservoirs and to sell their harvest to that company may stop and fishers should have the freedom to sell their product for a higher price.
7. Inactive fisher members are hampered and should be discouraged through an annual membership revision. The resources of the industry should be effectively managed to maintain the welfare of fishers as well as the sustainability of fish production.
8. The NAQDA should be made into a revenue-generating institution that can gradually reduce its dependence on public finances. It is suggested that the fisheries industry and NAQDA should make interdependent structural reforms.
9. Since the rural consumption demand around each reservoir is highly concentrated for the tilapia species, it is suggested that breeding should be done using the seeds obtained from the most suitable broodstock and for that, a method based on scientific research information should be maintained.
10. By providing free or subsidised fish fry, the responsibility of the industry is absolved by the fishers, and there should be a program where the right and responsibility of the investment is transferred to the fishers.
11. GFP farming should be considered as a more suitable alternative livelihood for women as a fishing industry with the ability to earn more income in less time while maintaining their household activities.

Finally, community perception, expectation and local knowledge are key to the successful CBF development of the irrigation reservoirs in Sri Lanka.

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5.4 Institutional robustness markedly aids in managing the long-term culture-based fisheries in selected dry zone reservoirs of Sri Lanka

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Abstract

Developing CBF in Sri Lanka's inland reservoirs represents a promising strategy for enhancing rural livelihoods, food security and sustainable fisheries management. This study assesses the institutional arrangements governing CBF in 23 irrigation reservoirs across 6 administrative districts of Sri Lanka, applying Ostrom's modified design principles for common-pool resource management as the analytical framework. Primary data were collected through semi-structured interviews, focus group discussions, participant observation and key informant interviews, with compliance levels evaluated using a 5-point Likert scale. The study confirms that fishers govern the fisheries through self-governing institutions. Results further highlight the critical role of Rural Fisheries Organizations (RFOs) in ensuring community participation, enforcement of fishery regulations and equitable benefit distribution. Community-based management structures facilitate the effective regulation of fishing practices and resource monitoring, but challenges persist in areas such as inter-organisational collaboration and legal enforcement against non-member infractions. The study highlights the significance of nested institutional arrangements, local governance legitimacy and supportive policy frameworks in maintaining CBF systems. Findings contribute to the growing literature on decentralised fisheries management and offer practical insights for enhancing institutional resilience in the CBF sectors.

Keywords: *aquaculture, fisher communities, inland fisheries, Sri Lankan reservoirs, stocking*

Introduction

Global demand for fishery products is expected to be largely supported by the growth of aquaculture production. Decentralisation, climate change, demographic transition and resource user rights influence the contributions of aquaculture to poverty alleviation, but

the mechanisms defining these influences are poorly understood. In addition to the challenges that can hinder contributions of aquaculture to poverty alleviation, aquaculture development poses threats to the environment (Costa-Pierce 2002). Therefore, engaging in environmentally friendly and efficient approaches that consider the interlinked social factors in accounting to enhance fish production is essential. CBF in inland waters are recognised as an environmentally friendly method for fish production that also supports poverty alleviation (De Silva 2003).

Sri Lanka is a country rich in irrigation reservoirs that vary significantly in size, age, hydrology and catchment characteristics. The cumulative area of these reservoirs is approximately 260,000 ha, which is categorised into perennial and seasonal reservoirs based on their hydrological regimes (Pushpalatha and Chandrasoma 2010). Perennial reservoirs are classified into 3 categories based on the extent of water spread at full supply level: major (>800 ha), medium (200–800 ha) and minor (<200 ha). Seasonal reservoirs are small bodies of water that are less than 30 ha in size and can retain water for 8 to 10 months. Almost all Sri Lankan reservoirs have been constructed in the past primarily for irrigating paddy fields. The country's dry zone has more than 10,000 small village reservoirs (Pushpalatha 2001). In these seasonal reservoirs, strategies for CBF are well established (Amarasinghe and Nguyen 2010). The NAQDA of Sri Lanka has initiated a program to introduce CBF in minor perennial reservoirs across Sri Lanka. The fish fingerlings of catla (*Catla catla*), rohu (*Labeo rohita*), common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*) are introduced into irrigation reservoirs (Pushpalatha and Chandrasoma 2010). Recently, NAQDA

also initiated the stocking of post larvae of the GFP, *Macrobrachium rosenbergii*, in several reservoirs, which has begun to gain momentum in CBF.

As Sri Lanka has plenty of reservoirs, CBF development in village reservoirs has a positive impact on enhancing inland fisheries. Rural development activities involving artisanal fisher communities and agricultural farming communities are essential strategies for CBF development in inland reservoirs (Amarasinghe and Nguyen 2010), and community participation is also a crucial component for success and sustainability (Pushpalatha et al. 2020). This approach is thought to be for ensuring the sustainability of resources by self-organising resource use mechanisms as an alternative to centralised management mechanisms, which involve imposing regulations by the fisheries authorities. In irrigation reservoirs utilised for CBF development, NAQDA, through its extension arm, has established fisheries management societies. These community-level institutions can thus be viewed as grassroots units for empowering communities in the management decision-making processes. The success of the management depends on the robustness of the institutions. Ostrom's design principles (Ostrom 1990) can be used to evaluate the robustness of the institutions managing common-pool resources (CPR), such as fisheries. Eight design principles of Ostrom are expanded to 11 principles by Cox et al. (2010) to investigate the strengths and weaknesses of institutional arrangements in community-based management of natural resources. Rural communities manage CBF systems, similar to traditional capture fisheries (Amarasinghe and Weerakoon 2009). The present study reveals the robustness of the self-governing



institutions that govern the CBF of dry zone reservoirs in Sri Lanka.

Materials and methods

Study sites

The study was carried out in 23 irrigation reservoirs located within 6 administrative districts in Sri Lanka (Figure 5.4.1).

Data collection

A questionnaire survey was conducted through a series of interviews (Pushpalatha et al. 2020). Data collection continued until the researcher felt comfortable that the desired saturation level had been achieved. The respondents for this study were selected based on their voluntary participation in the data collection process. Accordingly, Table 5.4.1 shows the number of fishers who participated in data collection at the study reservoirs.

Primary data were gathered through (1) semi-structured interviews, (2) participant observation, (3) focus group discussions, and (4) key informant interviews. Semi-structured interviews served as the primary instrument for data collection, widely recognised as a standard ethnographic method for gathering information in an open-ended format. A questionnaire was prepared to collect relevant data aimed at identifying the characteristics of the prevailing management system of CBF. Ostrom's modified design principles were employed as benchmarks to assess the community-based governance of CBF in study reservoirs. Consequently, a tool was developed to evaluate robust compliance with the modified design principles. In this context, a total of 3–6 components were prepared for each design principle. For example, design principle 1A is characterised by 4 components, including whether:

1. clearly defined user boundaries exist
2. non-appropriators accept the user boundaries
3. government authorities acknowledge the user boundaries
4. the user boundaries are employed for resource management purposes.

All components were pre-tested before final evaluation. In the final assessment, a 5-point Likert scale was applied as a psychometric approach (Likert 1932), constructed with a 5-point hedonic scale ranging from very prominently exist (value 5) at one end to non-exist (value 1) at the other end, with values 4, 3, and 2 assigned to reflect 'prominently', 'moderately', and 'slightly' exist, respectively. Each component was then assigned the corresponding value (from 1 to 5 on the Likert scale) based on the information extracted from the fishers and the researcher's observations and experiences. The veracity of the compliance level assigned by researchers was verified with community leaders and the aquaculture extension officer in the area. All interviews and discussions with respondents were conducted in the native languages of fisher communities – either Sinhalese or Tamil.

Data analysis

The information gathered was categorised into the principal organisational characteristics of community-based fisheries management systems proposed by Ruddle (1994) for coastal fisheries systems. To evaluate the compliance level of the prevailing institutional architecture of the governing system, overall mean values for each component and the design principle at each study site were computed to describe the level of compliance of each design principle, which were collected through interviews with traditional fishers and key informants.

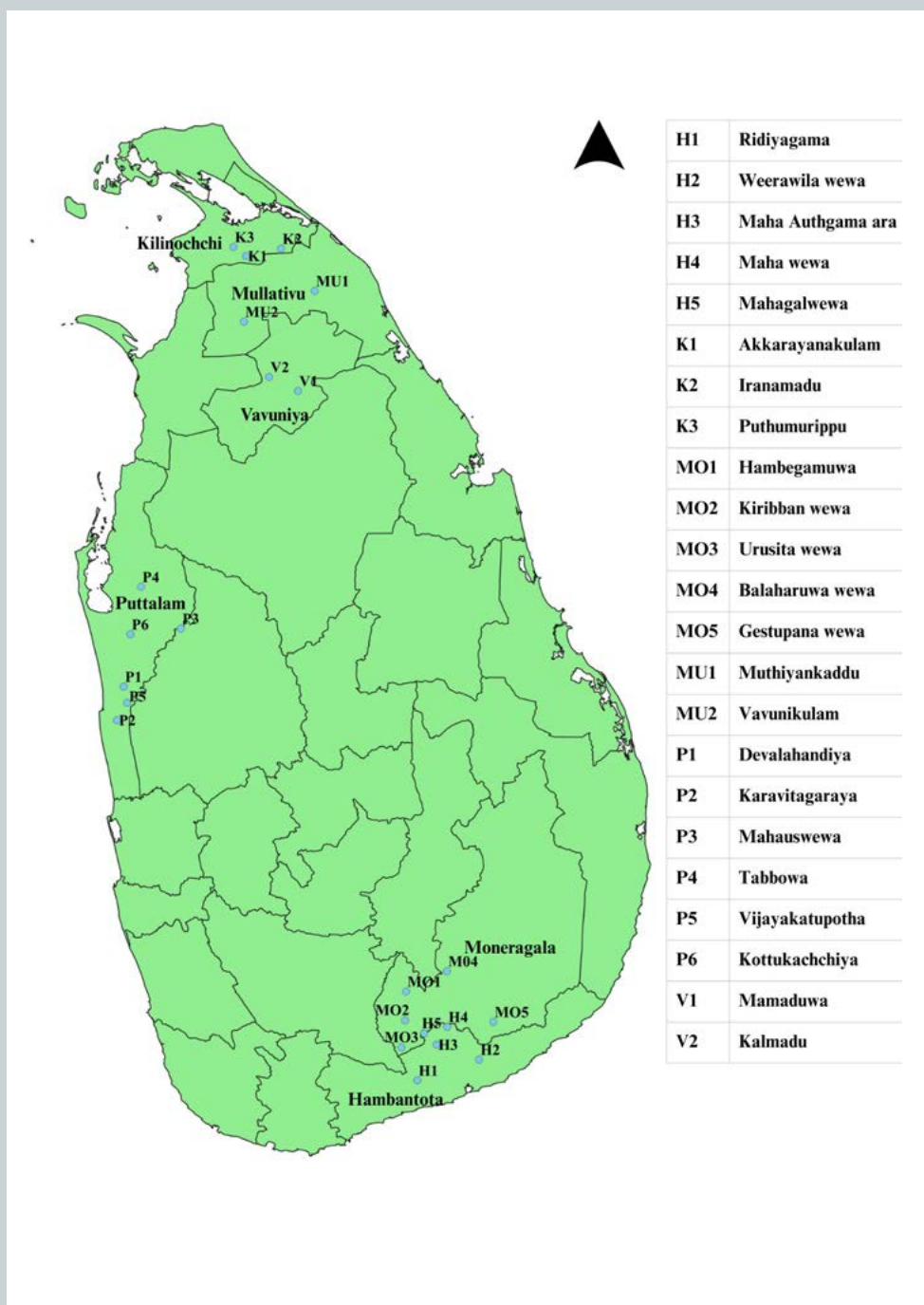


Figure 5.4.1: Map of Sri Lanka showing study reservoirs across 6 administrative districts

Table 5.4.1: The number of registered active fishers and the number of fishers interviewed for gathering requested information

No.	District	Reservoir type	Name of reservoir	Number of registered active fishers	Number of fishers interviewed
1	Hambantota	Major	Ridiyagama	47	12
2	Hambantota	Medium	Weerawila Wewa	39	11
3	Hambantota	Minor	Maha Aluthgam ara	18	8
4	Hambantota	Minor	Maha wewa	21	12
5	Hambantota	Minor	Mahagal wewa	31	10
6	Kilinochchi	Major	Akkarayankulam	24	8
7	Kilinochchi	Major	Iranamadu	60	15
8	Kilinochchi	Minor	Puthumurippu	21	12
9	Monaragala	Medium	Hambegamuwa	35	11
10	Monaragala	Medium	Kiribban wewa	24	8
11	Monaragala	Medium	Urusita wewa	31	9
12	Monaragala	Minor	Balaharuwa wewa	24	11
13	Monaragala	Minor	Gestupana wewa	8	8
14	Mullaithivu	Major	Muthiyankaddu	33	11
15	Mullaithivu	Major	Vavunikulam	38	9
16	Puttalam	Medium	Devalahandiya	26	9
17	Puttalam	Medium	Karavitagaraya	34	11
18	Puttalam	Medium	Mahauswewa	21	8
19	Puttalam	Medium	Tabbowa	41	15
20	Puttalam	Medium	Vijayakatupotha	35	13
21	Puttalam	Minor	Kottukachchiya	21	7
22	Vavuniya	Medium	Mamaduwa	18	8
23	Vavuniya	Minor	Kalmadu	19	15
Total				669	241

Results

Principal organisation characteristics

The study encountered 5 principal organisational characteristics proposed by Ruddle (1994) among the RFOs of the study reservoirs.

Authority

The RFO in each reservoir regulated fishing schedules, allowing netting activities in the evenings and fish harvesting in the mornings. To sustain its operational activities, the RFO maintained a financial fund, supported by a set membership fee and a fixed contribution per unit of fish harvested. These funds were designated for fish stocking and the overall management of the organisation.

Fishing rights

A structured fishing society was established for each reservoir, with membership being a prerequisite for participating in fishing activities. The constitution of each fishing society outlined the procedures for recruiting members into the RFO. In certain societies, membership was hereditary, with transfers occurring from father to son or, in cases involving female offspring, to the son-in-law. The general assembly of the RFO governed these inheritance-based admissions.

Rules and norms

RFOs enacted regulatory measures during monthly meetings, where new bylaws and operational protocols were established. In some instances, RFOs consulted extension officers of NAQDA to gain technical guidance for formulating these regulations.

Defining fishing boundaries: All reservoirs remained under governmental ownership and were managed by the Irrigation Department, the Mahaweli Authority and/or the Department of Wildlife Conservation. These agencies were responsible for delineating the boundaries. Seasonal fluctuations in water levels influenced the spatial extent available for fishing activities. Fishing boats (that is, fibre-reinforced plastic outrigger canoes) were employed for transportation within the reservoirs.

Eligibility rules: Eligibility criteria stipulated that individuals above 18 years of age, residing within the 'Grama Niladhari divisions' (that is, the smallest administrative unit in a village) bordering the reservoir, could apply for membership. Membership fees were mandatory, and each society-imposed restrictions on the number of fishers allowed, thereby limiting recruitment. These regulations were embedded within the constitution of the RFO and were endorsed by government officials and relevant stakeholders.

Intercommunity access rules: Individuals who were not members of the RFOs were granted limited access to fishing activities, specifically to use traditional fishing rods for subsistence or recreational purposes. However, those wishing to engage in fishing as a livelihood were required to obtain formal membership within the RFO. Admission as a member was contingent upon approval by the general assembly of the RFO, ensuring regulatory oversight and adherence to established community-based fisheries management protocols.

Gear rules: Fishing operations using gillnets were exclusively permitted for RFO members with valid fishing licences. Government regulations established a minimum mesh size for fishing; however, some societies opted for larger mesh sizes based on collective decisions within the RFO. Furthermore, operational guidelines restrict each member to a maximum of 6 net pieces, as specified in the fishing licence. Gillnets served as the primary fishing gear for harvesting. Nevertheless, some societies permitted specialised fishing techniques, such as striking the water with a lead ball attached to a string or wooden stick (Amarasinghe and Pitcher 1986) and utilising cast nets to capture native fish species like *Puntius dorsalis*.

Temporal allocation rules: The RFOs implemented a comprehensive regulatory framework outlining specific penalties for violations of bylaws. The nature and severity of each infraction dictate the appropriate sanctions. A notable form of disciplinary action includes the imposition of operational suspensions, whereby the violator's fishing vessel is prohibited from engaging in fishing activities for a specified period following its detention. These enforcement mechanisms aim to enhance regulatory compliance and support the sustainable governance of community-based fisheries.



Fishing behaviour rules: Harvesting operations typically occurred between 7 am and 10 am, during which fish were transported to designated landing sites for sorting by species and weight. Some RFOs facilitated wholesale and retail trade by purchasing catches from their members and selling them to external traders and local consumers. Other RFOs permitted direct transactions between fishers and buyers. After unloading the fish harvest, fishers cleaned and maintained their fishing crafts to ensure operational readiness and hygiene. Cultural and religious practices were also incorporated into their occupational routine before departing for fishing activities. Fishers commonly participated in religious observances. Notably, on 1 January, it was customary for them to allocate a portion of their income or resources as offerings to deities, accompanied by religious rituals, before commencing fishing activities for the new year. Fishing activities were occasionally suspended for religious observances. In predominantly Buddhist communities, fishing was forbidden on full moon (*Poya*) days each month. In mixed-religion societies, additional restrictions, such as bans on fishing during Easter, were enforced. The governing bodies of each fishing society established these regulations. Each fishing society upheld a code of conduct for its members, prohibiting activities such as fishing under the influence of alcohol (for example, Iramadu RFO).

Conservation rules: RFOs lacked an established framework for evaluating daily fish yield requirements and identifying fish aggregation sites. Barrier nets were installed at reservoir outlets and sluice gates to reduce the escape of stocked fish through the sluice gates. According to the Fisheries and Aquatic Resources

Amendment Act No. 35 of 2013, it is possible to gazette the designation of fisheries management areas. It can enact laws to conserve natural resources.

Cost-benefit distribution rules: A standardised pricing mechanism was introduced at landing sites. Furthermore, RFO members were required to pay a levy for each kilogram of fish harvested, a regulation adopted by the RFO. This levy varied among societies and was allocated to the Aquaculture Revolving Fund, which financed the stocking of fish seed for CBF and welfare initiatives. Government and non-governmental organisations periodically provided financial assistance to these societies, with funds distributed among members according to proportional allocation models, often under government supervision. Additional financial resources were obtained from membership fees, penalties imposed on members breaching RFO regulations and external donations.

Monitoring and accountability

The Fisheries and Aquatic Resources Act No. 2 of 1996, along with various government gazettes, provided the legal framework for fisheries management. Compliance with these regulations was mandatory for all communities. Each fishing society adhered to the RFO constitution, and resolutions passed during official meetings became binding regulations. The NAQDA monitored compliance with fisheries legislation. Additionally, enforcement officers appointed under the Fisheries and Aquatic Resources Act No. 02 of 1996 facilitated regulatory oversight. Fishing societies designated officers to ensure adherence to internal regulations, with enforcement authority granted by the RFO constitution. The NAQDA also conducted inspections and regulatory enforcement activities in conjunction with other government agencies. Fishing societies organised

patrol teams to monitor compliance with regulatory mandates.

Conflict resolution and sanctions

The conflicts often arise from competition over water rights, land use, fishing territories, and differing perceptions of sustainability and resource management. To tackle these issues, conflict resolution strategies in Sri Lanka's CBF sector typically involve a mixture of mediation, stakeholder dialogue and community-based management approaches. Additionally, sanctions are enforced to address non-compliance with regulations and unethical practices that jeopardise the sustainability of CBF systems. These sanctions can include fines, licence suspensions, and more severe measures such as confiscation of equipment or legal prosecution. Implementing sanctions is essential for safeguarding aquatic ecosystems, preserving fish stocks and maintaining the social fabric of local communities. However, the effectiveness of these sanctions depends on transparent governance, active engagement of local communities in enforcement, and a robust legal framework that considers the socioeconomic dynamics of the region.

In the CBF industry, fishing organisations were responsible for developing and implementing regulations that govern the conduct of their members. These regulations were typically formulated in response to issues that arose during regular monthly meetings. When a conflict or concern was identified, the necessary steps to address the problem and the corresponding procedures for managing members who deviated from established rules were defined in accordance with these internal regulations. The primary focus of these regulations pertains to fishing activities and member participation within

the association. The association imposes various penalties on members found to have violated the established rules, which may include monetary fines or temporary suspensions from fishing activities. However, enforcing these regulations requires the approval of at least two-thirds of the association's members during a general assembly, ensuring democratic participation in decision-making processes.

In instances where members fail to comply with imposed penalties, the leadership of the RFO may seek assistance from NAQDA officials for enforcement. Notably, the RFO possesses no authority to regulate illegal fishing activities conducted by non-members. Nevertheless, some fishing organisations implement surveillance measures, such as patrols, to protect their designated fishing areas. If unauthorised activities are detected, the association promptly informs the relevant government authorities for further action. Furthermore, in addition to the regulations established by the fishing organisations, national fisheries laws empower NAQDA extension officers to take necessary actions to protect and manage aquatic resources.

Institutional architecture and design principles

Evaluating institutional architecture with modified design principles reveals that 11 modified design principles were in place in the institutions governing the CBF of the study reservoirs in Sri Lanka. More importantly, the nested enterprises within these institutions were facilitated by the government's involvement and support in fisheries management, which was extended through the aquaculture extension officers. Legislative authority within the RFO was exercised through resolutions ratified by the general assembly. Government officials evaluated



the alignment of these resolutions with the Fisheries and Aquatic Resources Act. Additionally, RFO officers were appointed to oversee the implementation of RFO regulations. Conflict resolution mechanisms within the RFO relied on the leadership competencies of society representatives. However, the government had not granted formal jurisdiction to these societies for independent enforcement actions. While government officials supported ensuring compliance with the Fisheries Act, assistance in broader fisheries management remained limited. RFO members can influence policy decisions by passing resolutions. The effectiveness of society-led initiatives largely depends on the commitment and engagement of aquaculture extension officers. However, inter-organisational collaboration among different RFOs is minimal, and there are concerns that some RFO mergers are politically motivated. District-level and island-wide Fishermen's Associations show limited functionality. NAQDA appointed several officials, including aquaculture extension officers, district aquaculture extension officers, assistant directors, directors, and directors general, to assist in managing CBF. Additionally, designated officials responsible for overseeing CBF implementation in the Ministry of Fisheries and Aquatic Resources, the Provincial Ministry of Fisheries and the Mahaweli Authority were supported in fisheries management where applicable. Figure 5.4.2 illustrates the organisational hierarchy of NAQDA, the Provincial Ministry of Fisheries and the Mahaweli Authority.

Compliance with Ostrom's modified design principles

CBF demonstrated a strong adherence to principles such as clearly defined boundaries and collective choice arrangements, as local communities often manage fishery resources with established memberships and shared decision-making processes. The levels of compliance by institutional arrangements with most design principles vary from level 3 (moderate compliance) to level 5 (very prominent compliance). Design principles 7 and 8 showed moderate compliance (level 3) with the institutional architecture, while principles 2A and 4A demonstrated prominent compliance (level 4) with the local institutional arrangements. Design principle 6 exhibited either moderate (level 3) or prominent (level 4) compliance with institutions governing CBF in study reservoirs. The components evaluated under design principles 1A and 5 showed compliance levels ranging from level 3 (moderate) to level 5 (very prominent) in the institutions governing CBF. However, only the components assessed under design principle 2 demonstrated subtle compliance (level 2). The compliance level for each component evaluated under 11 design principles, along with the RFOs observed at each compliance level, is summarised in Table 5.4.2.

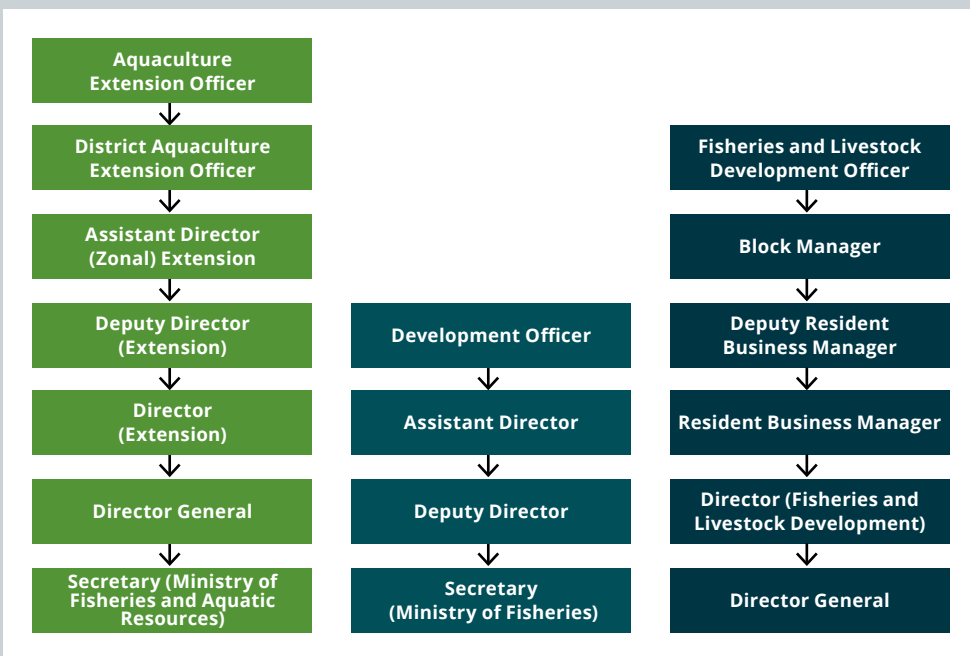


Figure 5.4.2: Organisational hierarchy (from lower level to higher position) of the NAQDA (left), Provincial Ministry of Fisheries (middle) and Mahaweli Authority (right), designated in supporting CBF management

Table 5.4.2: Level of compliance by component evaluated under 11 modified design principles, and RFO compliance level

Design principle	Components evaluated / examined	Level of compliance	RFOs / Reservoir
1A: Clearly defined user boundaries	Non-appropriators do not accept user boundaries	3	H3, P3, H4, H1, H2
	User boundaries are not accepted by the government authority / legitimacy		
	User boundaries exist at proximity to the home	4	MO4, P1, MO1, V2, P2, MO2, H5, V1, K3, P4, MO3, P5
	User boundaries accepted by non-appropriators		
	Getting membership from generation to generation		
	The RFO recruits people above 18 years of age from the personnel of the 'Grama Niladhari division' domains bordering the reservoir	5	K1, K2, P6, MU1
	User boundaries exist at proximity to the home		

(Continues on next page)

Design principle	Components evaluated / examined	Level of compliance	RFOs / Reservoir
1B: Clearly defined resource boundaries	There are no clearly defined resource boundaries	4	MU1, H1, K1, P1, P6, P3, V1, P4
	Government agencies have the power to control the reservoirs	5	MO4, MO1, K2, V2, P2, MO2, H3, H4, H5, K3, MO3, H2, P5
	Those agencies have marked the boundaries of the reservoir		
2A: Congruence with local conditions	User rights are restricted to members of RFO	4	MO4, P2, P6, V1, K1, P1, MO1, K2, V2, MO2, H3, P3, H4, H5, MU1, K3, P4, MO3, H2, P5, H1
2B: Appropriation and provision	A certain amount is given to the RFO every month	4	V1, H3, H4, H2
	For every 1 kg of harvested fish, the fishers should give a certain amount to society	5	K1, MO4, P1, MO1, K2, V2, MO2, P3, H5, MU1, K3, P4, MO3, P5, H1, P2, P6
3: Collective-choice arrangements	RFO conducts activities according to the Fisheries Act	4	V1, P2, K3
	Members of the society have the right to make, enforce and amend existing laws without challenging the Fisheries Act	5	K1, H1, MO4, P1, MO1, K2, V2, MO2, P6, H3, P3, H4, H5, MU1, P4, MO3, H2, P5
4A: Monitoring users	The officials appointed by the RFO and the aquaculture extension officers of the NAQDA will check whether the fisheries activities are being done in the reservoir according to the legal framework The RFO has appointed a committee to monitor the fisheries, but the effectiveness of these committees is low, and there is no law enforcement power for non-members of the RFO	4	V1, V2, P3, K3, P4, MO3, K1, P1, P2, P6, H4, H5, MU1, P5, MO4, MO1, K2, MO2, H3, H2, H1
4B: Monitoring the resources	The fisheries society does not care about the daily fish harvest There is no investigation of the places where fishing is A barrier net is applied to the sluice and spillway to prevent fish from escaping – Ridiyagama wewa, Mahagal wewa, Urusita wewa, Kottukachchiya Barrier nets are not allowed in sluice and spillway to prevent fish escape – Irrigation Department – Thabbowa, Maha Uswawa	2	P1, V2, P2, P3, P5, MO4, P6, H3, H4, K3, P4, MO3, H2, K1, MO1, MO2, V1, MU1, H1, K2, H5

(Continues on next page)

Design principle	Components evaluated / examined	Level of compliance	RFOs / Reservoir
5: Graduated sanctions	RFO formulates fishing rules, but the implementation process is weak	3	P4, P2, H3, H4
	RFO formulates and implements fishing rules through a collective agreement	4	K1, P1, MO1, V2, V1, MU1, P5
	RFO officers are appointed to implement and monitor the rural fisheries organisation system, and it is monitored by the aquaculture extension officer	5	MO4, K2, MO2, P6, P3, H5, K3, MO3, H2, H1
6: Conflict resolution mechanisms	Society assists government officials in making submissions under the Act The government has not delegated any special powers to the RFO	3	V2, P6, H3, V1, H1, K1, P2, P3, H4, MU1, P4, H2, P5
	It is decided based on the leadership qualities of the relevant organisation's officials to resolve the conflicts of RFO members and to take appropriate action for those who do not follow the rules	4	MO4, P1, MO1, K2, MO2, H5, K3, MO3
7: Minimal recognition of the right to organise	RFO members can pass resolutions of the RFO The government recognises the right of RFO members to self-governance There is a collaborative decision-making process between the RFO and government officers	3	V1, P1, P3, H1, H4, H5, MO4, MO1, P4, H2, P5, P2, V2, H3, K1, K2, MO2, P6, MU1, K3, MO3
8: Multi-level institutional structure	Vertical integration between one RFO and another RFO is minimal Officials have been appointed at various levels under the Fisheries Ministry, and officials from the Mahaweli Authority and the Provincial Fisheries Ministry Office have also been appointed for this purpose There are organisations at the district level covering the entire island, and these organisations are less active	3	K1, MO1, V2, P2, MO2, H3, H4, V1, MU1, K3, P4, MO3, P5, MO4, P1, K2, P6, P3, H5, H2, H1

Note: refer to Figure 5.4.1 for the names of study reservoirs where the community organised as RFOs in managing fisheries.



Discussion

CBF have been recognised as an effective means of providing a reliable supply of protein in rural areas at an affordable price. CBF also offer rural dwellers employment and supplemental income by strengthening their economy. The key factors for the successful implementation and sustainability of CBF in perennial reservoirs include the existence of active community-based organisations and their involvement in the planning and execution of CBF, adequate stocking of fish species and the establishment of a proper legal framework that facilitates the implementation of CBF (Chandrasoma and Pushpalatha 2018). In agreement with Pushpalatha et al. (2020), the findings confirm that self-governing institutions govern CBF in dry zone reservoirs of Sri Lanka. In this context, RFOs play a primary role as the authority in governing fisheries. Government support, provided through its bureaucratic officers, such as aquaculture extension officers, is significant in the process, primarily through the legitimacy it affords, which helps manage fisheries in the long run. As a communal activity, equity-sharing mechanisms for the benefits derived from CBF are essential for their sustainability. Therefore, effective community participation in the entire process, from stocking and harvesting to marketing and adopting mechanisms that strengthen the community's financial status, helps achieve equitable procedures for sharing the social and economic benefits of CBF. Effective conflict resolution heavily relies on local knowledge, which fosters cooperation through shared decision-making processes and ensures equitable access to resources for all parties. However, limited resources and informal enforcement mechanisms hindered effective compliance with the law, resulting in weaknesses in monitoring and sanctions. Dispute resolution

mechanisms were often informal, making it difficult to resolve disputes effectively. The government advisory support helps effectively implement the sanctions. There was also partial compliance with the principle of proportionality between costs and benefits, as fishers generally contribute equally to fish stocking efforts, but not for sharing the harvest. The sustainable fishing practices in CBF affirm that bottom-up mechanisms effectively manage fisheries, for which government bureaucratic support is integral.

The results divulge that institutions governing the CBF in dry zone reservoirs are aligned with the design principles of Ostrom (1990) and Cox et al. (2010), indicating well-recognised institutional arrangements. The existence of all design principles in institutional arrangements is evident, indicating that self-governing institutions have been formed with consideration for the socioeconomic aspects of the fisheries. The higher compliance of institutional arrangements with design principles indicates that institutions have evolved over time, providing maximum benefits to stakeholders. In this context, nested enterprises within institutional arrangements substantially support the formulation of robust institutions in the long run. Government support has become an integral part of the CBF, and the support of the officials in the appropriate government hierarchy in managing the fishery successfully is commendable. The high compliance further confirms that CBF in dry zone reservoirs are well established, with the knowledge gained and accumulated through engagement and management of the fishery. In light of the discussion, fishery associations govern the fisheries, maximising benefits for the appropriators, which aids in developing robust institutions for managing these resources.

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5.5 Strategies for achieving socially equitable and livelihood benefits from culture-based fisheries in Sri Lankan reservoirs

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Abstract

This study examines strategies for achieving socially equitable and livelihood benefits from CBF in Sri Lankan reservoirs. Conducted between October 2023 and March 2024, the research focused on 13 reservoirs across Anuradhapura, Kurunegala and Puttalam districts, selected based on geographical location and reservoir size. A total of 272 fishers, all members of reservoir fisheries societies, participated in face-to-face semi-structured interviews and large group discussions (LGDs). Using a Sustainable Livelihood Framework (SLF)-SWOT analysis, the study identified key socioeconomic, cultural and governance factors influencing equitable livelihood benefits.

The research employed both primary and secondary data collection methods, including a pretested household survey complemented by land-use data and annual reports. Data analysis was conducted using IBM SPSS Statistics (Version 22) to generate descriptive statistics and assess relationships between livelihood factors. Findings highlight that social equity and livelihood benefits from CBF vary across reservoir fishing communities, with socioeconomic and governance factors playing a crucial role in shaping outcomes. While opportunities exist to strengthen local governance, enhance capacity building and promote community participation, significant constraints such as policy gaps, financial limitations and inequitable resource distribution hinder progress.

To ensure sustainability, effective CBF integration should focus on equity and resilience within fishing communities. Policy enhancements must address governance weaknesses and promote equitable access to CBF benefits while introducing financial support mechanisms for small-scale fishers. Capacity building should be prioritised by empowering fisheries societies in decision-making and providing training for sustainable fishing practices.

Community engagement and collaboration through participatory governance models and partnerships with local authorities, research institutions and fishing communities can further drive progress. For future research, long-term studies on the impact of CBF on social equity and livelihoods are essential, alongside an exploration of gender dynamics to develop more inclusive fisheries policies. These measures can contribute to a more equitable and sustainable reservoir fishery system.

Keywords: *culture-based fisheries, socially equitable, livelihoods*

Introduction

Livelihoods are shaped by a combination of skills, resources and activities that individuals and households employ to sustain their wellbeing. These resources, commonly categorised as 5 types of capital – natural, physical, human, financial and social – play a crucial role in determining livelihood resilience and sustainability (Chambers and Conway 1992). A livelihood is considered sustainable if it can withstand external shocks, recover from stresses, and maintain or enhance its asset base without depleting natural resources. The Sustainable Livelihood Approach (SLA) has emerged as a valuable framework for analysing poverty reduction strategies and rural development, emphasising the importance of asset-based strategies in building resilient livelihoods (DFID 1998; Scoones 1998).

CBF have become a significant livelihood strategy for reservoir fishing communities in Sri Lanka. As a fisheries enhancement approach that integrates aquaculture practices with community participation, CBF are recognised for their potential to improve rural economies and contribute to food security (FAO 1994; De Silva et al. 2006). Given Sri Lanka's extensive network of irrigation reservoirs – many of which were originally constructed for agriculture – CBF have emerged as a secondary use of these water bodies, particularly in seasonal

reservoirs with short water retention periods (Amarasinghe and Wijenayake 2015). While CBF have contributed to increased fish production and income generation in rural communities, their sustainability is challenged by climate variability, socioeconomic disparities and governance issues.

A key concern in CBF management is ensuring that livelihood benefits are equitably distributed among fishers. Social equity in CBF involves fair access to resources, equal participation in decision-making and the ability of all stakeholders to benefit from fisheries-related income opportunities. However, structural inequalities, limited access to financial services and the absence of strong institutional mechanisms often hinder equitable benefit sharing among fishing communities.

This study aims to assess the strategies for achieving socially equitable livelihood benefits in CBF in Sri Lankan reservoirs. By applying the SLF, this research examines how the 5 forms of capital – natural, physical, human, financial and social – contribute to or constrain equitable livelihood outcomes. The findings of this study will provide insights into policy interventions and community-based strategies that can enhance social equity and sustainability in CBF-dependent fishing communities.

Materials and methods

The study on ‘Strategies for achieving socially equitable and livelihood benefits from CBF in Sri Lankan reservoirs’ was conducted between October 2023 and March 2024 in 13 selected reservoirs in 3 districts. The selection of reservoirs for this study was based on geographical location and reservoir size, covering major, medium and minor reservoirs in the Kurunegala, Puttalam and Anuradhapura districts. Fishing households were selected using a randomised sampling method, with participants drawn exclusively from the reservoir fisheries society members. Data were collected using 2 primary qualitative methods: semi-structured interviews and LGDs. A total of 272 face-to-face semi-structured interviews were conducted across these reservoirs with fishers to gather in-depth information on the strengths, weaknesses, opportunities and threats related to economic, social and cultural factors influencing socially equitable and livelihood benefits. These

findings were integrated into a SLF-SWOT analysis. The primary objective of this activity was to identify opportunities and constraints in achieving socially equitable livelihood benefits from CBF.

This study uses the SLF (Ashley and Carney 1999; DFID 1999) (Figure 5.5.1), which explores how and extent to which different types of livelihood assets combine and contribute to different livelihood strategies in order to achieve livelihood outcomes. Central to the framework is the analysis of the range of formal and informal organisational and institutional factors that influence sustainable livelihood outcomes (see Scoones 1998 for a full description on the framework). The livelihood assets explained in this framework are, in turn, classified into 5 major categories, including:

1. Human capital
2. Natural capital
3. Financial capital
4. Physical capital
5. Social capital.

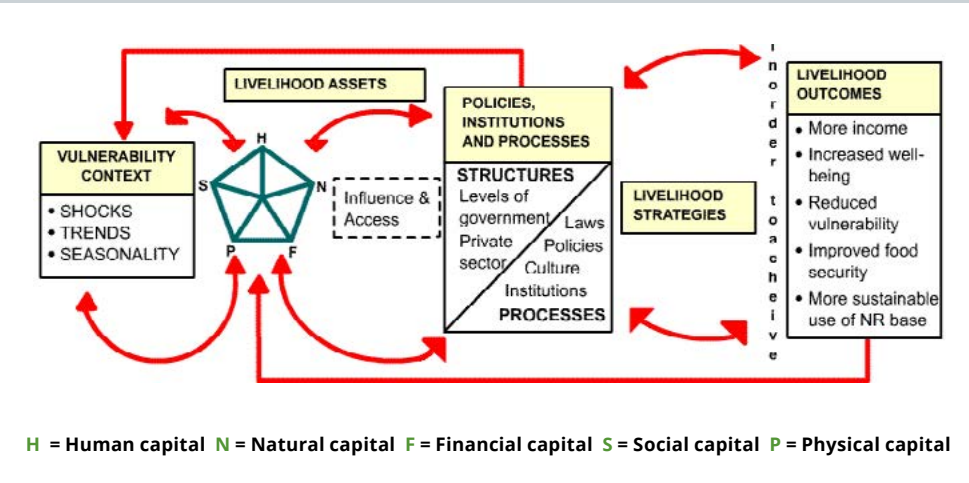


Figure 5.5.1: The sustainable livelihoods framework (Ashley and Carney 1999)

It proceeds by focusing on each component of this framework and with special reference to livelihood assets, and relates them to social equity and livelihood benefits by the CBF-related communities of concern.

In each reservoir, interviews included both male and female members of the fisheries societies, with 97% of respondents being male and 3% female. To ensure structured discussions, a list of topics and guiding questions was developed before conducting the interviews. The ethnic composition of participants consisted of 90% Sinhala, 2% Tamil, 2% Muslim and 6% Burgher. In terms of religion, 88% were Buddhist, 1% Hindu, 2% Muslim and 9% Christian.

Both primary and secondary data collection methods were employed in this study. A draft questionnaire was initially developed and pretested among fishers in the Vijayakatupotha (Puttalam district) and Maeliya (Kurunegala district) reservoirs to assess its suitability for achieving the study's objectives. The insights gained from pretesting facilitated the refinement of the final questionnaire, which focused on socioeconomic conditions, sources of income, family size and factors affecting livelihoods. Primary data collection was conducted through a household survey, complemented by land-use data and

relevant annual reports to validate field observations.

A total of 272 fishers from 13 reservoirs in 3 districts (Anuradhapura, Kurunegala and Puttalam) – Kottukachchiya, Andarawewa, Mahauswewa, Pahariya, Tabbowa, Ranawa, Huruluwewa, Hakwatunawa, Maeliya, Kibulwana Oya, Mahasiyambalagamuwa, Usgalasiyabalangamuwa and Karawitagaraya – were interviewed to provide a comprehensive understanding of the livelihood status among CBF communities.

The collected data were systematically processed and analysed using SPSS software.

Results and discussion

Sociodemographic characteristics of fishers and their households

All communities are shaped by their sociodemographic characteristics, which influence their livelihoods and economic wellbeing. The study included both male and female members of reservoir fisheries societies, with a significant gender imbalance observed. Overall, 97% of the participants were male, while only 3% were female. This disparity reflects the limited participation of women in fisheries activities, as some reservoir fisheries

Table 5.5.1: Reservoirs selected for the study

Reservoir size	District		
	Anuradhapura	Kurunegala	Puttalam
Major	Huruluwewa		
Medium		Hakwatunawa Mahasiyambalagamuwa	Karawitagaraya Mahauswewa Tabbowa
Minor	Ranawa	Kimbulwana Oya Maeliya Usgalasiyambalagamuwa	Andarawewa Kottukachchiya Phariya



societies do not allow or encourage female involvement. In terms of ethnicity, the majority of participants were Sinhala (90%), followed by Burgher (6%), Tamil (2%) and Muslim (2%). Religious composition showed that 88% of respondents were Buddhist, while Christians made up 9%, Muslims 2% and Hindus 1%. These demographic patterns highlight the dominance of Sinhala Buddhist fishers in the study areas, with relatively lower representation from other ethnic and religious groups.

Table 5.5.2 presents the sociodemographic characteristics of the target population in this study. The majority of respondents (35%) belong to the middle-aged (40–49 years) category, followed by 29% in the early middle-aged (30–39 years) group. The average age of the respondents falls within this range, indicating that middle-aged individuals play a dominant role in CBF, while the older generation (50 years and above) accounts for 29%, suggesting continued participation even at later stages of life.

In terms of education, 82% of respondents have received formal education up to secondary or tertiary levels, with the highest proportion (44%) attaining secondary education. This suggests that most fishers possess basic literacy, which may support their engagement in fisheries management and financial decision-making. However, 1% of respondents have no formal education, highlighting the need for educational support programs to enhance knowledge transfer within fishing communities.

Household size is another key factor influencing livelihood strategies. Most respondents (79%) live in medium-sized households (3–5 members), followed by 13% in small households (1–2 members) and 8% in large households (6+ members).

This indicates that fishing households are generally of moderate size, potentially balancing labour availability and economic sustainability.

Regarding marital status, an overwhelming 95% of respondents are married, while only 3% are unmarried and 1% are widowed. This suggests that fishing livelihoods often support family structures, reinforcing the importance of economic stability in sustaining household wellbeing.

Housing conditions and access to basic infrastructure also reflect the socioeconomic stability of the respondents. A significant 46% of respondents live in houses with asbestos roofing, while 58% have tiled shelters, indicating a relatively stable housing situation. Additionally, almost all respondents (99%) have access to electricity, and a considerable 97% own at least one mobile phone, suggesting high connectivity and access to communication. Furthermore, 77% of respondents own a refrigerator, indicating a reasonable standard of living and the ability to store food, which is essential for improving food security and reducing post-harvest losses.

Overall, the sociodemographic characteristics highlight that CBF communities are primarily composed of middle-aged, married men with moderate levels of education and medium-sized households. Their housing conditions and access to essential infrastructure suggest a relatively stable livelihood, though continued efforts are needed to enhance financial resilience and technological adaptation within these communities.

Perceptions of social equity and livelihood benefits in CBF

The perceived benefits of reservoir fisheries varied across major, medium and minor reservoirs. Income generation was identified as the most significant benefit,

Table 5.5.2: Sociodemographic characteristics of fishing communities

Category	Subcategory	Percentage (%)
Gender	Male	97%
	Female	3%
Age	20–29 (young)	7%
	30–39 (early middle-aged)	29%
	40–49 (middle-aged)	35%
	50–59 (older middle-aged)	21%
	60 and above (older)	8%
Household size	Small household (1–2)	13%
	Medium household (3–5)	79%
	Large household (6+)	8%
Education	No formal education (0)	1%
	Primary education (1–5)	17%
	Secondary education (6–10)	44%
	Tertiary education (11–13)	38%
Civil status	Married	95%
	Unmarried	3%
	Widowed	1%
	Other	1%
Ethnicity	Sinhala	90%
	Tamil	2%
	Muslim	2%
	Burgher	6%
Religion	Buddhism	88%
	Hinduism	1%
	Islam	2%
	Christianity	9%

with 100% of respondents in both major and medium reservoirs recognising it as a primary advantage, while 89% of respondents in minor reservoirs indicated the same. Food security was reported as a benefit by 26% of fishers in both medium and minor reservoirs, whereas none from major reservoirs mentioned it. Independence was cited as a benefit by 18% of fishers in medium reservoirs, 15% in minor and only 4% in major reservoirs. ‘Other benefits’ were minimally acknowledged, with only 2% of respondents

from minor reservoirs referring to any additional advantages (Figure 5.5.2). These findings suggest that while income remains the dominant benefit across all reservoir types, aspects such as food security and independence are more recognised in medium and minor reservoirs.

The study highlights key aspects of wellbeing, vulnerability and sustainability within fisheries societies and communities. Income maximisation was rated the highest (3.85), reflecting its critical role in fishers’ livelihoods, while future wellbeing (3.72)

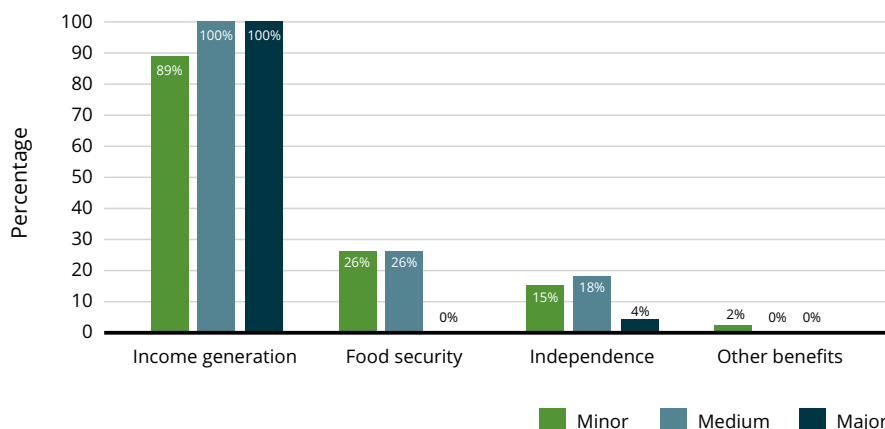


Figure 5.5.2: The perceived benefits of CBF

scored higher than past wellbeing (2.86), indicating a perceived improvement over time. The role of fisheries societies (3.71) and concerns related to vulnerability (3.7) and food security (3.68) were also acknowledged. In terms of social equity, fair distribution of fishing costs (3.66) and income among households (3.65) were rated positively, while fair participation in decision-making received the lowest score (3.59), suggesting a need for more inclusive governance in the fisheries sector.

The income distribution among fishing communities varies across major, medium and minor reservoirs, reflecting different economic conditions. In major reservoirs, the majority (80%) belong to the average income group, while 20% fall into the poor category. Medium reservoirs show a more diverse distribution, with 60% classified as average income, 38% as poor and a small fraction (1%) as very poor or better off. Minor reservoirs have a relatively higher percentage of low-income households, with 54% categorised as poor and 46% in the

average income group. These variations highlight the economic disparities among fishers, with minor reservoir communities experiencing higher levels of poverty compared to those in major and medium reservoirs.

Contributing factors to social equity and livelihood benefits

The analysis of human capital in reservoir fishing communities reveals significant differences in main occupations and training received across minor, medium and major reservoirs. In major reservoirs, fishing is the sole occupation (100%), whereas in medium reservoirs, 82% engage in fisheries, with 14% involved in farming and a small percentage in business (1%) or other activities (3%). In minor reservoirs, the dependence on fisheries is lower (50%), with a significant portion (44%) engaged in farming and 6% involved in other activities.

Regarding training received, participation is highest in medium reservoirs (73%), followed by minor reservoirs (20%) and

lowest in major reservoirs (7%). Fisheries training is the most common type across all reservoir categories, with medium reservoir fishers having the highest participation (63%), while minor (17%) and major (7%) reservoir fishers have lower engagement. Farming and business training are minimal across all reservoirs, and a small percentage in medium reservoirs (7%) have received other types of training. These findings indicate a disparity in skill development, with medium reservoir fishers having the most access to training opportunities, while major and minor reservoir fishers have limited exposure to capacity-building programs.

The financial capital analysis of reservoir fishing communities highlights significant differences in credit usage, savings and household income across major, medium and minor reservoirs. Credit usage is highest among fishers in medium reservoirs (65%), followed by minor reservoirs (23%), while it remains low in major reservoirs (12%). Similarly, savings behaviour follows the same trend, with 69% of fishers in medium reservoirs saving money, compared to 24% in minor and only 6% in major reservoirs.

Household income levels vary, with low-income households (earning $\leq$ LKR30,000) most prevalent in medium reservoirs (57%), followed by minor (32%) and major (11%) reservoirs. Middle-income households (LKR30,001–75,000) are relatively evenly distributed, with 48% in medium, 32% in minor and 20% in major reservoirs. High-income households ($\geq$ LKR75,001) are more common in major reservoirs (24%), followed by medium (44%) and minor (32%) reservoirs.

The reported monthly household income ranges from LKR10,000 to LKR150,000, with a mean income of LKR61,748.09. However, a

large standard deviation of LKR26,322.737 indicates substantial income disparity within the fishing communities. These findings suggest that medium reservoir fishers have greater access to financial resources, while major and minor reservoir fishers exhibit lower financial security and savings behaviour.

Natural capital, including access to drinking water and land ownership, varies significantly among reservoir fishers, influencing their livelihoods and wellbeing. Drinking water access is highest among medium reservoir fishers (72%), while only 19% in minor reservoirs and 9% in major reservoirs report having access, highlighting disparities in essential resources. Land ownership also differs across reservoir types; in major reservoirs, 72% are small landowners ($\leq$ 40 perches), whereas in medium reservoirs, land ownership is more evenly distributed, with 27% owning small plots, 30% medium-sized plots (41–100 perches), and 34% large plots (101–400 perches). In minor reservoirs, the majority (65%) own large plots, with only 5% holding small land. Additionally, a small percentage in each category owns very large plots exceeding 400 perches, with 15% in minor, 9% in medium and 8% in major reservoirs. These variations in natural capital demonstrate the unequal distribution of land and water resources, affecting the sustainability and resilience of fishing communities.

Physical capital, including household assets and fishing equipment, varies across reservoir fishing communities, influencing their productivity and quality of life. Mobile phone ownership is widespread, with 100% of major reservoir fishers owning one, followed by 98% in medium and 94% in minor reservoirs. Electricity access is nearly universal, with 100% in major and minor reservoirs and 99% in medium reservoirs.



Ownership of refrigerators, however, shows a decreasing trend from minor (80%) to medium (76%) and major (72%) reservoirs, indicating differences in household storage capacity. Fishing equipment availability also varies, with fibre boats being more common in major reservoirs (96%) compared to medium (83%) and minor (85%) reservoirs. Traditional rafts (Theppan) are used only in minor (17%) and medium (12%) reservoirs, while major reservoir fishers rely entirely on modern fibre boats. Fibre net usage is high across all categories, with nearly universal adoption (98% in minor, 97% in medium and 100% in major reservoirs). These differences in physical capital reflect variations in technological access and fishing practices among different reservoir communities.

Social capital plays a crucial role in shaping trust, cooperation and social relations within reservoir fishing communities. Trust in fisheries community leaders (3.72) and fisheries society members (3.74) is relatively high, indicating strong confidence in leadership and collective decision-making within fisheries societies. Trust in people within the fishing community (3.61) is slightly lower but still significant, suggesting a sense of unity among fishers. However, trust decreases when extending beyond the fishing sector, with people in the general community (3.4) and people in the village (3.38) receiving lower scores, reflecting weaker social ties with the broader community. Despite these differences, generosity within the fishing community scores the highest (3.84), highlighting a strong culture of mutual support among fishers. These findings indicate that while internal trust and cooperation within fisheries communities are strong, their social integration with the wider community remains relatively limited.

Constraints to maximising social equity and benefits

Several constraints hinder the maximisation of social equity and livelihood benefits in reservoir fishing communities, particularly environmental, governance and economic challenges. Unauthorised fishing is a significant issue across all reservoirs, reported by 100% of major, 90% of medium and 67% of minor reservoir fishers, threatening resource sustainability. Elephant threats are a major concern in all reservoir types, affecting 100% of major and 59% of both medium and minor reservoirs. The presence of excessive aquatic plants (8% in major, 29% in medium and 15% in minor reservoirs) and predator damage (76% in major, 18% in medium and absent in minor reservoirs) further disrupts fishing activities. Governance issues, such as compliance with rules and regulations, are relatively low, with 4% in major, 11% in medium and 7% in minor reservoirs identifying governance as a constraint.

Barriers to income, food security and fisheries sustainability also limit social equity. Unnecessary expenditure and excessive spending are high across all reservoirs (96% in major, 80% in medium and minor), alongside a lack of proper financial management (4% in major, 20% in medium and minor). The high cost of food is a universal challenge, affecting all fishers in major and minor reservoirs and 94% in medium reservoirs. While most communities can access food within a reasonable distance, long travel distances to buy food are a minor issue (5% in medium reservoirs). Additionally, limited knowledge (52% in major, 64% in medium, 50% in minor) and fisheries society crises (48% in major, 36% in medium, 50% in minor) indicate challenges in accessing education and maintaining cooperative structures. These constraints collectively

impact the sustainability, equity and economic stability of fishing communities.

Opportunities to maximise social equity and benefits

Opportunities to maximise social equity and livelihood benefits in reservoir fishing communities include improving access, income, wellbeing, and reducing vulnerability. Expanding fisheries societies by recruiting new members is a key opportunity, with the highest potential in minor (84%) and medium (77%) reservoirs, though lower in major reservoirs (40%). Supporting farmers' membership in fisheries societies could also strengthen social equity, though this is more common in major reservoirs (32%) compared to medium (14%) and minor (6%) reservoirs. Ensuring fair commission practices in the fish trade is a strong opportunity across all reservoirs, particularly in medium (79%), major (60%) and minor (70%) reservoirs. Diversifying income sources, such as promoting GFP, has potential in all reservoir types, with minor reservoirs showing the highest interest (28%). Financial stability could be enhanced by maintaining a savings system, which is consistently high across reservoirs (68% in major, 76% in medium and 74% in minor). Additionally, providing financial counselling may improve household financial management, though interest is relatively low (32% in major, 36% in medium and 26% in minor reservoirs).

Efforts to reduce vulnerability and improve food security are also promising. Risk management programs are crucial, with strong support in medium (73%), major (64%) and minor (54%) reservoirs. Insurance systems could help mitigate financial risks, especially in minor reservoirs (46%), though support is lower in medium (26%) and major (36%) reservoirs. Providing subsidised meals is a widely accepted

strategy (72% in major, 65% in medium and 77% in minor reservoirs), helping to improve food security. Establishing fish shops to enhance market access has lower but notable interest (28% in major, 32% in medium and 23% in minor reservoirs). These opportunities highlight pathways to strengthen social equity, economic resilience and food security within reservoir fishing communities.

Conclusion and recommendations

The findings highlight that social equity and livelihood benefits from CBF vary across reservoir fishing communities, with socioeconomic and governance factors playing a crucial role in shaping outcomes. While opportunities exist to strengthen local governance, enhance capacity building and promote community participation, significant constraints such as policy gaps, financial limitations and inequitable resource distribution hinder progress.

To ensure sustainability, effective CBF integration should focus on equity and resilience within fishing communities. Policy enhancements must address governance weaknesses and promote equitable access to CBF benefits while introducing financial support mechanisms for small-scale fishers. Capacity building should be prioritised by empowering fisheries societies in decision-making and providing training for sustainable fishing practices. Community engagement and collaboration through participatory governance models and partnerships with local authorities, research institutions and fishing communities can further drive progress.

For future research, long-term studies on the impact of CBF on social equity and livelihoods are essential, alongside an exploration of gender dynamics to develop more inclusive fisheries policies.



These measures can contribute to a more equitable and sustainable reservoir fishery system.

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5.6 Towards gender equality benefits in culture-based fisheries in reservoir communities in Sri Lanka

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Abstract

CBF play a significant role in Sri Lanka's rural economy, offering employment and food security to communities reliant on inland reservoirs. While both men and women contribute to the sector, gender disparities persist in access to resources, decision-making and economic benefits. Despite the potential contribution of CBF to rural livelihoods, gender differences in participation in CBF and their consequences have not been systematically researched in Sri Lanka. The study focused on addressing this knowledge gap by providing a comprehensive analysis of roles and relations of women and men in participating, and in decision-making, in CBF in reservoir communities to identify ways to increase benefits for women. This research is envisaged as a basis for recommendations to enhance equality within this sector in Sri Lanka. A gender-inclusive, multi-method ethnographic approach was used to collect iterative qualitative and quantitative data from households in CBF communities. The study covered 7 reservoirs, located in 5 districts in Sri Lanka. A purposive sampling method was used to select a total sample of 296 respondents (49.6% female, 50.3% male). This sample comprised 32.7% of total fishing households within reservoir communities and a smaller comparative sample of non-fishing households. The main data collection method was qualitative – in-depth interviews – based on a semi-structured questionnaire. In addition to the individual interviews, primary data were also collected through 12 FGDs with women and men. Quantitative data were analysed descriptively, while qualitative data were analysed using the thematic analysis method. The study demonstrated that there is potential for women to receive equitable benefits from CBF by engaging in more gainful activities along the value chain. There is a substantial gender gap in decision-making within fisheries societies across these reservoirs, with women being significantly under-represented. Both men and women need to receive systematic attention from fisheries authorities and institutions to ensure access to fisheries resources, suitable training and financial support to overcome these obstacles.

Keywords: *culture-based fisheries, gender equality benefits, gender gap, fisheries governance*



Introduction

The full and equal engagement and benefits for women and men – in other words, gender equality – in the fisheries and aquaculture sector is fundamental for the achievement of sustainability and inclusiveness (FAO 2020). Despite playing crucial roles and making up half of the workforce across fisheries and aquaculture value chains, women make up a disproportionately high share of those working in the lowest-skilled, least stable and informal sectors of the economy (FAO 2020). They make up 28% of the primary sector employment in aquaculture, 18% in fisheries, and an estimated 50% in the pre- and post-harvest value chains apart from serving as the foundation of rural economies (FAO 2020). When focusing on gender-specific roles in CBF, men predominantly engage in fish stocking, harvesting and market-related activities (Nwabeze et al. 2013). They often control decision-making in cooperatives and community-based fisheries organisations while women contribute through post-harvest activities such as processing, drying and marketing. However, women's roles are often undervalued, and they have limited access to financial resources and training (European Commission 2003).

In developing nations like Sri Lanka, CBF as a rural livelihood have the potential to increase income and food security (De Silva 2016). Women play a significant role in the fisheries and aquaculture industry, particularly in the pre- and post-harvest stages of value chains worldwide (FAO 2022a). However, they work primarily informally and are frequently underpaid, invisible and undercounted in the aquaculture and fishing industries. They have little influence over decisions pertaining to fishing. The state of fisheries management in Sri Lanka is not all that

dissimilar to the worldwide trend. In the fishing industry, low labour productivity may be a result of the pervasiveness of gender inequality (FAO 2013). In order to address this knowledge gap, systematic research is required. Hence, this study aimed to explore the opportunities and constraints for achieving equitable livelihood benefits for women and men from CBF in reservoir communities in Sri Lanka.

The main objective of the study was:

- To determine opportunities and constraints for achieving equitable livelihood benefits for women and men from CBF in reservoir communities in selected districts in Sri Lanka.

Specific objectives were:

- To identify the differences in women's and men's specific roles and relations within the livelihood system of CBF communities.
- To determine opportunities and constraints for increasing women's benefits from CBF.
- To assess differences in how women and men shape and influence fisheries governance and to explore whether the contribution of women can be increased.

This study is part of the social science component to determine opportunities and constraints to achieving socially equitable livelihood benefits from CBF, as formulated within the ACIAR project on 'Improved productivity, efficiency and sustainability of the CBF for finfish and GFP in Sri Lanka'.

Methodology

Conceptual approach

Gender equality both empowers women and contributes to the sustainability of fishery resources. Hence, a gender-equal approach in CBF is as much about justice as it is about utilising fisheries to their fullest

potential for sustainable development, healthy food systems and resilient livelihoods. By addressing gender dynamics in fisheries such as breaking stereotypes, sharing responsibilities and promoting inclusive governance, communities can foster sustainable development outcomes, such as improved food security and reduced poverty. The following conceptual approach (Figure 5.6.1), informed by the social relations approach and the theoretical perspective of Kabeer (1999), was formulated to understand how gender dynamics influence participation, decision-making and benefit sharing in the fisheries sector. The diagram presents a structural pathway to achieving gender-equal benefits, ultimately contributing to enhanced food security and poverty reduction. Gender equality in fisheries leads to achieving food security, as women prioritise household nutrition and community wellbeing; empowering them improves food availability and distribution. In terms of poverty reduction, both men

and women contribute to and benefit from economic growth, with equitable access to income and decision-making.

The approach begins with recognising both men and women as key participants in fisheries. Although both gender groups participate, this inclusive perspective recognises that their roles, relations, opportunities, constraints and contribution to decision-making may differ within the 3 dimensions delineated. As mechanisms to achieve gender equality, the following intermediary factors can transform current disparities within the 3 dimensions into tangible gender-equal outcomes:

- challenging norms and stereotypes
- promoting equal responsibility
- ensuring access and control over resources
- equitable control over income and benefits
- encouraging extended participation
- inclusive decision-making processes.

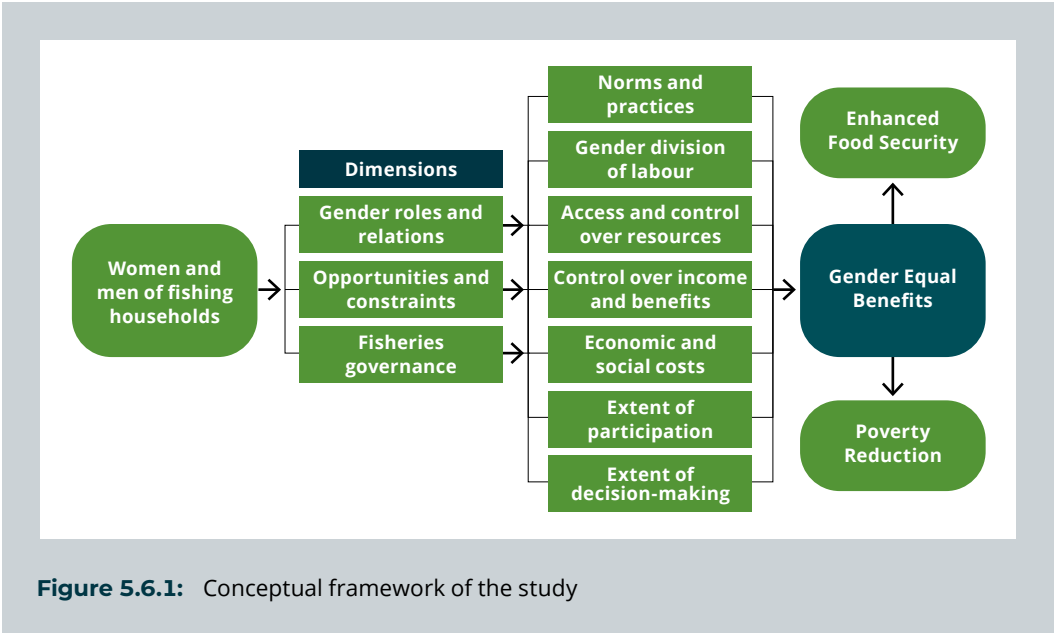


Figure 5.6.1: Conceptual framework of the study

This conceptual framework guides the core analysis presented below, centred on gender roles and relations, gendered opportunities and constraints, as well as gendered fisheries governance within the selected study communities in the CBF sector.

Methods

The ACIAR project initially selected 48 reservoirs for study, based primarily on size categories (large-scale, medium-scale and minor-scale) and geographical location to cover a range of districts within the island. Through a preliminary investigation, 7 reservoirs covering 5 districts were selected for this study, based on criteria such as reservoir size, geographical location, ethno-religious diversity and the extent of involvement (direct/indirect) of women in CBF. Of the 7 reservoirs, 2 were major, 3 were medium and 2 were minor (Table 5.6.1). The reservoirs were located in Mullaitivu, Hambantota, Monaragala, Puttalam and Trincomalee districts. While 5 of the 7 reservoir communities comprised Sinhala households, the major reservoir

community in Iranamadu included Tamil households, while the medium reservoir community in Mahadivulwewa included Muslim households.

The purposive sampling method (Patton 2002) was used to select individual respondents for interviews. As the main purpose of reservoirs is irrigated agriculture, with the livelihood system revolving around both farming and fishing, a larger sample (80%) of respondents from fishing households and a smaller, comparative sample (20%) from farming/ non-fishing households were selected for a more detailed analysis of gender roles and relations encompassing different livelihoods. Respondents selected from fishing households comprised a 32.7% sample of the total fishing households in the selected communities (Table 5.6.1). As a gender-focused study, 49.6% of the total individual respondents were women to ensure that women's views and perceptions were adequately captured, despite fisheries being generally considered a male sphere of activity. Data collection was primarily based on qualitative methods – in-depth

Table 5.6.1: Study sample

Type of reservoir	District	Name of the reservoir	Women's involvement (direct/indirect)	Total number of fishing households	Respondent sample size			
					Fishing		Non-fishing (8:2)	
					F	M	F	M
Major	Mullaitivu	Iranamadu	Direct	197	20	21	5	5
	Hambantota	Ridiyagama	Indirect	156	16	17	4	4
Medium	Monaragala	Urusitawewa	Indirect	43	10	10	3	2
	Puttalam	Tabbowa	Direct	135	31	31	7	8
	Trincomalee	Mahadivulwewa	Direct	130	30	30	7	8
Minor	Monaragala	Balaharuwa	Indirect	33	5	6	2	1
	Puttalam	Kottukachchiya	Direct	30	5	5	2	1
Total				724	237		59	

interviews based on semi-structured questionnaires and FGDs. A total of 296 individual respondents were interviewed and 12 separate FGDs with women and men were conducted. The thematic analysis method was used to analyse qualitative data. Descriptive statistics and analysis were used to calculate patterns and trends from the quantitative data generated by the study. Key concepts and themes that require further investigation were identified based on the research questions.

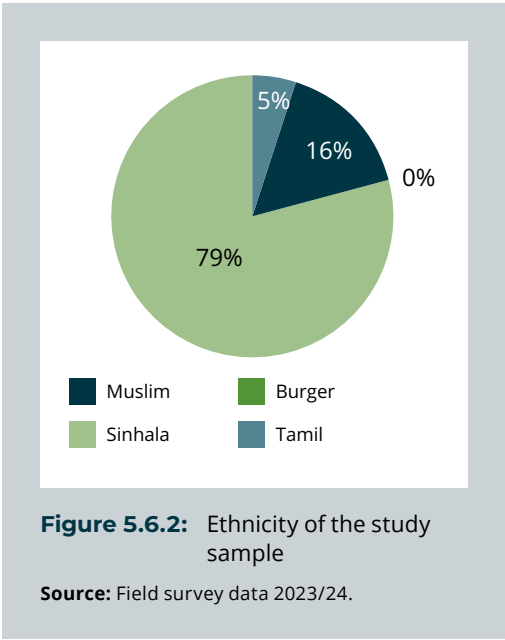
Results and discussion

The socioeconomic data of CBF communities have been initially analysed to provide the context for the main findings of the study. Social relations, centred on gender relations and roles, including the gender division of labour, gendered opportunities and constraints in engaging in fisheries, as well as gender gaps in fisheries governance are discussed in this section. This paper is based mostly on the qualitative interview data from the 237 fishing households and FGDs conducted for this study, as well as the literature review.

Socioeconomic profile

As indicated in Figure 5.6.2, the ethnic composition of the sample was predominantly Sinhalese, accounting for approximately 79% of households in the selected CBF communities. Around 16% of households were Muslim, while 5% were Tamil. While this sample captured some aspects of cultural diversity, it is not representative of the ethnic composition of the Sri Lankan population as a whole, and the number of households, especially of Tamils, were too small for comparative social analysis, based of ethnicity.

Fisheries are the core of all minor, medium and major reservoir fisheries communities, as seen in Table 5.6.2. As would be



expected from a study sample that focuses on fishing households, about 85% of the income of households in reservoir villages within the study sample is derived from fishing. This is particularly significant in small reservoir settlements, where 95.24% of income comes from fishing, highlighting the respondents’ strong reliance on fishing and lack of alternate sources of income.

Table 5.6.2: Main income source distribution

Income source	Minor (%)	Medium (%)	Major (%)
Agriculture	-	9.15	9.45
Fisheries	95.23	84.50	85.13
Casual labour	-	0.70	1.35
Self-employment	-	0.70	-
Government employee	4.7	3.52	-
Other	-	1.40	4.05

Source: Field survey data 2023/24.

Agriculture, as part of a mixed livelihood system, provides a lesser income for

respondents in medium reservoir communities (9.15%) and major reservoir communities (9.45%). The government employment income is low across all the reservoirs while minor reservoirs records slightly higher value (4.7%) compared to the medium reservoirs (3.52%), implying that fisheries related livelihoods in all the fisheries communities are predominantly dependent on non-government income sources with only marginal financial engagement from the government sector. Casual labour and self-employment contribute very little, with less than 2% of income of respondents. Other income sources exist but were minimal with 1.4% within the sample of households in medium reservoirs and 4.05% in major reservoirs. As most study participants were chosen from fishing households, even if there are a number of livelihood possibilities, they are not economically significant. As a result, this group's livelihood diversification was low. These households are economically vulnerable to changes in ecosystems, weather patterns and markets since they are predominantly dependent on fishing.

Table 5.6.3 indicates the household income and expense categories, ranging from under LKR10,000 to over LKR50,000, distributed across major, medium and

minor reservoir communities. The biggest proportion of households across all 3 types of reservoirs reported incomes between LKR20,000–30,000, except for those, which indicated a similar proportion in the LKR30,000–50,000 category, in minor reservoir communities. The majority (64.7%) of households in major reservoirs reported lower incomes between LKR10,000–30,000, while the majority of households in medium (80%) and minor (100%) reservoir communities indicated higher incomes between LKR20,000–50,000. Around 21.2% of households in medium reservoir communities had incomes above LKR50,000, whereas only 10–12% of households belonged to this category in minor and major reservoirs, respectively. In terms of expenses, there were more similarities among households in major and medium reservoir communities, in contrast to those in minor reservoir communities. The majority (95%) in minor reservoir communities indicated expenses between LKR20,000–50,000, in keeping with their income levels. However, the majority of households in major (54.8%) and medium (62%) reservoir communities reported expenses from LKR30,000 to above LKR50,000, above their reported income levels. As there can be under-reporting of income in surveys, reported expenditure levels might be a more accurate assessment of income. However, it is

Table 5.6.3: Income and expenses in fishing households in the study sample

Reservoir type	Income/ expenses categories	Income and expenses (%)					Total (%) HHs	Total # HHs
		<LKR 10,000	LKR 10,001 –20,000	LKR 20,001 –30,000	LKR 31,000 –50,000	>LKR 50,000		
Major	Income	4.2	23.9	40.8	18.3	12.6	100	74
	Expenses	1.4	18.3	25.3	32.3	22.5	100	74
Medium	Income	2.1	17.6	30.9	28.1	21.2	100	142
	Expenses	1.4	14.7	21.8	29.5	32.3	100	142
Minor	Income	0	0	45	45	10	100	21
	Expenses	0	5	55	30	10	100	21

Source: Field survey data 2023/24; HH=Households.

also possible that the discrepancy between income and expenditure is indicative of higher debt levels in major and medium reservoir communities.

Gender roles and relations within CBF communities

Gender roles and relations within the livelihood system of CBF communities reveal how men and women share responsibilities, access resources and engage in economic activities within households, which constitute the community. These roles and relations can differ across communities and societies due to cultural, social, economic and environmental factors. Gender roles define the expectations for men and women in economic, social and domestic spheres. These roles often dictate:

- Division of labour: Men often work in formal jobs, commercial farming and fishing, or other income-generating endeavours, while women handle childcare, housework and subsistence farming or fishing-related activities.
- Access to resources: Generally, men tend to have greater control over land, credit and technology, while women may have limited decision-making power in household and community matters.
- Income generation: In most societies, men dominate formal employment and entrepreneurial activities, while women engage in informal or unpaid labour.
- Decision-making power: Men often engage in household and community decision-making, while women’s voices may be marginalised.

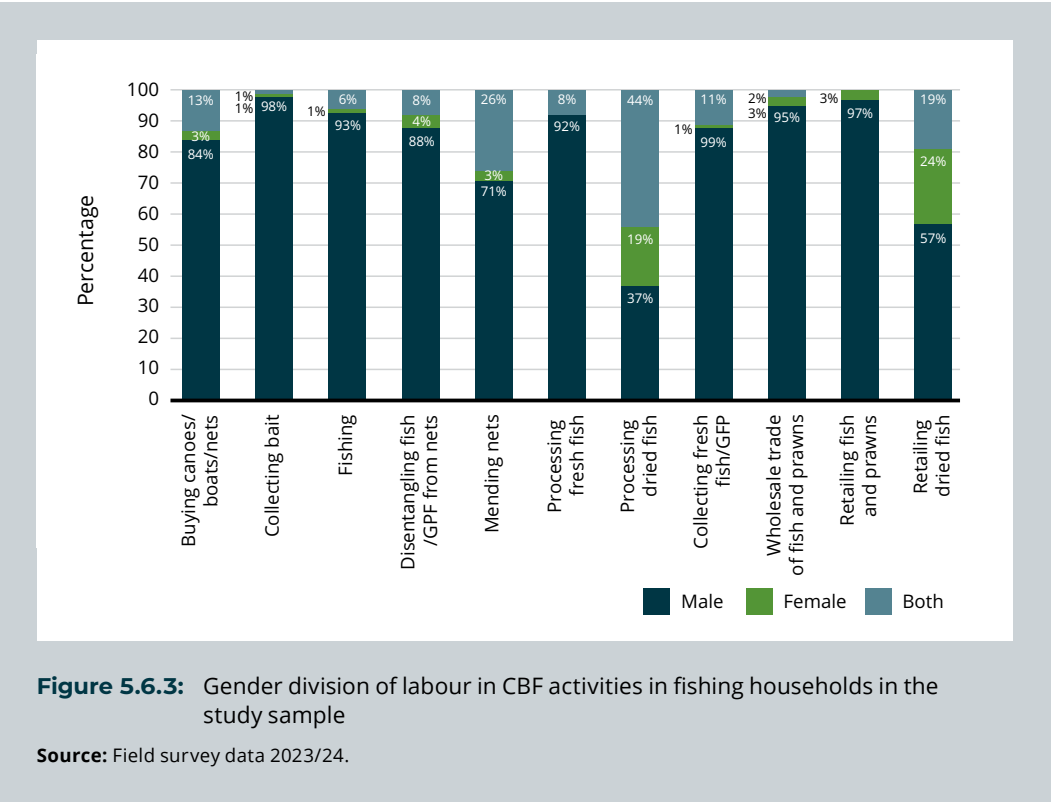


Figure 5.6.3: Gender division of labour in CBF activities in fishing households in the study sample

Source: Field survey data 2023/24.

These patterns are evident along finfish and GFP value chains within CBF communities in Sri Lanka as well. Figure 5.6.3 indicates the gender division of labour in fishing households in the reservoir communities selected for study. A traditional division, with women participating to some extent in pre- and post-harvest activities (such as net mending, dry fish processing and dry fish retailing), and men typically engaging in all pre-harvesting, harvesting and post-harvesting activities (such as collecting bait, fishing, processing fresh fish, trading), is evident. Dried fish processing and retailing are the only 2 activities in which both parties were involved together to a greater extent relative to other activities.

The majority of activities associated with fishing are dominated by men. Households indicated collecting bait (98%), fishing (93%), disentangling fish from nets (88%), mending nets (77%), processing fresh fish (92%), collecting fresh fish/GFP (88%), wholesaling (95%) and retailing (97%) fresh fish/GFP as male activities. In 19% of households, dried fish processing was indicated mainly as a female activity, while in 44% of households

it was indicated as a joint activity by women and men. In 24% of households, retailing of dried fish was indicated as a women's activity, while in 19% of households it was indicated as a shared activity between women and men. Thus, women were engaged in dried fish processing in 63% of households and in dried fish retailing in 43% of households (Figure 5.6.4). Fishing as a women's activity was only reported in 1% of households, while it was reported as a joint activity of men and women in 6% of households – revealing that women fished in 7% of households surveyed. Overall, women were more engaged in household chores and domestic tasks, such as cooking, cleaning and childcare than in CBF-related activities. Thus, underlying social norms or cultural practices, which shape men's roles within the public sphere and women's roles within the private sphere, are evident in this study of CBF communities in Sri Lanka.

In exploring social relations within CBF communities, social networks linking male and female household members to their communities emerge as significant. Both women and men rely heavily on their



Figure 5.6.4: Dry fish processing by women

Source: Field survey data 2023/24.

immediate family (spouses, children, in-laws) for emotional, financial and practical support. Financial support was frequently mentioned, especially in emergencies. Women emphasised cooperation and reciprocity helping with food, labour and caregiving in return for similar support. Some respondents highlighted neighbourly support, particularly in times of crisis (such as sickness, financial difficulties). In terms of livelihood support, family members play a central role in sustaining fishing-related work. Wives assist with mending nets and household finances, while husbands help with farming or household chores. Some respondents mentioned trust in buyers and traders, who provide fair prices or essential supplies at concessional rates. Except for a few instances where financial aid or subsidies were received, for example, the government had given subsidies to a small number of fishers to buy boats and fishing gear, there was little evidence of external support from NGOs or the government.

Gendered opportunities and constraints

Fieldwork data revealed a gendered division of opportunities and constraints within CBF communities. For male fishers, the opportunities are concentrated in the fishing activity itself and economic benefits derived from it as a primary income source, and potential for diversifying and/or increasing fish production. Thus, the expansion of GFP, as a high-value export product increases their prospects for higher incomes from CBF. Meanwhile, the prevailing opportunities for women of fishing households are mainly associated with post-harvest activities, such as dried fish processing and trading, and household financial management, rather than direct engagement in fishing. Women have some potential to increase incomes from dried fish processing and retailing. Even though women are considered skilled at primary

post-harvest handling of GFP, which needs to be treated carefully to prevent damage to the claws and carapace, and therefore potential to increase incomes from this product, current levels of GFP production do not appear to be sufficient to provide adequate employment opportunities for women.

Women face significant constraints related to societal expectations, sociocultural norms and practices, religious beliefs, and a lack of historical involvement and training in fishing itself. These constraints can limit their engagement in CBF-related economic activities and full participation in the fisheries sector. Women are expected to prioritise housework and childcare, which are consistent with their roles as housewives and mothers, according to underlying gender norms. Hence, fisheries activities are perceived as secondary to their domestic responsibilities. Religious perspectives, especially the prescription among Buddhists to refrain from taking life, influence women more than men, as women tend to be more involved in religious activities. Lack of knowledge and experience in fishing are other constraints that prevent them from receiving higher economic benefits from CBF activities.

The constraints for male fishers are not related to their gender role as fishers and income-earners of households. Access to fisheries resources due to tenure issues, negative impacts of illegal fishing, as well as environmental uncertainties, which affect fishing and fish stock directly, are some of the constraints faced by male fishers. These constraints can affect their fish catch, and thereby have an impact on the wellbeing of their families in terms of food security and incomes of the household.

In order for CBF communities to prosper equitably and sustainably, it is critical

to address the limitations that women encounter by:

- promoting women’s involvement in more stages of the fisheries value chain, by addressing restrictive gender norms and practices in a constructive manner
- providing financial assistance, appropriate training and access to the fisheries resource to women
- taking religious and cultural sensitivity into account while looking for greater gender inclusion
- addressing environmental uncertainties that affect both men and women to ensure wellbeing of fishing households.

Gendered fisheries governance

Effective governance is critical to ensuring the sustainability and productivity of CBF, requiring a multifaceted approach that integrates ecological, social and economic considerations (Linke and Bruckmeier 2014). The governance of fisheries in inland reservoir communities in Sri Lanka comes under community-based fisheries societies linked to these reservoirs, established within the purview of NAQDA. The levels of activity, efficiency, leadership and access to different groups, including participation by men and women, differ widely across fisheries societies. Table 5.6.4 provides disaggregated data on male and female

members of fisheries societies associated with the reservoirs selected for this study, categorised by their size (major, medium and minor).

Data analysis reveals predominance in male membership in all fisheries societies, with 4 of the 7 reservoir communities indicating a total lack of female membership. Male membership is substantially higher than female membership in fisheries societies in the other 3 reservoir communities as well. This includes Iranamdu (major) with the highest female representation of 28%, followed by Thabbowa (medium) with 25% and Urusita (medium) with 16.6% female membership. There is no necessary link between female involvement in fisheries societies and reservoir size. While fisheries societies associated with 2 two minor reservoirs selected for the study had no female members, those linked to one major reservoir and 2 minor reservoirs included some representation by women.

Participation in decision-making is crucial for promoting equitable and sustainable fisheries. Women also have accumulated knowledge, experiences and perspectives related to fisheries; these are vital to develop effective policies and sustainable strategies. As indicated in Figure 5.6.5, there is very low female participation in

Table 5.6.4: Membership in fisheries society by reservoir and gender in the study sample

Type of reservoir	Name of reservoir	Male %	Female %
Major	Ridiyagama	100	0
	Iranamadu	71	28
Medium	Mahadivulwewa	100	0
	Tabbowa	75	25
	Urusita	83	16.6
Minor	Kottukachchiya	100	0
	Balaharuwa	100	0

Source: Field survey data 2023/2024.

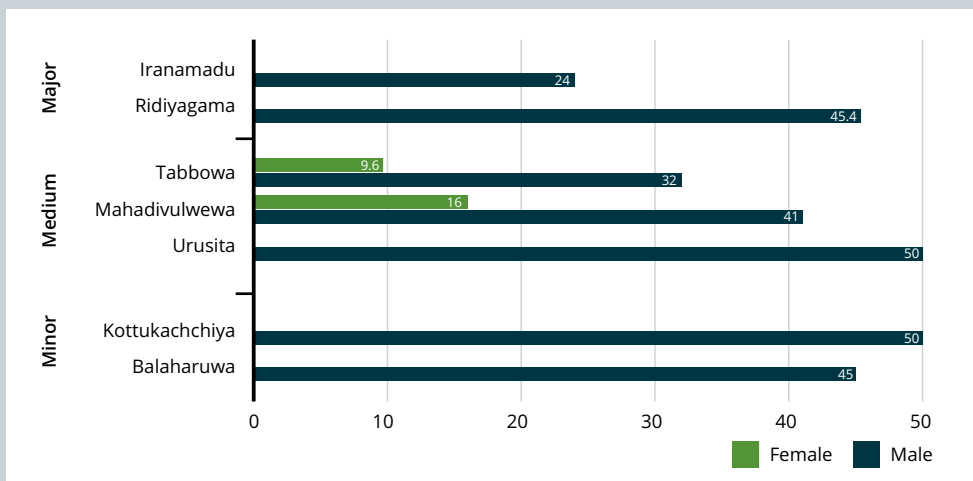


Figure 5.6.5: Participation in decision-making in fisheries societies

Source: Field survey data 2023/2024.

fisheries governance, as expressed in decision-making within community-based fisheries societies. Ridiyagama, Urusita, Kottukachchiya, Balaharuwa and Iranamadu reservoir communities reported no participation of women in decision-making within their fisheries societies. The highest female participation in decision-making was indicated in Mahadivulwewa (16%), despite not being members, it was said that the women of the Mahadivulwewa fishers' association attend meetings on behalf of their husbands and therefore express their thoughts. Even when women join fisheries societies as members, their participation in and contribution to decision-making, especially in terms of expressing their opinions, is minimal. They mostly attend society meetings to represent their husbands in cases where the latter are unable to participate, or to replace their deceased husbands. Therefore, women's voices within fisheries societies are very limited. While women reported that they

expressed their views at meetings in Iranamadu, they perceived that they did not contribute to decision-making. Thus, this analysis reveals a clear gender imbalance in leadership and influence. Limited voice of women reveals a lack of consideration of their perspectives, needs and priorities. The potential barriers to female participation are linked to sociocultural norms that result in lack of family support and opportunities for women to express their perspectives.

Conclusion

According to this analysis, CBF have the potential to benefit both men and women. However, the economic benefits currently accrued to men are greater than that received by women, due to the predominance of men in most nodes of CBF value chains. The CBF sector can maximise the productive potential of both male and female members and their wellbeing by fostering an inclusive atmosphere, which will increase sustainability, economic

development and food security. It is necessary to remove the fundamental constraints that exist in the CBF industry for both women and men to have better opportunities and to obtain equal benefits. In order to achieve such benefits, both men and women need to be involved in fisheries-related activities, and space has to be created for them to produce and process products that will bring higher returns. It is especially important to address gender disparities so that women are located in value-chain nodes which will bring them greater benefits. For women to have a greater voice in the operation and development of CBF, their contribution to the governance of the fisheries sector is critical. Thus, achieving equitable representation and more efficient, sustainable CBF management entails greater efforts to advance gender equality and inclusion along the value chain, as well as in fisheries governance.

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6 Additional studies



Project research assistants conducting limnological tests at the NAQDA regional station, Iranamadu Reservoir, Sri Lanka. Photo: Professor Asanka D Jayasinghe.

6.1 Beyond the frame: leveraging complementary studies to develop value-added products from giant freshwater prawn discards

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Abstract

This study explores the extraction of chitin from the shells of giant freshwater prawns (GFP) and the production of high-purity chitosan, which is then utilised for value-added applications in the food and cosmetic industries. Chitosan beads were developed as an alternative to microplastic beads in face wash products, demonstrating similar exfoliating properties. An edible, biodegradable and transparent food packaging film was also fabricated, serving as a sustainable alternative to polyethylene, with properties suitable for 'heat-and-eat' food products. The film's antimicrobial activity was evaluated, showing its potential as an active packaging material. Furthermore, a smart film was developed to indicate food spoilage, enhancing the functionality of food packaging. Additionally, the research focuses on the community empowerment potential of utilising discarded soft-shelled GFP. A simple cheese-making process incorporating soft-shelled GFP meat was developed, along with a 'heat-and-serve' soup using discarded whey, providing nutritional and economic benefits to rural communities.

Keywords: *culture-based fisheries, Macrobrachium rosenbergii, post-harvest*

Introduction

The GFP (*Macrobrachium rosenbergii*) is increasingly recognised as a key component in improving the livelihoods of rural fisheries in Sri Lanka. Known for its tender and flavourful meat, the GFP is predominantly marketed for export or to local restaurants. However, approximately 55% of the prawn, including shells and heads, is discarded after meat extraction. The shells, primarily composed of chitin, offer significant potential for value-

added products; however, their rigid structure limits utilisation (Ju et al. 2021). Deacetylating chitin to form chitosan opens opportunities for its application in industries such as food, cosmetics and biomedical.

Microplastic pollution, particularly from the cosmetic industry, has emerged as a global environmental challenge (Laskar and Kumar 2019; Wang et al. 2021). Microplastic beads, commonly used as exfoliants in face washes, contribute significantly to environmental contamination. As a

result, several countries have enacted bans on the use of microplastic beads (Kentin and Kaarto 2018). Likewise, the widespread use of polyethylene-based food packaging materials has raised concerns due to their environmental and health implications (Agarwal et al. 2023). These issues underscore the necessity for biodegradable and non-toxic alternatives. Chitosan, derived from natural sources, offers promising properties such as antimicrobial activity, antioxidant effects and biodegradability (Abd El-Hack et al. 2020; Muzzarelli 2009; Sharma and Batra 2019), positioning it as an ideal candidate for replacing microplastic beads and polyethylene packaging.

In many rural communities, discarded GFP shells – including soft-shelled and damaged prawns – result in both financial and nutritional losses. Additionally, cooked prawn shells from restaurants are frequently discarded. Developing simple, cost-effective technologies to utilise these waste materials could significantly contribute to the economic and nutritional wellbeing of rural communities engaged in GFP fisheries.

Development of value-added products from GFP shell waste and soft-shelled GFP

Chitosan extraction from GFP shell waste

Chitin, a natural polymer found in crustacean shells, has limited direct application due to its rigid structure. However, chitosan, its deacetylated derivative, offers greater versatility for value-added applications. In this study, chitosan was extracted from GFP shell waste discarded by restaurants, achieving a yield of 10.15% (dry weight basis), comparable to chitosan extracted

from blue swimming crab shells (11.39%). Characterisation of chitosan was performed using Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDS), confirming its purity and suitable physicochemical properties for use in cosmetics and food applications (Figure 6.1.1 A, B, C). Additionally, the extracted chitosan exhibited thermal stability up to 310 °C (Figure 6.1.1 D), with favourable viscosity, colour and antioxidant properties.

Value-added products from GFP shell waste

Chitosan beads as an alternative to microplastic beads in face wash

In our study, chitosan extracted from GFP shell waste was used to make beads in similar size to microplastic beads (Figure 6.1.2 A, B). This was a green approach as only the green chemicals were used in the preparation process and the chitosan beads are biodegradable. The structural change of chitosan to chitosan beads was confirmed using FTIR (Figure 6.1.2 C). Properties of chitosan beads were compared with that of microplastic beads and apricot granules to test the effectiveness. Beads should be stable in water without breaking, otherwise beads will be dissolved in liquid face wash with time. Results revealed an acceptable level of water stability (96.23 ± 0.01) which is not significantly different from the reference value (94.60 ± 0.02) ($p=0.240$) (Song et al. 2021).

The cleansing effectiveness of chitosan beads was tested by comparing the time taken to remove eyeliner marks on the skin after applying beads containing face wash to that of microplastic beads and apricot granules. According to the Figure 6.1.3 A, after 30 seconds of rubbing, chitosan

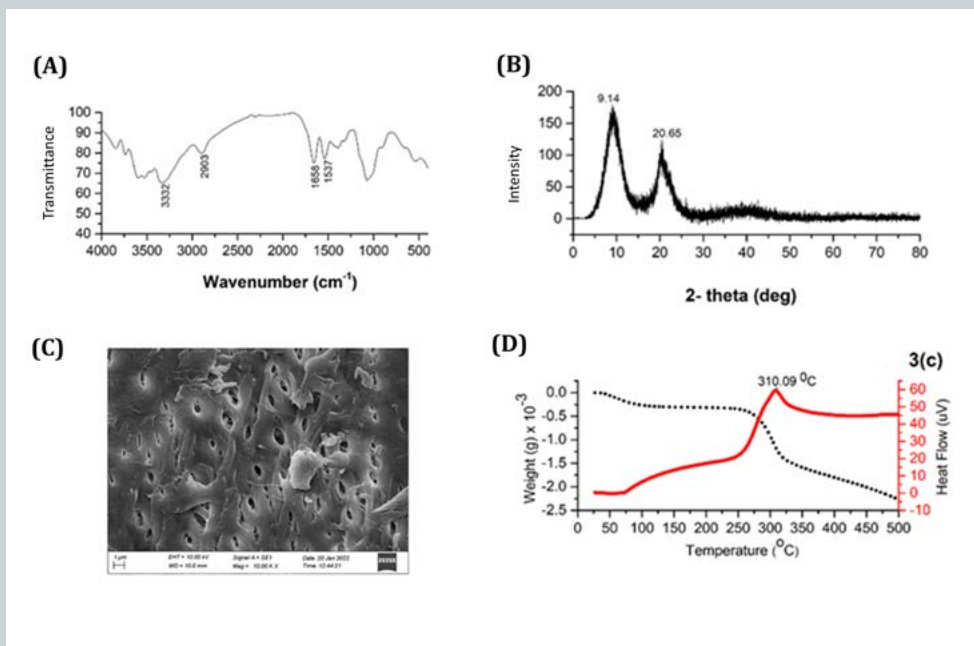


Figure 6.1.1: Characteristics of extracted chitosan

Note: (A) FTIR spectrum; (B) XRD spectrum; (C) SEM image; (D) Thermal degradation temperature.

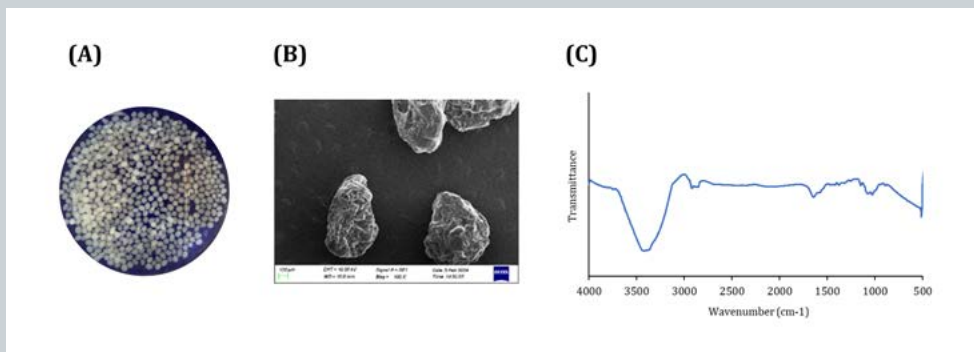


Figure 6.1.2: (A) Photograph of prepared chitosan beads; (B) SEM image; (C) FTIR spectrum

beads showed the highest cleansing effect compared to microplastic beads and apricot granules. This finding was further confirmed by the shortest time duration taken to remove eyeliner marks compared to microplastic beads and apricot granules as shown in Figure 6.1.3 B. According to the sunblock removal test (Figure 6.1.3 C), the highest effectiveness was shown by the chitosan beads.

Sensory evaluation revealed that the face wash containing chitosan beads was preferred over alternative apricot beads for its moisturising, cleansing and oil retention properties (Figure 6.1.4). However, textural

and colour properties of chitosan beads were ranked second to microplastic beads, suggesting further experiments to improve texture and colour of chitosan beads.

Edible and biodegradable food packaging film for 'heat-and-eat' foods

An edible, biodegradable food packaging film was developed from GFP-derived chitosan (Figure 6.1.5 A). This was a green approach as only green chemicals were used and the film is biodegradable. The structure of the chitosan film was confirmed by FTIR and XRD spectra (Figure 6.1.5 B, C). The properties of this

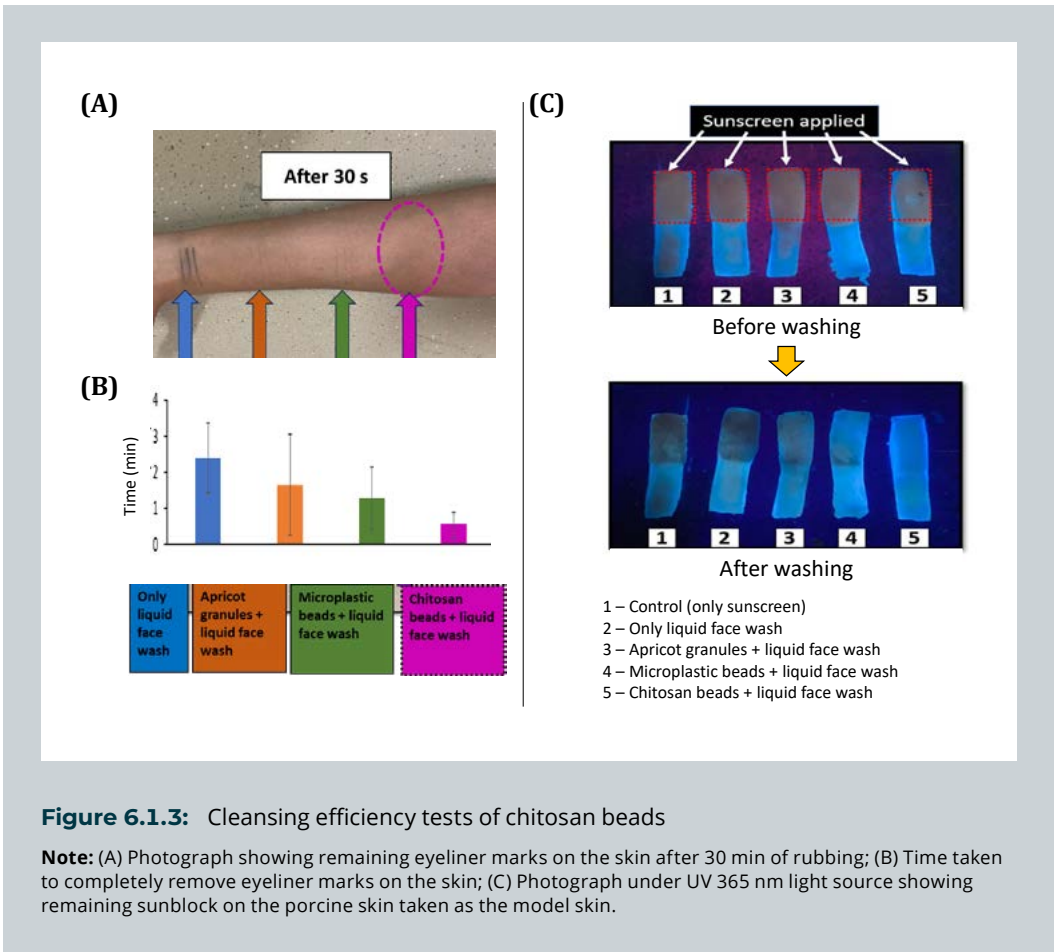


Figure 6.1.3: Cleansing efficiency tests of chitosan beads

Note: (A) Photograph showing remaining eyeliner marks on the skin after 30 min of rubbing; (B) Time taken to completely remove eyeliner marks on the skin; (C) Photograph under UV 365 nm light source showing remaining sunblock on the porcine skin taken as the model skin.

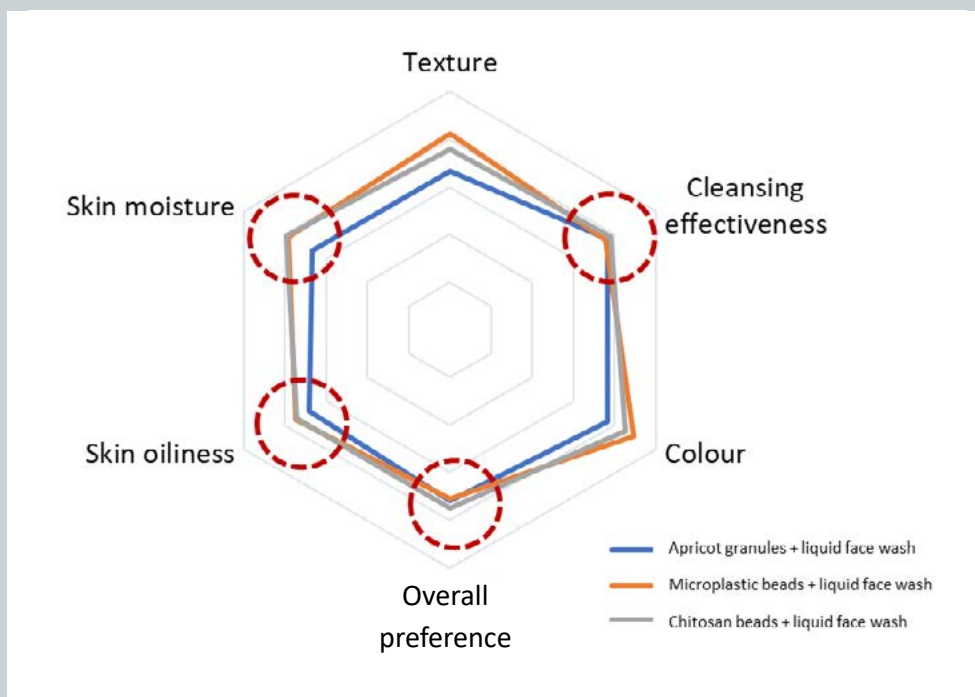


Figure 6.1.4: Sensory evaluation results of 6 attributes of 3 different bead types

film include thickness of 0.04 mm, density of 0.65 g cm^{-3} , grammage of 0.03 gm^{-2} , tensile strength of 37 MPa, antioxidant activity of 85% and biodegradability within 9 days. It remained intact in boiling water for one hour (not tested beyond this), and did not degrade or change colour in microwave oven for 45 minutes, and was heat resistance up to 225°C as tested by thermal gravimetric analysis (Figure 6.1.5 D) film is suitable for 'heat-and-eat' food products, offering an environmentally friendly alternative to polyethylene. Additionally, the film can be consumed with the food it packages, reducing waste, and is suitable for applications such as instant noodle sachets containing oil and spices (Figure 6.1.5 E).

Active packaging film for fish fillets

Due to their high moisture content, fish fillets are highly perishable, often packaged in polyethylene films under refrigerated conditions. Chitosan-based active packaging films, developed in this study, demonstrated antimicrobial properties (Liyanage et al. 2023) that significantly reduced microbial load on packaged fish fillets under refrigeration. In our research, the previously developed edible food packaging film was further evaluated as an active food packaging film for fish fillets stored at 4°C . The total plate count of the packaged fish fillets, and in inside and outside surfaces of the package were determined. The results proved that chitosan film had a positive effect on reducing microbial load in fish fillets (Figure 6.1.6).

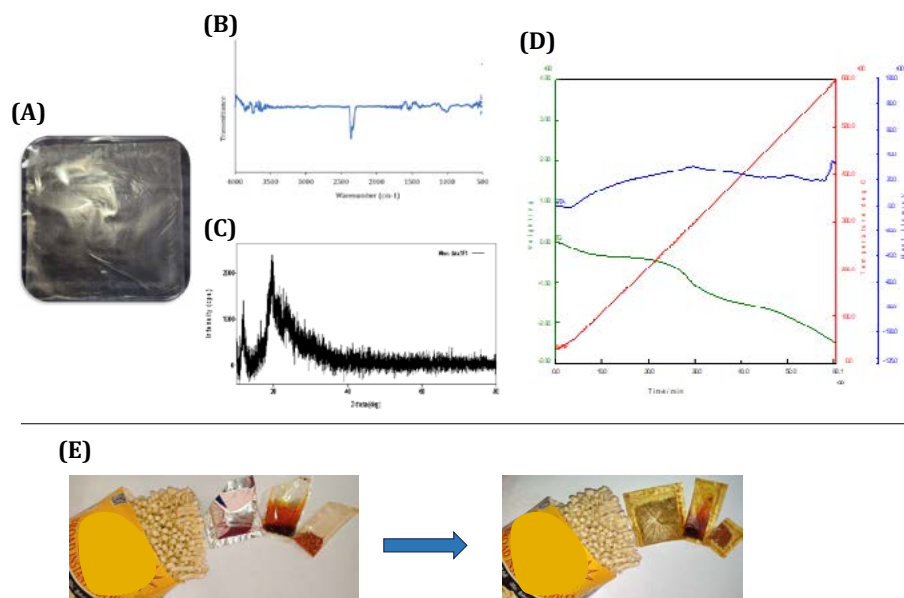


Figure 6.1.5: (A) Photograph of prepared chitosan film; (B) FTIR spectrum; (C) XRD spectrum; (D) Thermal degradation temperature; (E) Representation of the proposed use as sachets (left side – original sachets from polythene, right side – prepared sachets from chitosan)

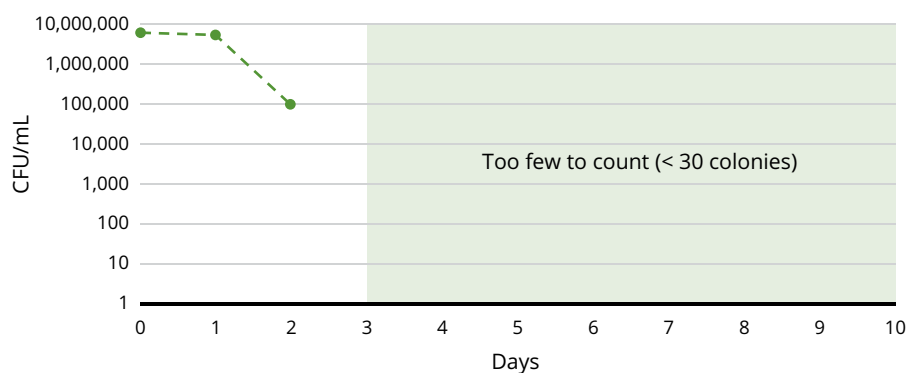


Figure 6.1.6: Total bacterial count of fish fillets packed in chitosan films at 4 °C

Note: The number of colonies in agar plates from 10₋₁ dilution was less than 30, therefore cannot present the values in CFU/mL.



Further, the films also showed promise in extending the shelf life of fish nuggets stored under frozen conditions, providing a biodegradable and non-toxic alternative to synthetic antimicrobial agents. In addition, due to the heat stability up to 225 °C as confirmed by our previous research, these chitosan films can be used for packaging of 'heat-and-eat' food, for example fish nuggets can be deep fried in cooking oil conveniently, without removing the package.

Intelligent and smart food spoilage sensor film

Consumers mainly depend on 'expiry date' given in the packaging as a measure of freshness and safety. However, perishable items like fish fillets spoil fast due to fluctuations in storage temperature although it is still within the expiry date. In addition to expiry date, consumers rely on colour and smell of the fish fillets as a measure of freshness. However, for the vacuum packed fish fillets, the colour alone cannot be taken as a reliable measure of freshness and safety.

Hence, to enhance food safety, a smart spoilage sensor film was developed by incorporating anthocyanins from red cabbage into GFP-derived chitosan to cause structural modifications as evident by the FTIR spectrum (Figure 6.1.7). This pH-responsive (pH 1-pH 13) film exhibited a colour change from purple to blue to green as fish fillets spoiled over a 9-day period under refrigerated conditions (Figure 6.1.8 A). The film also displayed pH-responsive colour changes in apple juice and milk. The colour of smart films changed from purple to yellowish red over a 5-day period for apple juice (Figure 6.1.8 B), and from purple to yellowish red over a 6-day period for milk (Figure 6.1.8 C) at refrigerated storage conditions. These results suggest

its potential for broader application in food products.

Value-added products from soft-shelled GFP meat for community empowerment

Soft-shelled GFP-incorporated fresh cheese

A fresh cheese was developed by incorporating soft-shelled GFP flesh using a simple, household-level technology. Two coagulants were used: commercial citric acid and lime juice. Two cheese types under each coagulant were made by incorporating prawn flesh in 2 forms: cube form and ground form (Figure 6.1.9). Properties of these cheeses were compared to cheese made using only milk by adding 2 coagulants separately. Hence, there were 6 cheese types: milk only – citric, cube prawn – citric, ground prawn – citric, milk only – lime, cube prawn – lime, ground prawn – lime. Textural properties of hardness, chewiness and gumminess were significantly different among all 6 cheese types (Figure 6.1.10). However, there were no significant differences in textural properties among 3 cheese types made with lime juice. Sensory attributes were evaluated using the lexicon method and hedonic scale test with the participation of 30 panellists. The results indicated that prawn incorporated cheese types scored higher ranks for sensory attributes; however, there is more room for further improvement of cheese made with lime (Figure 6.1.11 A). The most preferred cheese type was the ground-prawn flesh incorporated cheese made using lime juice as the coagulant (Figure 6.1.11 B). These findings suggest potential for local communities to utilise soft-shelled GFP in value-added food products. Further, this study suggested developing another product from leftover whey as nearly 70% of milk is discarded as liquid whey.

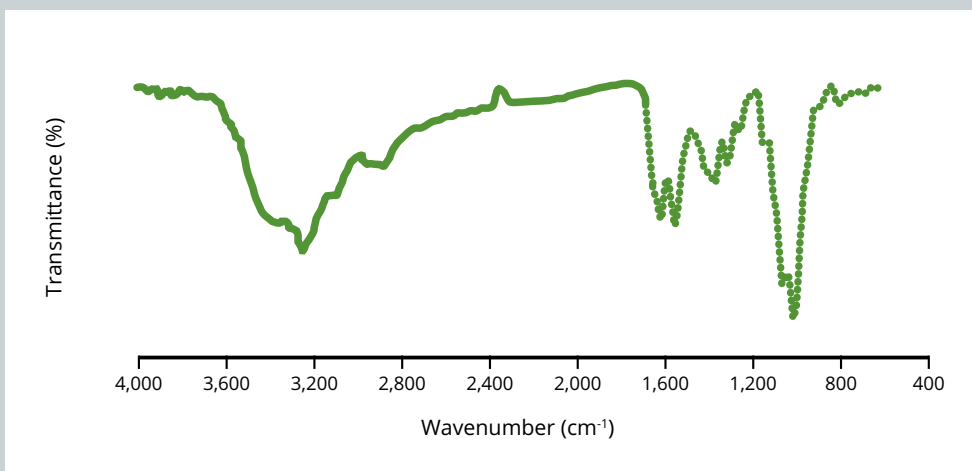


Figure 6.1.7: FTIR spectrum of pH responsive smart film made of chitosan

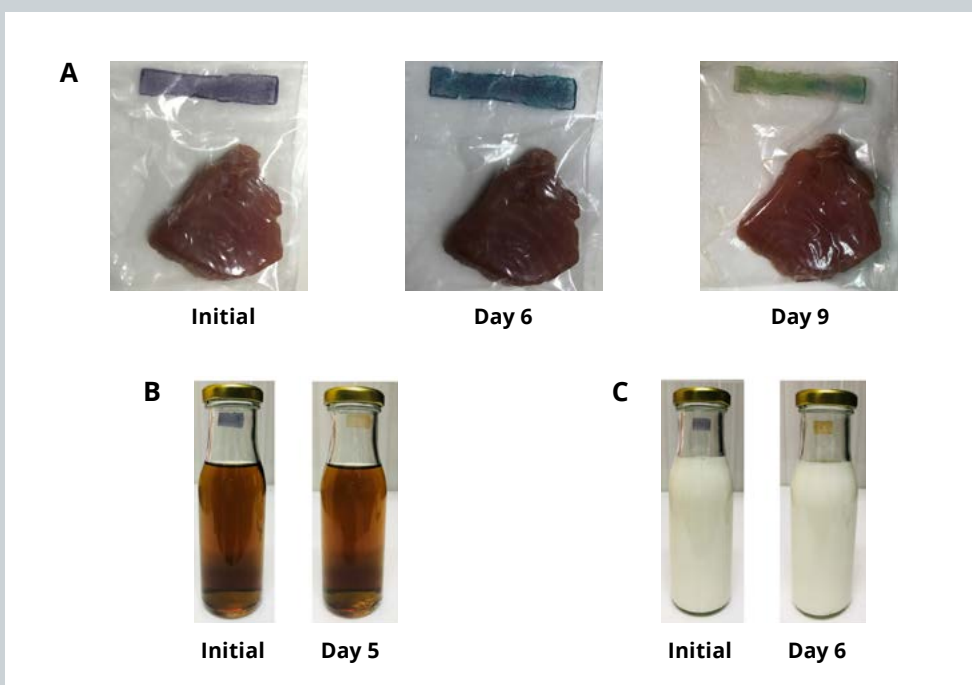


Figure 6.1.8: Photographs showing the colour changes of pH responsive smart films with spoilage

Note: (A) Fish fillet; (B) Apple juice; (C) Milk.

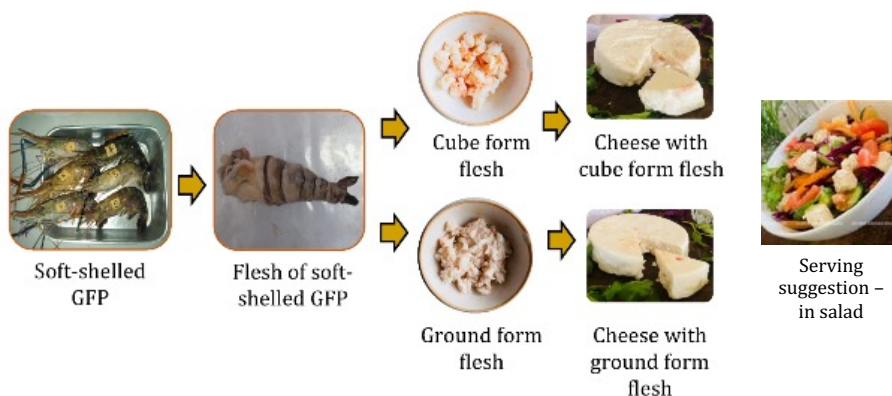


Figure 6.1.9: Photographs showing the use of soft-shelled GFP in cheese making

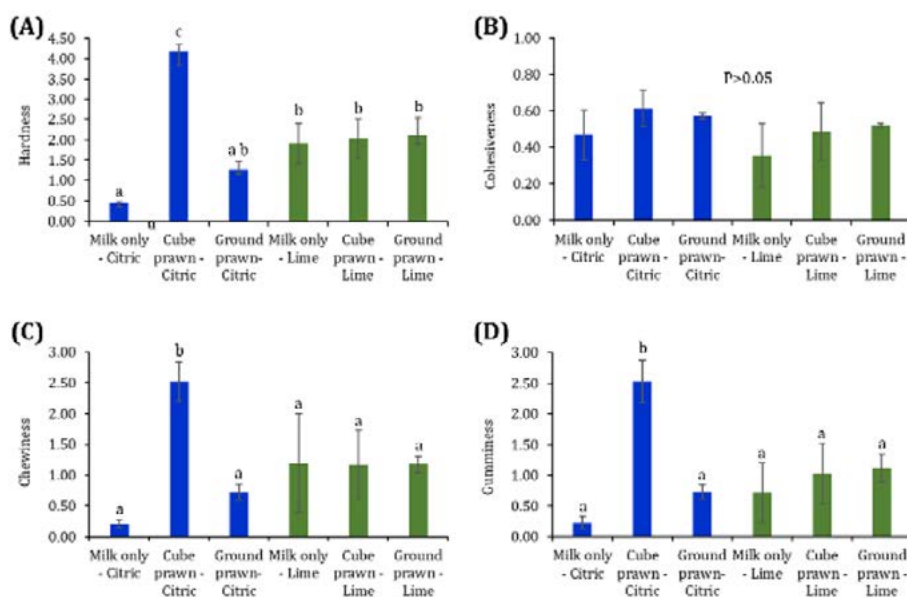


Figure 6.1.10: Textural properties of 6 different cheese types

Note: (A) Hardness; (B) Cohesiveness; (C) Chewiness; (D) Gumminess.

Whey-incorporated ‘heat-and-serve’ soup

According to the method of cheese preparation in our previous study, nearly 70% of milk is discarded as liquid whey. This liquid whey contains nearly 10% of whey in wet weight basis. To utilise this by-product of cheese preparation, a ‘heat-and-serve’ soup was developed which can also be prepared at household level. In this research, carrageenan extracted from a seaweed, *Kappaphycus alvarezii*, was used as the thickening agent. Different ratios of liquid whey, tomato pulp and carrageenan powder were tested to select the best ingredient

ratio. The proximate composition, viscosity, soluble fibre content and titratable acidity were compared. A sensory test was conducted using a hedonic scale test with the participation of 30 panellists. According to the sensory analysis results, the ingredient ratio of the most preferred soup was whey (20): tomato (80): carrageenan (0.1) (Figure 6.1.12). This simple, nutritious product can be easily prepared at the household level, offering another avenue for rural communities to capitalise on underutilised prawn and dairy by-products.

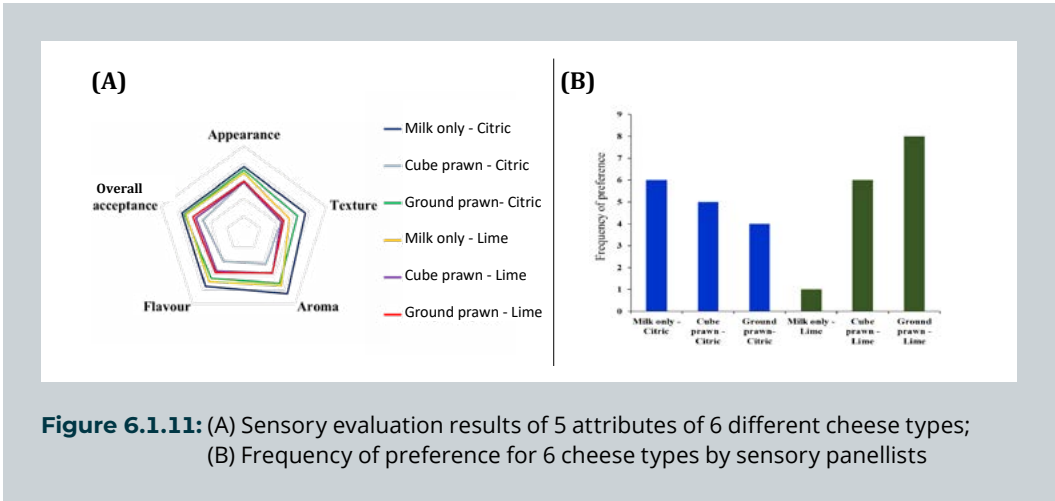


Figure 6.1.11: (A) Sensory evaluation results of 5 attributes of 6 different cheese types; (B) Frequency of preference for 6 cheese types by sensory panellists

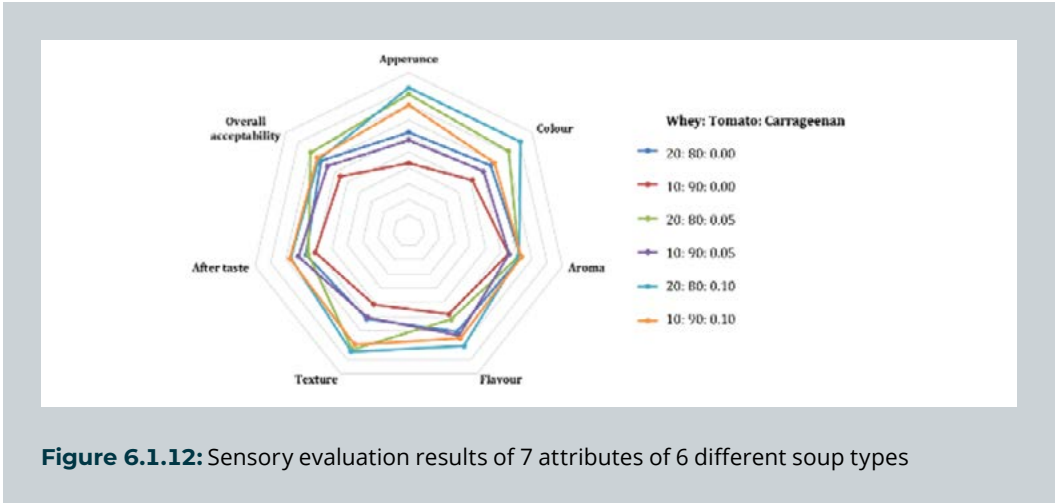


Figure 6.1.12: Sensory evaluation results of 7 attributes of 6 different soup types

Conclusion

This research demonstrates the potential for developing value-added products from the by-products of GFP fisheries, benefiting both the environment and rural communities. The successful extraction of chitosan from GFP shells and the development of biodegradable alternatives to microplastics and polyethylene packaging contribute to sustainability efforts. Furthermore, the innovative use of discarded soft-shelled GFP for food products offers an opportunity for economic and nutritional improvement in rural communities.

Contributors:

Contributor	Contribution
MNS Weerasekara	Preparation of chitosan beads as an alternative to microplastic beads to use in face wash.
KGY Ravihari	Preparation of edible and biodegradable food packaging film for 'heat-and-eat' foods as an alternative to polyethylene.
JAIPU Jayakody	Carrying out testing of active packaging film for fish fillets.
PLH Amandya	Preparation of intelligent and smart food spoilage sensor film.
AADAI Amarasinghe	Preparation of soft-shelled GFP-incorporated fresh cheese.
S Neeraja	Preparation of soft-shelled GFP-incorporated fresh cheese.
PGUS Ranasinghe	Preparation of whey-incorporated 'heat-and-serve' soup.

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6.2 Potential to estimate relative fish biomass in reservoirs using a commercially available hydro-acoustic fish finder

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Abstract

This study evaluates the potential of the Fish Smart Sonar Deeper CHIRP +2 for estimating relative fish biomass in reservoirs. Data were collected from 5 Sri Lankan reservoirs between 19 March and 1 April 2024: Kiriibban wewa, Handapanagala, Hakwatuna Oya, Maha Wilachchiya and Mahakanadarawa. Hydro-acoustic data were recorded in down-imaging mode using a 7° beam at 675 kHz, wirelessly connected to its official mobile app (Fish Deeper – Fishing App). Fish count, their size categories, swimming depth (ft) and depth at target location (ft) were manually extracted by observing the recorded survey in mobile and web applications. Statistical analyses revealed significant differences in mean fish swimming depths across reservoirs (ANOVA: $p < 0.001$), with larger fish occupying deeper waters compared to smaller fish. In Kiriibban Wewa, swimming depth of all fish size categories showed strong correlations with the depth at target locations ($R^2 = 0.94\text{--}0.96$). The number of fish living in each reservoir was estimated from the number of fish targets counted on the hydro-acoustic survey transects of corresponding reservoir. The findings suggest that the Fish Smart Sonar Deeper CHIRP+2 is a potential cost-effective tool for hydro-acoustic surveys subject to further research testing accuracy of the estimates.

Keywords: *hydro-acoustics, fish biomass estimation, sonar, agrarian reservoirs, Sri Lanka*



Introduction

Fish biomass is a crucial factor in aquaculture and fisheries management, enabling fishery managers to make effective decisions. Regular biomass assessments are essential for optimising feeding, controlling stocking and determining the optimal harvest time. In natural systems, directly measuring total biomass and species composition is not feasible. There are traditional methods based on manual sampling for biomass estimation, which are extremely time consuming, laborious, inaccurate and invasive towards the fish (Li et al. 2020). Over the past 3 decades, significant research and development efforts have advanced the use of sound waves for fish biomass estimation. This technology is known as hydro-acoustics and it provides a more efficient and non-invasive alternative to traditional biomass estimation methods (Ramírez-Coronel et al. 2024).

Hydro-acoustic fish biomass estimation is a non-invasive technique which uses sound waves to estimate fish biomass by emitting acoustic signals and analysing the reflected sound (echo) from the target (fish). These signals are used to determine the size, density, and distribution of fish populations (Simmonds and MacLennan 2005). Acoustic methods are useful tools in scientific research to calculate the size of fish stocks and to set catch limits for each species. Acoustics is advanced enough to locate targets of interest, interpret the signal strength to determine whether they are individuals or groups of organisms and calculate the shape and density of the aggregates (Romero et al. 2015). The same method aids in mapping depth profiles of the water body relating fish distribution to their habitats.

Scientific echosounders are employed for the acoustic fish biomass estimation, which have more advanced technology to identify fish, its size and measure their biomass using advance calculations. Furthermore, echosounders are invariably associated with hydro-acoustic data post-processing software to compute the mean density of fish and extract quantifiable descriptors on fish schools. Inexpensive and portable fish finders used in recreational and commercial fisheries share the same principles used in advanced scientific echosounders yet are more affordable and widely accessible. These devices are pre-calibrated, hence do not allow advance alterations to get accurate measurements on fish density and biomass like scientific echosounders do. Algorithms used in those devices to identify the fish or other targets are not usually exposed in their user manuals due to trade competition. In addition, fish finders lack advanced technical software for post-processing of data, which tends to be a drawback for scientific purposes. Despite those disadvantages, fish finders can be used to get a general idea on presence and absence of fish due to the prohibitive cost of scientific echosounders. Nevertheless, fish finders allow determination of fish density, if there is a way to measure the target strength (TS) of the individual fish located by those devices (McInnes et al. 2015).

Fish biomass estimation in Sri Lankan inland reservoirs is important due to several reasons, such as managing fisheries, conservation of aquatic ecosystems, and ensuring sustainable use of aquatic resources. Sri Lanka has been estimated to have more than 30,000 reservoirs and anicuts throughout the island especially in the dry zone (DAS 2000). After identifying the suitability of those reservoirs for inland fisheries development (Mendis

1965; Oglesby 1981; Rosenthal 1979), continuous fish stocking has been carried out in some reservoirs (Amarasinghe 1998; De Silva 2003; Chandrasoma and Pushpalatha 2018), and the current existing fish biomass is unknown. The aim of the present study is to assess the feasibility of using a commercially available hydro-acoustic fish finder as a tool for monitoring fish populations in reservoirs. No previous research has been recorded on using fish finders or echosounders in Sri Lankan inland reservoirs, therefore, this attempt would be an innovative approach to introduce a robust, non-invasive and affordable tool for managing inland fisheries in a developing country like Sri Lanka.

Materials and methods

Study area

The present study was conducted using a data set recorded during a bathymetric survey using a hydro-acoustic fish finder in 5 reservoirs. Selected 5 reservoirs were Mahawilachchiya, Mahakanadarawa and Hakwatuna Oya reservoir from North Western province and Handapanagala and Kiriibban wewa from Southern province (Figure 6.2.1). All the reservoirs were at their full supply level when the survey was carried out. The spatial distribution of

reservoirs is shown in Figure 6.2.1 along with their Global Positioning System (GPS) location and other relevant information in Table 6.2.1.

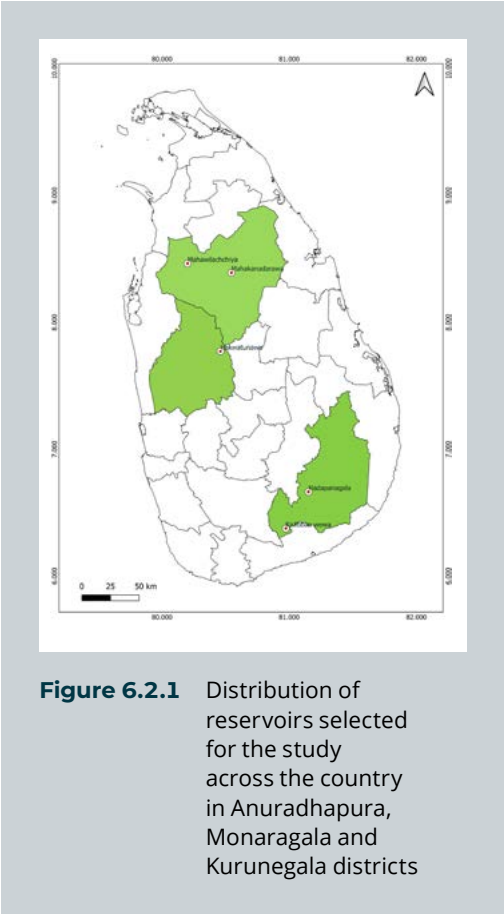


Table 6.2.1: GPS coordinates and the size of the studied reservoirs

Code	District	Name	Size	Surface area (ha)	Latitude	Longitude
Mo2	Monaragala	Handapanagala	Medium	264.0	6.665547	81.15166
Mo3	Monaragala	Kiribban wewa	Medium	324.0	6.375799	80.97003
Ku1	Kurunegala	Hakwatuna oya	Medium	362.2	7.772887	80.46125
A2	Anuradhapura	Mahawilachchiya	Major	1,188.6	8.466018	80.19969
A3	Anuradhapura	Mahakanadarawa	Major	1,287.1	8.387917	80.54395

Sampling design

The hydro-acoustic depth survey was conducted during the daytime from 19 March to 1 April 2024. Sonar data collection was performed using the Fish Smart Sonar Deeper CHIRP+2 (Deeper, Lithuania, EU). This device was equipped with 3 CHIRP (Compressed High-Intensity Radar Pulse) frequency modes: Narrow CHIRP at 675 kHz (cone angle: 7°), Medium CHIRP at 240 kHz (cone angle: 20°), and Wide CHIRP at 100 kHz (cone angle: 47°). Additionally, it integrated various GPS technologies within a compact, portable floating ball measuring 67 mm in diameter (Figure 6.2.2). Though the device has been designed as a castable sonar, it was adapted for boat-mounted use, allowing it to be dragged along the water surface during data collection. Traditional canoes were used to navigate along predetermined paths, covering both lacustrine and intermediate regions of each reservoir. The fish finder was connected via Wi-Fi to an Android mobile phone using the Fish Deeper application. The application categorised fish into

3 size groups: small, medium and large, but the specific length range in cm for each size group has not been mentioned in user manuals. Therefore, laboratory analyses were performed for fish size category identification by using known fish targets of different sizes in a cement pond of 45x15x3 ft. All sonar readings, along with reservoir depth measurements, were recorded directly into the mobile application and later, utilised for the analysis.

Data collection

Deeper Smart Sonar CHIRP+2 fish finder, which emits 15 pulses per second, was dragged along systematically designed transects at a constant boat speed of approximately 2.5 km/h to record fish distributions. Figure 6.2.3 shows the observed transect in each reservoir. While drifting, the fish finder continuously recorded hydro-acoustic data in down imaging mode in real time. The surveys were carried out in the daytime between 8 am and 5 pm. Of the 3 beams (7°, 20° and 47°), the 7° beam was utilised to detect



Figure 6.2.2: Fish Smart Sonar Deeper CHIRP+2

fish targets since the narrow beams give clearer acoustic images. The Deeper sonar was fully charged before deployment, and a stable Wi-Fi connection between the sonar and the mobile device was ensured throughout the survey. During the survey, at random locations, dissolved oxygen (DO) and chlorophyll-a content were measured using a multipara water quality meter (YSI ProDSS) to get an idea about the surrounding environment.

Post-processing of acoustic data

The Fish Deeper application displayed fish location using fish icons, categorising them into 3 size groups: small, medium and large.

It also indicated the swimming depth of the fish along with the overall reservoir depth. Fish count data were extracted manually along with the corresponding swimming depth by observing the sonar recording in the mobile application and web portal (<https://maps.fishdeeper.com/en-us>). Scatter plots and analysis of variance (ANOVA) were used to identify the spatial distribution of fish and its significance according to their relative size categories. QGIS and Google Earth pro were used to create spatial maps. All the analyses were done in RStudio (version RStudio 2024.12.0+46) and Microsoft Excel.

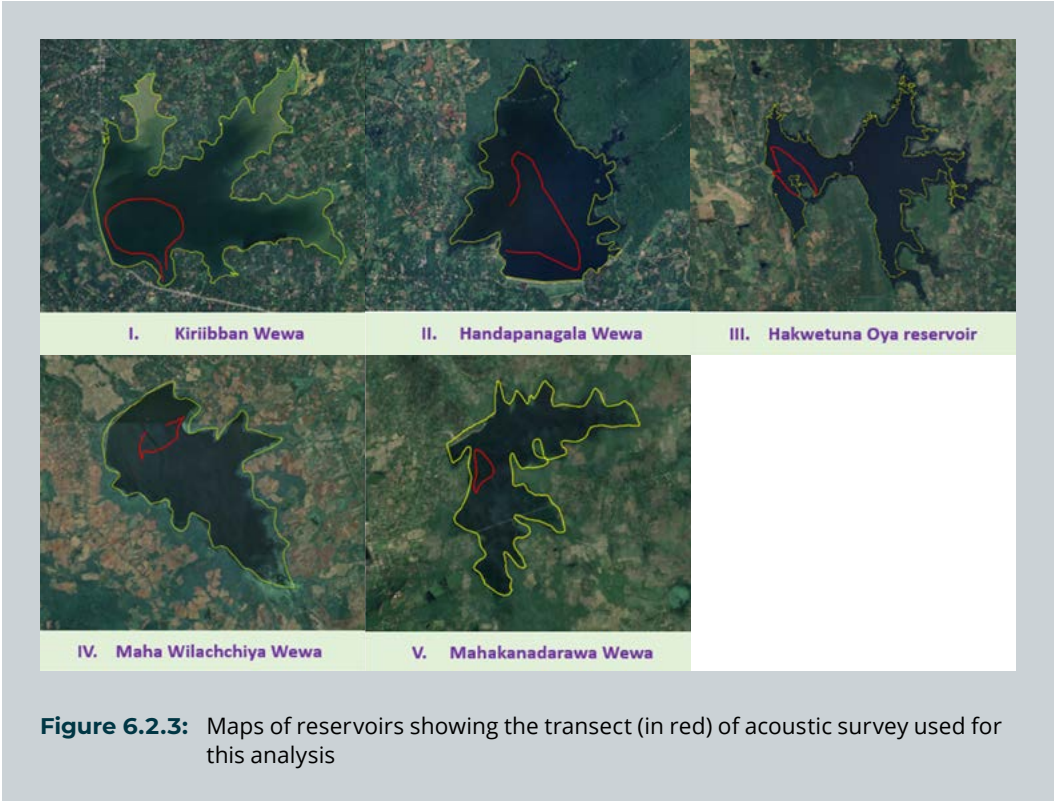


Figure 6.2.3: Maps of reservoirs showing the transect (in red) of acoustic survey used for this analysis

Results

Table 6.2.2 shows the maximum recorded depths of the selected reservoirs by the sonar device. Maha Wilachchiya and Mahakanadarawa are shallower compared to the other reservoirs, which have over 35 ft of maximum depth.

Table 6.2.2: Maximum depths recorded by the sonar device in the reservoirs

Reservoir name	Maximum depth (ft)
Kiriibban wewa	39
Handapanagala	37
Mahawilachchiya	24
Mahakanadarawa	27
Hakwatuna Oya	35

According to the boxplots shown in Figure 6.2.4, average fish swimming depth varied significantly among reservoirs ($p<0.001$). Hakwatuna Oya was recorded with the highest average fish swimming depth.

Kiriibban wewa was the second highest when the average is considered; however, fish seemed clustered at 2 depth layers in the reservoir, making a bimodal skewed distribution in the plot. Significantly, lowest average fish swimming depth was observed in Maha Wilachchiya.

When the fish target sizes as identified by the fish finder are separated, the resulted distribution is shown in Figure 6.2.5. Large fish have a significantly higher average swimming depth when compared to both the medium and small categories ($p<0.001$). Swimming depths of medium- and small-sized fish targets are not different from each other. To clarify more, swimming depths of fish targets were separated based on both target size and the reservoir, and the distributions were arranged according to the increasing order of swimming depths in Figure 6.2.6. It showed that Hakwatuna Oya had the highest average values for fish swimming depths for all 3 size categories of

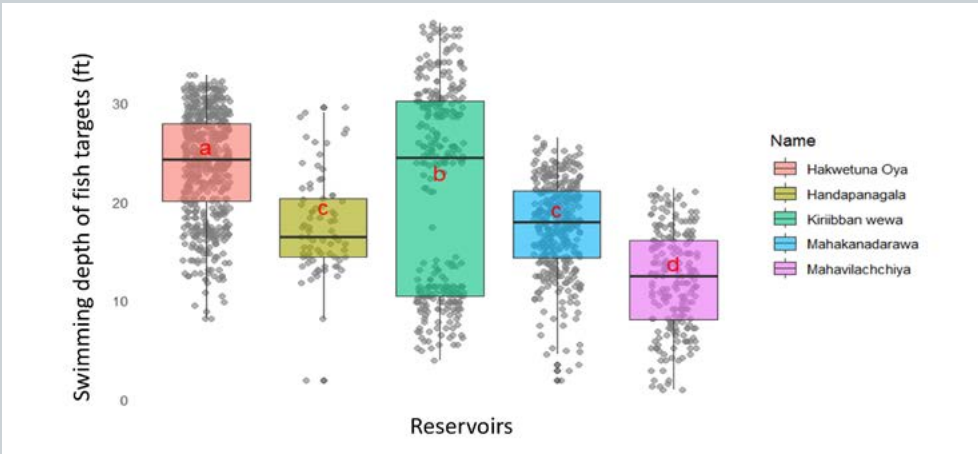


Figure 6.2.4: Box plots showing the data distribution of swimming depths of fish targets captured by the fish finder in 5 reservoirs

Note: Simple letters 'a, b, c, d' depict the significant differences between average swimming depth values for reservoirs based on Tukey's test.

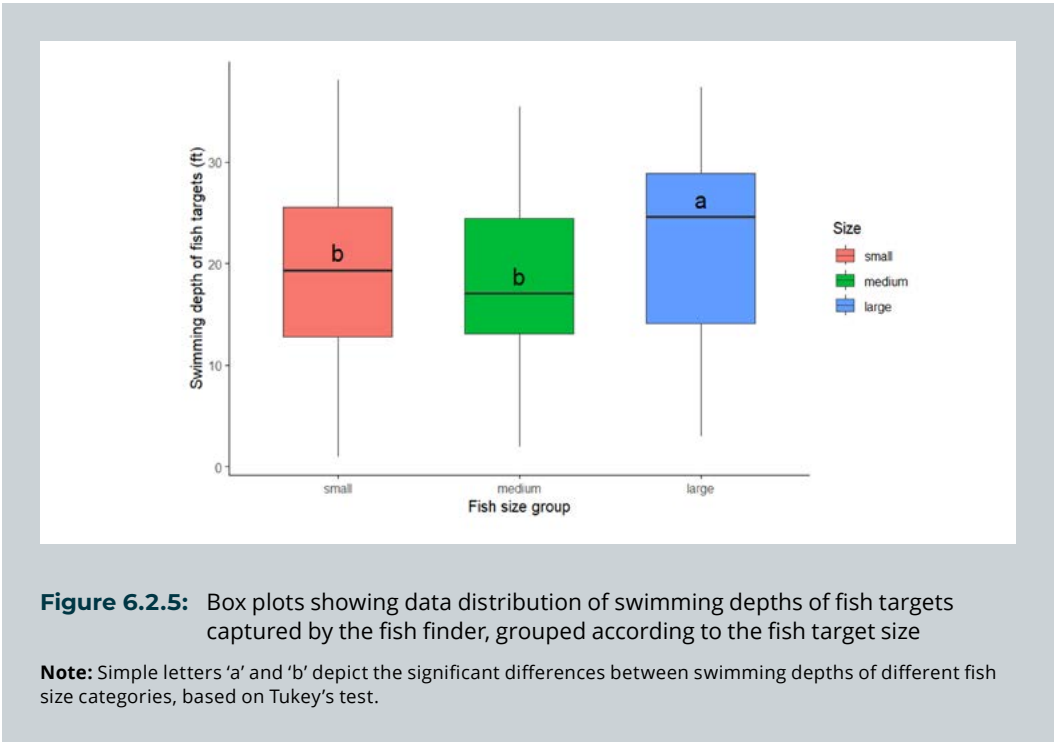
fishes. In general, large fishes tend to have higher values of swimming depth in their respective reservoirs.

When reservoirs are considered separately, Kiriibban wewa shows a strong positive correlation between swimming depth of fish targets and the reservoir depth at the target location (Figure 6.2.7). There are correlations for all 3 size groups. That means, regardless of the body size, fish tend to swim in the deeper layers of that particular location. But in other reservoirs studied, there were no such correlations, and larger fish targets tend to cluster in deeper layers.

Table 6.2.3 shows the measurements of DO and chlorophyll-a content collected at random locations in the reservoirs. Here the depth measurements were recorded from the values shown in the water quality meter. At some locations, high chlorophyll-a

values were observed even beyond the depths of 20 ft, but relatively DO values were low.

To estimate the number of fish in the reservoirs, observed hydro-acoustic transect was used. Since this is an average estimate, average fish swimming depth was considered as the observed plain. From the tan value of the half of the acoustic beam angle (i.e. 3.5°), half of the width of the transect could be calculated. By multiplying that value with 2 and the length of the transect, the area of the observed transect was estimated. When the number of fish targets observed is divided by the observed transect area, and multiplied with the reservoir area, the total number of fish targets that can be expected from the whole reservoir can be estimated (Table 6.2.4).



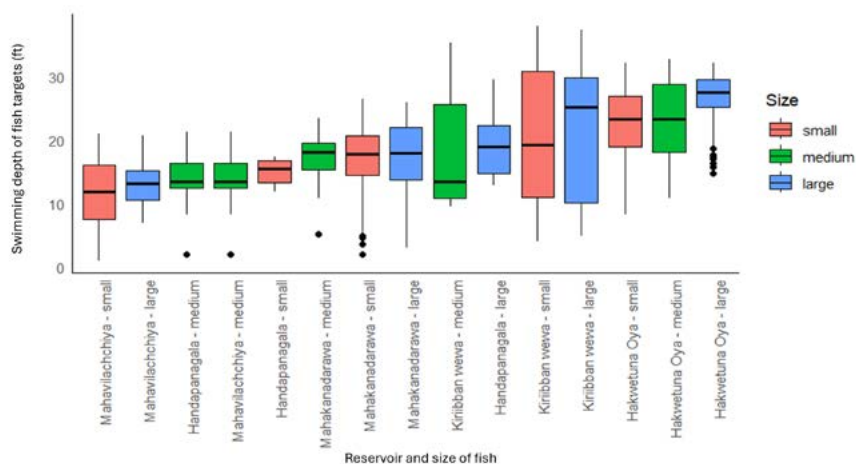


Figure 6.2.6: Box plots showing data distribution of swimming depths of fish targets captured by the fish finder, grouped according to the reservoir and the size of fish

Note: Box plots are arranged from the smallest to biggest values of average swimming depth.

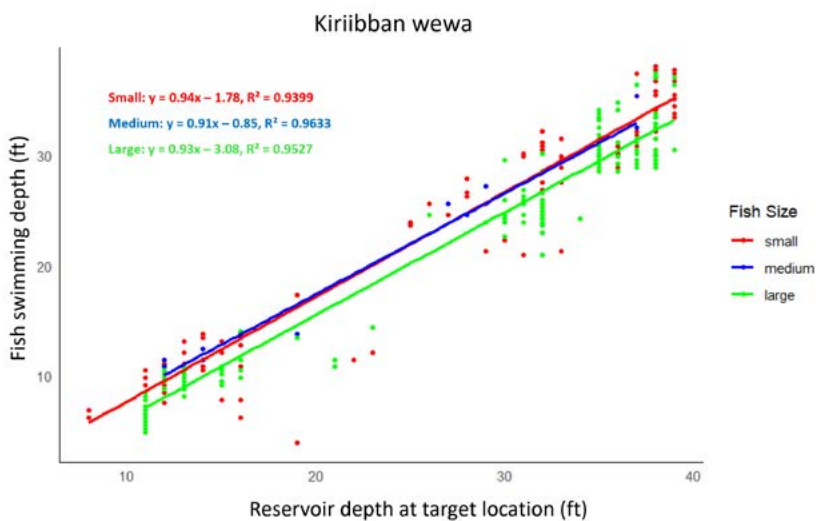


Figure 6.2.7: Correlation between fish swimming depth and corresponding reservoir depth at the target location in Kiriibban wewa

Table 6.2.3: DO and chlorophyll-a values measured at different depths at random locations in each reservoir, using a multipara water quality meter during the hydro-acoustic survey

Reservoir	Sampled location	Depth (ft)	DO (mg/L)	Chlorophyll-a (µg/L)
Kiriibban wewa	1	21.58±0.01	0.40±0.02	39.55±1.17
	2	29.9±0.05	1.48±0.17	1.64±0.18
Handapanagala	1	22.73±0.01	3.89±0.14	24.29±2.77
Hakwatuna Oya	1	13.09±0.00	4.25±0.27	3.90±0.05
	2	30.49±0.00	1.00±0.03	4.75±0.11
	3	3.44±0.00	7.99±0.00	4.23±0.11
Mahawilachchiya	1	21.25±0.01	1.95±0.02	7.63±0.24
	2	1.00±0.00	9.28±0.00	3.52±0.01
Mahakanadarawa	1	25.66±0.00	1.63±0.04	41.19±16.74

Table 6.2.4: Total number of fish in each reservoir estimated through the sampled hydro-acoustic transect

Reservoir	Average swimming depth (ASD)/ft	Average width of transect at ASD/ft	Length of transect/ ft	Average surface area covered by transect/ ha	Number of fish targets covered by transect	Estimated total number of fish in the reservoir
Hadapanagala	17.7	2.2	12,566	0.253	77	80,426
Kiriibbanwewa	21.2	2.6	8,967	0.216	308	462,258
Mahakanadarawa	17.5	2.1	6,442	0.128	360	3,625,188
Hakwatunawa	23.7	2.9	8,131	0.220	582	960,364
Mahawilachchiya	12.0	1.5	8,765	0.120	212	2,104,388

Discussion

The aim of the present study is to assess the feasibility of using a commercially available hydro-acoustic fish finder as a tool for monitoring fish populations in reservoirs. The fish community in the agrarian reservoirs utilised for inland fisheries development primarily consisted of exotic species such as GIFT tilapia (Genetically Improved Farmed Tilapia), *Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*, *Hypophthalmichthys molitrix*, *Hypophthalmichthys nobilis* and *Cyprinus carpio*. In addition, commercially important indigenous species such as

Etroplus suratensis, *Puntius sarana*, *Channa striata* could be there. Indigenous GFP (*Macrobrachium rosenbergii*) are also stocked in these reservoirs, but since they are bottom dwelling, it is hard to observe through echosounders. Even scientific echosounders are not capable of distinguishing species underwater. Yet, verification of the commonly available species in the water could be possible by operating suitable fishing gear parallel to the acoustic survey, and the results could be meaningful. In this case, we are using hydro-acoustic data obtained from a fish finder during a bathymetric survey;



therefore, we could not verify at that time using a fishing gear.

There are attempts to use commercial grade fish finders for scientific surveys (Buscombe 2017; Nishikawa et al. 2025); however, the use of Deeper Smart Sonar CHIRP+2 fish finder is not evident. In that case, our small analysis might be the first attempt to use this portable, less expensive sonar device. Even scientific echosounders have limitations in detecting near surface and near bottom targets, and scientists have to find ways to overcome those limitations (Baran et al. 2017). In shallow water bodies, limitations are aggravated due to surface and bottom effects to the vertical acoustic beam; therefore, horizontal beaming could be an alternative if there is no misidentification of the size of the fish in its side aspect (Frouzova et al. 2005).

Since these commercial-grade sonar suppliers do not reveal the underlying mechanisms of identifying the fish targets separate from other living and non-living objects in the water column, it is always challenging to use this kind of apparatus for accurate measurements. Instead, we have to depend on indirect measurements and look for correlations between those measurements and population parameters taken by other means. The software application of Deeper Smart Sonar CHIRP+2 shows 3 size classes of fish but do not specify the real size range of each size class. When attempting to determine those size classes under a controlled environment it was found that the sonar recognised a fish <10 cm of size as a 'small' fish and 10–22 cm of size as a 'medium' fish. There were no >22 cm fish in the experiment pond. Sonar did not recognise dead specimens, and practically it was difficult to find a live specimen of bigger size to decide the upper limit of 'medium' and the fish of 'large' category.

The present study found that the reservoirs observed possess common and identical fish distribution patterns probably due to similar environmental conditions in those reservoirs. Fish were not seen closer to the surface, probably due to the disturbance created by the moving canoe or avoidance of higher temperatures by the fish at the surface. Hakwatuna Oya reservoir showed the highest average fish swimming depth. It suggests that the reservoir provides preferred conditions for fish to swim deeper. Figure 6.2.4 showed fish distribution over 30 ft, although the random measurements of DO at that depth were low. Kiriibbanwewa showed 2 clusters of fish distribution in which the number of fish targets was low in between 15 to 25 ft depth range. At the same depth range, very low DO values and unusually high chlorophyll-a values were observed. Fish are missing probably due to an algal bloom at that depth range. Mahakanadarawa also has high chlorophyll-a values around 25 ft of depth, and fish targets were found shallower than that.

Larger fish targets had the deepest mean swimming depth compared to the other 2 groups. This indicated that large fish tended to swim deeper than small ones. However, it is not known how large those fish are. This preference could be due to fishing pressure as well as their physiological capabilities to overcome competition for the limited resources. Since random measurements showed low DO levels at deeper layers, it can be a species like tilapia which can tolerate such conditions (Bergstedt et al. 2021). However, further research is needed to verify the size classes of fish identified by the fish finder before coming to concrete conclusions. Counting the number of targets would instead be a better option. The examined hydro-acoustic transect provides an average estimate of the total

number of fish. To increase the accuracy of this estimate it is recommended to increase the survey length and/or increase the number of surveys throughout a longer period of time – preferably one year – to count the seasonal differences as well.

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7 Conclusions and recommendations



Fishers leaving the shore to set gillnets at Vijayakatupotha Reservoir, Sri Lanka.
Photo: Professor Asanka D Jayasinghe.

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

MDST de Croos

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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 GFP 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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8 Appendix



Giant freshwater prawn temporarily stored in a Styrofoam box with ice to deliver to the agent from export company. Photo: Professor Asanka D Jayasinghe.

Appendix 1: Workshop details

Final Project Workshop for ACIAR project 'Improved productivity, efficiency and sustainability of the culture-based fishery for finfish and giant freshwater prawn in Sri Lankan reservoirs' (FIS/2018/157).

Venue: Shangri La Hotel Colombo, Sri Lanka

Dates: 19–20 February 2025

Program

Wednesday, 19 February 2025

Time	Topic	Presenter
8:30 – 8:35	Arrival and Introductions	Dr Clive Jones Prof Upali Amarasinghe
8:35 – 8:45	Welcome address	Australian High Commission Deputy High Commissioner Lalita Kapur
8:45 – 9:00	Meeting Purpose and Housekeeping	Dr Clive Jones
9:00 – 9:30	Status of Sri Lankan Culture-Based Fisheries: An Overview	Prof Upali Amarasinghe
9:30 – 10:00	The ACIAR Project – its goals and planned outcomes	Dr Clive Jones
10:00 – 10:30	NAQDA perspective on development of Sri Lanka Culture-Based Fisheries	Mr RH Pothuwila NAQDA
10:30 – 11:00	Morning Tea Break	
	Objective 1. Biophysical research	
	Investigate stocking, monitoring and harvesting practices, including the development of biodynamic models, that optimise fish and GFP production, product quality and sustainability	
11:00 – 11:30	Development of a culture-based fishery for giant freshwater prawn in Sri Lankan reservoirs	Mr Senathira Digamadulla
11:30 – 12:00	Production trends and yield predictive models for culture-based fisheries in irrigation reservoirs of Sri Lanka	Ms Amitha Adikari
12:00 – 12:30	Giant freshwater prawn and finfish distribution in microhabitats in irrigation reservoirs of Sri Lanka	Mr Dhanuka Perera
12:30 – 1:00	Reservoir food web with an emphasis on culture-based fisheries	Ms Subodha Silva
1:00 – 2:00	Lunch	

Time	Topic	Presenter
2:00 – 2:30	Population dynamics of freshwater prawn, <i>Macrobrachium rosenbergii</i> and other constituent finfish species in the culture-based fisheries in irrigation reservoirs of Sri Lanka, and evaluation of the performance of fishing methods for freshwater prawn	Mr Amila Suraj Pilagolla
2:30 – 3:00	Influence of limnological characteristics on culture-based fisheries in irrigation reservoirs of Sri Lanka	Mr Ishan Silva
3:00 – 3:30	Pollution status in dry zone reservoirs utilised for culture-based fisheries in Sri Lanka	Ms Dilki Lakchani
3:30 – 4:00	Post-harvest product quality of giant freshwater prawn	Ms AU Kuragodage
4:00 – 4:30	Afternoon Tea Break	
4:30 – 4:50	Potential to estimate relative fish biomass in reservoirs using a commercially available hydroacoustic fish finder	Kithmini Salgado, Chamikara Rodrigo, Ishan Silva, Asanka Jayasinghe and Clive Jones
4:50 – 5:20	Analysing the agrarian reservoir environment to optimise culture-based fisheries in Sri Lanka	Prof Asanka Jayasinghe
5:20 – 5:40	Discussion of Objective 1	Prof Asanka Jayasinghe Prof Dileepa de Croos Dr Chintha Perera Prof Upali Amarasinghe
5:40 – 6:00	Group Photo	
6:30 – 8:00	Dinner at Central Restaurant	Shangri-La Hotel

Thursday, 20 February 2025

Time	Topic	Presenter
8:00 – 8:10	Arrival and Welcome	Dr Clive Jones Prof Upali Amarasinghe
Objective 2. Value Chain research		
Conduct an inclusive, complete market chain analysis from harvest to plate, to ensure post-harvest and supply practices meet market requirements and both male and female actors in the supply chain gain maximum benefits		
8:10 – 8:40	Equity dimensions of emerging economic value and value chains from culture-based fisheries in Sri Lankan reservoirs	Ms Gayani Paranamana
8:40 – 9:00	Value chain considerations of culture-based fisheries in Sri Lankan reservoirs	Dr Liz Petersen
Objective 3. Bioeconomics		
Assess the economic performance of reservoir fisheries and identify changes in management practices that can increase their economic value for local communities		

Time	Topic	Presenter
9:00 – 9:30	Maximum economic and sustainable yields in perennial reservoir fisheries of Sri Lanka: Insights into stocking practices and fishing intensity for multi-species management	Ms Amitha Adikari
9:30 – 10:00	A transdisciplinary approach to understand the CBF bioeconomy and taboos for development	Mr Senathira Digamadulla
10:00 – 10:20	Bioeconomic considerations of culture-based fisheries in Sri Lankan reservoirs	Dr Liz Petersen
10:20 – 10:30	Discussion of Objectives 2 & 3	Dr Liz Petersen Prof Kularatne Prof Dileepa de Croos Dr Kelum Wijenayake
10:30 – 11:00	Morning Tea Break	
Objective 4. Social Science / Livelihoods / Gender		
Determine opportunities and constraints to achieving socially equitable livelihood benefits from culture-based fisheries		
11:00 – 11:30	Social economy in culture-based fisheries in reservoirs of Sri Lanka and implication for sustainable; livelihoods of rural communities	Prof Mohottala G Kularatne
11:30 – 12:00	Community perception issues and expectation on efficient culture-based fisheries production in irrigation reservoirs of Sri Lanka	Prof Mohottala G Kularatne
12:00 – 12:30	Unpacking social-ecological systems for the development of culture-based fisheries in reservoirs of Sri Lanka	Mr GMAG Chandrarathne
12:30 – 1:00	Strategies for achieving socially equitable livelihood benefits from culture-based fisheries in Sri Lankan reservoirs	Mr Dinusha Ekanayake
1:00 – 2:00	Lunch	
2:00 – 2:30	Gender aspects related to culture-based fisheries in reservoirs for the rural development	Ms Chesika Kanchana
2:30 – 3:00	Addressing gender equity and wellbeing in culture-based fisheries communities	Dr Nireka Weeratunge
3:00 – 3:30	Science to practice in culture-based fisheries in Sri Lankan reservoirs: Synthesis and lessons learned	Prof Dileepa de Croos
3:30 – 3:45	Discussion of Objective 4	Prof Dileepa de Croos Dr Nireka Weeratunge Dr Liz Petersen Prof Mohottala G Kularatne Prof Ashoka Deepananda
3:45 – 4:00	Final words and close meeting	Prof Upali Amarasinghe Dr Clive Jones

