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Fish diversity and assemblage structure along the river-estuary continuum in the River Cauvery, India

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*A comprehensive study on the fish assemblages of the River Cauvery was conducted during 2017–2020 by structured fish sampling surveys, encompassing various sampling sites situated along the upper, middle, lower, and estuarine stretches. The present study recorded a total of 146 fish species belonging to 52 families from the River Cauvery. The highest recorded fish diversity was at Hogenakkal (76 species) as it is situated in the transition zone between Deccan Plateau and the plains of Tamil Nadu. Lowest diversity was recorded at Bhagamandala (23 species), as this site represented a narrow hillstream habitat. As per SIMPER analysis, the silver razor-belly minnow (*Salmostoma acinaces*) was the most representative species in Upper Cauvery, with percentage similarity contribution (% SC) of 36.55%. The Middle Cauvery situated in the plateau zone was mainly represented by* Labeo calbasu *(14.01% SC), the exotic Nile tilapia (*Oreochromis niloticus*) with 8.45%, and the bagrid catfish* Mystus cavasius *(5.1%). The exotic species contributed to maximum fish catch and gradually replaced the native fish fauna in Lower Cauvery. The fish fauna of Cauvery Estuary is distinct from other zones with a characteristic fish assemblage represented by the glassy perchlet,* Ambassis miops *(11.97% SC),* Crenimugil buchanani *(11.14 %), and* Mugil cephalus *(6.23 %). Among the fish species recorded during the present study, 29 species were endemic to Western Ghats, of which 10 species were categorized as threatened by the IUCN, including 2 critically endangered (*Barbodes bovanicus*, and* Hemibagrus punctatus*), 5 endangered (*Dawkinsia arulius*,* Hypselobarbus curmuca*,* H. mussullah*,* H. micropogon*, and* Nemacheilus pulchellus*) and 3 vulnerable species (*Hypselobarbus kolus*,* Hyporhamphus xanthopterus*, and* Wallago attu*). A holistic study on the fish communities of Cauvery along the spatio-temporal scale is imperative to ensure sustainable management for conservation of endemic fish fauna.*

Keywords: Cauvery, Western Ghats, endemic fishes, fish assemblage, Cauvery estuary

Introduction

Riverine ecosystems epitomize vital freshwater fish habitats owing to the disproportionately large number of the world's fish species they harbour (Nelson et al., 2016), though they comprise only a small proportion of the Earth's surface water. The incredible fish diversity of the world's rivers can be ascertained by the fact that 43% of the total extant fish species are predominantly freshwater fish, and two-thirds of all fish species in the largest families are freshwater fishes (Nelson et al., 2016),

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with some rivers regarded as global biodiversity hotspots (Myers et al., 2000).The Indian rivers are facing serious threats to their biodiversity and ecological integrity, mainly due to anthropogenic stressors such as construction of dams, abstraction of water for irrigation and power generation, destructive fishing practices, and pollution due to the discharge of sewage and industrial wastes (Pathak and Tyagi, 2010). Many freshwater fish species have become endangered due to habitat degradation of Indian rivers resulting from the combined effects of these anthropogenic stressors, along with the compounding effects of global climate change.

Among major river basins of India, the Cauvery holds a unique status in harbouring a high number of endemic fish fauna owing to the remarkable habitat heterogeneity throughout its course, since a major part of the basin lies within the Western Ghats biodiversity hotspot (Dahanukar et al., 2004; Chidambaram et al., 2018 and Sreenivasan et al., 2021). Out of the 118 fish species endemic to Western Ghats (Dahanukar et al., 2004), 62 species were recorded from the Cauvery basin alone. Despite its ecological significance, there have previously been no comprehensive studies on the fisheries of Cauvery. Unlike the other major estuaries of India (Hooghly-Matla, Godavari, Mahanadi, Narmada, and Krishna), the studies on the fish assemblages of the Cauvery estuary is very scant. The present work describes the fish diversity and assemblage structure of the River Cauvery along the river-estuary continuum.

Methods

Study area

The Cauvery is a major river of peninsular India and its basin lies between the coordinates of 75°27’ -79°54’E longitude and 10°09’-13°30’N latitude, with a total drainage area of 81,155 km^2 (Chidambaram et al., 2018) distributed across the States of Karnataka (34,273 km^2), Kerala (2866 km^2), Tamil Nadu (43,856 km^2), and the Union Territory of Puducherry (160 km^2). The river originates from a perennial spring at Talakaveri (altitude of 1341 m asl) situated along the Brahmagiri Range of the Western Ghats in the Kodagu District of Karnataka, and traverses a total length of 800 km through the States of Karnataka and Tamil Nadu before its confluence with the Bay of Bengal at Poompuhar in the Mayiladuthurai District of Tamil Nadu.

From its origin, the river flows through a deep gorge of dense evergreen forest for about 19 km as a narrow hill stream up to Bhagamandala (Jayaram et al., 1982), where its first tributary, the Kannige, joins it. Throughout its course, the river receives 21 principal tributaries, each with a catchment area of above 250 km^2. At Kudige, its first principal tributary, the Harangi, joins the Cauvery. The Krishnarajasagar (KRS) Dam (Figure 1) is the first man-made barrier along the main course of the Cauvery and is built at the confluence of the river with its two other principal tributaries, *viz*., the Hemavati and the Lakshmanatirtha. The first tributary that joins the river in its course downstream of KRS Dam is the Kabini, which merges with Cauvery at Tirumakudalu Narasipura. A weir is constructed upstream of the Shivanasamudram Falls, which diverts 810 MLD of water to Bengaluru City. The river bifurcates at Shivanasamudram and flows downstream in a series of falls and rapids. The western branch drops off from a height of 91 m (Central Water Commission [CWC], 2019) through the Gaganachukki Falls, the second highest waterfall in India, and the hydropower station downstream of these falls is the oldest major hydropower station in Asia (commissioned in 1902). The eastern branch of the river drops down from a height of 70 m through the Bharachukki Falls. The two branches join downstream of the falls and the river traverses through the Cauvery Wildlife Sanctuary, where the Shimsha and Arkavathi Rivers join it. The river then flows through a gorge called Mekedatu (Goats’ leap), continues its journey as the boundary between the States of Karnataka and Tamil Nadu, and reaches the Hogenakkal Falls, where the river drops through a height of about 40 m (Kale et al., 2014).

The river takes a southerly course downstream of Hogenakkal Falls and enters the Salem District of Tamil Nadu, where, the Mettur Dam (Figure 1) was constructed across the river in 1934 with the purpose of hydropower generation and improving irrigation. About 45 km downstream of Mettur Dam, another principal tributary, the Bhavani, joins

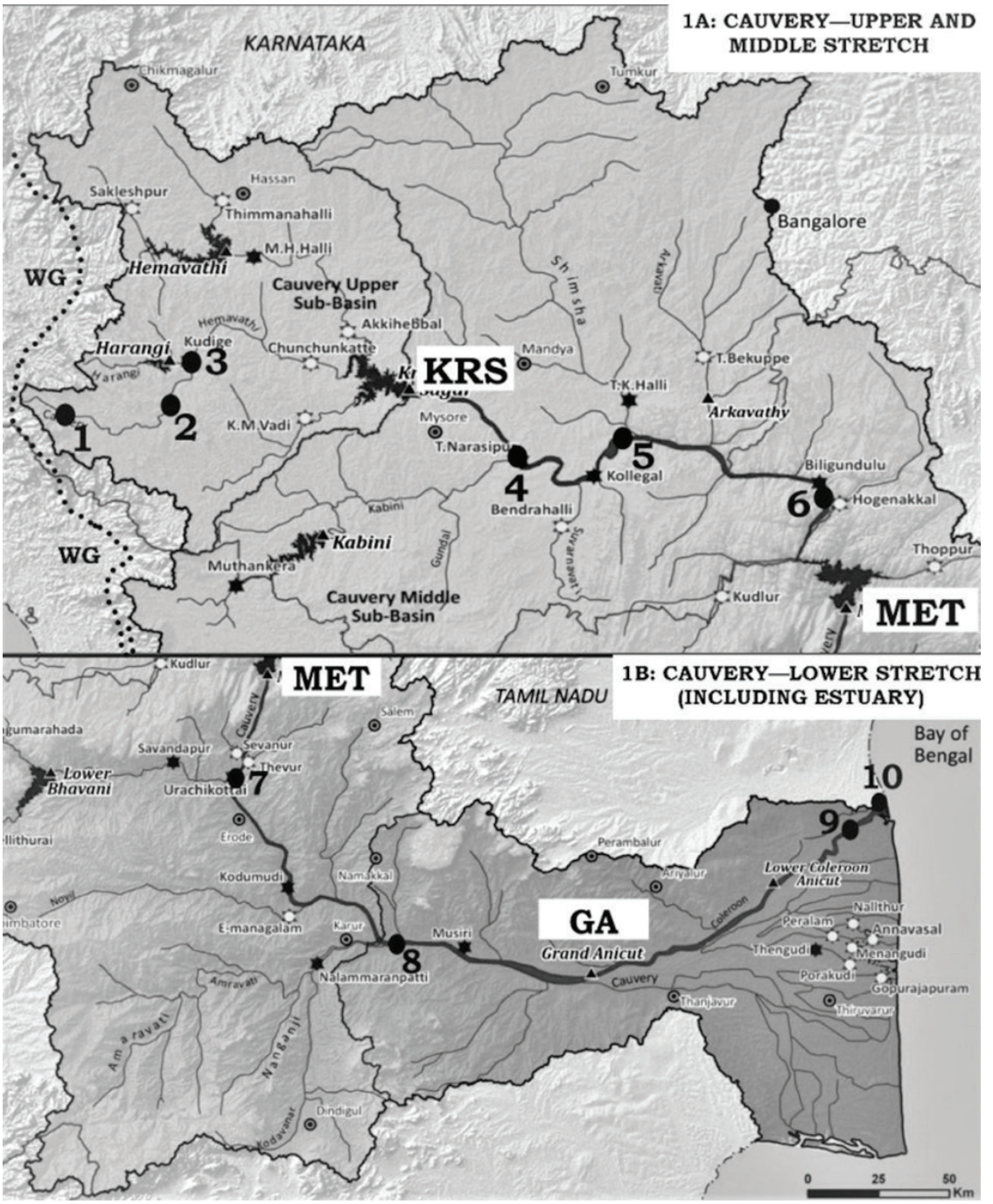

Figure 1. Map of Cauvery basin depicting the sampling sites. (*Source*: Modified from India WRIS, 2014; KRS – Krishnarajasagar Dam; MET – Mettur Dam; GA – Grand Anicut; WG – Western Ghats)

Cauvery at Bhavani town in the Erode District of Tamil Nadu. The river channel widens in the Tamil Nadu plains with a sandy bed (CWC, 2019), and is broadest (about 1.5 km) at Mayannur Barrage (constructed across the river in 2014). At the Upper Anicut in Tiruchirapally District, the river splits into two branches, *viz*., the Coleroon (Kollidam) which is the Northern branch and the main flood carrier, and the Southern branch which retains the name Cauvery. The Cauvery branch divides into Cauvery

and Vennar below the Grand Anicut (Jayaram et al., 1982), which is one of the oldest functional dams in the world. The two rivers (Cauvery and Vennar) further divide into 36 distributaries and several sub-channels, forming a vast network of irrigation canals in the Nagapattinam and Tiruvarur districts. The main Cauvery River is reduced into a small channel before its confluence with the Bay of Bengal at Poompuhar. The Northern branch of Cauvery (Coleroon) continues to flow in a Northeasterly direction and joins the Bay of Bengal at Pazhaiyar in the Nagapattinam District of Tamil Nadu.

Though the Cauvery basin experiences tropical climate with reversal of winds during South-West (SW) and North-East (NE) monsoons, there is high variability in the rainfall pattern throughout the basin. Heavy rainfall occurs in the Western part of the basin in Karnataka, which gradually decreases along the middle stretch of the Cauvery in the plateau region and rolling uplands due to orographic effect as the area forms a part of the rain shadow region of the Western Ghats. However, the rainfall intensity increases towards the delta, as this region receives rainfall during NE monsoon. The river stretch in Karnataka receives an average annual rainfall of 600–800 mm, with maximum rainfall recorded at the headwaters of the Cauvery in the Kodagu District. The basin in Tamil Nadu receives maximum precipitation during the NE monsoon (October–December), with average annual rainfall varying from 500 to 1000 mm (India WRIS, 2014); whereas, the rainfall is more intensive along the Cauvery Delta Zone (CDZ) with annual averages ranging from 1000 to 1140 mm. The annual average rainfall for the whole Cauvery basin has been estimated to be 1250 mm, of which 60.6% is received during SW monsoon (June–September) and 24.2 % during the NE monsoon period (RMSI, 2015).

Sampling methodology

Characterization of a river stretch into distinct hydroecological zones is the most important pre-requisite for conducting comprehensive studies on riverine fish communities. The earliest work in this area dates back to the categorization of European freshwater streams by Huet (1959) for comparative study of their fish fauna. Earlier studies (Jayaram et al., 1982; Singh et al., 2003; Jain et al., 2007; Pathak and Tyagi, 2010; Kale et al., 2014 and India Water Resource Information System [India, WRIS], 2014) adopted various criteria for delineating the Cauvery River into different hydroecological zones based on characteristics such as geomorphology, nature of river bed/bottom, gradient and flow velocity. In the present study, we followed the India WRIS (2014) with sufficient modifications for incorporating the estuarine stretch of the Cauvery. The sampling stations were categorized under distinct zones, *viz*., the Upper Cauvery (origin to KRS Dam), the Middle Cauvery (downstream of KRS to Hogenakkal Falls) ,and the Lower Cauvery (downstream of Hogenakkal Falls to confluence with Bay of Bengal). The sites subjected to tidal action with influence of salinity were categorized into a separate hydroecological zone, the Cauvery Estuary. Since the Coleroon (Kollidam) branch of Cauvery is the main flood carrier that receives riverine freshwater influx from the Cauvery, the estuarine part of Coleroon is considered as the Cauvery Estuary.

The sampling surveys were carried out from July 2017 to January 2020 in three distinct phases representing different seasons, *viz*., the pre-monsoon (March–May), the monsoon (July–October), and the post-monsoon (November–February). The entire river stretch was divided into 10 sampling sites, *viz*., Bhagamandala (S1), Valnoor (S2), Kudige (S3), T. Narasipura (S4), Shivanasamudram (S5), Hogenakkal (S6), Bhavani confluence (S7), Mayannur (S8), Kollidam (S9) and Pazhaiyar (S10). These sites represented different hydroecological zones of the Cauvery such as the Upper Cauvery (S1, S2 and S3), the Middle Cauvery (S4, S5 and S6), the Lower Cauvery (S7 and S8), and the Cauvery Estuary (S9 and S10).

In describing the abundance pattern and seasonality of fish communities, we adhered to the catches of multi-meshed gill nets (mesh sizes include 18, 30, 45, 60, 90, 110, 120 and 150 mm) operated by hired local fishers. The nets were set in the evening hours and hauled in the next morning. In addition, the fish catches of different gears (drag nets, traps, hook and line, trammel nets, and cast nets) operational during the sampling period were observed for recording the overall fish diversity. In the case of sampling sites situated in the protected areas where fishing is prohibited

(such as Bhagamandala and Valnoor), sampling was carried out with cast nets with prior permission from the local administration. The fish species in these areas that are categorized as threatened by the IUCN (2020) were released back into the river after counting and length-weight measurements.

The fishes caught were photographed, counted, and weighed. The majority of the species were identified on the field itself by following standard taxonomic literature (Jayaram et al., 1982; Jayaram, 1999). In case of unidentified fish samples, further analysis was done at CIFRI Biodiversity Laboratory after preserving in 10% formalin. For family level classification, we followed Nelson (2006), whereas the fish species names were in accordance with the Eschmeyer Catalog of Fishes (Fricke et al., 2020).

Data analysis

The fish abundance (numbers) data collected at various sampling sites were log transformed and converted into a similarity matrix by using the Bray-Curtis similarity coefficient, followed by hierarchical clustering to group the sampling sites based on the fish assemblages. For comparison of fish community structure between the sampling zones, we adhered to the c-dominance plot, where cumulative relative abundance/dominance (y-axis) of fish species from a sampling zone is the increasing species rank on the x- axis. To determine whether the fish community structure exhibited any signs of ecological stress, the c-dominance curves for all zones were compared. The similarity percentage (SIMPER) analysis was used to determine the key species responsible for sample groupings and for discrimination between the various sampling zones. All these analyses were performed using the PRIMER v6 (Plymouth Routines in Multivariate Ecological Research) statistical package (Clarke and Warwick, 2001).

Results and discussion

During the present study, a total of 146 fish species (Supplementary Table A) belonging to 52 families were recorded from the River Cauvery. The highest recorded fish diversity (Figure 2) was at Hogenakkal (76 species) owing to the high habitat heterogeneity (falls, cascades, runs, riffles and pools), as it is situated in the transition zone between Deccan Plateau and the plains of Tamil Nadu. Lowest diversity has been observed at Bhagamandala (23 species), as this site represented a narrow hillstream with low habitat heterogeneity. The findings were in accord with Jayaram et al. (1982), which emphasized that the upper reaches of the Cauvery have impoverished fish fauna due to the combined influence of factors such as reduced water temperature, presence of waterfalls that impede migration, sudden reduction in water level during the dry season, and streambed scouring. In addition to the habitat heterogeneity, the high fish diversity at Hogenakkal could also be attributed to the presence of fish fauna that generally inhabit the plains, such as *Labeo bata*, *L. boggut*, *Cirrhinus reba,* and *Puntius chola*. During monsoon, the water spread area of Mettur extends to the Hogenakkal Falls and has enabled many fish species inhabiting the plains to colonise the plateau region upstream of Hogenakkal (Jayaram et al., 1982).

Among the different hydroecological zones, the fish diversity was highest at Middle Cauvery (78 species), followed by Cauvery Estuary (65 species), Lower Cauvery (57 species), and Upper Cauvery (51 species). A unique pattern of fish diversity distribution has been observed along the river-estuary continuum (Figure 2), in which, the diversity steadily increased from upper to middle stretches and reached its maximum at station S6 (Hogenakkal) in the middle stretch (Figure 2). The diversity drastically reduced in stations at Lower Cauvery (S7 and S8) situated downstream of Mettur Dam, since the riverine habitat and fisheries in this region are completely dependent on the regulated discharge from Mettur Dam and a major part of this zone dries up during pre-monsoon months. The stagnant water conditions in the remaining areas resulted in the heavy infestation of aquatic weeds, thereby favouring the establishment of exotic fish species that are highly tolerant to these extreme conditions. The diversity increases at the Cauvery Estuary owing to the tidal influx of stenohaline marine species that utilize the moderately dense mangrove habitats along the estuary as feeding and nursery grounds. The riverine influx of freshwater species during monsoonal floods also adds to the fish diversity if the estuary.

Among the fish species recorded during the present study, 29 species were endemic to Western Ghats, of which10 species were categorized

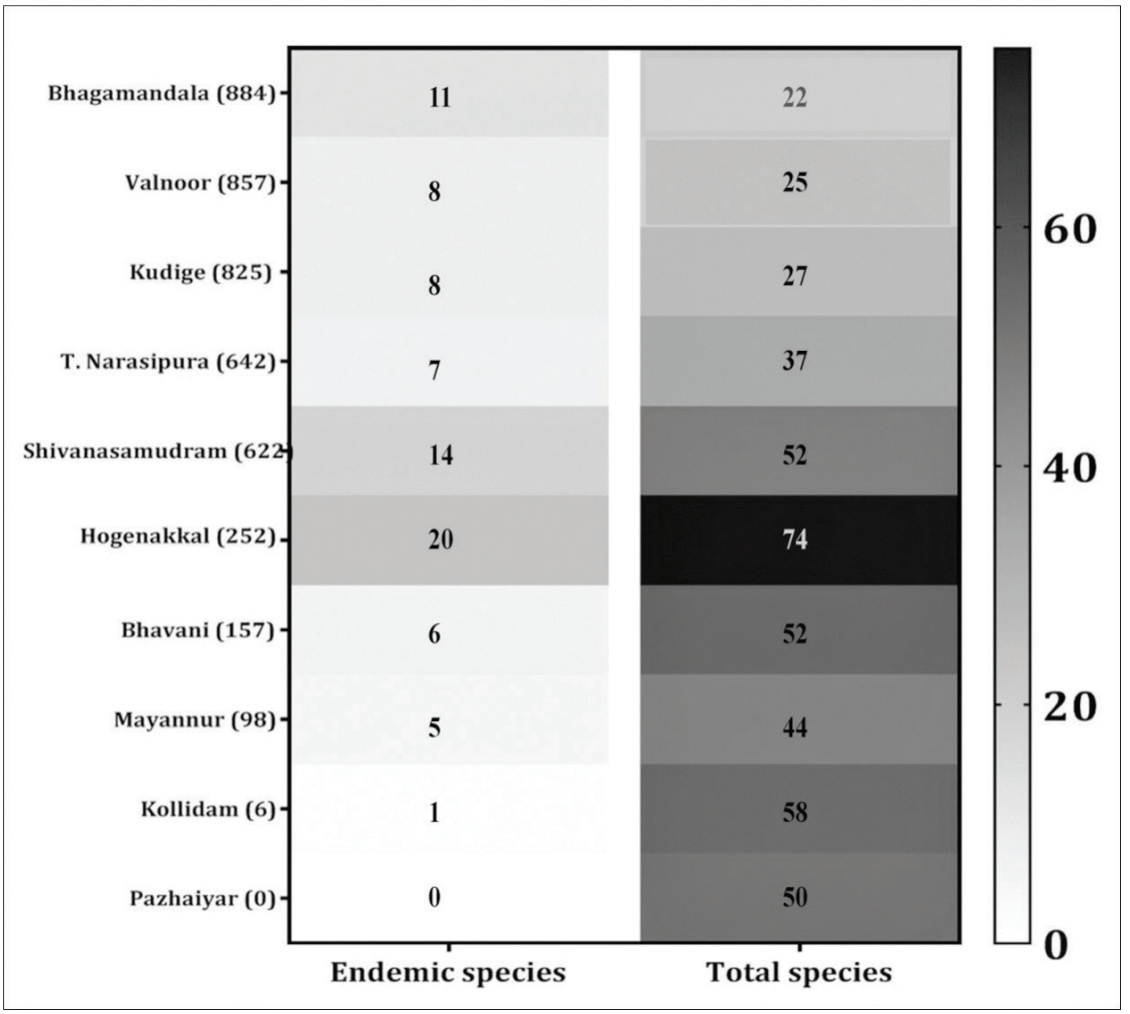

Figure 2. Number of endemic species and total species recorded at different sampling stations (numbers in parenthesis represent the altitude in meters above MSL).

as threatened by the International Union for Conservation of Nature (IUCN, 2020). This includes 2 critically endangered (*Barbodes bovanicus* and *Hemibagrus punctatus*), 5 endangered (*Dawkinsia arulius*, *Hypselobarbus curmuca*, *H. mussullah*, *H. micropogon,* and *Nemacheilus pulchellus*) and 3 vulnerable species (*Hypselobarbus kolus*, *Hyporhamphus xanthopterus,* and *Wallago attu*). The highest number of endemic species were recorded at Hogenakkal (20 species), followed by Shivanasamudram (14 species), and Bhagamandala (11 species). Thus, the upper stretch of the Cauvery at Bhagamandala is a critical fish habitat owing to the high degree of endemism (47.8%) compared to the other stations. The lowest endemic fish diversity was recorded at station S9 (one species), whereas no endemic species were recorded at S10. With regard to the number of endemic species (Figure 2), the stretch of Middle Cauvery from Shivanasamudram to Hogenakkal (altitude range from 622–252 m above MSL) harbours the highest number of endemic species (20 species) due to high habitat heterogeneity. Moreover, the fisheries along the middle stretch of the Cauvery recently gained worldwide attention from scientific communities owing to the abundance of mahseer populations (Sreenivasan et al., 2021), especially the critically endangered hump-backed mahseer (*Tor remadevii*) which inhabit the deep pools and rapids along the region. A recent study on fish faunal diversity of a 37 km stretch of River Cauvery between Shivanasamudram Falls to Mekedatu Gorge inside

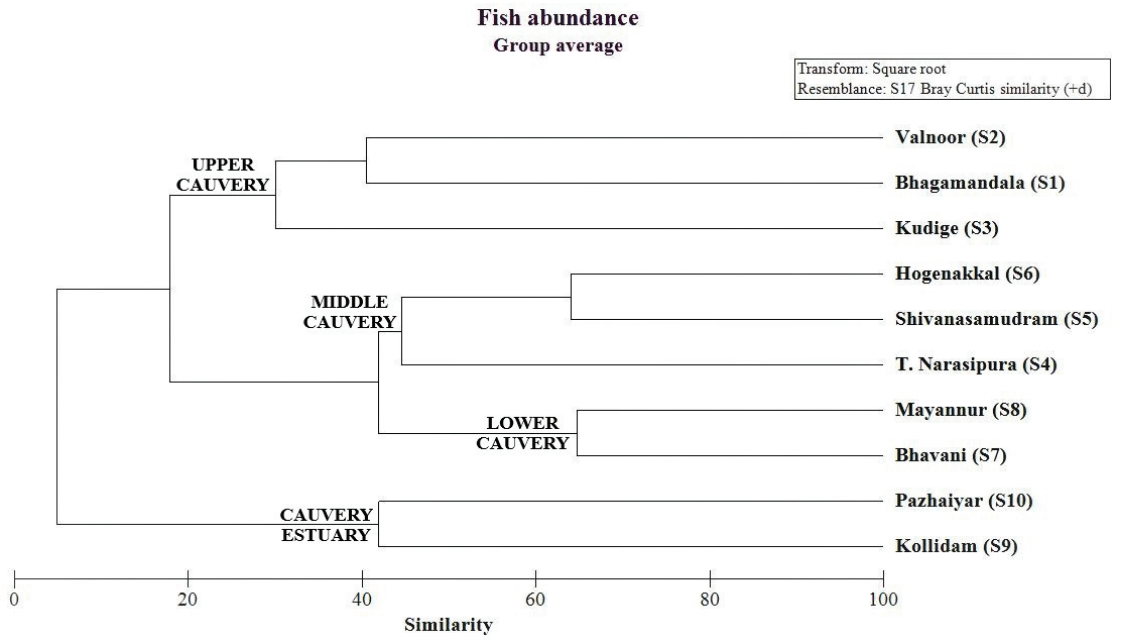

Figure 3. Clustering of sampling sites based on similarities in fish assemblage structure.

the Cauvery Wildlife Sanctuary (Sreenivasan et al., 2021) reported 58 species and observed abundant populations of the hump-backed mahseer (*T. remadevii*) and the endangered schilbeid catfish, *Silonia childreni*. Our survey could not record these species, since their populations are restricted to specific areas such as the Mekedatu Gorge that was not surveyed in the present study.

Table 1. Discriminating species of each hydroecological zone as per SIMPER analysis.

Fish species	% similarity contribution			
	UC	MC	LC	CE
Salmostoma acinaces	36.55	3.6		
Pethia conchonius	17.22	4.07		
Garra mcclellandi	8.28		3.27	
G. stenorhynchus	7.42			
Tor khudree	6.69			
Dawkinsia arulius	4.34			
Systomus sarana	3.7	4.77	3.32	
Barbodes carnaticus	3.46			
Labeo calbasu		14.01		
Oreochromis niloticus		8.45	21.23	
O. mossambicus			3.83	
Mystus cavasius		5.1	10.64	
Labeo dyocheilus		4.38		
Bangana dero		3.46		
Hyporhamphus xanthopterus			6.19	
Cirrhinus reba			6.14	
Etroplus suratensis			5.87	
Puntius amphibius			3.77	
Mastacembelus armatus		3.33	3.27	
Ambassis miops				11.97
Crenimugil buchanani				11.14
Mugil cephalus				6.23
Photopectoralis bindus				6.04
Gerres erythrourus				5.91
Elops machnata				3.74

(UC – Upper Cauvery, MC – Middle Cauvery, LC – Lower Cauvery, and CE – Cauvery Estuary)

The hierarchical clustering of sampling sites (Figure 3) clearly manifested the role of physical

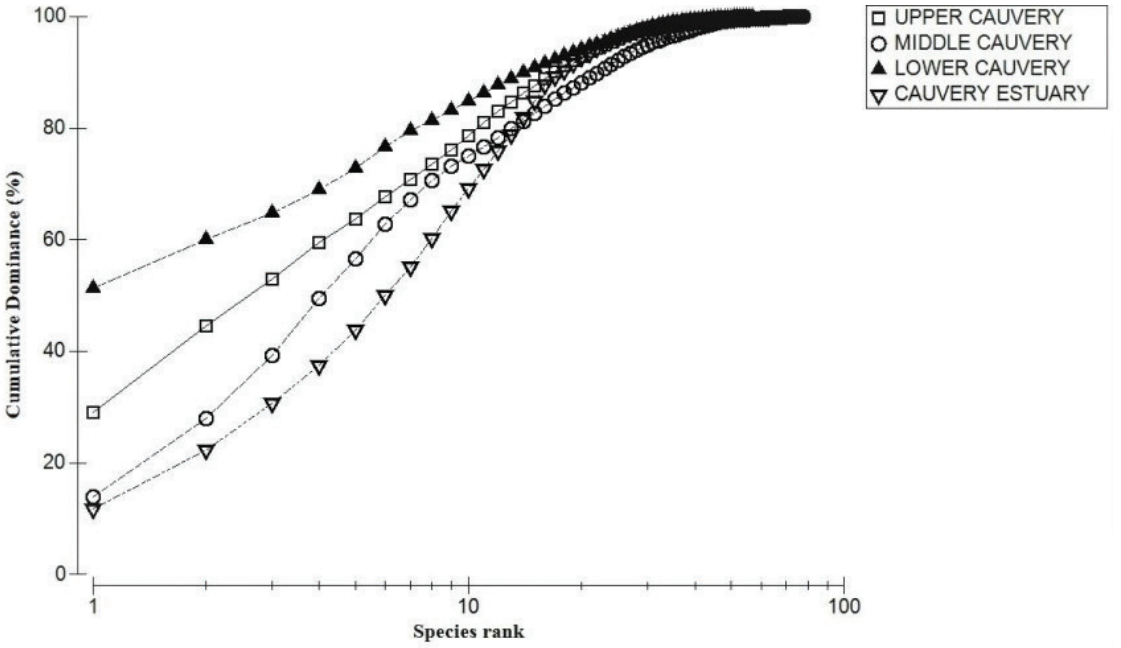

Figure 4. c-dominance plot of fish abundance across different hydroecological zones of River Cauvery (c-dominance curve of Lower Cauvery is J-shaped, indicating the stressed condition of fish assemblage).

habitat features in structuring the fish assemblages. Since the fish assemblage of the estuarine zone is very distinct from other zones due to bidirectional flow and influence of salinity that favours the ingress of stenohaline marine fish species, the sites S9 and S10 formed a separate cluster from the freshwater zones. The fish assemblage along the Upper Cauvery was distinct from the Middle and Lower Cauvery zones and formed a separate cluster. The most discriminating or representative fish species of each ecological zone was determined by the SIMPER analysis (Table 1). The most representative species of Upper Cauvery were the silver razor-belly minnow (*Salmostoma acinaces*) with % similarity contribution (% SC) of 36.55%, followed by *Pethia conchonius* (17.22%), and *Garra mcclellandi* (8.28%). The Middle Cauvery situated in the plateau zone was mainly represented by *Labeo calbasu* (14.01% SC), the exotic Nile tilapia (*Oreochromis niloticus*) with 8.45 %, and the bagrid catfish *Mystus cavasius* (5.1%). In the Lower Cauvery, exotic species contributed to the maximum fish catch and appear to be gradually replacing the native fish fauna. This is reflected in the c-dominance plot (Figure 4), where the c-dominance curve of Lower Cauvery is J-shaped indicating the stressed condition of fish assemblage due to dominance of exotics. The discriminating species at Lower Cauvery include *O. niloticus* (21.23%), *M. cavasius* (10.64 %), *Hyporhamphus xanthopterus* (6.19%), and *Cirrhinus reba* (6.14%). The fish fauna of Cauvery Estuary is distinct from other zones with a characteristic fish assemblage represented by the glassy perchlet, *Ambassis miops* (11.97% SC), *Crenimugil buchanani* (11.14%), *Mugil cephalus* (6.23%) and *Photopectoralis bindus* (6.04%).

Conclusions

Despite its high conservation significance in harbouring the largest number of endemic fish fauna, the River Cauvery is facing serious anthropogenic pressures. With three major reservoirs, and a number of weirs/anicuts built across the main river channel and its tributaries, Cauvery is the most exploited river of India with 95% abstraction of water (Chidambaram et al., 2018). All these anthropogenic disturbances along with the invasion of exotics are detrimental to the endemic fish fauna of the Cauvery. Moreover, the present study has significant implications for protecting the largest free-flowing stretch of the Cauvery (middle stretch) which is threatened by

various developmental projects, *viz*., the Mekedatu project (Karnataka), the Rasimanal dam (Tamil Nadu), and the Hogenakkal Integrated Drinking Water Project (Tamil Nadu). Thus, holistic study on the fish communities of the Cauvery along the spatio-temporal scale is imperative to ensure sustainable management for conservation of endemic fish fauna.

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Supplementary material

Supplementary materials are available for this article. Please visit the publisher's online edition of *Aquatic Ecosystem Health and Management* to view the supplementary files.

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