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 (km²)	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

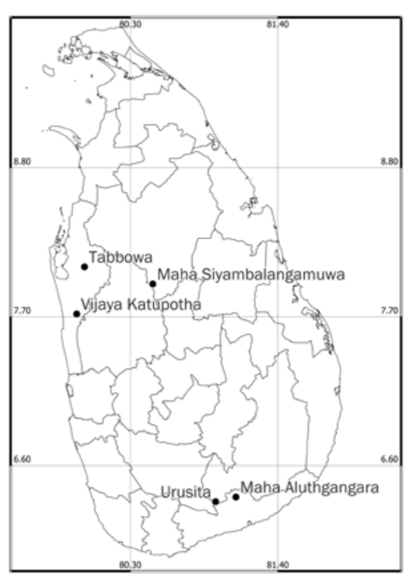

Figure 2.4.1: Location of the reservoirs

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 (H_2SO_4), 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	*Oreochromis* spp.
	Etroplus suratensis
Oxudercidae	*Awaous grammepomus*
Palaemonidae	*Macrobrachium rosenbergii*
Cyprinidae	*Catla catla*
	Labeo rohita
	Hypophthalmichthys molitrix
	Systomus sarana
	Cyprinus carpio
Channidae	*Channa striata*
Loricariidae	*Pterygoplichthys* spp.
Mastacembelidae	*Mastacembelus armatus*
Bagridae	*Mystus ankutta*
Siluridae	*Ompok bimaculatus*

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.

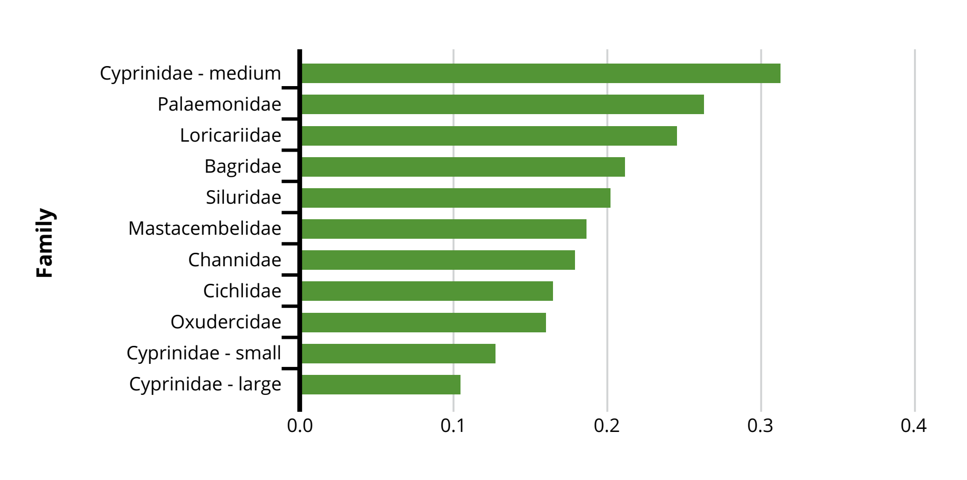

Figure 2.4.2: Multi-level indicator species analysis for families

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

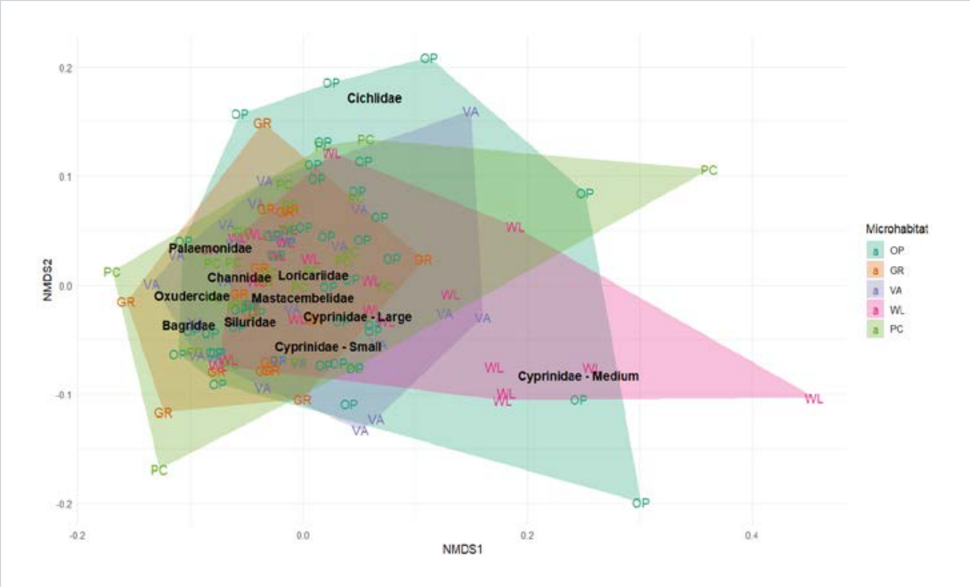

Figure 2.4.3: NMDS ordination plot (distribution of families and microhabitats based on Bray–Curtis dissimilarity)

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

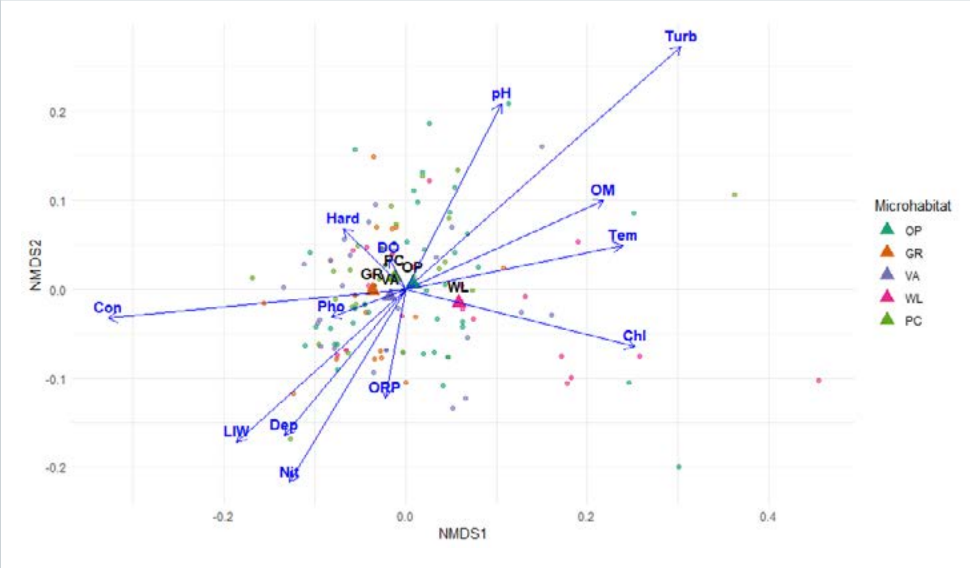

Figure 2.4.4: NMDS ordination plot based on species composition of 154 samples, with superimposed influence of environmental variables and microhabitat categories

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 = Chlorophyl, 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.

References

Choi J-Y et al. (2021) 'Microhabitat Characteristics Determine Fish Community Structure in a Small Stream (Yudeung Stream, South Korea)', doi:10.22920/PNIE.2021.2.1.53.

De Caceres M and Legendre P (2009) 'Associations between species and groups of sites: indices and statistical inference', *Ecology*.

De Silva SS (2003) 'Culture-based fisheries: An underutilised opportunity in aquaculture development', *Aquaculture,* 221: 221-243, doi:10.1016/S0044-8486(02)00657-9.

De Silva SS, Ingram B and Wilkinson S (2015) *Perspectives on culture-based fisheries developments in Asia*.

FAO (2015) *Responsible stocking and enhancement of inland waters in Asia*, FAO Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand.

Gurevitch J and Padilla DK (2004) 'Are invasive species a major cause of extinctions?', *Trends in Ecology and Evolution*, 19(9):470–474, doi:10.1016/j.tree.2004.07.005.

Heck Jr KL, Hays G and Orth RJ (2003) 'Critical evaluation of the nursery role hypothesis for seagrass meadows', *Marine Ecology Progress Series*, 253:123–136.

Jayasinghe UAD, Amarasinghe US and De Silva SS (2006) 'Culture-based fisheries in non-perennial reservoirs of Sri Lanka: influence of reservoir morphometry and stocking density on yield', *Fisheries Management and Ecology*, 157–164, doi:10.1111/j.1365-2400.2006.00488.x.

Jere A et al. (2021) 'Breeding pattern of *Oreochromis niloticus* (Linnaeus, 1758) versus native congeneric species, *Oreochromis macrochir* (Boulinger, 1912), in the upper Kabompo River, northwest of Zambia', *Ecology and Evolution*, 11(23):17,447–17,457, doi:10.1002/ece3.8377.

Johnson DH (1980) 'The Comparison of Usage and Availability Measurements for Evaluating Resource Preference', *Ecology*, 61(1):65–71, doi:10.2307/1937156.

Mchenry M et al. (2007) *The Physical and Biological Effects of Engineered Logjams (ELJs) in the Elwha River*, Washington Executive Summary Salmon Recovery Funding Board (SRFB) Interagency Committee for Outdoor Recreation (IAC) Executive Summary.

MOF (2023) *Fisheries Statistics – 2023*, Ministry of Fisheries, Colombo, Sri Lanka, accessed 2 May 2025.

Newcomb TJ, Orth DJ and Stauffer DF (2006) ‘Habitat Evaluation’, in Guy CS and Brown ML (eds), *Analysis and interpretation of freshwater fisheries data*, American Fisheries Society.

Olentino D, Lubich C and Yamamoto K (2024) ‘Fish associated with microhabitats of submerged fallen logs in a lake in the Brazilian Amazon’, *Acta Scientiarum – Biological Sciences*, 46, doi:10.4025/actascibiolsci.v46i1.70913.

Perry D, Staveley TAB and Gullström M (2018) ‘Habitat connectivity of fish in temperate shallow-water seascapes’, *Frontiers in Marine Science*, 4(JAN). Available at: https://doi.org/10.3389/fmars.2017.00440.

Pushpalatha, K.B.C. et al. (2017) ‘Impacts and importance of introduction of culture-based fisheries in three medium sized perennial reservoirs in Sri Lanka’, *Asian Fisheries Science*, 30(3):139–151, doi:10.33997/j.afs.2017.30.3.001.

Pushpalatha KBC and Chandrasoma J (2010) ‘Culture-based fisheries in minor perennial reservoirs in Sri Lanka: Variability in production, stocked species and yield implications: Technical note’, *Journal of Applied Ichthyology*, 26(1):99–104, doi:10.1111/j.1439-0426.2009.01361.x.

Rajeevan R, Edirisinghe U and Athauda A (2021) ‘Role of giant freshwater prawn (*Macrobrachium rosenbergii*) in livelihoods of the rural fishers of Northern Province of Sri Lanka’, *International Journal of Fisheries and Aquatic Studies*, 9(2):44–51, doi:10.22271/fish.2021.v9.i2a.2441.

Reyjol Y et al. (2001) ‘Modelling of microhabitat used by fish in natural and regulated flows in the river Garonne (France)’, *Ecological Modelling*.

Rodgers EM and Isaza DFG (2024) ‘Multiple stressors- physiological responses to multivariate environments’, *Second Edition*, doi:10.1016/B978-0-323-90801-6.00140-3.

Vlach P, Dusek J and Svatora M (2005) ‘Fish assemblage structure, habitat and microhabitat preference of five fish species in a small stream’, *Folia Zoologica Praha*, 54:421–431.

Welcomme RL and Bartley DM (1998) ‘Current approaches to the enhancement of fisheries’, *Fisheries Management ecology* [Preprint], doi:10.1046/j.1365-2400.1998.550351.x.

Wijenayake WMHK, Jayasinghe UAD, Amarasinghe US, Athula JA, Pushpalatha KBC and De Silva SS (2005) 'Culture-based fisheries in non-perennial reservoirs in Sri Lanka: production and relative performance of stocked species', *Fisheries Management and Ecology*, 12:249–258, doi:10.1111/j.1365-2400.2005.00447.x.

Wijenayake WMHK, Najim MMM and Amarasinghe US (2021) ‘Constraints in culture-based fisheries of Sri Lanka and strategies for future development’, *Sri Lanka Journal of Aquatic Sciences*, 26(2):81, doi:10.4038/sljas.v26i2.7589.

Zar Jerrold (1996) *Biostatistical analysis*, 3rd Edition, Prentice Hall.