ISSN: 0973-4929, Vol. 18, No. (1) 2023, Pg. 311-330

Current World Environment

www.cwejournal.org

Geographic Information System-Based Analysis of Fish Diversity Trends of River Meenachil, Southern Western Ghats, Kerala.

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Abstract

In this study, the fish fauna of different geographical zones of Meenachil River was investigated using the spatial interpolation techniques of the Geographical Information System. The variations in fish diversity trends during the pre-monsoon, monsoon, and post-monsoon seasons from 2016 to 2020 along the longitudinal gradient of the Meenachil River were determined using the Kriging interpolation method and semivariograms. Sixty-seven fish species belonging to 15 orders, 29 families, and 46 genera were recorded from the river during the study period. Twenty-five were endemic to the Western Ghats, three were exclusive to Kerala, five were nearly threatened, and three were vulnerable. The midstream of the river recorded maximum diversity indices ranging from *(H')* 2.608 to 3.171, reflecting the outcome of local river conservation efforts, and the downstream station with the lowest range *(H')* 2.305 -2.643. Cluster analysis showed the spatial similarities in fish diversities between sampling stations. Deterioration in water quality downstream was reflected in the fluctuating levels of TDS (ppm) (21.300±116.828 to 365.000±116.828), Conductivity(μSmcm-1) (42.500±252.372 to 815.000±252.372), Salinity(ppt) (0.100±0.083 to 0.400±0.083) and dissolved oxygen levels(mgL-1) (2.900±0.876 to 5.600±0.876). The study highlights the necessity to broaden local conservation efforts and implement legal measures to protect the habitats and the native fish fauna of the tourism-dominated lower

Article History
Received: 03 November 2022
Accepted: 11 February 2023

Keywords
Conservation Status;
Riverine Fishes;
Semivariograms;
Water Quality.

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Doi: http://dx.doi.org/10.12944/CWE.18.1.26

stretches of the Meenachil River. By integrating data in spatial maps, the geographic component added by GIS gives a clearer insight into the various data and efficiently supports global conservation measures, enhancing biodiversity protection.

Introduction

Gradual changes in fish community composition along the linear gradient of a river from upstream to downstream are better predicted by the longitudinal zonation hypothesis.[1] Tropical and temperate rivers usually exhibit a fairly homogenous river zonation pattern with upstream rithral areas of low species diversity followed by transitional areas with comparatively high diversity and downstream potamal areas with maximum species richness and abundance.[2] Reference 3 mentions the anthropogenic impacts on the downstream of rivers and the deviating trends in fish diversity gradients. The Meenachil River of Kerala is the only river of the Western Ghats, having human inhabitancy right from its root source till its mouth, where it confluence to Vembanad Lake.[4] The riverine ecosystem is under multiple stressors, which include catchment disturbances, water diversions, habitat loss and fragmentation, loss of riparian, water pollution, and overfishing exacerbated by climatic fluctuations, which have resulted in substantial shifts in diversity and distribution patterns of many endemic fishes of the region.[5,6]

Ecological patterns, changes in community composition, and diversity trends can be examined critically using diversity and similarity indices. Distribution and abundance are the main criteria used to ascertain species' status as "threatened" or "endangered" for the implementation of species-targeted conservation measures. The conservation strategy should be more effective by integrating the complementary use of the various methodologies and the improved utilization of the available information.[7] Despite the fact that GIS is getting extra attention in the fields of hydrology and aquaculture management, their adoption for spatial decision support in this area is still moving extremely slowly.[8] The addition of the geographic dimension in the form of GIS provides a better perspective on the diverse data and contributes effectively to global conservation efforts enhancing the conservation of biodiversity by providing integration of information in spatial overlays.[9] GIS has been used in conservation biology not just for identifying and mapping a region's biodiversity but also for identifying and prioritizing the conservation areas by examining the habitat features and alterations for the implementation of proper restoration strategies.[10,11] In order to triangulate its own position, the GPS recovery system uses at least three satellites and between 24 and 32 microwave-transmitting medium earth orbit satellites.[12] To positionize deforestation, river pollution, substratum habitat structure, fish faunal variety, and interpolation, those satellites are currently being used.[8] Several researchers have taken biophysical data from satellite photography and incorporated them into simulation models.[13]

By using the tools for deriving scientific output from the gathered data, GIS and its technologies have added additional flexibility to marine fisheries to produce marine environmental data useful to detect contaminants, keep tabs on fishing activity, map habitats on the sea floor, and quantify the physical and biological characteristics of the water column.[14] For the first time in India, a project including the use of GIS in marine fishing is being carried out along the coast of Karnataka state.[15]

A few GIS-based studies have been conducted on the fish distribution and abundance pattern of marine fish species of the Arabian sea,[16] but no such works have been conducted on the riverine fishes of Kerala.[17] suggested that the application of RS for studies on the environmental characteristics of the oceans could provide a comprehensive picture on fish distribution, abundance, migration, and other information required for monitoring and managing the ocean ecosystems. The International Symposium on Remote Sensing and Fisheries was hosted in 2010 by the Project "Social Applications in Fisheries and Aquaculture using Remotely Sensed Imagery" (SAFARI) and took place in Kochi, Kerala covered the most recent applications to improve fisheries and aquaculture research, particularly in the creation of possible fishing zones.[17]

Studies on freshwater ichthyology in Kerala can be traced back to Bloch's work in the late 18th century, followed by[18-24] made substantial contributions after Francis Day's work to the study of freshwater fishes in Travancore. Despite the several fish diversity studies conducted in the rivers of Kerala, no works have been documented so far on GIS-based zonation and the patterns of fish assemblage in Kerala's rivers. Fish diversity measurements from the Upper Ganges were analysed and mapped utilising spatial interpolation techniques of geographic information systems by.[25] A study was done by[26] using Kriging spatial interpolation methods for the spatial analysis and geographical information system mapping of fish diversity in the Pong reservoir in Himachal Pradesh. From seven locations along the Cauvery River basin in Tamilnadu, India, fish and water samples were collected, examined, and the results were entered into a GIS platform.[8]

Rivers of the Southern Western Ghats are hotspots of many threatened and endemic species of fishes, which emphasize an urgent need to consider their conservation.[27] The fish fauna of the rivers of Southern Western Ghats documented was based on the taxonomy, geographical distribution, and ecological aspects.[28] Due to the growing trend of site-specific distinct threats, such information is insufficient to address the essential concerns pertaining to the regional conservation and management of fish biodiversity[29] conducted a geomorphic assessment of the Meenachil river basin using the Geographic Information system. There are no thorough going efforts to assess the present conservation status of the fishes of Meenachil River, their distribution, and ecological requirements utilizing the spatial interpolation techniques of geographic information systems, other than a few baseline inventories.

This study uses GIS technology to explore how fish diversity changed along the longitudinal gradient during 2016-2020 along the river and to assess the river’s present conservation and fish distribution status.

Material and Methods

Study Area

Meenachil River (Fig. 1) with a length of 78 km has a basin area of 1272 km², with a watershed extending from northern latitudes of 9^0.51’ to 9^0.55’ and east longitudes of $76^0$20’ to 76.55’.[41] The major tributary originates from Annakunnumudi at an elevation of +922m above MSL, confluence to Vembanad lake.[42]

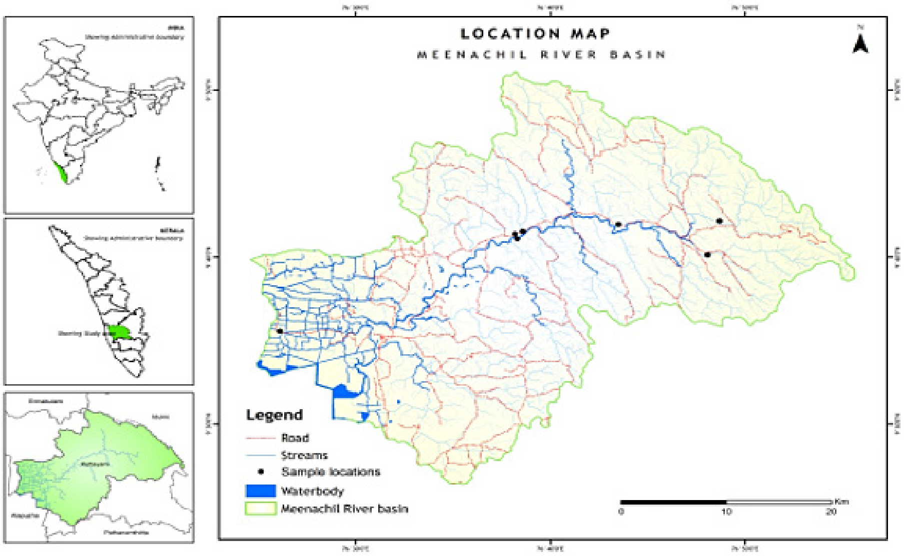


Fig. 1: Map of Meenachil River showing the sampling sites

Sampling Sites

Seven different sampling sites were chosen from the upper, middle, and lower stretches of the Meenachil River. The study sites selected were Teekoy (TKY), Poonjar (PNJ), Bharananganam (BGM), Mutholy (MLY), Cherpunkal (CPL), Kattachira (KTA), and Kumarakom (KUM) (Table 1). The study period ranged from January 2016 to December 2020.

Table. 1: Details of the sampling sites with geographic co- ordinates

Sample site	Geographical location			Shoreline	
	Latitude	Longitude	Altitude	Riparian	Recreation
TKY	76.8115°E	9.7028 °N	274m	High- Partially covered by forest, tea plantation, coconut and pineapple plantation	Tourism destination
PNJ	76.8012 °E	9.6690°N	98m	Medium- Rubber, coconut and pineapple plantation	Not a tourist site
BGM	76.7250°E	9.6994°N	35m	Medium - Rubber, coconut, cocoa and nutmeg	Not a tourist site
MLY	76.6431°E	9.6923°N	31m	High- Bamboo, Rubber, coconut, cocoa and nutmeg	Not a tourist site
CPL	76.6384°E	9.6852°N	22m	High- Bamboo, Rubber, coconut, nutmeg and paddy	Not a tourist site
KTA	76.6364°E	9.6899°N	19m	Very High- “Reserve Riparian Forest” with rich bamboo and *Madhuca nerifolia* plantations.	Not a tourist site
KUM	76.2607°E	9.3534°N	9m	Very low- Paddy cultivation, coconut, mixed vegetation	Backwater Tourism destination

SAMPLING SITES

Fig. 2: Upstream

Fig. 3: Midstream

Fig. 4: Downstream

SAMPLING METHODS

Fig. 5: Trap - perumkoodu

Fig. 6: Midstream casting

Fig. 7: Gill net

Sampling Methods

Fish samples were collected from seven different sites falling in the up, mid, and downstream of the river (Figs. 2, 3 & 4). Collections were done from January 2016 to December 2020. Fish sampling was executed with the help of fishing experts using different gears based on the physical nature of the habitat. In addition, to cast nets, gill nets, and bag nets, specially designed traps were used to collect fish (Fig. 5, 6 & 7). Species for identification were collected and preserved in 70% ethyl alcohol. Identification was done using standard literature by[43,44] and the conservation status was documented according to IUCN red list 2022 with modifications based on updated literature.[45]

Ethical Statement

The least number of fish was used for the study and the remaining ones caught were immediately released into the river without harming them. The study was carried out in accordance with the regulation of the Animal Ethics Institutional Committee.

Water Quality Parameters

Temperature, conductivity, total dissolved solids (TDS mg/L), dissolved oxygen (DO), Salinity (ppt) and pH were evaluated from different sites during different seasons from 2016 to 2020 using a Multiparameter portable meter, HANNA, Model HI 2020-02.

Species Richness and Diversity

Species richness and diversity of the different zones were assessed by Shannon's diversity index, similarities between different zones of the river were compared using by Neighborhood Based Clustering using the software, PAST.[46]

GIS Analysis

Study area boundaries were prepared from DEM (Digital elevation model) downloaded from the USGS website.[47] The data has a resolution of 30m. DEM was used for the delineation of river basin boundaries and morphometric attributes like drainages and their tributaries. The waterbody (River) in the study area was digitized from the Survey of India Toposheets. The data pertaining to fish were collected from different stretches of the river using GPS and cross-checked with google imagery and toposheet for further verification.[42] All the data layers were cross-checked and processed in WGS 1984 datum. Final data sets were converted and plotted over the ArcGIS Platform for further analysis. After the preliminary data entry process, the dataset was subjected to spatial variation analysis using the Inverse distance weighted (IDW) technique interpolation process.[48] IDW software forecasts the values that greatly influence more than those with less influence.[49] DEM and Vectorised GIS layers were used to prepare the various thematic layers depicting the spatial variation and related aspects in the current study.

Result

Fish Species Distribution and Conservation Status

Sixty-seven fish species belonging to 15 orders, 29 families, and 46 genera were recorded from the river during the period. Cypriniformes was the most abundant order having 23 species, and Siluriformes second with 11 species. Cyprinidae was the most dominant family comprising 14 species, followed by Bagridae, comprising six species (Table 2). Twenty-five species were endemic to the Western Ghats (WG), three were exclusive to Kerala (KL), five were categorized as nearly threatened (NT), and three were vulnerable (VU) according to the IUCN criteria. The exotic species reported were distributed in the lower stretch of the river (Fig. 8 & Fig.9 a, b, c & d).

Fish Diversity Along the Longitudinal Gradient

Fish diversity assessed by Shannon- Weiner Diversity Indices as in Table 3 showed significant seasonal variations in seven different sites along the longitudinal gradient of the river and was depicted through GIS mapping (Fig. 9-11). Neighborhood-based clustering of sampling sites based on the similarities in their diversity indices is given in Fig. 12-14.

Table 2: Fish species collected from the upstream, midstream, and downstream sites of Meenachil River during different seasons (2016-2020).

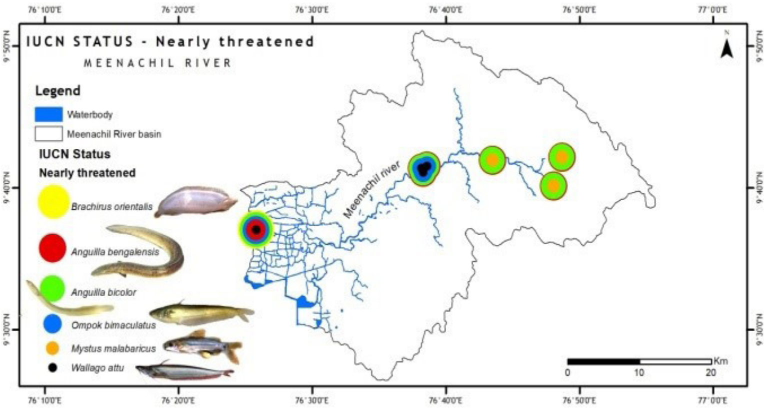
SPECIES NAME	UP			MID		DOWN		IUCN STATUS	Endemicity
	TKY	PNJ	BGM	MLY	CPL	KAT	KUM		
ANGUILLIFORMES									
Anguillidae									
Anguilla bengalensis (Gray, 1831)	✓	✓	✓	✓	✓	✓	✓	NT	
Anguilla bicolor (McClelland, 184I)	✓	✓	✓	✓	✓	✓	✓	NT	
CYPRINIFORMES									
Danionidae									
Amblypharyngodon melettinus (Val, 1844)				✓	✓	✓	✓	LC	
Devario aequipinnatus (McClelland, 1839)	✓	✓	✓	✓	✓	✓		DD	WG
Barilius bakeri (Day, 1865)	✓	✓	✓	✓	✓	✓		LC	WG
Rasbora daniconius (Hamilton, 1822)	✓	✓	✓	✓	✓	✓		LC	
Horadandia brittani (Menon & RemaDevi, 1992)				✓✓	✓	✓	LC	WG	
Cyprinidae									
Hypselobarbus kurali (Menon & RemaDevi, 1995)	✓	✓	✓	✓	✓	✓	✓	LC	WG
Labeo dussumieri (Val, 1842)				✓	✓	✓	✓	LC	
Dawkinsia filamentosa (Val, 1844)	✓	✓	✓	✓	✓	✓	✓	LC	WG
Puntius mahecola (Val, 1844)				✓	✓	✓	✓	DD	KL
Pethia punctata (Day, 1865)	✓	✓	✓	✓	✓	✓		LC	WG
Pethia ticto(Hamilton, 1822)			✓	✓	✓	✓		LC	
Puntius vittatus (Day, 1865)				✓	✓	✓	✓	LC	WG
Systomus sarana (Hamilton, 1822)				✓	✓	✓	✓	LC	
Puntius parrah (Day, 1865)				✓	✓	✓	✓	LC	WG
Haludaria fasciata (Jerdon, 1849)	✓	✓	✓					LC	WG
Puntius bimaculatus (Bleeker, 1863)							✓	NE	
Cyprinus carpio (Linnaeus, 1873)				✓	✓	✓	✓	LC	EX
Osteobrama bakeri (Day, 1873)				✓	✓	✓		LC	KL
Gibelion catla(Hamilton, 1822)				✓	✓	✓	✓	LC	EX
Balitoridae									
Garra mullya (Sykes, 1839)	✓	✓	✓					LC	WG
Cobitidae									
Lepidocephalichthys thermalis (Val, 1846)							✓	LC	
Nemacheilidae									
Nemacheilus triangular (Day,1865)	✓	✓	✓					LC	WG
Schistura scaturigina	✓	✓	✓					LC	

(McClelland, 1839)										
PLEURONECTIFORMES										
Soleidae										
Brachirus orientalis (Bloch & Schneider, 1801)							✓	NT		
SILURIFORMES										
Horabagridae										
Horabagrus brachysoma (Günther, 1864)				✓	✓	✓	✓	VU	WG	
Bagridae										
Mystus oculatus (Val, 1840)							✓	LC	WG	
Mystus cavasius (Hamilton, 1822)							✓	LC		
Mystus montanus (Jerdon,1849)	✓	✓	✓	✓	✓	✓		LC	WG	
Mystus gulio (Hamilton, 1822)							✓	LC		
Mystus malabaricus (Jerdon, 1849)	✓	✓	✓					NT	WG	
Mystus atrifasciatus (Fowler, 1937)							✓	LC		
Siluridae (buttercatfishes)										
Ompok bimaculatus (Bloch, 1794)				✓	✓	✓	✓	NT		
Ompok malabaricus (Val, 1840)	✓	✓	✓	✓	✓	✓		LC	WG	
Wallago attu (Bloch & Schneider, 1801)					✓	✓	✓	✓	N	T
Heteropneustidae (stinging catfishes)										
Heteropneustes fossilis (Bloch, 1794)				✓	✓	✓	✓	LC		
CYPRINODONTIFORMES										
Aplocheilidae (panchax)										
Aplocheilus lineatus (Val, 1846)	✓	✓	✓	✓	✓	✓	✓	LC		
Aplocheilus blockii (Arnold, 1911)	✓	✓	✓	✓	✓	✓	✓	LC		
BELONIFORMES										
Belonidae (Needlefihes)										
Xenentodon cancila (Hamilton, 1822)				✓	✓	✓		LC		
Hemiramphidae (Halfbeaks)										
Hyporhamphus limbatus (Val, 1847)							✓	LC	WG	
Hyporhamphus quoyi(Val, 1847)							✓	NE		
SYNBRANCHIFORMES										
Mastacembelidae(spiny eels)										
Mastacembelus armatus (Lacepède, 1800)				✓	✓	✓		LC		
Macrognathus guentheri (Day, 1865)	✓	✓	✓	✓	✓	✓		LC	WG	
Macrognathus aral (Bloch & Schneider, 1801)							✓	LC		
PERCIFORMES										
Ambassidae (Asiatic glassfihes/perchlets)										
Parambassis ranga (Hamilton, 1822)							✓	LC		
Parambassis dayi (Bleeker, 1874)				✓	✓	✓	✓	LC	WG	
Parambassis thomassi	✓	✓	✓	✓	✓	✓	✓	LC	WG	

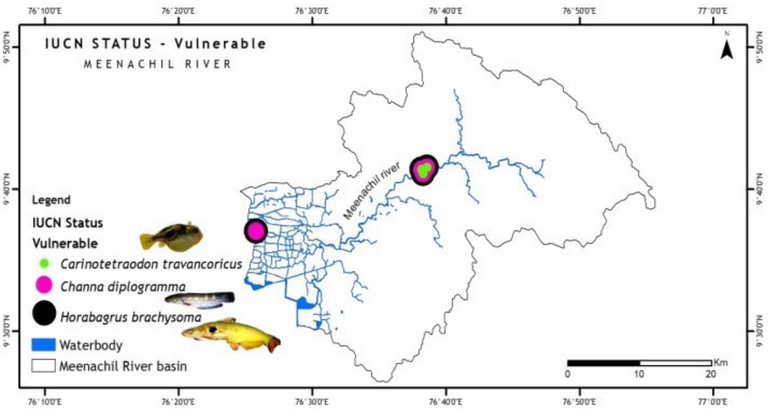
(Day, 1870)									
Scatophagidae									
Scatophagus argus (Linnaeus, 1766)							✓	LC	
Gerreidae									
Gerres setifer (Hamilton, 1822)							✓	NE	
Sillaginidae									
Sillago sihama (Forsskal, 1775)							✓	NE	
CICHLIFORMES									
Cichlidae (pearl spot)									
Etroplus suratensis (Bloch, 1790)				✓	✓	✓	✓	LC	
Etroplus maculatus (Bloch, 1795)	✓	✓	✓	✓	✓	✓	✓	LC	
Oreochromis mossambicus (Peters, 1852)				✓	✓	✓	✓	LC	EX
GOBIIFORMES									
Gobiidae (gobies)									
Glossogobius giuris (Hamilton, 1822)							✓	LC	
Glossogobius aureus (Akhito & Meguro, 1975)							✓	LC	
ANABANTIFORMES									
Nandidae (Leaf fishes)									
Nandus nandus (Hamilton, 1822)	✓	✓	✓	✓	✓	✓	✓	LC	
Pristolepididae									
Pristolepis rubripinnis (Britz & Kumar, 2012)				✓	✓	✓		NE	KL
Anabantiae (climbing perch)									
Anabas testudineus (Bloch, 1792)				✓	✓	✓	✓	DD	
Channidae (snakeheads)									
Channa marulius (Hamilton, 1822)				✓	✓	✓	✓	LC	WG
Channa striata (Bloch, 1793)				✓	✓	✓	✓	LC	WG
Channa diplogramma (Day, 1865)				✓	✓	✓	✓	VU	WG
Channa gachua (Hamilton, 1822)	✓	✓	✓	✓	✓	✓		LC	WG
TETRAODONTIFORMES									
Tetraodontiae (puffer fish)									
Carinotetraodon travancoricus (Hora & Nair, 1941)				✓	✓	✓		VU	WG
ELOPIFORMES									
Megalopidae									
Megalops cyprinoides (Broussonet, 1782)							✓	DD	
CLUPEIFORMES									
Clupeidae									
Ehirava fluviatilis (Deraniyagala, 1929)				✓	✓	✓	✓	DD	
CHARACIFORMES									
Serrasalmidae									
Piaractus brachypomus (Cuvier, 1818)				✓	✓	✓	✓	NE	EX

Belonidae (Needlefihes)									
Xenentodon cancila (Hamilton, 1822)				✓	✓	✓		LC	
Hemiramphidae (Halfbeaks)									
Hyporhamphus limbatus (Val, 1847)							✓	LC	WG
Hyporhamphus quoyi(Val, 1847)							✓	NE	
SYNBRANCHIFORMES									
Mastacembelidae(spiny eels)									
Mastacembelus armatus (Lacepède, 1800)				✓	✓	✓		LC	
Macrognathus guentheri (Day, 1865)	✓	✓	✓	✓	✓	✓		LC	WG
Macrognathus aral (Bloch & Schneider, 1801)							✓	LC	
PERCIFORMES									
Ambassidae (Asiatic glassfihes/perchlets)									
Parambassis ranga (Hamilton, 1822)							✓	LC	
Parambassis dayi (Bleeker, 1874)				✓	✓	✓	✓	LC	WG
Parambassis thomassi (Day, 1870)	✓	✓	✓	✓	✓	✓	✓	LC	WG
Scatophagidae									
Scatophagus argus (Linnaeus, 1766)							✓	LC	
Gerreidae									
Gerres setifer (Hamilton, 1822)							✓	NE	
Sillaginidae									
Sillago sihama (Forsskal, 1775)							✓	NE	
CICHLIFORMES									
Cichlidae (pearl spot)									
Etroplus suratensis (Bloch, 1790)				✓	✓	✓	✓	LC	
Etroplus maculatus (Bloch, 1795)	✓	✓	✓	✓	✓	✓	✓	LC	
Oreochromis mossambicus (Peters, 1852)				✓	✓	✓	✓	LC	EX
GOBIIFORMES									
Gobiidae (gobies)									
Glossogobius giuris (Hamilton, 1822)							✓	LC	
Glossogobius aureus (Akhito & Meguro, 1975)							✓	LC	
ANABANTIFORMES									
Nandidae (Leaf fishes)									
Nandus nandus (Hamilton, 1822)	✓	✓	✓	✓	✓	✓	✓	LC	
Pristolepididae									
Pristolepis rubripinnis (Britz & Kumar, 2012)				✓	✓	✓		NE	KL
Anabantiae (climbing perch)									
Anabas testudineus (Bloch, 1792)				✓	✓	✓	✓	DD	

Channidae (snakeheads)									
Channa marulius (Hamilton, 1822)				✓	✓	✓	✓	LC	WG
Channa striata (Bloch, 1793)				✓	✓	✓	✓	LC	WG
Channa diplogramma (Day, 1865)				✓	✓	✓	✓	VU	WG
Channa gachua (Hamilton, 1822)	✓	✓	✓	✓	✓	✓		LC	WG
TETRAODONTIFORMES									
Tetraodontiae (puffer fish)									
Carinotetraodon travancoricus (Hora & Nair, 1941)				✓	✓	✓		VU	WG
ELOPIFORMES									
Megalopidae									
Megalops cyprinoides (Broussonet, 1782)							✓	DD	
CLUPEIFORMES									
Clupeidae									
Ehirava fluviatilis (Deraniyagala, 1929)				✓	✓	✓	✓	DD	
CHARACIFORMES									
Serrasalmidae									
Piaractus brachypomus (Cuvier, 1818)				✓	✓	✓	✓	NE	EX



a



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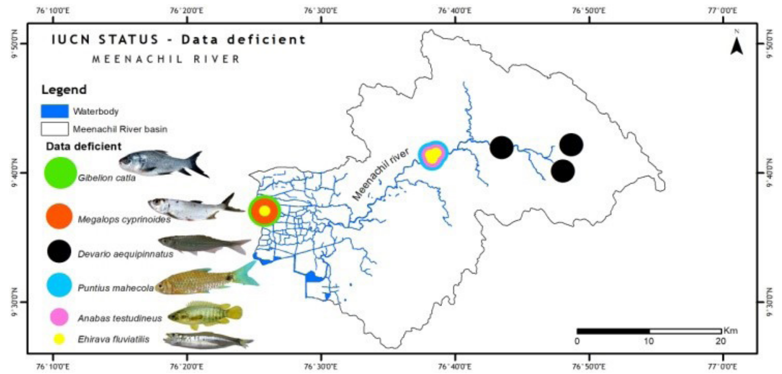

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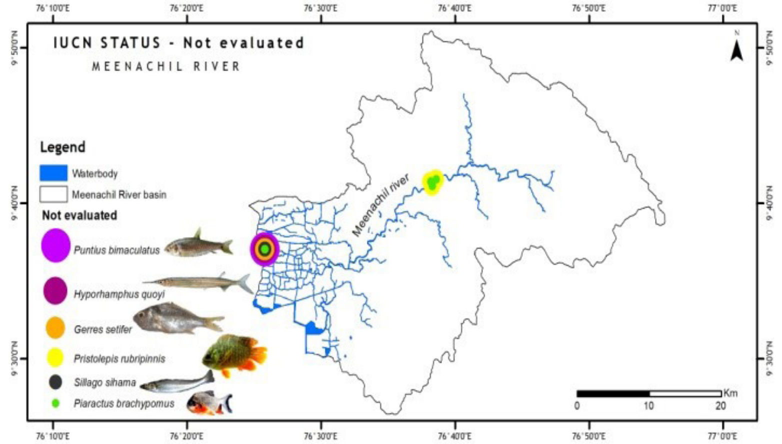

d

Fig. 8: Spatial map showing the IUCN conservation and distribution status of fishes of Meenachil River (a) Nearly Threatened NT; (b) Vulnerable VU; (c) Data deficient DD; (d) Not Evaluated (NE)

Table 3: Shannon- Weiner Diversity Indices (H') of fishes from the different sampling sites from 2016- 2020

YEAR	SEASON	SITE						
		TKY	PNJ	BGM	MLY	CPL	KTA	KUM
2016	PRM	2.622	2.552	2.693	2.777	2.988	3.217	2.567
	M0N	2.354	2.624	2.827	3.019	2.8799	2.783	2.609
	POM	2.348	2.237	2.576	3.077	3.087	2.993	2.499
2017	PRM	2.551	2.635	2.498	3.011	2.967	3.22	2.377
	M0N	2.48	2.526	2.623	3.115	2.836	2.988	2.729
	POM	2.451	2.397	2.217	2.924	2.781	2.962	2.284
2018	PRM	2.498	2.501	2.233	2.951	2.851	3.197	2.638
	M0N	2.523	2.385	2.356	2.962	3.011	3.059	2.713
	POM	2.784	1.926	2.079	2.766	2.913	2.881	2.342
2019	PRM	2.554	2.481	2.554	2.943	2.616	2.992	2.538
	M0N	2.504	2.645	2.484	2.517	2.528	2.062	2.719
	POM	2.346	2.459	2.743	3.216	3.072	3.172	2.493
2020	PRM	2.283	2.482	2.752	3.232	3.024	3.249	1.968

	M0N	2.357	2.494	2.803	2.578	2.654	2.149	2.447
	POM	2.298	2.488	2.698	2.499	2.299	2.692	1.909
AVERAGE	PRM	2.501	2.533	2.5465	2.982	2.889	3.171	2.417
	M0N	2.443	2.534	2.618	2.838	2.781	2.608	2.643
	POM	2.445	2.301	2.462	2.893	2.828	2.944	2.305

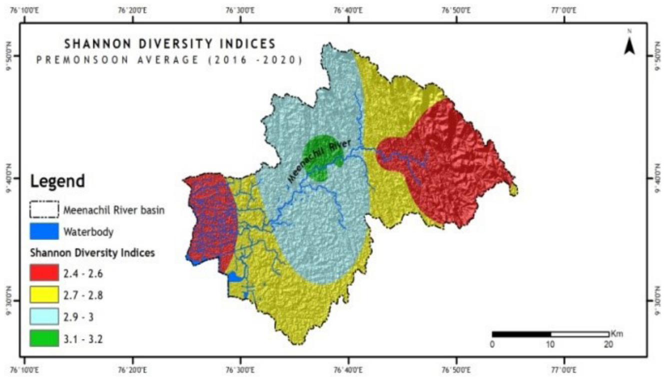

Fig. 9: Map showing the spatial variation of diversity indices during the pre-monsoon period (2016-2020) in Meenachil River

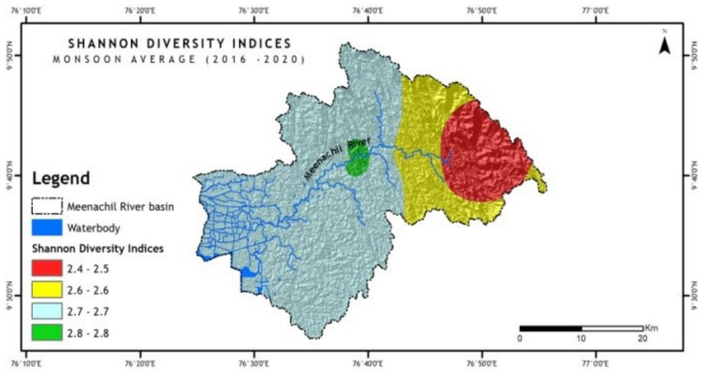

Fig. 10: Map showing the spatial variation of diversity indices during the monsoon period (2016-2020) in Meenachil River

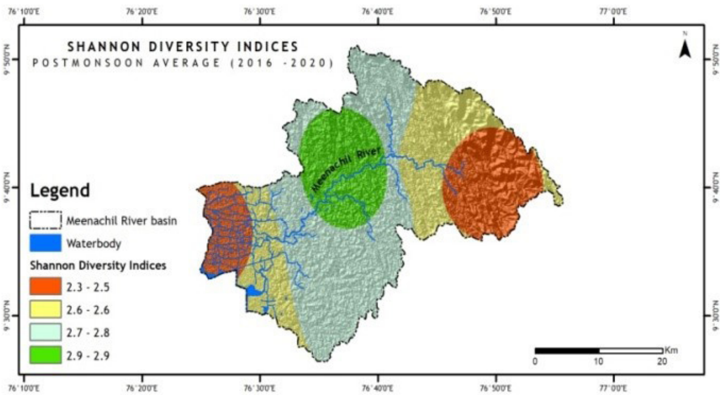

Fig. 11: Map showing the spatial variation of diversity indices during the post-monsoon period (2016-2020) in Meenachil River

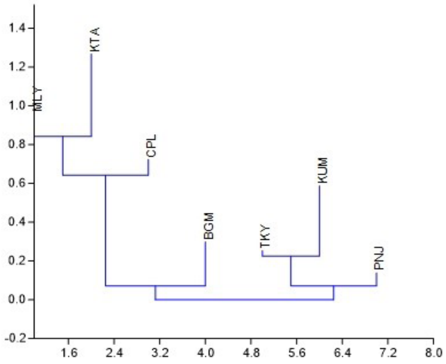

Fig. 12: Neighborhood joining based on the Shannon- Weiner Diversity Indices of different sites during the pre-monsoon season (2016-2020)

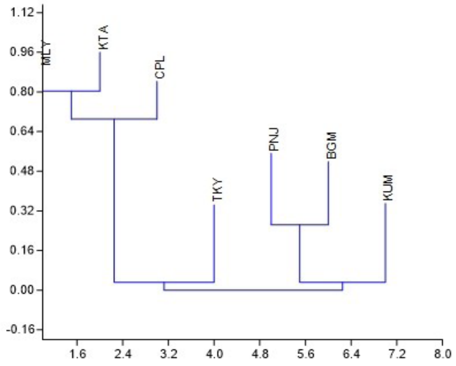

Fig. 13: Neighborhood joining based on the Shannon- Weiner Diversity Indices of different sites during the monsoon season (2016-2020)

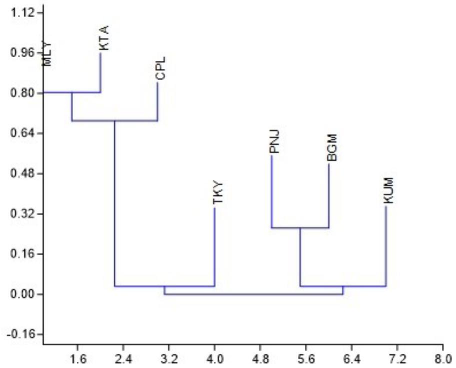

Fig. 14: Neighborhood joining based on the Shannon- Weiner Diversity Indices of different sites during the post-monsoon season (2016-2020)

The Shannon diversity indices of seven different sampling sites (Table 3) for the study period indicated a strong relationship with overall species richness, having considerable variations ranging from a minimum of 1.909 at Kumarakom during the post-monsoon of 2019 to a maximum of 3.249 at Kattachira during the monsoon of 2019. Kattachira zone showed maximum diversity, consistently maintained over the three seasons from 2016-2020, peaking during the post-monsoon period (Fig. 9-11).

In Neighborhood joining based on Shannon diversity indices, the midstream sites formed a cluster during all three seasons, with the Kattachira site out-grouping the rest, having the highest diversity index of all other locations throughout the seasons. The upstream site Teekoy clustered with the downstream site Kumarakom showing dwindling diversity at the headwaters and estuarine zone. Poonjar and Bharananganam clustered together due to their similar diversities (Fig 12-14).

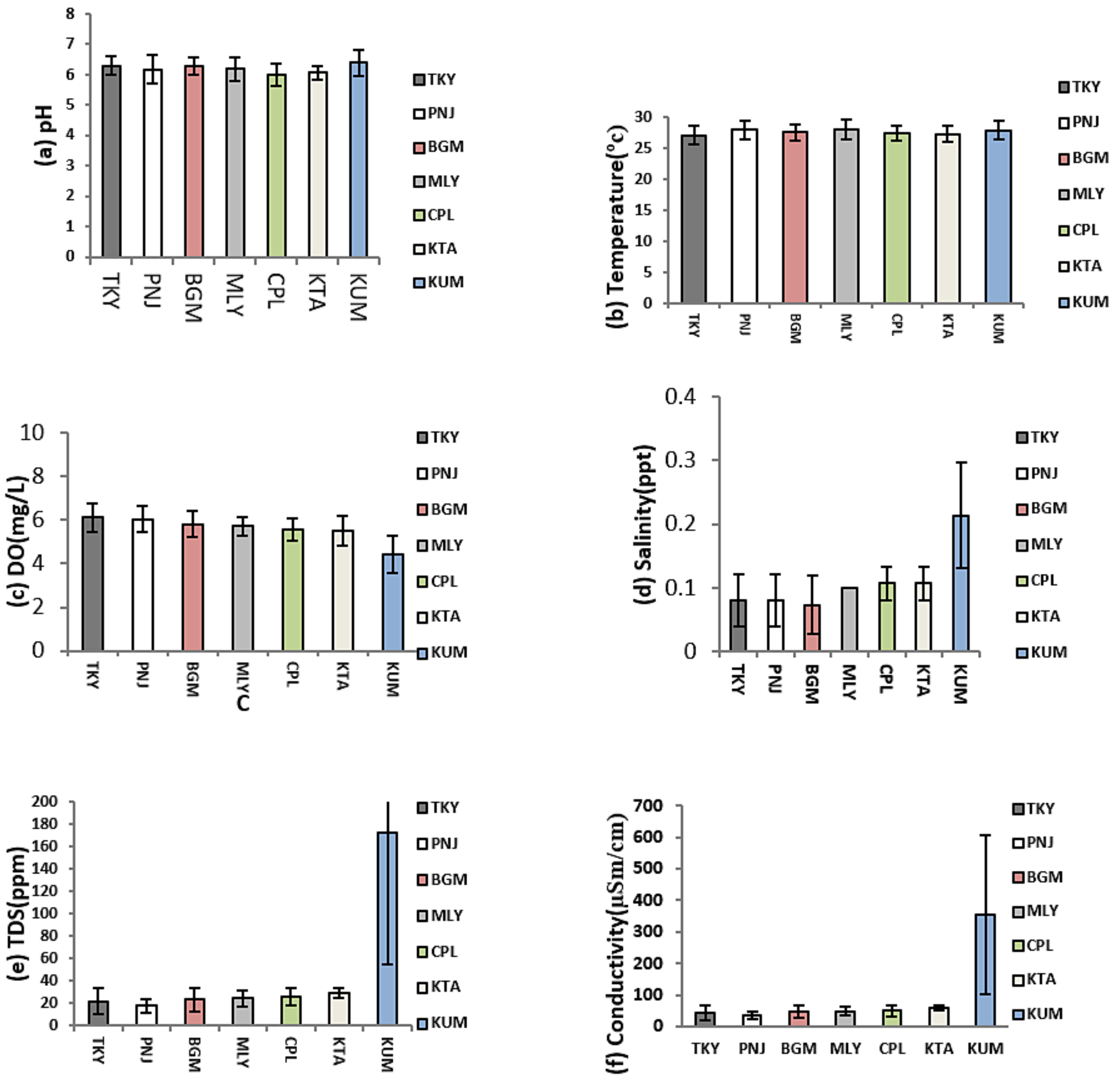

Fig. 15: Mean of water quality parameters assessed from different sites of Meenachil River (2016-2020) (a) pH(b)Temperature (c)Dissolved Oxygen (DO) (d) Salinity (e) TDS (f)Conductivity

Among the water quality parameters, total dissolved solids, conductivity, salinity, and dissolved oxygen varied considerably from upstream to downstream stream stretches of the river. Their means showed maximum fluctuations in the downstream Kumarakom station. A more or less uniform temperature and pH were maintained at different sites from 2016-2020 (Fig. 15 a-f).

Discussion

Conservation of riverine fish diversity at the regional level needs spatially mapped information on the current trends of fish diversity and site-specific conservation targets at a relatively accurate scale.[50] GIS-based research comprised a breakthrough in revealing the trends of riverine fish diversity and prioritizing global conservation.[51] In Meenachil River, the lowest fish species heterogeneity was recorded at the Teekoy headwaters, increasing towards Poonjar and Bharananganam down the longitudinal gradient. Diversity increased towards the midstream stations, Mutholy and Cherpunkal, with maximum diversity recorded at the Kattachira site (Table 3 & Fig. 9-11). From the midstream, diversity and abundance were declining towards the estuarine downstream zone of the river at Kumarakom station, where the river confluences to Vembanadu Lake. Contrary to forecasts of higher species richness at the downstream reaches of tropical rivers, the Meenachil River's unexpected species richness and abundance were found in the midstream stretch rather than the downstream estuarine zone.[3] The decline in fish diversity and abundance in rivers due to habitat destruction and deterioration in water quality was reported.[52]

The present study results were consistent with Huet's longitudinal fish zonation concept,[53] emphasizing different river zones along the longitudinal gradient with specific community structures. The headwater system of rivers with low diversity was usually occupied by small-sized nektonic fishes restricted to the region mainly dependent on allochthonous resources, *N. triangularis, S.scaturigina, G. mullya, P. fasciata, B. bakeri, and M. guntheri,* while the downstream is home to bigger species that are sustained by autochthonous resources.[1,54]

The midstream geographical zone of Meenachil River was found to be the most diverse region, which maintained consistently high diversity throughout the study period from 2016 to 2020 despite seasonal variations (Table. 3 & Fig.9-11). Species richness generally increased with the area sampled.[55] Leaving the headwater tributaries Teekoy and Poonjar, the river gradually widens from Bharananganam and forms the open channel of the midstream zone. The sites Mutholy, Cherpunkal, and Kattachira, falling within the wide-open channel of the river, showed maximum diversity (Table 3), and shared almost similar taxa representations (Fig. 12-14). The order Cypriniformes was 17 in number representing the highest number of taxa (Table. 2). Nearly threatened species (NT) *Anguilla bengalensis, Anguilla bicolor, Ompok bimaculatus* and *Wallago attu,* vulnerable species (VU) *Horabagrus brachysoma, Channa diplogramma* and *Carinotetraodon travancoricus*, data deficient species (DD) *Devario aequipinnatus, Puntius mahecola, Anabas testudineus and Ehirava fluviatilis*, and the not evaluated species (NE) *Pristolepis rubripennis* and *Piaractus brachypomus* were found in the midstream zone (Fig. 8a-d). Species distribution pattern showed more addition than a replacement from the upstream to downstream,[56,57] with a positive relationship between fish size and river width.[1,54,58] The highest heterogeneity, maximum abundance, and a maximum number of large-sized fish species were characteristic of the midstream zone of the Meenachil River. The larger species were the *W. attu, C. diplogramma, C. marulius, Mastacembelus armatus, A.bengalensis,* and *Gibelion catla.* As the stream size increases, more resources and different niches become available, allowing the co-existence of species from the same trophic level, which resulted in increasing species richness.[59-61] The midstream stretch receives several tributaries linked to the major flood plains of the river basin.[62] reported the proximity of rivers to flood plains as another significant factor contributing to the higher species richness and diversity of the river's middle reaches than the upper stretches.

"The fish diversity hotspot" Kattachira station of Meenachil River consistently maintained high diversity throughout the study period. The region is ecologically unique, with a 'Reserve Riparian Forest' belt and lateral connectivity to the floodplains of the river. The higher fish diversity and unusual abundance of species were in line with the findings of,[63] describing the riparian zone as one of the most influencing "in-stream diversifier" elements that provide leaves, branches, and wood debris yielding to complex microhabitat patterns, including the riffles, pools, and runs which sustained high species richness.

From the midstream, diversity and abundance were declining towards the downstream estuarine zone of the river, the Kumarakom station, where the river confluences to Vembanadu Lake (Table.3 & Fig.9-11). The wide-open channel of the river splits into distributaries of smaller size in the Kumarakom station before its confluences (Fig. 1). In addition to the true freshwater fishes, the downstream fauna includes secondary species, *Brachirus orientalis, Megalops cyprinoides, Scatophagus argus, Ehirava fluviatilis, Gerres setifer,* and *Sillago sihama* which are the anadromous migrants to the estuarine zone of the river from the Arabian Sea. The affected downstream stretch homes five nearly threatened species *Anguilla bengalensis, Anguilla bicolor, Brachirus orientalis, Ompok bimaculatus AND Wallago attu, two vulnerable species, Horabagrus brachysoma* and *Channa diplogramma;* four data deficient species *Anabas testudineus, Megalops cyprinoides, Ehirava fluviatilis, and*

Puntius mahecola; and five not evaluated species *Hyporhamphus quoyi, Gerres setifer, Silago sihama, Puntius bimaculatus and Piaractus brachypomus* (Fig. 8 a-d).

A major ecological problem affecting the downstream of the Meenachil River is the temporary retention of water in the lower stretches due to the closure of the barrage, Thanneermukkam Bund. The barrage was constructed in 1974 across Vembanad Lake and the Arabian Sea to prevent saltwater intrusion into the low-lying paddy fields.[6] Closing the bund for six months every year prevents the easy discharge of waters from the rivers before emptying into the Arabian Sea. Organic pollution of the Lake due to the closure of the bund and the drastic decline of the fish populations in Vembanad backwaters and associated water bodies was documented by.[64,5] Retention of water in the interconnected distributaries has resulted in the water quality deterioration in the river's lower stretches. This was indicated by the extremely high TDS, conductivity, varying salinity, and very low levels of dissolved oxygen recorded from the Kumarakom station during the present study (Fig. 15 e, f, d & c). In addition, in the past two decades, there has been significant growth in backwater tourism, specifically in the estuarine zone of the river and Vembanadu Lake reported.[65] Approximately 187 tons/day of solid waste ultimately reach the Lake from the houseboats, resorts, and hotels without adequate treatment. The downstream fish fauna gets regularly exposed to fluctuating environmental attributes, particularly salinity, conductivity, and TDS, along with the accumulation of high levels of pollutants from various sources. Pollutants from various sources have exacerbated the region's water quality deterioration.[66] The riparian belt has also been cleared away for tourism development.[67]

Analysis and Geographic Information System-based mapping by[25] using the spatial interpolation methods of the many assessments of the Upper Ganges basin's freshwater fish biodiversity showed disparities in spatial overlays which is in agreement with the present study results of varying diversity trends in the different zones of Meenachil River. The upper northern section of the Ganga1 and the mid and lower southern parts of the Alaknanda/ Pindar subbasins were found to have increased species abundance and diversity, according to the composite evaluation of species abundance and index of fish diversity. Contradictory to the above findings, in the present study, the mid-stream zone of the Meenachil River maintained consistently high diversity throughout the study period when compared to the upstream and midstream geographical zones of the river. The abundance of threatened fishes was also found to be fairly distributed among the tributaries of the main waterways of all three subbasins of the Upper Ganges whereas the highest distribution of the threatened species was confined to the lower stretches of the Meenachil River. GIS-based fish distribution analysis of Meenachil River reveals the significance of extending the local conservation efforts to the river's most pollution-affected zones to protect the threatened endemic fish species of the river.

Conclusion

The midstream zone of the Meenachil River supported diversified fish species and a high degree of endemic, nearly threatened, and vulnerable species. The declining native fish diversity from downstream stretches of the Meenachil River has reflected the extent of habitat alterations and pollution due to anthropogenic interventions. Higher diversity recorded at the midstream stretches of the Meenachil River reflected the outcome of local conservation efforts initiated by "Meenachil Nadee Samrakshana Samithi," which was acknowledged by the Government of India as the "Bhaghirath Prayas Samman" on the 'River Day' of 2017.[68] Similar efforts should also be extended to the tourism-affected downstream stretches to restore its rich fish faunal diversity. The integration of geographic features with the help of GIS provided a better perspective on the fish diversity data of Meenachil River contributing effectively to regional and global biodiversity conservation efforts. The present study recommends that local conservation efforts should continue along with the bio-banking to check further species loss, adoption of sustainable management policies for riverine habitat and biodiversity conservation, ecosystem functioning and resilience, and the livelihood of humans, to provide a better long-term basis for the conservation of freshwaters and its unique fish resources considering the present global biodiversity crisis.

Acknowledgement

The authors are grateful to the Principal, Dr Icy K John of Mar Thoma College Thiruvalla, for providing the necessary work facilities. We are greatly indebted to the fishing craft and gear operators and "Meenachil River Restoration Samithi" members for their support during the fieldwork and data collection during the study period.

Funding

No funding was received for the work.

Conflicts of interest

The authors declare that they have no conflict of interest.

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