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Fisheries as ecosystem services: A case study of the Cauvery river basin, India

V. Pownkumar[1], P.S. Ananthan[1]*, A. Ekka[2,3]*, Neha W. Qureshi[1] and Velumani T[1]

[1]Fisheries Economics, Extension and Statistics Division, ICAR- Central Institute of Fisheries Education, Mumbai, India, [2]ICAR-Central Inland Fisheries Research Institute, Barrackpore, India, [3]Department of Water Management, The Delft University of Technology, Delft, Netherlands

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EDITED BY
Angela Helen Arthington,
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Jason DeBoer,
Illinois Natural History Survey, United States

*CORRESPONDENCE
A. Ekka,
A.Ekka@tudelft.nl
P.S. Ananthan,
ananthan@cife.edu.in

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Habitat alterations and fragmentation caused by anthropogenic modifications of the riverine landscape have affected fish biodiversity by reducing the number of fish species. Fish are a major element of the aquatic environment, and they play an important role in maintaining ecosystem resilience. However, an incomplete understanding of links between river ecosystem functions and processes with fisheries is one of the major reasons for the alarming rate of decline of fish species. Recognizing the ecosystem services generated by fish populations is essential and is one step toward comprehensive, ecosystem-based management of riverine fisheries. Therefore, this paper is motivated by the need to explore the dimensions of fisheries as an ecosystem service. The data was collected from primary field observations and checklist-based key informant interviews at the seventeen fishing sites selected across an 800 km river stretch of the river. In addition, two focused group discussions with fishers at two sampling sites were held to provide first-hand knowledge of ecosystem services generated by fisheries. At first, the role of fisheries in generating ecosystem services for riverine ecosystem functioning and human demands is outlined using the Millennium Ecosystem Assessment approach. Then, the findings of a survey carried out from the headwaters to the delta of the Cauvery river are presented detailing the fisheries provisioning services, livelihoods, and other ecosystem services. The findings showed that the provisioning and cultural services are highly represented among the four categories of ecosystem services identified by the Millennium Ecosystem Assessment. However, in the literature reviewed, supporting, and regulating services are not well-represented. Based on these findings, the applicability of the ecosystem service concept can be elaborated to inform researchers and policymakers to enhance conservation efforts for fisheries.

KEYWORDS

ecosystem services, fisheries, livelihood, Cauvery, economic valuation, India

1 Introduction

Since 1970, the global freshwater species have declined to 83% (Grooten and Almond, 2018). The decline in biodiversity of freshwater ecosystems was strongly affected by human activities (Jenkins, 2003; Grizzetti et al., 2016). Climate change and anthropogenic modification of river hydrological regimes are two of the main threats to freshwater biodiversity (Nilsson et al., 2005; Vörösmarty et al., 2010; Dias et al., 2017; Ekka et al., 2020). No doubt, the alteration of river water has benefited human development in many ways (Lehner et al., 2011) but it has impaired the ecological integrity of rivers (Grizzetti et al., 2016; Roobavannan et al., 2017; Datry et al., 2018). The modification of these natural river flow caused numerous effects on the ecological status of rivers (Poff et al., 1997), and disturbed the natural biological cycle of the aquatic species (Dudgeon et al., 2006; Lakra et al., 2011; Ziv et al., 2012). Fish is one of the most significant components of freshwater ecosystem function which also contribute to providing food and livelihood for millions of people around the world. (The World Bank 2012; Lynch et al., 2016).

However, the role of fisheries has been overlooked in many ecosystem management decisions, especially in the context of competing for freshwater uses for irrigation, hydropower, and domestic and industrial use (Cooke et al., 2016). The importance of fisheries for human welfare has focused more on generating livelihood, food production, and providing nutritional security (Holmlund and Hammer, 1999; Smith et al., 2005). The contribution of freshwater fisheries goes beyond just being a source of food and livelihood. The fish populations play a crucial role in maintaining the river ecosystem that contributes to river sustainability and resilience (Holmlund and Hammer, 1999). However, an incomplete understanding of linking river ecosystem functions and processes with the fisheries is one of the major reasons for declining fish species at an alarming rate (Fausch et al., 2002). Much of the understanding of the aquatic species is based on observation and experiments on organisms and habitats in fragments, limiting our understanding and conservation efforts.

Intergovernmental and national climate assessments have pointed to an ecosystem-based approach to promoting resilient ecosystems and fisheries (Barange et al., 2018; Holsman et al., 2020). This approach to fisheries management takes into account all significant ecological, functions and services (Garcia and Cochrane, 2005). For example, the geomorphic patterns and landforms in the river channel and floodplains such as gravel beds, meanders, gravel bars, and oxbow lakes are critical for aquatic habitats including fisheries (Newson and Newson, 2000; Grabowski et al., 2014). These formations facilitate ecological function, habitat characteristics, and species assemblages which in turn contribute to the regulation of various ecosystem services (Newson & Newson, 2000; Thorp et al., 2006; Grabowski et al., 2014). Fish plays an important role in the circulation of nutrients and energy at different trophic levels regulating the food web dynamics of the ecosystem (McManamay et al., 2011). They are often used as bio-indicators for evaluating the level of pollution in aquatic ecosystems (Authman et al., 2015; Saad et al., 2022). Therefore, recognizing the ecosystem services generated by fish populaces is essential and is one step toward comprehensive ecosystem-based management of riverine fisheries (see Figure 1)

The Cauvery River in southern India is one such river that has been significantly altered. Out of 30 world river basins marked for the protection of aquatic biodiversity, nine basins are from India and Cauvery basin is one of them. The alterations of the river flow regime over the past centuries had helped to expand irrigated areas in the basin, securing water availability during water stress conditions (Vanham et al., 2011). The construction of dams affected the river flow regime. The low flow in rivers impacts the aquatic life cycle resulting in fewer fish caught in the river. The loss of fish directly affected the fishers' livelihoods and the introduced non-native fish species (*Tilapia sp*) compensates for the loss of livelihood through it adversely impacted the fish species diversity, especially in reservoirs. The decline in fishery diversity and production reflects considerable ecological impacts on lower trophic levels.

The challenge is to understand how ecosystem functions and processes in the river landscape are linked by the fish movement to influence the persistence, abundance, and productivity of the fish population including the ecosystem services offered by the river landscape. As a result, the paper is motivated by the need to investigate different aspects of fisheries as ecosystem services. Initially, the role of fisheries in generating ecosystem services is documented using the Millennium Ecosystem Assessment, 2005 approach. Following that, different dimensions of ecosystem services are explored with specific references to the Cauvery River basin based on the literature review and field visits. Thus, this study will advance our understanding of the ecological, social, and economic importance of fisheries. It may also aid in the governance of fisheries resources, management of stakeholders, and the resolution of resource conflicts related to water allocation issues.

2 Methodology

2.1 Study area

Cauvery River is one of the major rivers in peninsular India and is called Dakshin Ganga. The Cauvery basin extends between 75° 27′ and 79° 54′ E, and between 10° 9′ and 13° 30′ N. It is the biggest river in South India and the 8th largest in the subcontinent and ranks as a medium river at a global level. It rises at an elevation of 1,341 m at Talakaveri on the Brahmagiri range in the Western Ghats in the Kodagu district of Karnataka and its many distributaries drain into the Bay of Bengal with the main branch at Poombukar in Nagapattinam district, Tamil Nadu. The total

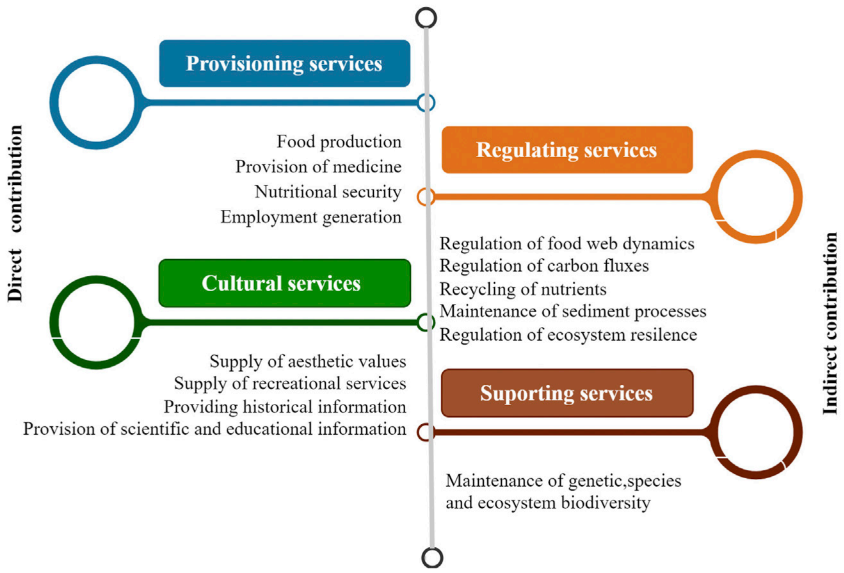

FIGURE 1
An overview of ecosystem services generated by riverine fisheries. Adapted from (Holmlund and Hammer, 1999).

length of the river from origin to an outfall is around 800 km. It extends over the states of Tamil Nadu (42%), Karnataka (54%), and Kerala (4%). There are three sub-basins and 132 watersheds falling in the basin. Major reservoirs such as Harangi, Kabini, Krishna Raja Sagar, Mettur, Bhavanisagar, check dams such as Mayanur, Mukkombu, Kallanai, Anaikarai and major fishing villages such as Tirumakudalu Narasipura, Sathegala, Hogenakkal, Bhavani, Kollidam and Pazhayar dot the course of river Cauvery. It has 3 sub-basins i.e., the upper basin (Harangi- Krishna Raja Sagar), the middle basin (Kabini-Bhavani), and the lower basin (Mayanur-Pazhayar) (Cauvery basin report, 2014) with 96 dams, 10 barrages and 16 anicuts or weirs built across the main river and the tributaries. The Cauvery River is essential to the livelihood of inland fishers. More than 4,000 fishers rely on the Cauvery River for food production, employment generation, nutritional security, and livelihood support. The Cauvery is critical to the habitat for many fish species. For example, the Mahseer population which is known as hump-backed mahseer (*Tor remadevii*) is listed as endangered on the IUCN red list and is found only in the Cauvery basin (Pinder et al., 2015; Sreenivasan et al., 2021). Along the river, many old fish sanctuaries are considered sacred which has the potential to contribute significantly to biodiversity conservation.

2.2 Methods and data collection

A total of 17 fishing sites were selected across the river stretch, i.e., lower, middle, and upper which includes five major reservoirs, three minor dams/check dams, and nine fishing villages (Figure 2). Each fishing site was selected at roughly 40–50 km distance, with the purpose to cover the entire stretch to capture all the necessary information on fisheries and associated ecosystem services provisioning along the Cauvery River. For more information, see Supplementary Materials. Based on Figure 1, the data collection of specific ecosystem services is described below.

2.2.1 Regulating and supporting services

An extensive review of the literature was conducted to identify the regulating and supporting services associated with the Cauvery River Basin. Biophysical and environmental science studies that are directly or indirectly linked to ecosystem functions and fisheries were also considered. Using the regulating and supporting services as indicated in Figure 1, the literature was searched using the electronic database Scopus with keywords such as "Cauvery" and "watershed/basin/river". The keywords used to search literature are indicated in Table 1. The title and abstract of each publication were scrutinized to fit references with the aim of the search. Papers specifying evidence of linking riverine ecosystem function and processes with fisheries are further analyzed and included in the sample.

2.2.2 Provisioning services

Products obtained from the ecosystem are traded in the market and employ a large number of people. The present study identified four kinds of provisioning services in the river which include food production, nutritional security, employment generation, and production of medicine. Cauvery river supports

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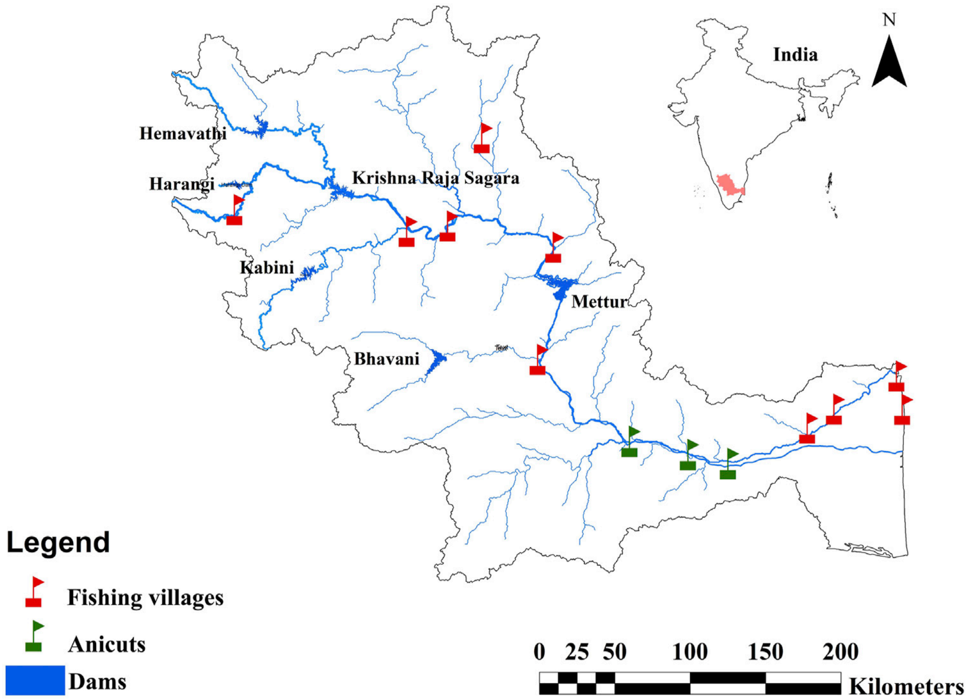

FIGURE 2
Location of sampling sites on the cauvery river.

TABLE 1 Different keyword combinations for the literature search.

Ecosystem service type	Different keywords combination were used with “cauvery” and “watershed/basin/river”
Regulating services	Food web, Trophic level, Population dynamics, Bioturbation, sediment processes/sedimentation, Carbon cycle/carbon flux/carbon-fixation/net primary productivity bio-indicator, Pollution indicator
Supporting services	Biodiversity/fish species richness

livelihood based on commercial fishing, subsistence fishing, recreational fishing, and fish market (ing). The market value method was adapted to evaluate commercial fishing in the river. The fish catch for every 40–60 km stretch in each of the three basins was estimated by taking the average of fish catch estimated from the respective sample fishing sites located within each of the three basins. For instance, the Upper Basin which runs for about 160 km included four sample sites where a survey was conducted at Kanave, Harangi, Valnur, and Krishna Raja Sagar. Considering the major type of fishery and the fish catch reported in this region, Fishers were asked for their daily average fish capture, which was then extrapolated to the entire year while accounting for the number of fishing days and months to determine the Total Fish Catch (TFC). Seasonality (peak and lean seasons) was also taken into account since the quantity of fish caught frequently changes over time. Similarly, it was done for the Middle and Lower River basins.

The primary observation and key informant interview (KII) methods were used, besides literature review, to obtain information on reservoirs, riverine stretches, fishing villages, and fish markets. In this method, information was obtained directly by visual observation, photography, and interaction with people present at each site. This was supported and triangulated with the help of interviews with key informants from a wide range of people including community leaders, professionals, and experienced fishers who have first-hand knowledge about fishing. Key informants’ interviews were carried out using a detailed checklist to get a first-hand idea about the dependent fishers, fishing efforts and catch, intuitional arrangements, services, co-operatives, fish consumption at home, fish marketing, etc.

In addition, two focused group discussions (FGD) were carried out. First FGD was conducted with fishers to know in detail about the leasing and licensing practices for fishing in the riverine stretches, and the prevalence of any conflicts between the leasing/licensing authority and the lessees. Second FGD was conducted with fishers in Mukkombu to understand fishing, recreational, and tourism services obtained from the Cauvery River. Triangulation is a powerful technique that facilitates the validation of data through cross verification from two or more sources. This technique has been used to verify the data collected, e.g. number of active fishers, fishing days, average daily fish catch, average selling price, and the seasonal variations in effort catch and price were collected directly from at least two fishers at each site as well as cross verified with observed fish catch, and the key informants including fisheries department staff for authentication.

$$\text{The economic value of fish} = \text{Total Fish Catch (TFC) X Average Fish Price (P)}$$

Where TFC is the Total Fish Catch (or produced), and P is the average fish price per kg of fish which is determined by the local market.

Number of people employed in fisheries-related occupation were evaluated through fisheries cooperative society membership, leasing, and licensing in major reservoirs/ barrages and fishing villages along the Cauvery River basin.

2.2.3 Cultural services

The study identified recreational activities, spiritual expression (local deity and ritual of ancestral worship), and aesthetic values as the major cultural services provided by the river. The primary data has been collected through visual observation and interaction with key informants. For identifying the places of worship (temples and other sites of worship), Google maps were used.

3 Results

3.1 Regulating services

3.1.1 Regulation of food web dynamics

Fisheries play an important role in regulating the food web dynamics of the riverine and floodplain ecosystem (Khan et al., 2015; Panikkar et al., 2021). For example, in freshwater systems, the feeding behaviour of many adult and young fishes has cascading effects on population dynamics down the food web (Carpenter et al., 1985). They also form an important part in the development and maintenance of the microbial food web structure (Felip et al., 1996; Simon and Wunsch 1998). The feeding pattern of fishes can also influence the temporal availability of nutrients and the potential for algal blooms in nutrient-rich lakes, since fish mineralize nitrogen and phosphorus through excretion and defecation, thereby making these nutrients available for primary production (Schindler, 1992). As a result, knowledge of the food-web structure and ecosystem features is required for developing management protocols for conserving biodiversity and maintaining the fish population (Sarkar et al, 2018; Panikkar et al., 2021).

The research on fisheries providing regulating services has not been recognized in terms of riverine ecosystem services research in India. However, some case studies indicated the importance of fish in regulating food web dynamics in the Cauvery basin (Khan et al., 2015; Panikkar et al., 2021). For example, the food web dynamics study of the Hemavathi reservoir focused on understanding the food-web structure and energy flow of fishes at different trophic levels (Khan et al., 2015). When fed by other organisms, fish, including eggs, fry, and carcasses, serve as passive links between aquatic, aerial, and terrestrial ecosystems, contributing to other food webs (Panikkar et al., 2021). Food web models that explicitly consider energy flow from pelagic and benthic sources will provide a more realistic energy flow template for understanding the regulation of ecosystem functioning which has direct implications for river ecosystem sustainability and resilience (Vander Zanden and Vadeboncoeur, 2002).

3.1.2 Maintenance of the sediment processes

A limited number of studies about the relationship between fish, bioturbation, and the structuring of bottom conditions have been done in rivers and lakes (Persson and Svensson, 2006). Fish acts as ecological engineers (Persson and Svensson, 2006) by changing the nutrient level through a shift in the fish community composition (Persson and Svensson, 2006). Moreover, significant effects of fish on both phosphorus and nitrogen concentrations were reported in the lake sediments (Persson and Svensson, 2006). Similarly, there were cases of salmonids bioturbation reported in streams (Montgomery et al., 1996). No similar studies, however, were published specifically for the Cauvery River basin.

3.1.3 Regulation of carbon fluxes from water to the atmosphere

The study by Schindler. (1992) illustrates that the structure of fish communities can regulate the carbon-fixing capacity of nutrient-rich lakes, and thus indirectly mediate the flux of carbon between the lake and atmosphere. However, no comparable studies were recorded, notably for the Cauvery River basin.

3.1.4 Recycling of nutrients and pollution indicator

Fishes act as active and passive transporter of nutrients and energy in the aquatic environment and thereby link the aquatic and terrestrial ecosystem (Fore et al., 1994; Vander Zanden and

Vadeboncoeur, 2002). Their movement patterns, including daily, seasonal, and yearly migration patterns in an aquatic environment contribute to the recycling of nutrients (Fore et al., 1994). In addition, the fish species richness, abundance, and composition, also influence the nutrient composition of the aquatic environment and can be used for monitoring water quality in rivers and lakes (Fore et al., 1994; Polis et al., 1997).

More specifically for the Cauvery basin, few studies have been reported where the impact of river pollution was observed on fish (Saravanan et al., 2003; Tawari-Fufeyin and Ekaye, 2007; Bhuvaneshwari et al., 2012; Authman et al., 2015). More importantly, the fish fauna in the Cauvery River was negatively impacted by pollution resulting in reduced species diversity (Saravanan et al., 2003). Some authors reported that the fish *Parastromateus niger* found in the Cauvery River has shown a higher concentration of zinc due to river pollution and thus it can be used as a bio-indicator species for zinc pollution in an aquatic environment (Bhuvaneshwari et al., 2012). Metals induce an early response in the fish as evidenced by alterations both at structural and functional levels of different organs including enzymatic and genetic effects and therefore can be used as pollution indicator (Tawari-Fufeyin and Ekaye, 2007; Authman et al., 2015; Anandakumar and Thajuddin, 2021).

3.2 Supporting services

3.2.1 Maintenance of genetic, species, and ecosystem biodiversity

Fisheries play a major role in maintaining genetic, species, and ecosystem diversity. The ichthyofauna diversity of the river Cauvery has recorded 146 fish species belonging to 52 families (Koushlesh et al., 2021). The majority of the fish species that occur in the Cauvery basin are assessed as "Least Concern" on the IUCN Red List of Threatened Species (IUCN, 2021), however, eight species are threatened including two that have been assessed as 'Critically Endangered', four as 'Endangered' and two as "Vulnerable" (Sreenivasan et al., 2021). Fifteen of these species are endemic to the Western Ghats region, of which eight have a restricted range and occur only in the Cauvery River system (Sreenivasan et al., 2021). The Mahseer population known as the 'hump-backed' Mahseer (*Tor remadevii*) is considered critically endangered according to the IUCN Red List and is on the verge of extinction (Pinder et al., 2015). The invasion of highly carnivorous suckermouth catfish (family Loricariidae, species unverified) has become a potential threat to the native aquatic biodiversity of the Cauvery River basin (The Hindu, 2015).

3.3 Provisioning services

3.3.1 Food production and nutritional security

Major fishes found in the Cauvery River include Catla (*Labeo catla*), Rohu (*Labeo rohita*), Mrigal (*Cirrhinus cirrhosis*), Nile Tilapia (*Oreochromis niloticus*), African catfish (*Clarias gariepinus*) Spiny eel (*Mastacembelus armatus*) and Murrel (*Channa striata*). Minor fishes include Pangas (Pangasius pangasius), Freshwater Gar (*Xenentodon cancila*), Goby (*Glossogobius giuris*), sea bass (*Lates calcarifer*) and black carp (*Mylopharyngodon piceus*). Black Rohu (*Labeo Calbasu*) usually inhabits hilly regions. Nile Tilapia is the major catch in the entire river due to the wide tolerance of the fish to different habitats. African catfish, another invasive and banned fish, is also found abundantly in fish catch perhaps due to the illegal and unregulated farming in ponds adjacent to the river. Native fish species like the Mahseer (*Tor* sp.), Carnatic carp (*Hypselobarbus carnaticus*), Spiny eel (*Mastacembelus armatus*) and Murrel (*Channa striata*) were said to be declining because of the river's low flow (Raj, 1941).

A total of 17 sample sites, five reservoirs and 12 riverine fishing sites were evaluated using a survey schedule and key informants across the river stretch for estimation of fish catch. Following a market price-based valuation method, the economic value of fish caught was calculated. The total fish produced from the sampling sites along the Cauvery River was estimated to be around 12.202 tonnes day^{-1}. The total market value of fish thus produced was estimated to be ₹439.8 million per year at the first point of sale (*i.e.* producer's value). Out of this, the riverine fishing itself contributes 86% to the total fish catch of the Cauvery basin. It may be inferred that, at least in the case of the Cauvery River, riverine fishing is still a thriving economic activity with about 4,395 active fishers fishing regularly and supporting their family, and generating an income of USD 6.2 million every year (Table 2).

Table 3 presents the summary values for both commercial and subsistence fishing in the Cauvery River as per estimates carried out for 17 sample-fishing sites. The results show that commercial fishing is the most important ecosystem service that generates almost 99% of value due to the involvement of a large number of active fishers in commercial fishing. Subsistence fishing was practiced only at four of the sampled river sites. An estimated 40 tonnes of fish are produced annually through subsistence fishing and the market value of the fish catch was estimated to be ₹ 6.19 million. (0.08 million USD).

Based on the fish catch estimates from the sampled sites, the annual fish catch for the entire 800 km stretch of Cauvery River was extrapolated (Table 3) to be 6,038 tonnes for the year 2018–19. The estimated market value of this fish caught at the first point of sale is substantial at ₹913 million (USD 13 million) for the year 2018–19.

3.3.2 Employment generation

Most of the sampled sites studied were engaged in commercial fishing. Subsistence and commercial fishing are supported at places like Hogenakkal and Mayanur. The Cauvery River was projected to be the principal source of livelihood for at least 4,395 fishers who were actively engaged

TABLE 2 The total value of fish caught from sampled fishing sites in the Cauvery River.

Fisheries provisioning services	Total catch day^{-1} (kg)	Total catch Month^{-1} (kg)	Total catch year^{-1} ('000′ kg)	Economic value (million ₹)
Commercial fishing	12090	258868	2967.47	433.57
Subsistence fishing	112	3,345	40.14	6.19
Total Value	12202	262213	3007.61	439.8 (USD 6.2)

Source: Computed from primary field survey.

TABLE 3 Value of estimated fish production in Cauvery River during 2018–19.

S. No	Basin area	Length (Km)	Estimated fish catch (000′ kg)	Value (million ₹ INR)
1	Upper basin	160	472.36	48.18 (5.28%)
2	Middle basin	400	3,027.59	405.70 (44.42%)
3	Lower basin	240	2538.35	459.44 (50.30%)
	Total	800	6038.30	913.32 (100%)

Source: Computed from primary field survey.

in fishing activities. The five major reservoirs and several minor barrages support a significant number of fishers where commercial fishing is concentrated. Most of the reservoir fishers have membership in the fisheries cooperative society and are actively involved in fishing. These cooperative societies represent the collective voice of fishers in the reservoir and take up fishers' concerns with fisheries department officials for redressal. Interestingly, many reservoir fishers said they were involved in fishing for more than two generations.

All of the commercial fishing locations along the Cauvery River basin have fish markets. Out of the 17 sampling sites, 13 (or 76%) had female fishers who were actively engaged in both fishing and fish marketing. Similar to how men participate in riverine and reservoir fisheries in the Cauvery river, women also make substantial economic contributions.

3.3.3 Production of medicine

Fish serve as the major source of protein and contain a large amount of health-beneficial vitamins, minerals, and fatty acids. Eating fish once a week significantly reduces coronary heart disease risk compared to the non-eating fish group (Kromhout et al., 2012). An old tradition of giving Murrel fish (*Channa sp*) seed with herbal paste to cure bronchial asthma has been practiced for 170 years in the southern region of India (Indian Express, 2018). River Cauvery was the major source of Murrel seed used for this practice. The practice has been followed for many years, however, it has not been scientifically validated.

3.4 Cultural activities

3.4.1 Recreational activities

Angling (sports fishing) is practiced in the Cauvery River. The fishing season starts in November and continues till March. The sports fishing in Cauvery is managed by Coorg Wildlife Society (CWS), a Non-Governmental Organization (NGO) that coordinates the catch and release angling in the upper stretch of the river basin.

Apart from angling, there are 60 water tourism sites along the Cauvery basin. The recreational activities based on fisheries were documented at Hogenakkal, a popular waterfall on the Cauvery River. It is also a popular weekend getaway for both domestic and foreign tourists. On a normal day, Hogenakkal falls receives 2,000 visitors, while in the summer months, the count goes up nearly five folds touching 10,000 a day. Hogenakkal supports the livelihoods of 3,000 people living in nearby villages. They fish, offer boat rides, work as masseurs, market fish, and run fish eateries (Figure 3).

Another significant leisure activity offered by fishers is coracle boat riding in the Hogenakkal tourist spot. Riding in the coracles made of iron and bamboo was a major attraction that draws a lot of tourists. Additionally, fishers offer their catch for sale to tourists at the fish market near the waterfall, where they may purchase their preferred fresh fish and have it prepared at one of the fish restaurants near the river. In Hogenakkal, women run and manage fish restaurants to supplement their families' income from fishing.

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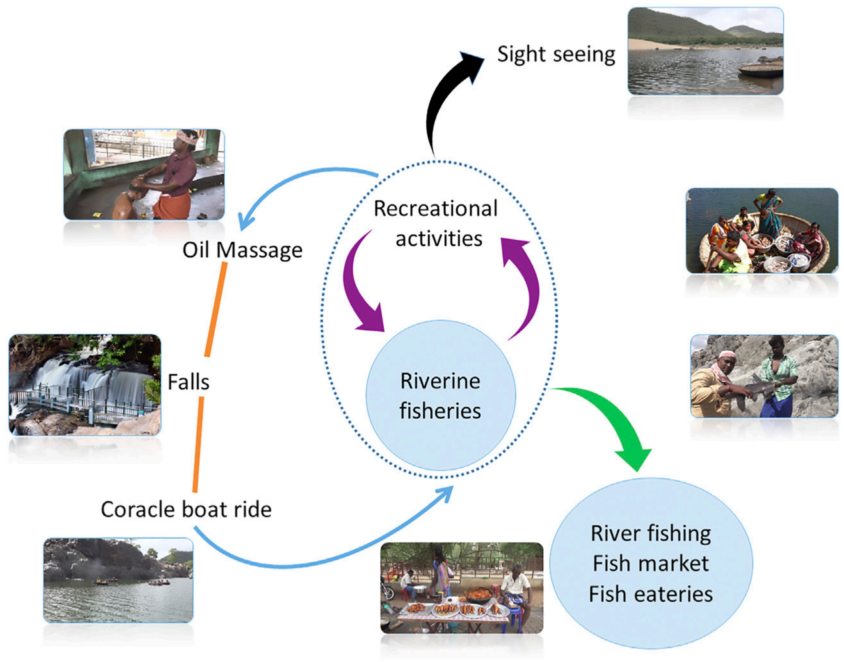

FIGURE 3
An overview of fisheries-related activities on hogenakkal waterfall of the cauvery river, photo credit: Velumani T and V. Pownkumar.

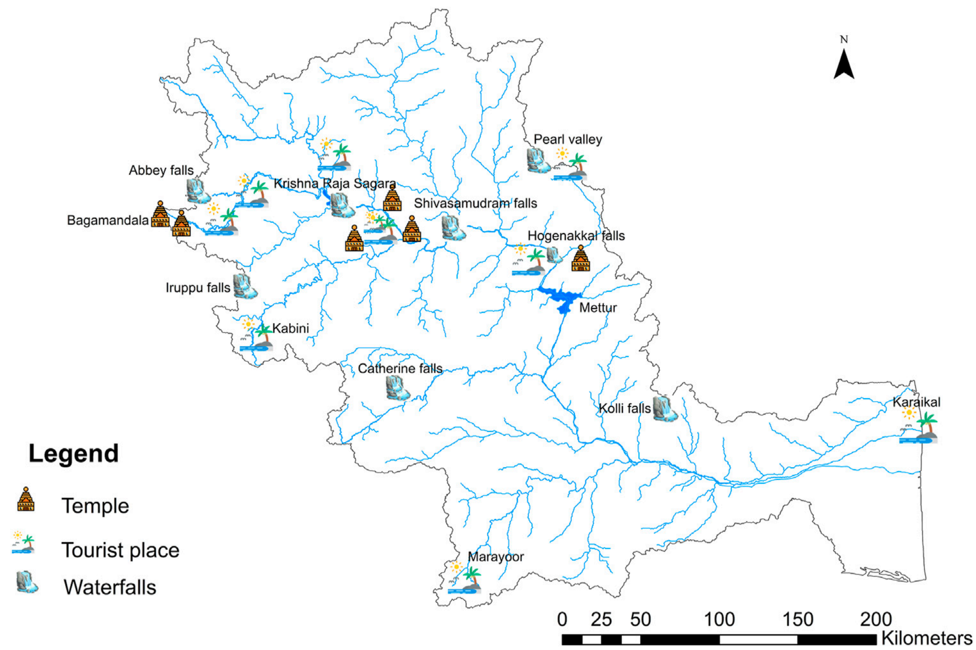

FIGURE 4
An overview of major cultural services in the cauvery basin.

3.4.3 Spiritual expression and Aesthetic values

Since ancient times, freshwater fishes have been considered blessed in many parts of India (Nautiyal, 2004). Many holy temples, ancient and recent, have found their places on the banks of River Cauvery, all through the upper, middle, and lower basins (Figure 4). River Cauvery itself is worshipped as Mother Cauvery by the people inhabiting the basin. The Cauvery delta with numerous distributaries and water channels crisscrossing the districts of Trichy, Thanjavur, Kumbakonam, Tiruvarur, and Nagapattinam is home to hundreds of temples. Many of them dated between 800 and 1100 AD and protected as part of UNESCO World Heritage, are still in worship and hold lasting civilizational value. Closer to the river origin, one such temple was established nearly 1,200 years ago on the banks of River Tunga adjoining the Cauvery basin which hosts a fish sanctuary of local Mahseer populations known as Deccan Mahseer (*Tor khudree*). The sanctuary prohibits fishing and therefore it is an effective way of conservation of aquatic species by linking it with the spiritual values of the local people. Outside the sanctuaries' boundaries, fishers are allowed to fish sustainably using traditional methods.

4 Discussion

4.1 Provisioning and cultural services

In developing countries like India, fisheries are an important source of food, nutrition, employment, and income (GOI, 2020) and therefore, provisioning ES value of fish is well documented. In the present study, the total market value of fish thus produced was estimated to be ₹439.8 million per year at the first point of sale (*i.e.* producer's value). Around 4,395 fishers were actively engaged in fishing activities in the Cauvery River stretch. A similar study was conducted in Egypt in the aquaculture sector, and it was estimated that 19.56 FTE (Full Time Equivalent) jobs were created across the value chain per 100 tons of fish produced (Nasr-Allah et al., 2020) It also contributed to Sustainable Development Goals (SDGs) number 8 and five of the United Nations which focuses on sustainable economic growth, employment generation and gender equality (Nasr-Allah et al., 2020). Nevertheless, the present study in the Cauvery basin is limited to estimating the economic value of commercial and subsistence fishing. Future research should focus on researching the contribution of fisheries to sustainable development goals.

An old tradition of using Murrel fish (*Channa sp*) from the Cauvery River as medicine to cure bronchial asthma has been practiced since the olden days. Though the scientific investigation has not been carried out, research conducted in England demonstrated that fish consumption reduced the mortality rate among humans from coronary heart disease (Shekelle et al., 1985). In addition, fish collagen has been found suitable to use in regenerative medicine (Hayashi et al., 2012; Yamada et al., 2014). The raw fish scales of two fish species namely, Catla (Catla catla) and Tilapia (*Oreochromis niloticus*) are used for tissue regeneration (Al Buraiki et al., 2020). Future studies concerning regenerative medicine should be explored as these fish species are native to the Cauvery River basin as well.

The cultural and aesthetic value of fisheries were well recognized. Many holy temples, both ancient and modern, have been found in the upper, middle, and lower basins of the river Cauvery. Along the Cauvery basin, there are 60 water tourism destinations in addition to angling that offer local and international visitors a place to relax and enjoy. Additionally, it creates chances for employment and a means of subsistence for people dependent on the Cauvery River.

4.2 Regulating and supporting services

Since the regulating and supporting services of fisheries are neither quantified nor captured, they have often been devalued, jeopardizing conservation and sustainability efforts. (Costanza and Daly, 1992). Fish are used as bio-indictors, playing an important role in monitoring heavy metals pollution (Authman et al., 2015). Only a few cases of fish as a pollution indicator have been reported in water quality studies in the Cauvery basin (Saravanan et al., 2003; Tawari-Fufeyin and Ekaye, 2007; Bhuvaneshwari et al., 2012; Authman et al., 2015). Research in the Ganga River showed how lead, copper, nickel, mercury, and other heavy metals have affected common carp fish (*Cyprinus carpio Var. Communis*) (Gopal et al., 1997). Similar research used Common carp fish (*Cyprinus carpio*) as a target organism to investigate the presence of microplastic pollution in the Vaal River, South Africa (Saad et al., 2022). Another study on the river Ganga demonstrated that fish fauna is being harmed by extended exposure of the fish to stressed environmental conditions because of the synergistic influence of both human activities and the naturally harsh conditions (Khanna et al., 2007). These studies offer the possibility of using fish as a river pollution indicator.

There is increasing evidence that fish play a significant role in the rapid recycling of nutrients (McIntyre et al., 2007; McIntyre et al., 2008; McManamay et al., 2011) which supports primary productivity in tropical aquatic ecosystems (André et al., 2003; McManamay et al., 2011). As reported by McIntyre et al., 2007, the high primary productivity that depends on nutrient recycling rates may be threatened by the overfishing of tropical fish communities Therefore, fish extinctions have serious implications for ecosystem productivity.

Instances of salmon fisheries providing regulating services have been documented in the United States (Montgomery et al., 1996). There have been cases reported in coastal areas of the North Pacific Ocean, where the annual returns of spawning salmon provide a substantial influx of nutrients and organic matter to streams and enhance the productivity of recipient ecosystems (Holtgrieve and Schindler 2011). Bioturbation by salmon can mitigate fine sedimentation of streambeds, which suggests an active role for salmon in restoring fish habitat in streams (Gottesfeld et al., 2008; Holtgrieve and Schindler, 2011; Buxton, 2018). In European rivers, it was projected that the enhancement of fish stocks would reduce biological congestion and boost oxygen availability in aquatic organisms via top-down managing periphyton through benthic grazing and increased bioturbation (Gerke et al., 2021).

When rivers flood seasonally, there are many chances for fish to travel between rivers and their floodplains, perhaps mediating food web subsidies between ecosystems (Jardine et al., 2012; Winemiller and Jepsen, 1998; Mercado-Silva et al., 2009). There is evidence demonstrating the Mitchell River's high degree of food web connectedness, which is mediated by moving fish between the river and its floodplains in Northern Queensland, Australia (Jardine et al., 2012). Similar research was conducted by Winemiller and Jepsen (1998) in South America and Africa, where they looked at the connections made by migratory fishes among food webs across a hierarchy of spatiotemporal scales. They discovered that these fishes have a cascading direct and indirect impact on other species in local food webs. Habitat modifications, non-native species, and other anthropogenic impacts have restructured fish communities in many riverine ecosystems around the world (Araújo-Lima et al., 1995; Mercado-Silva et al., 2009; Burgad et al., 2019). Therefore, successful management of many of the most important stocks of tropical river fishes requires conceptual models of how fish movement influences food web structure and dynamics (Winemiller and Jepsen, 1998; Mercado-Silva et al., 2009; Burgad et al., 2019).

4.3 Research gap and emergent challenges

Fisheries in the Cauvery River basin have also shown decreasing trend in the last few decades, mainly due to river impoundment, water abstraction, habitat loss, pollution as well as fishing pressure. Indiscriminate and destructive fishing practices (using dynamites) have been observed along the river stretch. River impoundment affects species composition due to habitat destruction and modification of trophic structure (Allan and Flecker 1993). In addition, hydrological alterations promote the invasion of non-native species (Joshi et al., 2014). In upper Cauvery, the presence of a large number of African Catfish (*Clarias gariepinus*) is considered a primary threat to native biodiversity. Similarly, the introduction of *Tilapia sp.* in reservoirs to compensate for the loss of native fishes in the rivers appear to be further impacting the fish biodiversity in the long run.

The ecosystem services concept is crucial and has direct implications for the conservation of biodiversity in freshwater. There is an urgent need to take up studies on the importance of the fish population in managing, regulating, and supporting ecosystem services. The importance of regulating services like nutrient cycling, trophic structure, and food web dynamics should be studied and practically incorporated into the river basin management plans. In India, river basins are governed by many stakeholders from a national level to a local level, each having different priorities and preferences. River water diverted by those stakeholders with greater influence obstructs the freely accessible benefits (livelihood, cultural, traditions, aesthetics) available to the less powerful or influential stakeholders of the river basin. State Fisheries Department (DoF) and local Panchayats are the custodian owners of fisheries resources along the Cauvery River basin. In most cases, it was found that DoF and Panchayats were not able to manage the resources effectively due to inadequate staff and widespread interference from different stakeholders Moreover, the factors such as river flow and pollution are beyond the control of the state DoF and Panchayats. In the context of the increasing stressors, the involvement of different stakeholders is crucial in river basin management plans.

Further, the study suggested that to sustain the generation of ecosystem services, management approaches need to focus on the initiation of seed ranching along identified river stretches, controlling invasive alien species, protecting of few river stretch as fish sanctuaries, observing of fishing ban season, and promotion of community-driven eco-tourism for sustainable fisheries management.

5 Conclusion

An ecosystem service concept is a promising tool for articulating numerous social, cultural, ecological, and economic values connected to fish and fisheries. These different ecosystem services can be further examined, evaluated, and implemented to enhance fisheries' sustainability in the riverine-related ecosystem. Ecosystem services knowledge also improves our understanding of the dynamics of ecosystem functions and processes and bridges the gaps between different management scales. However, a literature review is not enough for the assessment of overall ecosystem services for fisheries management and therefore empirical research is required. Based on this paper, the applicability of the ecosystem service can be elaborated to inform researchers and policymakers to enhance conservation efforts for fisheries. The research should also concentrate on assessing the contribution of fisheries to the United Nation's sustainable development goals, especially for the Cauvery River basin. Additionally, it is important to evaluate the regulating and supporting services related to the role of fish in the nutrient cycle, food web structure, pollution indicators, and sustaining species diversity**.** Through these approaches, fisheries can be better evaluated and recognized in river-related management frameworks enhancing the socio-ecological resilience of fisheries in the future.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

VP, PSA, and AE conceptualized the idea. VP and PSA designed the survey questionnaires and wrote the first draft of the manuscript. VP and AE conducted the survey. PSA, AE, NWQ, and VT supervised and contributed to the interpretation of the results. All authors contributed to manuscript revision and approved the submitted version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.892012/full#supplementary-material

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