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RESEARCH PAPER

Finfish harvest trends in the Chalakudy River within the Western Ghats biodiversity hotspot in the Southwest of India

Chelapurath Radhakrishnan Renjithkumar [1*], Kuttanellor Roshni[2]

[1]*Research Department of Fisheries and Aquaculture, St. Albert's College (Autonomous), Ernakulam, Kochi-682018, Kerala*
[2]*School of Environmental Studies, Cochin University of Science and Technology (CUSAT), Kochi-682022, India*

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Corresponding Author

Chelapurath Radhakrishnan Renjithkumar

E-mail: renjith.kumar347@gmail.com
Tel: +91 999 53 96 149

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CPUE

Abstract

Accurate quantification of fish harvest is a crucial prerequisite for effective fisheries management. This study aimed to estimate the finfish harvest in the Chalakudy River, a vital riverine aquatic ecosystem located in the Western Ghat biodiversity hotspot on Southwest coast of India. The research was conducted from June 2019 to May 2020, covering major fish landing centres, to provide essential data for sustainable fisheries management and conservation of this critical ecosystem. The total fishery yield from the Chalakudy River was estimated at 68.53 tonnes, comprising 68 finfish species across 37 families. Seasonal variations in fish landings were observed, with the post-monsoon season accounting for the highest yield (38.34%) and the pre-monsoon season the lowest (28.87%). The family Cyprinidae dominated the catch, with 19 species, followed by Cichlidae (5 species), Channidae, and Bagridae (three species each). Cyprinids (48.42%), cichlids (14.56%), catfishes (12.66%), and murrels (8.79%) constituted the major fish groups that contributed to the fishery. The landings were represented by one critically endangered (CR) (*Hypselobarbus thomassi*), two endangered (EN) (*Osteochilichthys longidorsalis*, and *Tor malabaricus*) and five vulnerable (VU) (*Hypselobarbuas kolus*, *Hyporhamphus xanthopterus*, *Wallago attu*, *Channa diplogramma* and *Horabagrus brachysoma*) fish species. The dominant fish species in the fishery were *Cyprinus carpio* (6.36 t), *H. kolus* (5.23 t), *Barbodes carnaticus* (4.85 t), *Etroplus suratensis* (4.07 t), and *T. khudree* (3.46 t). Notably, the fishery included 15 non-native species, comprising 12 exotic species introduced from outside India and three species transplanted from Northeast India. Gill nets (91.77%) was the dominant gear used in the riverine fishery followed by seine nets (4.99%), hooks and lines (2.02%), cast nets (0.98%) and fish traps (0.23%). Our research findings indicates that the fish population in the river is under severe pressure with significant catches of non-native fish species posing challenges to the survival of indigenous fish species.

Introduction

Inland capture fisheries exploit wide variety of fishery resources in various inland water ecosystems including rivers, reservoirs, flood plains, wetlands, lakes, canals, and even rice fields (Funge-Smith and Bennett, 2019). They are diverse, use multiple species, are often geographically dispersed, and involve commercial, subsistence, small-scale, and aquaculture components (Cooke et al., 2016). These fisheries play a vital role in global food production, contributing 11.5 million tonnes in 2020, which represents 12% of the total global fish catch (FAO, 2022). The majority of inland fishers operate in the small-scale sector, ranging from family-based artisanal units in small lakes or larger river channels to commercial enterprises with motorized boats (Welcomme et al., 2010). These fishes are traded in the local fish market and a substantial part of the fishery may be consumed by inland urban dwellers (Welcomme et al., 2010). Small-scale inland fisheries not only contribute to nutrition, food security, and the national economy but also the livelihoods of up to 820 million fishers and fish workers across the world (Kanthiah, 2010; Silvano and Kurien, 2023). Globally, small-scale fisheries account for over half of the world's total fish catch, with a significant 90-95% of their catch being consumed locally (FAO, 2022). In various regions of Africa and Asia, small-scale fisheries play a vital role in harvesting large-sized freshwater species, which are highly valued for both food security and medicinal purposes (Belton and Thilsted, 2014). Despite the important contributions, inland fish and fisheries generally remain economically and socially undervalued and biologically underappreciated because accurate information about this small-scale highly dispersed sector is inherently difficult to acquire (Youn et al., 2014; Allan et al., 2005). However, inland fisheries face myriad threats such as overfishing, destruction of fish habitats, flooding events, water pollution, increasing human population, and demand for land in coastal areas (Barange et al., 2018). Though having immense importance, global studies regarding small-scale inland fisheries like fishing gear, seasonality, catch composition, and catch per unit effort (CPUE) are limited.

The global inland fisheries catch is predominantly concentrated in tropical and subtropical regions, with India emerging as the leading producer in 2020, accounting for an impressive 1.8 million tonnes of capture production (FAO, 2022). The inland fisheries sector makes a notable contribution to India's economy, accounting for approximately 1% to the National Gross Value Added (GVA) and 5.43% to Agricultural GVA. Moreover, this sector supports the livelihoods of over 14.5 million people directly and almost twice the number along the value chain (NIFAP, 2019). India's inland water bodies, comprising rivers, estuaries, reservoirs, freshwater lakes, and streams, play a vital role in the country's fish production, supporting a diverse array of fish species. The riverine resources of India have been approximately 3.12 million km^2 and the fish productivity from these rivers varies from 0.64 to 1.64 tonnes per km (CEBPOL, NBA, 2018). The majority of these river-caught fishes were consumed locally, contributing to the food security of millions of people directly and indirectly dependent on fishing and related activities (Montaña et al., 2011; Raghavan et al., 2011). The fishery resources in many Indian riverine waters are still harvested using traditional fishing methods and gear. The choice of fishing gear in these riverine habitats is often dictated by the target species, fishing location, season, and fish abundance, resulting in a diverse range of fishing gear being employed, including gill nets, cast nets, seine nets, drag nets, and hook and lines. Due to the absence of consistent and accurate data on riverine fisheries, it becomes challenging to pinpoint trends in fisheries production within these river systems. The reasons for poor data related to riverine fisheries are due to the widely dispersed fish landing centres, high seasonal nature of catch, low economic value, extended livelihood activities of fishers, and local and domestic trade of catch (Bartley et al., 2015).

The Western Ghats a discrete biogeographical region along the west coast of peninsular India has been designated a global biodiversity hotspot because of its remarkable diversity and high level of endemic species (Myers et al., 2000). 320 species of freshwater fishes including 212 endemic fishes and one-third threatened fishes reported from the streams and rivers originating

from the Western Ghats ecoregion (Dahanukar and Raghavan, 2013). A total of 54 finfish species are being exploited in the major rivers of Kerala, which originate from the Western Ghats (Renjithkumar, 2015). The total annual catch from these rivers is estimated at 854.75 tons. The fishing gear used in these rivers includes gill nets, cast nets, seine nets, drag nets, and hook and line, highlighting the diverse and extensive fishing practices in the region (Renjithkumar, 2015). Chalakudy River, originating from the Anamalai hills of the Western Ghats, is the fifth-longest among Kerala's 44 perennial rivers (Ajithkumar et al., 1999). The river harbours a rich and diverse fish fauna of 98 species, and many of them are endemic (36%) and threatened (33%) (Ajithkumar et al., 1999; Raghavan et al., 2008a). The indigenous ornamental fish resources of Chalakudy River are considered to be in high demand in the international aquarium fish markets and the river has currently become a hotspot for their indiscriminate collection of ornamental fishes (Sekharan et al., 2002; Raghavan et al., 2008a). Habitat destruction, overexploitation of fish for food and ornamental purposes, pollution, and introduction of exotic fish species due to extreme climate events and illegal and unmanaged aquaculture menacing the fish fauna in the river (Raghavan et al., 2008b; Raj et al., 2021). Despite the importance of fisheries conservation, research on the quantification of exploited fisheries in Kerala's rivers is scarce, with only a few notable exceptions in the Pampa, Kallada, Bharathapuzha, and Muvattupuzha Rivers (Renjithkumar et al., 2011, 2016, 2020, 2021). Despite earlier research on the fish fauna diversity in Chalakudy River (Ajithkumar et al., 1999; Raghavan et al., 2008a), there is a significant knowledge gap regarding the exploited fishery in this river. To address this, the present study aimed to: (1) determine the species-wise harvest (2) assess the landing centre-wise harvest (3) evaluate fishing gear-wise harvest. The findings of this study will inform the development of targeted conservation measures, ensuring the sustainable harvest and conservation of native fish fauna in the Chalakudy River.

Materials and methods

Study area

Chalakudy River (10°10'0" to 10°33'30" N; 76°17'0" to 77°4'0" E) is 145 km long and is one of the major river systems in Kerala state originates from the Anaimalai and Nelliampathy Hills of Southern Western Ghats and flows through three districts namely Palakkad, Thrissur, and Ernakulam before emptying into the Arabian Sea (Fig 1). The drainage area of the Chalakudy River basin is around 1704 km^2, 1404 km^2 lies in Kerala, and the rest of the 300 km^2 flows through Tamil Nadu state (Nameer and Raghavan, 2019). The river receives an average annual rainfall of 3600 mm and an annual stream flow of 169.3 mm^3 (Parvathy and Thomas, 2021). Out of the total area of the river basin, 54% is occupied by dense forest, 12% by plantation crops, 14% by agricultural plantations, and 16% comes under homesteads with crops in Kerala and Tamil Nadu state (Chattopadhyay and Rani, 2005).

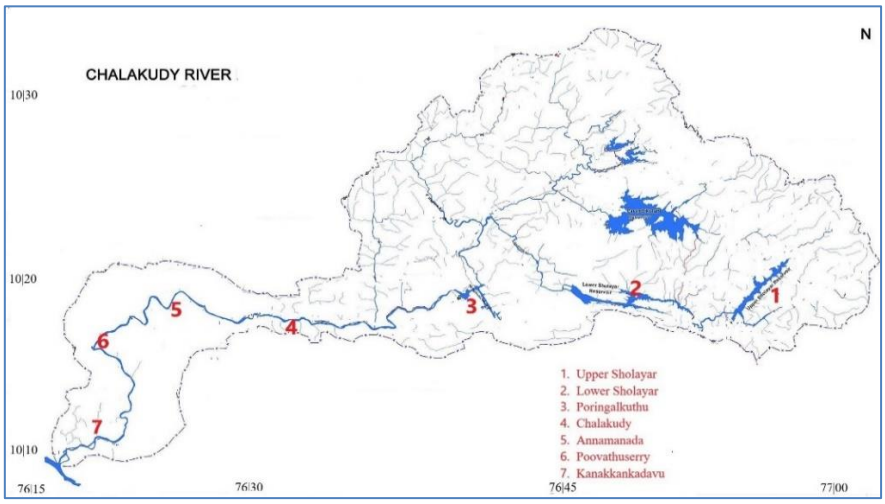

Figure 1. Map showing the stretch of Chalakudy River, Western Ghats, India along with study locations.

Methodology

The selection of sampling stations was based on a preliminary survey conducted in a month, covering the full gradient of the river. The locations were identified following interviews conducted with local fishermen and residents living in the river's vicinity. It was determined that there are seven primary fish landing centres: Upper Sholayar (10°18'22.84"N, 76°53'14.43"E), Lower Sholayar (10°19'02.24"N,76°44.06"57E), Poringalkuthu (10°18'47.55"N,76°38'06.75"E), Chalakudy (10°17'40.08"N,76°20'14.70"E), Annamanada (10°14'29.00"N,76°19'49.23"E), Poovathuserry (10°12'16.15"N, 76°19'22.93"E) and Kanakkankadavu (10°10'27.54"N,76°16'24.36"E) (Fig.1). These seven landing sites are the main locations where commercial fishermen bring their catches for sale. The exploited fishery was estimated from June 2019 to May 2020 based on regular systematic surveys and stratified random sampling method was carried out on major landing sites of the river on a monthly basis. The fishing activity of the study locations was monitored in the early morning (6-8 am) and information on catches was collected from more than 30% of total gears operated, giving importance to the species-wise total weight, type of gear, and mesh size, fishing hours and manpower involved (Kurup et al., 1993). Fish specimens collected were preserved in 8% formalin and identified using standard keys (Talwar and Jhingaran, 1991; Jayaram, 2009). Based on interviews, the number of fishermen on a given day at a given landing site varied from 4–12 individuals. The number of fishermen in a day may be influenced by fluctuations in fish availability and season. The catch from every fisherman who arrived at a given landing site on a given morning was examined. The landing data were pooled into three seasons, monsoon (June- September), post-monsoon (October-January), and pre-monsoon (February-May).The daily species-wise landings from each type of gear were computed following Kurup et al. (1993), using the formula: w= (W/n) x N, where, w= total weight of species; W= total weight of species from gear sampled; n = number of gears sampled; and N = total number of similar gears operated. The monthly production was estimated by multiplying daily landings with the total number of fishing days in a month. The annual exploited quantity was calculated by adding the landings of all the seasons. The gear-wise CPUE (catch per unit effort) for fish caught per unit hour of operation was calculated by dividing the total sampling gear catch in biomass (TSGCB) which is the observed value of fish caught by a particular gear, by total sampling effort hours (TSEH) (Ghosh and Biswas, 2017; Renjithkumar et al., 2011) TSEH is calculated as the product of average sampling effort hour of operation of a particular gear per day and total numbers of such gear used, i.e. sampling gear density.

CPUE (g/h) = TSGCB ÷ TSEH

Results

Species composition in the catch

Exploited fish diversity of Chalakudy River comprised 68 species belonging to 51 genera and 37 families (Table 1). Family Cyprinidae was the most diverse family representing 19 species followed by Cichlidae (5 species), Channidae, and Bagridae (3 species each). Based on IUCN criteria, the landings were represented by one critically endangered (EN) (*Hypselobarbus thomassi*), 2 endangered (EN) (*Osteochilichthys longidorsalis* and *Tor malabaricus*), and 5 vulnerable (VU) (*H. kolus*, *Hyporhamphus xanthopterus*, *Wallago attu*, *Channa diplogramma*, and *Horabagrus brachysoma*) fish species (Fig 2). 15 alien fish species were recorded in the fishery of which 12 (*Atractosteus spatula*, *Ctenopharyngodon idella*, *Cyprinus carpio*, *Hypophthalmichthys molitrix*, *Oreochromis niloticus*, *O. mossambicus*, *Mayaheros urophthalmus*, *Osphronemus goramy*, *Clarias gariepinus*, *Pangasianodon hypophthalmus*, *Pterygoplichthys multiradiatus* and *Piaractus brachypomus*) are exotic to the country; while rest were the Indian major carps (*Labeo rohita*, *L. catla*, and *Cirrhinus mrigala*) transplanted from Gangetic plains of Northern India.

Table 1. Species composition and landing in the exploited fishery of Chalakudy River, India

SL no	Order	Family	Species	Landing (t)	IUCN
1	Elopiformes	Elopidae	*Elops machnata*	0.07	LC
2		Megalopidae	*Megalops cyprinoides*	1.01	LC
3	Anguilliformes	Anguillidae	*Anguilla bengalensis*	0.29	NT
4	Clupeiformes	Clupeidae	*Dayella malabarica*	0.08	LC
5		Engraulidae	*Thryssa dussumieri*	0.05	LC
6	Gonorhynchiformes	Chanidae	*Chanos chanos*	0.11	LC
7	Cypriniformes	Cyprinidae	*Amblypharyngodon microlepis*	0.23	LC
8			*Barbodes carnaticus*	4.85	LC
9			*Cirrhinus mrigala*	1.69	LC
10			*Ctenopharyngodon idella*	0.50	EX
11			*Cyprinus carpio*	6.36	EX
12			*Dawkinsia filamentosa*	1.87	LC
13			*Labeo catla*	0.56	LC
14			*Hypselobarbus kolus*	5.23	VU
15			*Hypselobarbus kurali*	0.61	LC
16			*Hypselobarbus thomassi*	0.15	CR
17			*Hypophthalmichthys molitrix*	0.31	EX
18			*Labeo dussumieri*	1.49	LC
19			*Labeo rohita*	2.19	LC
20			*Osteobrama bakeri*	0.19	LC
21			*Osteochilichthys longidorsalis*	0.32	EN
22			*Puntius mahecola*	0.92	DD
23			*Systomus subnasutus*	1.16	LC
24			*Tor khudree*	3.46	LC
25			*Tor malabaricus*	1.08	EN
26	Siluriformes	Bagridae	*Horabagrus brachysoma*	2.01	VU
27			*Mystus gulio*	0.39	LC
28			*Mystus oculatus*	0.02	LC
29		Siluridae	*Ompok malabaricus*	0.90	LC
30			*Wallago attu*	0.83	VU
31		Pangasiidae	*Pangasianodon hypophthalmus*	1.39	EX
32		Clariidae	*Clarias dussumieri*	0.04	NT
33			*Clarias gariepinus*	0.15	EX
34		Heteropneustidae	*Heteropneustes fossilis*	2.68	LC
35		Ariidae	*Arius maculatus*	0.12	NE
36		Loricariidae	*Pterygoplichthys sp*	0.14	EX
37	Beloniformes	Belonidae	*Xenentodon cancila*	0.17	LC
38		Hemiramphidae	*Hyporhamphus xanthopterus*	0.26	VU
39	Synbranchiformes	Mastacembelidae	*Macrognathus aral*	0.16	LC
40			*Mastacembelus armatus*	0.11	LC
41	Perciformes	Ambassidae	*Parambassis dayi*	1.24	LC
42			*Parambassis thomassi*	0.74	LC
43		Latidae	*Lates calcarifer*	0.10	LC
44		Serranidae	*Epinephelus malabaricus*	0.17	LC
45		Sillaginidae	*Sillago sihama*	0.16	LC
46		Carangidae	*Caranx ignobilis*	0.21	LC

47		Leiognathidae	*Leiognathus equula*	0.09	LC
48		Lutjanidae	*Lutjanus argentimaculatus*	0.15	LC
49			*Lutjanus malabaricus*	0.22	LC
50		Gerreidae	*Gerres filamentosus*	0.07	LC
51		Nandidae	*Nandus nandus*	0.57	LC
52		Pristolepididae	*Pristolepis rubripinnis*	0.05	NE
53		Mugilidae	*Mugil cephalus*	0.10	LC
54		Cichlidae	*Etroplus suratensis*	4.07	LC
55			*Oreochromis mossambicus*	2.94	EX
56			*Oreochromis niloticus*	2.47	EX
57			*Pseudetroplus maculatus*	0.45	LC
58			*Mayaheros urophthalmus*	0.05	EX
59		Gobiidae	*Glossogobius giuris*	0.50	LC
60		Scatophagidae	*Scatophagus argus*	0.31	LC
61		Anabantidae	*Anabas testudineus*	0.84	DD
62		Osphronemidae	*Osphronemus goramy*	0.55	EX
63		Channidae	*Channa diplogramma*	0.29	VU
64			*Channa pseudomarulius*	2.48	LC
65			*Channa striata*	3.26	LC
66	Pleuronectiformes	Soleidae	*Brachirus orientalis*	0.11	LC
67	Lepisosteiformes	Lepisosteidae	*Atractosteus spatula*	0.10	EX
68	Characiformes	Serrasalmidae	*Piaractus brachypomus*	2.06	EX
		Total		68.53	

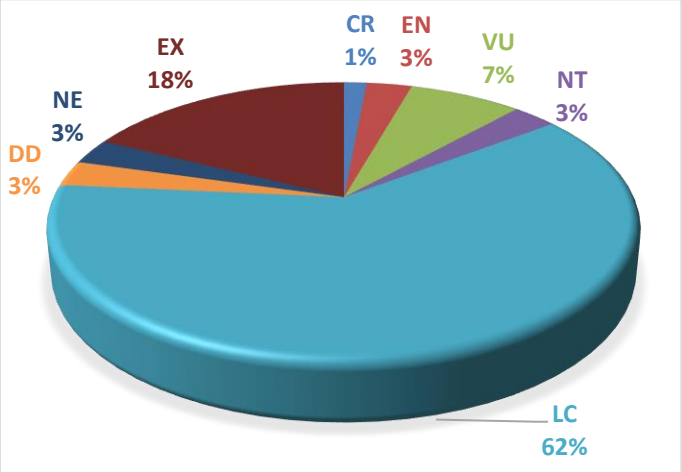

Figure 2. Biodiversity assessment of fish species in the exploited fishery of River Chalakudy, India.

Estimates of fish production

The annual exploited fishery of the river for a period of one year (2019-2020) was estimated to be 68.53 t. The highest landings were reported in the post-monsoon season (38.34%) and the lowest during the pre-monsoon season (28.87%). Cyprinids (48.42%), cichlids (14.56%), catfishes (12.66%), and murrels (8.79%) constituted the major fish groups that contributed to the fishery. *C. carpio* contributed the highest in the catch (9.28%) followed by *H. kolus* (7.64%), *Barbodes carnaticus* (7.08%), *Etroplus suratensis* (5.94%), and *Tor khudree* (5.05%). Cyprinids represented 19 species and contributed 48.43% to the annual fish landing. The main cyprinids are *C. carpio*

(6.36 t), *H. kolus* (5.23 t), *B. carnaticus* (4.85 t) and *T. khudree* (3.45 t). Cichlids contributed 14.57 % of the total landing comprised of five species viz., *E. suratensis* (4.07 t), *O. mossambicus* (2.94 t), *O. niloticus* (2.47 t), *Pseudetroplus maculatus* (0.45 t) and *Mayaheros urophthalmus* (0.05 t). Catfishes mainly *Heteropneustes fossilis* and *Horabagrus brachysoma* contributed 2.68 t and 2.01 t respectively in the fish landing. Murrels were represented by *Channa pseudomarulius, C. striata* and *C. diplogramma,* contributed 2.47 t, 3.26 t, and 0.29 t, respectively in the catch. Monthly fluctuations of the fishery resources in the river indicated the highest quantity in August (7.35 t) and lowest in May (3.41 t).

Exotic and transplanted species contributed 24.84% and 6.48% respectively in the exploited fishery. The important exotic species are *C. carpio* (6.36 t) followed by *O. mossambicus* (2.94 t), *O. niloticus* (2.47 t) and *P. brachypomus* (2.06 t). 17 secondary freshwater fish species including *Megalops cyprinoides* (1.01 t), *Scatophagus argus* (0.31 t), and *Hyporhamphus xanthopterus* (0.26 t) contributed 4.83% in the fishery. The period between May to July showed a lower fishing activity even though an increasing trend was noticed from August to January. The landing centre-wise fishery showed that the highest landing was reported in Kanakkankadavu (16.18 t) followed by Annamanada (11.11 t) and Upper Sholayar (10.49 t). Among the threatened fish groups, critically endangered (EN) *H. thomassi* contributed 0.15 t whereas endangered (EN) (*O. longidorsalis* and *T. malabaricus*) contribute 0.32 t and 1.08 t respectively to the annual fish landing.

Gear-wise fish landing

Gill nets formed the most dominant fishing gear operated in the river contributing 91.77% to the fish landing followed by seines (4.99%), hooks and lines (2.02%), cast nets (0.98%) and traps (0.23%) (Fig. 3). Gill nets operated varied from 75-150 cm in length with a mesh size range of 20-80 mm. The main fish species caught in gill nets were *C. carpio, B. carnaticus, E. suratensis, H. kolus, T. khudree,* and *O. mossambicus.* These nets are of different names locally *Odakkuvala* and *Neettuvala* which differ from each other in the mode of fabrication, length, and mesh sizes. For gillnets, the highest catch per unit effort (CPUE) was recorded for *C. carpio* (2.09 kg h^{-1}) followed by *H. kolus* (2.01 kg h^{-1}), *B. carnaticus* (1.80 kg h^{-1}), *E. suratensis* (1.3 kg h^{-1}) and *T. khudree* (1.26 kg h^{-1}) (Fig. 4). Gill nets are operated throughout the length of the river, unlike other gears, widely used in upper reaches of the river especially in reservoirs. Gill net is usually operated as drift or set in the water column by one or two fishermen from a canoe mainly made up of wood.

Seine nets are locally known as *koruvala* and it is mainly used for the exploitation of small-sized fishes. The net is rectangular made of nylon (PA) multifilament having a 6-18 mm mesh size. One end of the net is handed over to the fisherman standing in the water and the other fisherman releases the net from the canoe in a circular fashion along the direction of water flow to spread the net properly. Simultaneously the other end of the net is taken inside the circle by the second fisher and he moves circularly to collect fish into the pocket on the same side of the net. Depending on the water depth and conditions 6-10 hauls/ day/net could be made. The main fish species caught in seine nets were *Dawkinsia filamentosa*, *Parambassis dayi, Puntius mahecola, Anabas testudineus,* and *Heteropneustes fossilis*. The net is operated mainly during the pre-monsoon season with low water levels in the river preferably during day and night. In seines, the highest catch per unit effort was recorded for *D. filamentosa* (0.38 kg h^{-1}) followed by *P. dayi* (0.33 kg h^{-1}), *P. mahecola* (0.31 kg h^{-1}), *H. fossilis* (0.25 kg h^{-1}) and *A. testudineus* (0.24 kg h^{-1}) (Fig. 5).

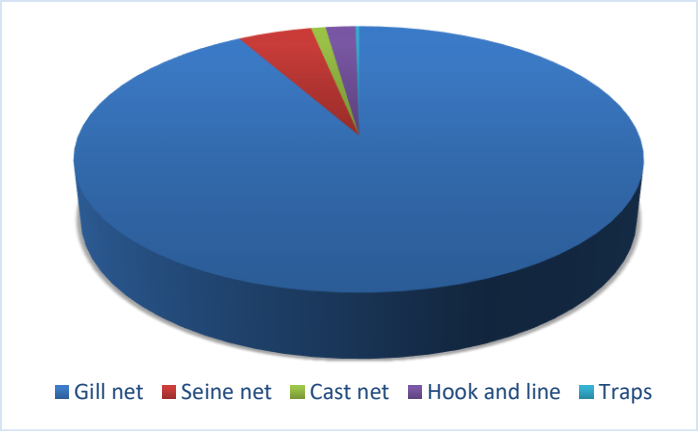

Figure 3. Percentage contribution of various gears in the exploited fishery from the River Chalakudy, India.

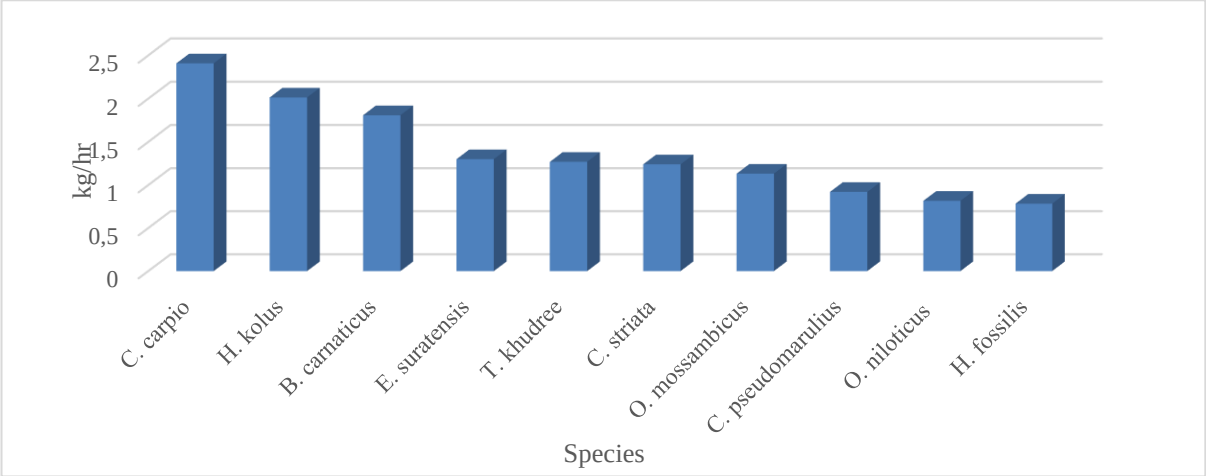

Figure 4. Catch per unit hour of major fish species exploited by gillnets in the River Chalakudy, India.

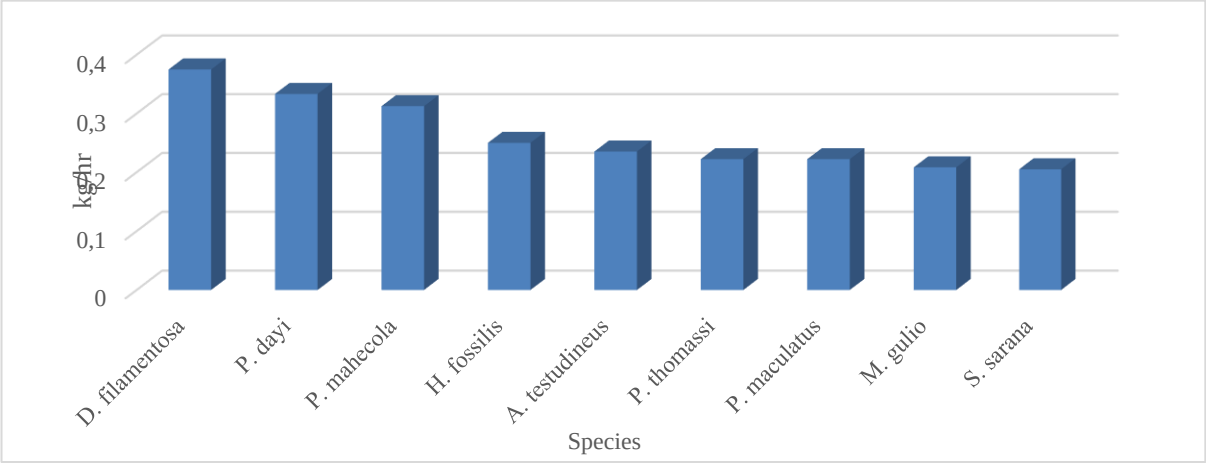

Figure 5. Catch per unit hour of major fish species exploited by seine nets in the River Chalakudy, India.

Hook and lines were used to catch *Anguilla bengalensis*, *T. khudree*, *B. carnaticus*, *Wallago attu*, and *C. carpio*. *A. bengalensis* (0.4 kg h^{-1}) recorded the highest CPUE for *A. bengalensis* (0.4 kg h^{-1}) in hook and lines followed by *T. khudree* (0.33 kg h^{-1}), *B. carnaticus* (0.30 kg h^{-1}) and *W. attu* (0.26 kg h^{-1}). (Fig. 6). The length of the line varied from 3 to 40 m in length according to the depth and flow of the water area where the gear is operated. The commonly used baits were

live or dead prawns and small fishes and a small thermocole or cork or sponge float is used in calm waters. Cast nets are mainly used for the capture of small shoaling fishes such as *D. filamentosa*, *P. dayi*, *Mystus gulio*, *A. microlepis*, and *P. maculatus*. Highest catch per unit effort for *D. filamentosa* (0.71 kg h^{-1}) followed by *P. dayi* (0.58 kg h^{-1}), and *M. gulio* (0.39 kg h^{-1}) (Fig 7) in cast nets.

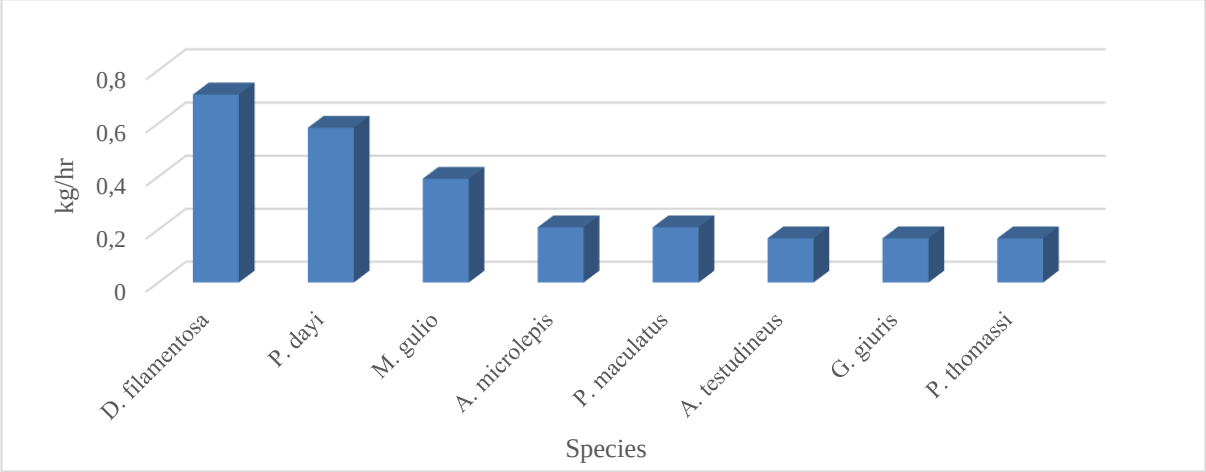

Figure 6. Catch per unit hour of major fish species exploited by hook and lines in the River Chalakudy, India

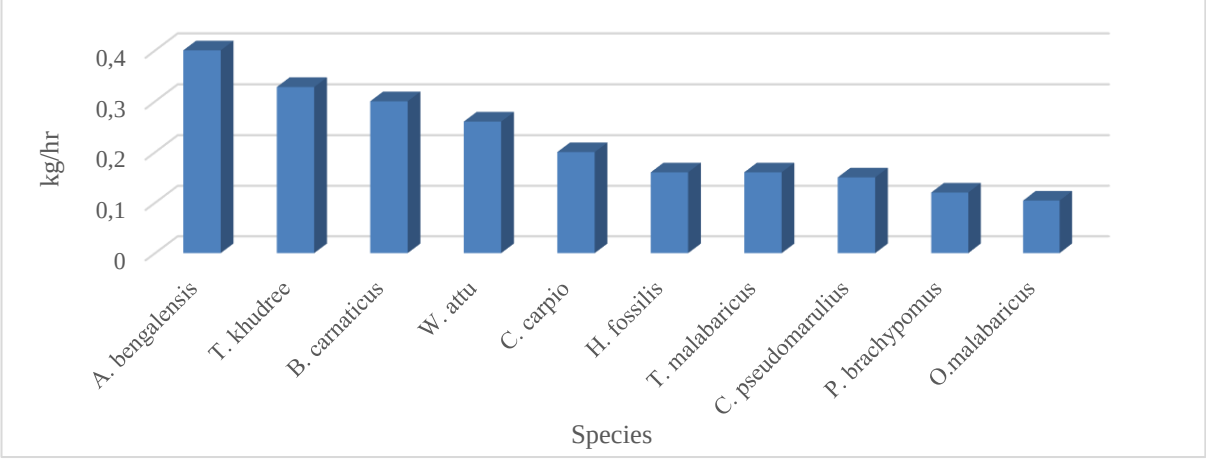

Figure 7. Catch per unit hour of major fish species exploited by cast nets in the River Chalakudy, India.

Discussion

The Chalakudy River's exploited fishery stands out for its remarkable diversity, supporting a total of 68 fish species. This is significantly higher than the number of species found in other rivers of the Western Ghats region, including Bharathapuzha (31 species), Pampa (26 species), Muvattupuzha (23 species), and Kallada (21 species) (Renjithkumar et al., 2011, 2016, 2020, 2021). Raghavan et al. (2008a) reported 71 fish species, including five exotic species, while Ajithkumar et al. (1999) documented a higher total of 98 species, including 12 secondary freshwater and migratory fishes in the Chalakudy river system. The family Cyprinidae which include carps, barbs, and minnows held dominance among various fish groups, with a numerical strength of 19 species accounting for 25% of the total fish species. Raghavan et al. (2008a) also observed the prominence of the Cyprinidae family, documenting 24 species belonging to this family in the Chalakudy River. The present study revealed that the annual exploited fish landing in the Chalakudy River was 68.53 tonnes, which is relatively lower compared to the total landings in the Pampa (394.22 t) and Bharathapuzha Rivers

(112.56 t) (Renjithkumar et al., 2011, 2020). However, the fishery of the Muvattupuzha River (45.01 t) and Kallada River (16.58 t) recorded even lesser annual fish landings when compared to the present study (Renjithkumar et al., 2016, 2021). The threat status of fishes in river represented one critically endangered (CR), two endangered (EN), and five vulnerable (VU) fish species contributed respectively 0.22 %, 2.04%, and 12.59% to the annual fishery. Rajeev et al. (2008a) reported 4 'critically endangered' (CR), 16 'endangered' (EN), and 11 'vulnerable (VU) from this river system. Migratory and secondary freshwater fishes like *Megalops cyprinoides, Scatophagus argus, Hyporhamphus xanthopterus, Epinephelus malabaricus, Lutjanus malabaricus* and *L. argentimaculatus* have been observed in the midstream regions of the river, extending their habitat up to approximately 60 km. The increased salinity gradient, suitable breeding habitat, availability of food niches, and food abundance in the riverine area, and climate change in the ocean are the major factors responsible for the migration (Brönmark et al., 2014). Migratory fishes contributed to 3.56% of the fishery in the Bharathapuzha River (Renjithkumar et al., 2020).

Tribal people and forest-dwelling communities residing in the upper reaches of the Chalakudy River basin are highly dependent on the native fish species for their sustenance and livelihoods (Raghavan et al., 2008a). These communities have traditionally depended on the river's fish resources, which are an integral part of their food security, cultural practices, and economic well-being. The forest-dwelling communities in the Chalakudy River basin primarily exploit a range of native cyprinid species, including *T. khudree*, *H. kolus, B. carnaticus,* and *O. longidorsalis,* and introduced species like the *C. carpio* and *Oreochromis mossambicus. T. khudree* (Deccan mahseer) and *T. malabaricus* (Malabar mahseer) are highly valued food and game fish species in India, inhabiting the fast-flowing streams and rivers of the country's hilly regions. In the Chalakudy River fishery, these species are prized catches, with a total landing of 4.54 t. In the Pampa River, *T. khudree* contributed an annual landing of 0.65 t, while in the Kallada River, it accounted for 0.36 t of the annual landing (Renjithkumar et al., 2011, 2021). Cast nets and gill nets were the primary fishing gears utilized for the exploitation of mahseer in the Periyar and Chalakudy Rivers within the Western Ghats. Unfortunately, in some areas, there were reports of indiscriminate fishing practices involving dynamite and poison, posing a threat to the fish populations and the overall river ecosystem (Raghavan et al., 2011). The mahseer species catches in Periyar Lake and Chalakudy River have experienced a drastic decline over the recent years (Minimol, 2000; Raghavan et al., 2011). The introduced species *C. carpio* and *O. mossambicus* pose a significant threat to the native *T. khudree* population in Periyar Lake (Kurup et al., 2006). The fishing mortality rate of *T. khudree* in Poringalkuthu Reservoir in Western Ghats was one of the highest of any other species of mahseer in India and this is due to the indiscriminate exploitation of the species (Raghavan et al., 2011) highlighting the need for urgent conservation measures to regulate fishing practices and protect this valuable species from overfishing. The decline in the fishery of mahseer due to indiscriminate fishing of brood and juvenile fish and adverse effects of dams (Bhatt et al., 2000, 2004; Nautiyal et al., 2008). The introduction of *O. mossambicus* to Periyar Lake, Kerala, has posed a significant threat to the survival of *T. khudree*. A remarkable 78% overlap in their dietary preferences has been observed, indicating intense competition for limited resources. Furthermore, *C. carpio* has been found to exhibit a significant 57% overlap in its dietary preferences with those of *T. khudree*, indicating another potential source of competition for resources in the ecosystem (Kurup et al., 2006). Two crucial management strategies have been identified for the conservation of *T. khudree*: firstly, regulating fishing efforts to prevent overfishing and reduce pressure on the species, and secondly, implementing a breeding season ban on fishing (October to December) to protect the species during its most vulnerable life stage (Arun et al., 2001; Raghavan et al., 2011).

H. brachysoma commonly known as Asian Sunfish formed the mainstay in the exploited fisheries of the rivers of Kerala (Sunil et al., 1999) and contributed 17.11 t and 3.67 t in Pampa and Muvattupuzha Rivers respectively (Renjithkumar et al., 2011, 2016). The landing of *H. brachysoma*

in the Chalakudy Rivers was low (2 t) when compared to these rivers. It is one of the important food fish species that is exploited frequently by artisanal fishermen using gill nets, hook and lines, and drag nets (Sreeraj et al., 2007; Prasad et al., 2012). The populations of golden catfish have declined drastically and the fish are restricted to tributaries of Chalakudy, Meenachil, Manimala, and Pamba Rivers (Padmakumar et al., 2011). *H. brachysoma* is an important catfish species that is largely exploited during their breeding migration in rivers during monsoon floodplain fishery (Shaji and Laladhas, 2013) and more than 100 kg of mature *H. brachysoma* are caught in a week-long monsoon floodplain fishery (Shaji and Laladhas, 2013). Overexploitation, habitat destruction, invasion of exotics, and pollution have resulted in the population decline of the species (Raghavan et al., 2016). Various management strategies including restrictions on fishing gear, enforcement of minimum size limits, implementation of closed fishing seasons, and fish sanctuaries should be adopted for the conservation of this catfish species (Raghavan et al., 2016).

Murrels, also known as snakeheads, are highly prized food fish in tropical Asia, renowned for their unique flavour and nutritional value (Wee, 1982), and the third most important group of freshwater fishes in India after carps and catfishes (Laxmappa, 2017). Snakeheads play a vital role in small-scale fisheries in India, making a significant contribution to the catch in rivers and reservoirs across the country's and are also popular for pond and cage aquaculture (Adamson, 2010; Poulsen et al., 2008; Ali et al., 2013). The three snakeheads (*Channa striatus, C. pseudomarulius,* and *C. diplogramma*) contributed to a significant fishery (6.02 t) in the Chalakudy River. *C. pseudomarulius* (great snakehead) is considered an important food fish in India showed a high landing in Pampa River (30.36 t) when compared to Chalakudy River (2.47 t) and a low landing in Muvattupuzha (2.24 t) and Bharathapuzha Rivers (0.34 t). *C. striatus* commonly known as 'Cherumeen' in vernacular contributed an annual landing of 3.26 t in the river. The landing of the species was highest in the Pampa (36.34 t) and Muvattupuzha (4.60 t) Rivers compared to Chalakudy River. *C. diplogramma* commonly known as Malabar snakehead (*Puli vaka* in vernacular) contributed a low landing (0.29 t) in Chalakudy River. In Pampa River, this species also showed a reduced landing (0.79 t) (Renjithkumar et al., 2011). This species showed an alarming decline in its population due to destructive type fishing activities including dynamiting and poisoning, overexploitation for food and international aquarium trade, Epizootic Ulcerative Syndrome (EUS), habitat alteration, and pollution, and local fishers operating in the rivers have confirmed that populations have declined considerably (> 90%) over the last two decades (Benziger et al., 2011; Sajeeven et al., 2014; Kurup, 2000).

Data on the exploited fishery of Chalakudy River indicate that pearl spot, *E. suratensis* (4.07 t) is one of the dominant fish species that appeared in the landing. This species is economically important both as food fish and aquaculture candidates in its home range and contributes significantly to the inland fishery of Kerala (Roshni et al., 2017). This species contributes a high landing in Pampa (31.88 t) and Bharathapuzha (4.23 t) Rivers (Renjithkumar et al., 2011; 2020). A decline in the landings of *E. suratensis* from 1252 t (1969), 458 t (1989), and 200 t (2002) to 135.28 t (2012-13) indicate a high reduction in the stock of the species in the Vembanad Lake of central Kerala (Samuel, 1969; Kurup et al., 1995; Padmakumar et al., 2002; Roshni et al., 2017). The major threats to the reduction of the species in their native habitats are to degradation of their breeding grounds habitats and the indiscriminate collection of mature fishes owing to their immense market value may gradually lead the fish to a death hole (Roshni et al., 2017). The government of Kerala state declared *E. suratensis* as a "State fish" due to very little attention that has been received towards the protection of the species (Padmakumar et al., 2012).

Gillnets are simple, selective, and inexpensive fishing gear, which, therefore, is one of the most widely used gears by small-scale fishermen in the inland waters of India (Remesan and Ramachandran, 2005). The gillnet was the primary fishing gear employed in the Chalakudy River, accounting for a staggering 91.77% of the total annual fish catch. The gillnet catches in the Chalakudy River are dominated by four key

species: *C. carpio, B. carnaticus, E. suratensis*, and *H. kolus*. According to research conducted by Renjithkumar et al. (2011, 2016, 2020, 2021), gillnets are the predominant fishing gear in several rivers in the region, including Pampa (77%), Muvattupuzha (88%), Bharathapuzha (87%), and Kallada (99%). Gill nets are easy to use, even in difficult environmental conditions, and were used for fishery exploitation in riverine waters in Kerala state (Baiju and Hridayananthan, 2003). Gill net is the only gear in which the 'mesh' of the gear itself aids in obtaining the maximum yield, protecting small fishes, and minimizing escapement of injured or dying fishes (Ishida,1961; Ueno et al., 1965; Thomson et al., 1971).

Seine net is a fine-meshed net operated in the lower stretches of the Chalakudy River and the main species caught in the nets are *D. filamentosa, P. dayi*, and *P. mahecola*. Indiscriminate collection of these small-sized ornamental species for the aquarium trade is considered to be one of the major threats to the fish fauna of Chalakudy River (Raghavan et al., 2008a). Hook and lines have three types of categories viz., (i) hand lines (ii) rod & lines, and (iii) long lines. Hand lines is the simplest form made of polyamide monofilament lines with single hooks were prevalent in the river. In Pampa River, hooks and lines are commonly used during post-monsoon season for catching mainly *W. attu* (Renjithkumar et al., 2011). Hook & lines accounted for only 1% of the total fish landing in Bharathapuzha River and the major species consisted of *C. striata, C. marulius,* and *Mastacembelus armatus*. The cast nets are generally made of PA multifilament and the length and mesh size of the gear varies from 2 to 4.5 m length and 6-20 mm respectively. They are generally operated throughout the year in the Pampa River, including during June - August when the river gets flooded with monsoon runoff (Renjithkumar et al., 2011). Stringed and stringless cast nets were common in the downstream areas of Chalakudy River, and in upstream areas, mainly stringless cast nets were used.

The introduction of alien or non-native fish species for aquaculture and ornamental purposes poses a significant threat to freshwater ecosystems globally (Ehrenfeld, 2010). This study reveals a concerning trend, with alien species accounting for 31.32% of the total fish catch in the river. Notably, 12 of these species are non-native to the country, while the remaining three are Indian major carps (IMCs) that were introduced from the Gangetic plains for aquaculture purposes. The threats posed by these invasive species involve the decline of native biodiversity, extinction of endemic and threatened species, habitat alterations, introduction of new parasites or diseases, and production of hybrid fishes (Singh and Lakra, 2011). The introduction of Indian Major Carps (IMCs) into Kerala's riverine ecosystems was intended to enhance capture fisheries (Sugunan, 2000). However, these non-native species escaped from aquaculture sites in the lower reaches of the Western Ghats rivers and have since established wild populations, thriving in their new environment. The introduction of *Labeo catla* had a profound impact on the indigenous fish fauna in Santhanur reservoir, Tamil Nadu. Historically, *L. fimbriatus* was the dominant species, accounting for 36% of the total catch in the mid-1960s. However, by the 2000s, *L. catla* had become the dominant species, contributing a staggering 80-90% to the total catch (Sugunan, 2000). The introduction of Indian Major Carps has been identified as the primary factor contributing to the decline of endemic Peninsular carps (*Cirrhinus cirrhosa, Labeo kontius, Puntius carnaticus, P. dubius,* and *P. pulchellus*) in numerous reservoirs of Southern India (Sreenivasan, 1996). IMCs contribute an annual landing of 12.86 t landing in the Bharathapuzha River (Renjithkumar et al., 2020). State Fisheries Department officials of Kerala argue that introducing Indian Major Carps (IMCs) through ranching does not harm indigenous species, citing their supposed inability to breed in Kerala's ecological conditions. However, local fishermen disagree, pointing out that these non-native species are already breeding in Kerala's waters, posing a significant threat to the state's endemic cyprinid fish species (Renjithkumar et al., 2020) The present report on the high landings of IMCs in Chalakudy river (6.48 t) shows a possibility of their natural expansion and creating the possibility for interbreeding between non-native/cultured stock and native/wild stock (Silas, 2010).

The exotic *Cyprinus carpio* was introduced to India to promote aquaculture development (Singh and Lakra, 2006) and was the dominant species in the landing of Chalakudy River (6.36 t). Common carp implicate environmental changes such as eutrophication through an increase in turbidity and mobilization of nutrients to the water column through its habit of rooting or digging in the bottom (Britton et al., 2007). The introduction of common carp had devastating effects on native fish populations in various ecosystems, leading to declines in iconic species such as the golden mahseer (*T. putitora*), the snow trout (*Schizothorax richardsonii*), and several carp and catfish species (Petr, 1999; Singh and Lakra, 2006; Lakra et al., 2008). Its increasing population has been found to reduce the endemic *Osteobrama belangiri* from Loktak Lake, India (Singh and Lakra, 2006). Common carp invasion causes a sharp decline in the catches of endemic schizothoracids in the lakes of Kumaon (Singh and Lakra, 2006, Lakra et al., 2008). The increasing abundance of invasive *C. carpio* has created a low landing of indigenous fish species in River Ganga (Ray et al., 2021).

The invasive, *O. mossambicus* contributed a high landing (2.94 t) in Chalakudy River compared to Bharathapuzha River (2.83 t). Roshni et al. (2016) reported that *O. mossambicus* contributed a tune of 2.59 t in the annual fish landing in Poringalkuthu reservoir, and also recorded the highest abundance index compared to other fish fauna. The introduction of tilapia had a profound impact on the reservoirs of Kerala state, with this exotic species now accounting for up to 25% of the total catch (Lakra et al., 2006). The introduction of the Mozambique tilapia has been linked to declines in indigenous fish populations in Indian waters (Bijukumar, 2000). This invasive species poses a significant threat to native fish communities globally, outcompeting them for resources, habitat, and spawning sites, and also predating on them (Russell et al., 2012). In Vaigai Reservoir, the population of *L. kontius* has been severely depleted, while *Puntius dubius* has suffered a similar fate in Amaravathy Reservoir (Sreenivasan and Sundarajan, 1967; Natarajan and Menon, 1989). Tilapia decreased the catch of *Cirrhinus reba* from 70% to 20% in Kabini Reservoir (Murthy et al., 1986). A significant diet overlap existed among the two indigenous cichlid (*E. suratensis* and *P. maculatus*) and exotic *O. mossambicus* in the Vembanad estuary, India (Roshni et al., 2021). Both *E. suratensis* and *O. mossambicus* often utilise benthic zones of the estuary, thereby exacerbating chances for food and habitat overlap (Roshni et al., 2021). The established population of tilapia in the Chalakudy River has also been found to impact the native Orange Chromide (*Pseudetroplus maculatus*) population, as both species compete for the same ecological resource (Raghavan et al., 2008b).

The introduction of tilapia has facilitated the establishment and spread of other invasive species, including Common Carp, Bighead Carp, and African Catfish, in a process known as *'invasional meltdown'* (Simberloff, 2006; Braga et al., 2018; Singh, 2021). This phenomenon occurs when multiple invasive species interact positively, enhancing each other's survival, growth, reproduction, abundance, and density, without negatively impacting one another. Nile tilapia, *O. niloticus* was introduced into open water to increase aquaculture fish production and contributed 2.47 t in the fish landing of Chalakudy River. They are voracious herbivores decreasing plant density in an aquatic ecosystem and changing the composition of native plants which can threaten many native aquatic organisms that depend on such plants for forage, protection, or spawning (Shuai et al., 2023). The invasion of Nile tilapia can decrease local biodiversity and lead to the extinction of native fish species through competitive displacement (Starling et al., 2002; Figueredo and Giani, 2005). The Nile tilapia invasion seems to induce trophic dispersion, thereby disrupting trophic positions and destabilizing the food webs of the impacted aquatic ecosystem (Shuai et al., 2023). There is often substantial diet overlap between Nile tilapia and native fishes in most tropical and subtropical countries in the world (Henson et al., 2016). Invasion of this species produces a diet shift and a decline in the trophic position of three fish piscivores in the invaded Dongjiang River, Brazil (Shuai et al., 2023). In addition to its ecological impacts, the introduction of Nile tilapia in a reservoir in northeastern Brazil has also had significant economic consequences. The invasion has led to a substantial decline in the Catch per

Unit Effort (CPUE) of commercially valuable species, indicating a decrease in the reservoir's fisheries productivity and potential economic losses for the fishing industry (Attayde et al., 2011).

The introduction of the red-bellied pacu (*Piaractus brachypomus*), native to the Amazon River basin, into India for aquaculture purposes has led to its establishment in the Chalakudy River, with a notable annual catch of 2.06 t. This species is highly adaptable and resilient, capable of thriving in diverse aquatic environments and exhibiting a flexible diet (Roshni et al., 2014; Singh and Lakra, 2011). However, its presence also poses significant concerns, as its powerful dentition can inflict serious injuries on humans and other aquatic organisms, damage fishing nets, and cause substantial economic losses to local fishers (Robins et al., 1991; Singh and Lakra, 2011). Two human deaths were reported due to Pacu attack by biting off the testicles of fishermen from Papua New Guinea (Singh, 2018) and also causes outbreaks of parasitic infestations (Moravec, 1998). These features may lead to severe habitat and trophic niche overlapping between this fish and other native fishes sharing similar ecological resources (Roshni et al., 2014). The striped catfish (*Pangasianodon hypophthalmus*), native to the Mekong and Chao Phraya River basins in Southeast Asia (Castellanos-Mejía et al., 2021), has been introduced to the Chalakudy River, where it has established a significant population, contributing 1.39 t to the catch. Its invasive nature is attributed to its high reproductive capacity, parental care, carnivorous and cannibalistic feeding behaviour, and ability to migrate long distances between ecosystems, including upstream movements to spawning habitats. These traits enable it to outcompete native species, potentially disrupting the ecosystem balance and causing ecological and economic impacts (Castellanos-Mejía et al., 2021).

The Alligator gar (*Atractosteus spatula*) a species native to the United States and Mexico (Raz-Guzmán et al., 2018), was introduced to Kerala's waters following the devastating floods in 2018, which led to the escape of the species from ornamental fish farms (Kumar et al., 2019). Although its contribution to the fishery was relatively small, at 0.1 t, this species poses a significant threat to native ecosystems. The alligator gar is a large predator, capable of growing up to 3 meters in length and weighing up to 137 kilograms (Froese and Pauly, 2022), making it a potential apex predator in its introduced range, with potentially severe consequences for native fish populations and ecosystem balance The impacts of the introduction of alligator gar on native species are unknown because only a few studies on this matter, mostly as a result of the recent introduction of this species into non-native habitats (Kumar et al., 2019). The worldwide invasion of Alligator gar suggests that invasion is at an early stage and a greater focus on early prevention and immediate response is critical (Xie et al., 2023). Considering its opportunistic piscivores, adaptations to wider ecological conditions, and large body size, precautionary methods need to be adopted and detailed research on the impacts of the introduction of the species will be carried out (Fuller, 2019).

Conclusion

The present study provides baseline information on the finfish harvest pattern in Chalakudy River in Southern Western Ghats of India. Cyprinids, cichlids, catfishes, and murrels were the major fish groups contributed in the fishery. The high contribution of alien fishes in the fishery is a serious concern to the native fish diversity in the river. The mesh size of the seine nets used in the river ranging between 8-16 mm, which goes against the mesh size regulation (>20 mm) outlined in section 6 (3) of the Inland Fisheries and Aquaculture Act of Kerala 2010. A large number of fish species caught during monsoon floodplain fishery in river causing overexploitation of many mature indigenous species (*Horabagrus brachysoma, Wallago attu, Labeo dussumieri, Channa striata* etc.) causing recruitment failure. Based on the study, it is proposed that strict legal control on the pollution, overexploitation, mesh size regulation and dispersal of exotic species is to be implemented in the river to conserve its rich biological diversity. Detailed studies regarding on the fish assemblage pattern, reproductive biology, stock assessment of indigenous species in the prevailing environmental conditions is the essential

prerequisites for sustainable exploitation and management of the riverine fishery in the river.

Informed consent

Not available.

Data availability statement

Data will be made available on request.

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Declaration of competing interest

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Author contributions

Chelapurath Radhakrishnan Renjithkumar: Conceived and designed the work, Methodology, Formal analysis, Writing – original draft, review & editing. Kuttanelloor Roshni: Writing – original draft, review & editing.

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