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Integrated fisheries and limno-ecological assessment of a medium reservoir in Central India: Implications for sustainability and the inland blue economy

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Abstract

Reservoirs play an important role in inland fisheries, biodiversity conservation and rural livelihoods in India. This study presents an integrated assessment of the limno-chemical characteristics, fish diversity, fishery production, management practices and livelihood contribution of Kodar Reservoir, a medium reservoir in Chhattisgarh, Central India. The study recorded 52 fish species, increasing the cumulative checklist to 60 species across 10 orders and 21 families, including 11 species not reported in earlier inventories and four exotic species. The reservoir exhibited marked seasonal variation in limno-chemical characteristics, with principal component analysis showing that the first three components explained 85.4% of the total variance. Fishery production during 2019–20 was 40.9 t, corresponding to a yield of 19.95 kg ha^{-1} yr^{-1}, with variations in catch composition and fishing activity. The fishery was supported by cooperative based management involving stocking, mesh size regulation and seasonal fishing restrictions. An exponential decay survival model estimated a stocking requirement of 600 Indian major carp fingerlings ha^{-1} yr^{-1}. Fishing contributed approximately 40% of household income, complementing agriculture and other livelihood activities. The findings highlight the relationships between environmental conditions, fish assemblage and fishery performance within a cooperative management framework and provide a baseline for adaptive management of medium reservoir fisheries. Continued ecological and fishery monitoring, species specific stocking, protection of potential breeding habitats, surveillance of exotic fishes and strengthening of cooperative management could support sustainable fisheries and livelihood security.

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Introduction

Reservoirs constitute an expanding class of inland aquatic ecosystems globally, making significant contributions to fish production, biodiversity conservation, and socio-economic resilience (De Silva and Amarasinghe, 2009; Parisek *et al*., 2024). In India, reservoirs are categorised according to their water spread area as small (<1,000 ha), medium (1,000–5,000 ha), and large (>5,000 ha) (Srivastava, 1985; Sarma, 1990). Open water inland fisheries form a vital component of India's food and livelihood systems, providing nutritional security and supporting millions of rural households (Jyothishi and Parthasarathy, 2007; Das *et al*., 2022b). Among these, large and medium reservoirs together constitute the backbone of inland capture fisheries, although their management outcomes differ widely depending on institutional mechanisms and levels of community participation. Medium reservoirs, in particular, hold considerable importance as they contribute substantially to inland fish production while sustaining the livelihoods of rural and tribal populations across Central India. These waterbodies serve as crucial socio-economic assets, functioning as livelihood hubs for cooperative fishing societies and strengthening local food and nutritional security. However, their productivity remains below potential; with the national average yield from medium reservoirs estimated at only 12.3 kg ha^{-1} yr^{-1}, compared with the projected target of 147 kg ha^{-1} yr^{-1} under the Pradhan Mantri Matsya Sampada Yojana (PMMSY) (Das *et al*., 2021). Persistent constraints such as inadequate stocking practices, habitat

degradation, declining catches, and weak institutional enforcement continue to limit their performance. In this context, the emerging blue economy framework, which promotes the sustainable use of aquatic resources while harmonising ecological integrity with economic growth, offers a promising pathway for improving both productivity and resilience in community managed inland reservoirs (Das *et al*., 2021).

The productivity of reservoir ecosystems is shaped by their morphometry, hydrology, nutrient regime, and biological structure (Thornton *et al*., 1990; Wetzel, 2001). However, most Indian reservoirs perform below their potential due to a combination of interacting stressors, including irregular water inflow patterns, nutrient imbalances, proliferation of aquatic weeds, invasion by exotic fishes, and weak fisheries management systems (Sugunan, 1995; Sarkar *et al*., 2018). These factors can influence the fish assemblage structure and ultimately affect fishery production, highlighting the importance of understanding the linkages between environmental conditions and fisheries performance for effective reservoir management. Despite the ecological and economic importance of reservoirs, integrated assessments linking limno-ecological characteristics with fish diversity, fishery production and management practices remain limited for many medium reservoirs in India.

Within this framework, Kodar Reservoir in Mahasamund District, Chhattisgarh, represents a medium reservoir where fisheries are managed through a cooperative system and where ecological conditions, fish assemblage characteristics and fishery practices interact to influence production. The present study provides an integrated appraisal of its limnological and fisheries characteristics with particular emphasis on integrating information on environmental conditions, fish assemblage and fishery performance. Accordingly, the study aimed to characterise seasonal and spatial variation in the limno-chemical environment and fish diversity; assess fishery production, catch composition and management practices; estimate stocking requirements for Indian Major Carps (IMCs) and assess the contribution of fisheries to household livelihoods. By bringing these components together, the study provides a baseline for understanding the ecological and management factors influencing fisheries in a medium reservoir and identifies practical considerations for sustainable fisheries enhancement.

Materials and methods

Study area

Kodar Reservoir, situated near Tumgaon in Mahasamund District, Chhattisgarh, and constructed across the Kodar River, a tributary of the Mahanadi River, was first impounded in 1976–77. The catchment area up to the dam site is 317.17 km², with a gross storage capacity of 160.35 MCM (WRD, 2013). The Kodar River provides the primary inflow, thereby linking the reservoir to the larger Mahanadi river system. Classified as a medium-sized reservoir, it supports inland fisheries and serves as an important water resource in the region.

Sampling design

To ensure representative coverage of the reservoir, ten sampling stations were established across distinct ecological zones. These included three stations in the lacustrine (dam) zone, three stations in the transitional (intermediate) zone, three stations in the riverine zone, and one station in the upstream river stretch. Seasonal sampling was carried out from June 2020 to February 2023, covering pre-monsoon, monsoon and post-monsoon periods. During each seasonal sampling campaign, water and soil samples were collected and analysed for physical and chemical parameters following standard methods (APHA, 2017). The same ecological zoning was used for subsequent analysis of spatial variation in environmental characteristics. The geographical distribution of sampling sites across Kodar Reservoir is depicted in Fig. 1.

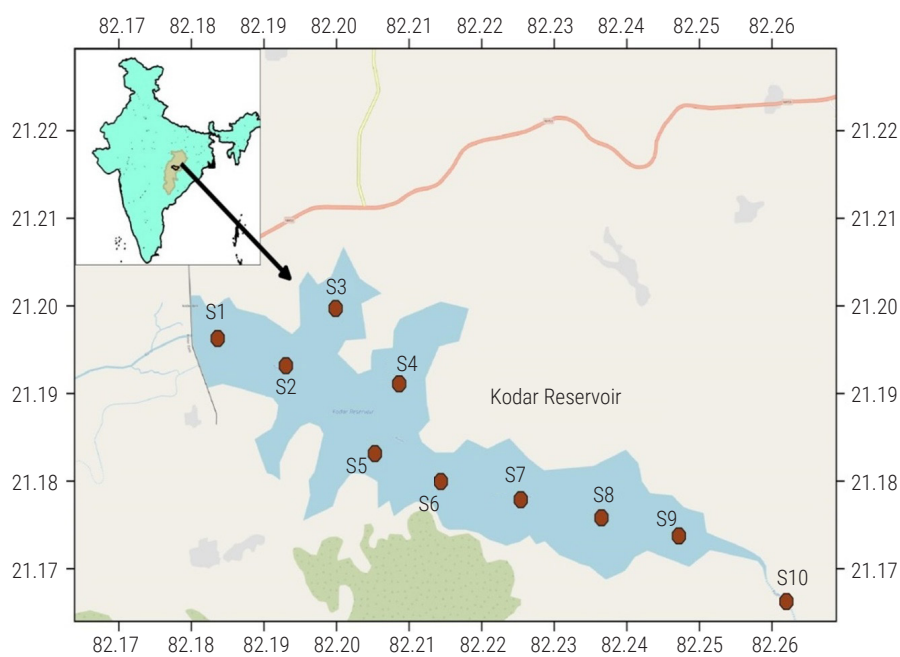

Fig. 1. Map showing the location of Kodar Reservoir, Mahasamund District, Chhattisgarh, India, with designated sampling stations (S1–S10) across different ecological zones

Fisheries data

Catch records from landing centres, fisher interviews and cooperative society records were used to assess fish production, yield, species composition and fishing practices. Stocking details were obtained from cooperative management records. Information on fisheries management practices, including stocking, fishing regulations and cooperative arrangements, was compiled from cooperative records and interactions with fishers. Participatory Rural Appraisal (PRA) exercises were conducted with experienced local fishers to identify potential breeding and spawning grounds of indigenous fish species within the reservoir. The identified areas were subsequently examined through field observations and fish/plankton sampling to support the assessment of their ecological relevance.

Data analysis

Fish assemblage composition was assessed based on taxonomic identification, species richness and catch composition. Environmental variables were summarised by ecological zone and season using descriptive statistics. To examine the major environmental gradients and the combined influence of water-quality variables, principal component analysis (PCA) was performed on 28 complete station-season observations for which data were available for all variables included in the analysis. Variables were centred and scaled prior to analysis, and the principal components and their loadings were used to identify the environmental variables contributing most strongly to the observed spatial and seasonal patterns. Spatial differences in selected soil characteristics, including pH, specific conductivity, organic carbon, total nitrogen and available phosphorus, were evaluated among ecological zones using the non-parametric Kruskal–Wallis test, where significant differences were detected, Dunn's post-hoc test with Benjamini–Hochberg adjustment was used for pairwise comparisons. Soil texture variables were summarised descriptively.

Fish yield was expressed as kg ha^{-1} yr^{-1}, and available catch and production records were examined to describe temporal variation in fishery performance and changes in catch composition. Management practices, including stocking, fishing regulations and cooperative arrangements, were assessed using information obtained from cooperative records and fisher interactions. Optimal stocking density for IMCs was estimated following the method proposed by Welcomme (1976), which models survival using an exponential decay function. The number of fish to be stocked (S, number ha^{-1}) was calculated as:

$$S=(qP/W)\cdot e^{-Z(tc-t0)}$$

where q represents the proportion of yield attributable to the target species, P is the natural annual potential yield of the reservoir, W is the mean weight at capture (kg), t_0 is the age at stocking, t_c is the age at capture, and Z is the instantaneous total mortality rate. The parameter P was derived independently using the Morpho-Edaphic Index (MEI), calculated as the ratio of specific conductivity to mean depth, and converted to fish yield potential using the empirical relationship proposed for Indian reservoirs. Species-specific estimates were generated for IMCs under different mortality scenarios, and the most realistic outputs were considered as the recommended stocking densities.

Results

Morphometry and hydrology

Kodar Reservoir, a medium impoundment, has a water-spread area of 3,588 ha at full reservoir level (FRL), with an average depth of 9.3 m and a maximum depth of 27.8 m. A water-spread area of 2,050 ha was used as the reference area for the corresponding fishery yield and stocking calculations df=3. The reservoir follows a typical monsoonal filling pattern, receiving inflow during the south-west monsoon and gradually receding through summer. Distinct lacustrine, transitional and riverine zones occur along the reservoir.

Soil characteristics and seasonal water quality

The sediments of Kodar Reservoir were predominantly sandy, with sand forming the major fraction, followed by clay and silt across the ecological zones (Table 1). Sediment pH was slightly acidic, while specific conductivity indicated moderate ionic content. Organic carbon and total nitrogen were moderate, resulting in a relatively low C/N ratio, whereas available phosphorus remained low.

Kruskal–Wallis analysis indicated significant spatial differences among ecological zones for sediment pH (χ^2=19.41, df=3, p<0.001), specific conductivity (χ^2=25.60, df=3, p<0.001), total nitrogen (χ^2=27.09, df=3, p<0.001), and available phosphorus (χ^2=18.48, df=3, p<0.001), whereas organic carbon did not differ significantly among zones (χ^2=7.57, df=3, p=0.056). Pairwise Dunn's tests with Benjamini–Hochberg adjustment further identified significant differences between selected ecological zones for pH, specific conductivity, total nitrogen and available phosphorus.

Water quality in Kodar Reservoir exhibited clear seasonal and spatial variation across ecological zones (Table 2). Water temperature

Table 1. Zone-wise soil quality parameters of Kodar Reservoir (post-monsoon)

Parameter	Lacustrine zone	Transitional zone	Lotic zone	Upstream
Sand (%)	78.6±4.5	79.2±4.7	80.1±4.9	79.4±5.0
Silt (%)	7.6±1.9	7.1±1.8	6.8±1.7	6.5±1.6
Clay (%)	13.8±2.6	13.7±2.5	13.1±2.4	14.1±2.7
pH	5.9±0.3	5.8±0.3	5.7±0.2	5.8±0.3
Specific conductivity (µS cm^{-1})	302±38	295±35	287±33	296±37
Total nitrogen (%)	0.31±0.05	0.30±0.05	0.28±0.04	0.29±0.05
Available phosphorus (mg 100 g^{-1} soil)	1.28±0.23	1.21±0.22	1.16±0.21	1.18±0.20
Organic carbon (%)	1.05±0.19	1.01±0.18	0.96±0.17	0.99±0.18
C/N ratio	4.6±0.6	4.5±0.6	4.4±0.5	4.5±0.6

Values represent mean± standard deviation of pooled samples

Table 2. Seasonal variation in water quality parameters of Kodar Reservoir

Parameter	Season	Lacustrine (S1–S3)	Transitional (S4–S6)	Lotic (S7–S9)	Upstream (S10)
Depth (m)	Pre-monsoon	8.3±0.7	7.4±0.6	6.2±0.6	5.4±0.4
	Monsoon	10.1±0.9	9.2±0.8	8.1±0.7	7.3±0.6
	Post-monsoon	9.0±0.8	8.1±0.7	7.0±0.6	6.2±0.5
Water temperature (°C)	Pre-monsoon	31.8±0.6	31.1±0.5	30.6±0.7	30.2±0.4
	Monsoon	29.1±0.5	28.6±0.6	28.2±0.5	27.8±0.4
	Post-monsoon	24.3±0.4	23.7±0.3	23.4±0.4	22.9±0.3
Transparency (cm)	Pre-monsoon	116±14	111±11	108±10	102±9
	Monsoon	76±12	70±10	68±11	62±9
	Post-monsoon	134±16	128±14	121±13	114±11
pH	Pre-monsoon	8.58±0.12	8.47±0.10	8.41±0.09	8.32±0.08
	Monsoon	7.95±0.15	7.88±0.13	7.82±0.14	7.76±0.12
	Post-monsoon	8.42±0.11	8.31±0.10	8.25±0.09	8.17±0.08
Dissolved oxygen (mg l^{-1})	Pre-monsoon	7.3±0.4	7.6±0.3	7.8±0.5	8.0±0.3
	Monsoon	7.2±0.5	7.4±0.4	7.7±0.6	7.9±0.4
	Post-monsoon	7.9±0.3	8.1±0.3	8.3±0.4	8.5±0.3
Total alkalinity (mg l^{-1} as $CaCO_3$)	Pre-monsoon	39±5	37±4	36±4	34±3
	Monsoon	52±6	49±5	47±5	46±4
	Post-monsoon	43±5	41±4	39±4	37±3
Nitrate-N (mg l^{-1})	Pre-monsoon	0.061±0.015	0.052±0.014	0.046±0.012	0.043±0.011
	Monsoon	0.039±0.013	0.031±0.012	0.034±0.014	0.028±0.010
	Post-monsoon	0.048±0.014	0.041±0.013	0.044±0.015	0.035±0.012
Total phosphorus (mg l^{-1})	Pre-monsoon	0.22±0.05	0.19±0.04	0.16±0.04	0.15±0.03
	Monsoon	0.07±0.03	0.05±0.02	0.06±0.03	0.04±0.02
	Post-monsoon	0.12±0.03	0.10±0.03	0.09±0.03	0.08±0.02
Chlorophyll *a* (µg l^{-1})	Pre-monsoon	0.03 (0.00–0.08)	0.02 (0.00–0.06)	0.02 (0.00–0.05)	0.01 (0.00–0.04)
	Monsoon	4.8 (2.9–6.7)	4.1 (2.4–5.9)	4.4 (2.6–6.8)	3.6 (2.1–5.0)
	Post-monsoon	1.9 (0.9–2.8)	1.6 (0.8–2.4)	1.4 (0.7–2.2)	1.3 (0.6–2.0)

Values represent mean± standard deviation, except for chlorophyll *a*, which is presented as mean (range) due to high spatial variability and occasional missing observations. Data are pooled across sampling stations within each ecological zone

was highest during the pre-monsoon and declined through the monsoon to the post-monsoon, whereas water depth increased markedly during the monsoon, reflecting peak inflow and storage, and decreased thereafter. Transparency declined sharply during the monsoon due to increased turbidity and improved during the post-monsoon as suspended sediments settled, with consistently higher clarity in the lacustrine zone.

The reservoir waters remained slightly alkaline throughout the study period, with only minor seasonal fluctuations in pH. Dissolved oxygen concentrations were relatively stable, but marginally higher during the post-monsoon, particularly in riverine and upstream zones. Nutrient concentrations showed pronounced seasonal contrasts, with higher levels during the pre-monsoon, dilution during the monsoon, and partial recovery in the post-monsoon, and were generally higher in the lacustrine and transitional zones (Table 2). Chlorophyll *a* exhibited strong seasonal variability and spatial heterogeneity, remaining very low during the pre-monsoon, peaking during the monsoon, and declining in the post-monsoon. Owing to high variability and occasional missing observations, chlorophyll a is presented as mean (range), with higher values consistently observed in the lacustrine and transitional zones (Table 2).

PCA of the standardised water-quality variables showed that the first three principal components explained 85.4% of the total variance, with PC1, PC2 and PC3 accounting for 47.8, 21.5 and 16.2%, respectively (Fig. 2). PC1 had relatively high loadings for pH, alkalinity, chlorophyll *a*, total phosphorus and transparency. PC2 was strongly associated with dissolved oxygen and water temperature, whereas PC3 had relatively high loadings for water temperature and depth. The score plot showed greater separation among seasons than among ecological zones.

Primary productivity

Net primary productivity (NPP) showed both seasonal and spatial variation. During the pre-monsoon, NPP was relatively high, averaging 55.55 mg C cm^{-3} h^{-1}, with values in lentic and transitional zones (62.5 mg C cm^{-3} h^{-1}) being higher than in the lotic zone (41.66 mg C cm^{-3} h^{-1}). In contrast, during the monsoon, NPP declined markedly to an average of 30.86 mg C m^{-3} h^{-1}, with the lowest values recorded in the intermediate zone (20 mg C m^{-3} h^{-1}). The overall trend indicates higher productivity under stable pre-monsoon conditions and reduced productivity during monsoon-driven turbidity and dilution.

Macrophyte diversity and infestation

Aquatic macrophyte infestation was observed in Kodar Reservoir, with dense vegetation forming thick beds in the shallow marginal areas. These mats obstruct fishing operations and hinder boat navigation. Approximately 10–15% of the reservoir surface was covered by aquatic plants during the study period. The dominant macrophytes included *Hydrilla verticillata, Vallisneria* sp.,

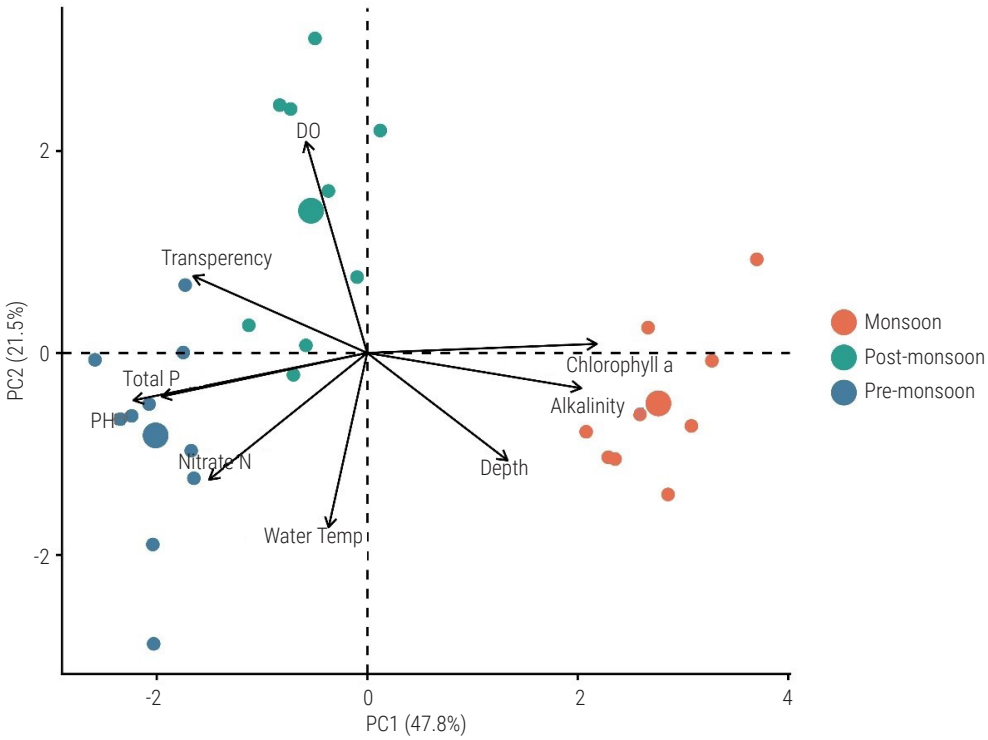

Fig. 2. PCA biplot showing seasonal variation in water-quality variables in Kodar Reservoir

Ceratophyllum sp., *Potamogeton crispus*, *Potamogeton* sp., and *Ipomoea carnea*. Dense macrophyte beds were particularly observed in shallow marginal areas and were encountered during fishing and boat operations.

Fish species diversity and composition

During the present study, a total of 52 fish species were recorded from Kodar Reservoir. Integration of the present findings with earlier records by Sugunan (1995) and Mishra *et al*. (2017) resulted in a comprehensive checklist of 60 species, belonging to 10 orders, 21 families, and 49 genera (Table 3).

Among the recorded taxa, Cypriniformes was the most species rich order (Fig. 3). At the family level, Cyprinidae was dominant, contributing 21 species (35.0%) of the total assemblage. This was followed by Danionidae and Bagridae, each represented by 7 species (11.7%), while Siluridae and Channidae contributed 3 species each (5.0%). Families Notopteridae, Clariidae, Ambassidae, Cichlidae, and Anabantidae were represented by 2 species each (3.3%), whereas the remaining families individually contributed a single species (1.7%) to the total composition (Fig. 3). The assemblage was dominated by food fishes, although several species of ornamental value were also documented (Table 3).

Eleven species recorded during the present study were not reported in the previous inventories consulted; namely, *Labeo gonius*, *Osteobrama cotio*, *O. vigorsii*, *Salmostoma phulo*, *Cabdio morar*, *Esomus danrica*, *Pethia conchonius*, *P. gelius*, *Pachypterus atherinoides*, *Channa punctata*, and *Xenentodon cancila*. The fish assemblage also included four exotic species- *Ctenopharyngodon idella*, *Cyprinus carpio*, *Hypophthalmichthys nobilis*, and *Oreochromis niloticus*.

Breeding and spawning areas

Through PRA exercises with experienced fishers from the surrounding villages, the area near the river mouth was identified as a potential breeding and spawning area for several indigenous species, including the IMCs. The occurrence of eggs, fry and juveniles provided field evidence of reproductive activity in this zone (Fig. 4).

Fish production, catch composition and fishing practices

In 2019-2020, Kodar Reservoir produced an estimated 40.9 t of fish, corresponding to a yield of 19.95 kg ha^{-1} yr^{-1}. The average daily catch was 147.94 kg, with the highest landings recorded in August (377.15 kg day^{-1}) and the lowest in April (54.43 kg day^{-1}). On a per-unit basis, the catch per unit effort (CPUE) was approximately 8-12 kg per boat per day. Fishing is carried out year-round, except during the closed season (15 June-15 August), which coincides with the monsoon spawning period. The peak fishing season occurs in the post-monsoon months (November-December), whereas a lean season is typically observed during the pre-monsoon months (March–May). The monthly variation in fish catch is illustrated in Fig. 5.

Small and medium-sized fishes accounted for approximately 50% of the catch and included *L. gonius, Systomus sarana, O. niloticus, Cirrhinus reba, Osteobrama* spp., *Notopterus notopterus,* and *Anabas testudineus*. IMCs contributed 37% of the catch, *Labeo catla* forming the bulk (72%), followed by *Labeo rohita* (16%) and *Cirrhinus mrigala* (12%). Along with them, exotic carps such as grass carp (*C. idella*), bighead carp (*H. nobilis*), and common carp (*Cyprinus carpio*) were also represented. The remaining 13%

Table 3. A comprehensive checklist of fishes reported from Kodar Reservoir

Sl. No.	Species	Common name	Use	ICUN status	Author (First reported)	Reported in the present study
	Order Osteoglossiformes					
	Family Notopteridae					
1	*Notopterus chitala* (Hamilton, 1822)	Clown knifefish	F	LC	Mishra *et al*. (2017)	-
2	*Notopterus notopterus (Pallas 1769)*	Asian knife fish	F	LC	Mishra *et al*. (2017)	√
	Order Cypriniformes					
	Family Cyprinidae					
3	*Cirrhinus mrigala* (Hamilton, 1822)	Mrigal	F	LC	Sugunan (1995)	√
4	*Cirhhinus reba* (Hamilton, 1822)	Reba carp	F	LC	Sugunan (1995)	√
5	*Ctenopharyngodon idella* (Valenciennes, 1844)	Grass carp	F	NE	Mishra *et al*. (2017)	√
6	*Cyprinus carpio* (Linnaeus, 1758)	Common carp	F	VU	Mishra *et al*. (2017)	√
7	*Hypophthalmichthys molitrix* (Valenciennes, 1844)	Silver carp	F	NT	Mishra *et al*. (2017)	√
8	*Hypophthalmichthys nobilis* (Richardson, 1845)	Bighead carp	F	DD	Mishra *et al*. (2017)	√
9	*Labeo bata* (Hamilton, 1822)	Bata	F	LC	Sugunan (1995)	√
10	*Labeo boga* (Hamilton, 1822)		F	LC	Mishra *et al*. (2017)	-
11	*Labeo calbasu* (Hamilton, 1822)	Orange fin labeo	F	LC	Sugunan (1995)	√
12	*Labeo catla* (Hamilton, 1822)	Catla	F	LC	Sugunan (1995)	√
13	*Labeo fimbriatus* (Bloch, 1795)	Fringed-lipped peninsula carp	F	LC	Sugunan (1995)	√
14	*Labeo gonius* (Hamilton, 1922)	Kuria labeo	F	LC	Present study	√
15	*Labeo rohita* (Hamilton, 1822)	Rohu	F	LC	Sugunan (1995)	√
16	*Osteobrama cotio* (Hamilton, 1822)		O	LC	Present study	√
17	*Osteobrama vigorsii* (Sykes, 1839)		F	LC	Present study	√
18	*Pethia conchonius* (Hamilton, 1822)	Rosy barb	O	LC	Present study	√
19	*Pethia gelius* (Hamilton, 1822)	Golden barb	O	LC	Present study	√
20	*Pethia ticto* (Hamilton, 1822)	Ticto barb	O	LC	Mishra *et al*. (2017)	√
21	*Puntius chola* (Hamilton, 1822)	Swamp barb	O	LC	Mishra *et al*. (2017)	√
22	*Puntius sophore* (Hamilton, 1822)	Pool barb	O	LC	Mishra *et al*. (2017)	√
23	*Systomus sarana* (Hamilton, 1822)	Olive barb	F/O	LC	Mishra *et al*. (2017)	√
	Family Danionidae					
24	*Amblypharyngodon mola*	Mola carplet/ Morula	F	LC	Mishra *et al*. (2017)	√
25	*Cabdio morar* (Hamilton, 1822)	Morari	F	LC	Present study	√
26	*Devario devario* (Hamilton, 1822)	Sind Danio	O	LC	Mishra *et al*. (2017)	√
27	*Esomus danrica* (Hamilton, 1822)	Flying barb	O	LC	Present study	√
28	*Rasbora daniconius* (Hamilton, 1822)	Slender rasbora	O	LC	Mishra *et al*. (2017)	√
29	*Salmostoma bacaila* (Hamilton, 1822)	Large razorbelly minnow		LC	Mishra *et al*. (2017)	√
30	*Salmostoma phulo* (Hamilton, 1822)	Finescale razorbelly minnow		LC	Present study	√
	Order Siluriformes					
	Family Siluridae					
31	*Ompok pabda* (Hamilton, 1822)	Pabdah catfish	F	NT	Sugunan (1995)	-
32	*Ompok bimaculatus* (Bloch, 1794)	Butter catfish	F/O	NT	Mishra *et al*. (2017)	√
33	*Wallago attu* (Bloch & Schneider, 1801)	Wallago	F	NT	Sugunan (1995)	√
	Family Pangasiidae					
34	*Pangasius pangasius* (Hamilton, 1822)	Pangas catfish	F	LC	Mishra *et al*. (2017)	√
	Family Horabagridae					
35	*Pachypterus atherinoides*				Present study	√
	Family Bagridae					
36	*Mystus armatus* (Day, 1865)	Kerala Mystus	F	LC	Sugunan (1995)	-
37	*Mystus bleekeri* (Day, 1877)	Day's mystus	O	LC	Mishra *et al*. (2017)	-
38	*Mystus cavassius* (Hamilton, 1822)	Gangetic mystus	F	LC	Mishra *et al*. (2017)	√
39	*Mystus tengara* (Hamilton, 1822)	Tengara catfish	F	LC	Mishra *et al*. (2017)	√
40	*Mystus vittatus* (Bloch, 1794)	Striped dwarf catfish	F	LC	Mishra *et al*. (2017)	-
41	*Sperata aor* (Hamilton, 1822)	Long-whiskered catfish	F	LC	Sugunan (1995)	√
42	*Sperata seenghala* (Sykes, 1839)	Giant river-catfish	F	LC	Sugunan (1995)	√
	Family Schilbeidae					
43	*Eutropiichthys vacha* (Hamilton, 1822)	Batchwa vacha	F	LC	Mishra *et al*. (2017)	-
	Family Clariidae					
44	*Clarias gariepinus*(Burchell, 1822)	African sharptooth catfish	F	LC	Mishra *et al*. (2017)	-
45	*Clarias magur*(Hamilton, 1822)	Walking catfish	F	LC	Sugunan (1995)	√
	Family Heteropneustidae					
46	*Heteropneustes fossilis* (Bloch,1794)	Stinging catfish	F/O	LC	Sugunan (1995)	√
	Order Gobiiformes					
	Family Gobiidae					
47	*Glossogobius giuris* (Hamilton, 1822)	Tank goby	F	LC	Mishra *et al*. (2017)	√
	Subseries Ovalentaria					
	Family Ambassidae/Chandidae					
48	*Chanda nama* (Hamilton,1822)	Ganges river sprat	F/O	LC	Mishra *et al*. (2017)	√
49	*Parambassis ranga* (Hamilton,1822)	Indian glassy fish	F/O	LC	Mishra *et al*. (2017)	√
	Order Cichliformes					
	Family Cichlidae					
50	*Oreochromis mossambicus* (Peters, 1852)	Mozambique tilapia	F	LC	Mishra *et al*. (2017)	√
51	*Oreochromis niloticus* (Linnaeus, 1758)	Nile tilapia	F	LC	Mishra *et al*. (2017)	√
	Family Belonidae					
52	*Xenentodon cancila* (Hamilton, 1822)	Freshwater garfish	F/O	LC	Present study	√
	Order Synbranchiformes					
	Family Mastacembelidae					
53	*Mastacembelus armatus* (Lacepède, 1800)	Zig-zag eel	F	LC	Mishra *et al*. (2017)	√
	Order Anabantiformes					
	Family Anabantidae					
54	*Anabas oligolepis* (Bleeker, 1855)	Gangetic Koi	F	DD	Mishra *et al*. (2017)	-
55	*Anabas testudineus* (Bloch, 1792)	Climbing perch	F	DD	Mishra *et al*. (2017)	√
	Family Osphronemidae					
56	*Trichogaster fasciata* Bloch & J. G. Schneider, 1801	Banded gourami	O/F	LC	Mishra *et al*. (2017)	√
	Family Channidae					
57	*Channa marulius* (Hamilton, 1822)	Great snakehead	F/O	LC	Sugunan (1995)	√
58	*Channa punctata (Bloch, 1793)*	Spotted snakehead	F/O	LC	Present study	√
59	*Channa striata* (Bloch, 1793)	Striped snakehead	F/O	LC	Sugunan (1995)	√
	Family Nandidae					
60	*Nandus nandus* (Hamilton, 1822)	Gangetic leaffish	O	LC	Mishra *et al*. (2017)	√

O – Ornamental value; F – Food value; LC – Least Concern; VU – Vulnerable; NT – Near Threatened; DD – Data Deficient; NE – Not Evaluated

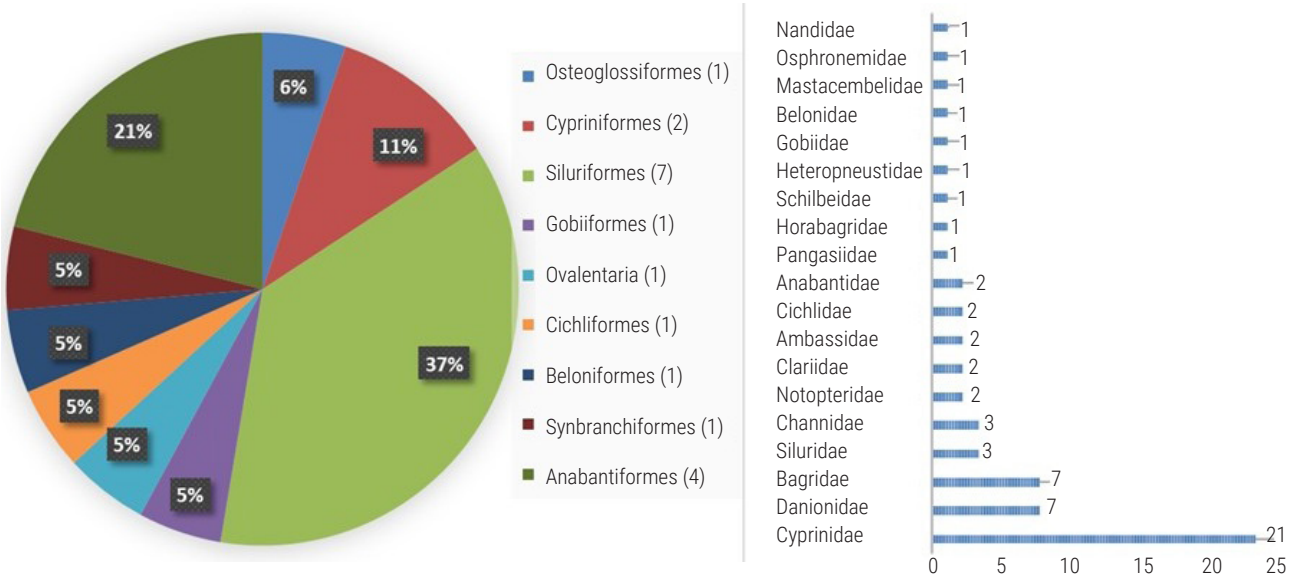

Fig. 3. Taxonomic structure of the fish assemblage in Kodar Reservoir

Fig. 4. Spawning/breeding ground identified near the river mouth of Kodar Reservoir through PRA and validated by plankton/fry sampling

comprised other large and priced indigenous species, including *Labeo calbasu, Sperata* spp., *Channa* spp., *Ompok* sp., *Mystus* spp., *Wallago attu,* and *Mastacembelus armatus*.

Fishing activities are undertaken by around 230 registered fishers operating 40 boats. The most commonly used craft is a 10 ft wooden boat, primarily employed for gill-netting, while smaller tin boats (~5 ft) are used for hook and line fishing. Gill nets with mesh sizes ranging from 0.5 to 14 inches are the principal gear, supplemented by cast nets, hook and line, hand seine nets (*Pelni jal*), and traditional bamboo traps, particularly for freshwater prawns and small indigenous fishes.

Temporal changes in fish production

Compiled information from departmental records and earlier reports indicates notable temporal variation in fish yield and production of Kodar Reservoir (Fig. 6). In 2008–09, the reservoir reported a yield

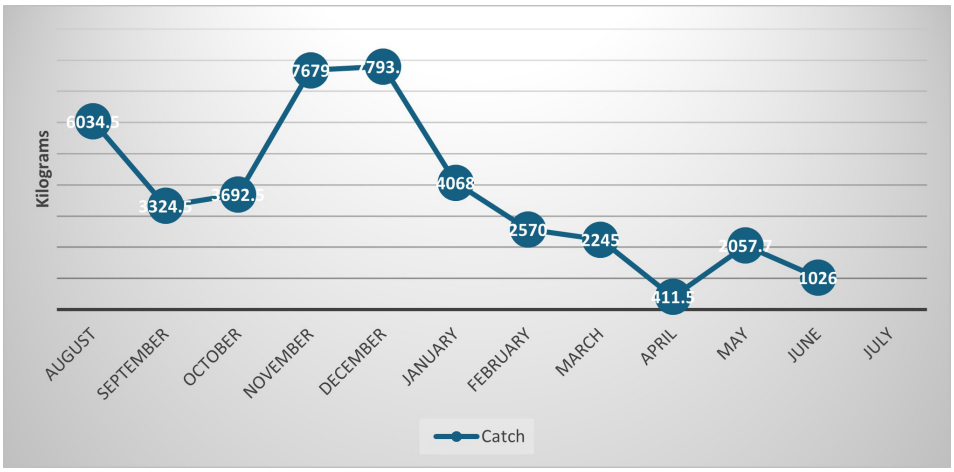

Fig. 5. Monthly variation in fish catch of Kodar Reservoir

of 27.79 kg ha⁻¹ yr⁻¹ with a total production of 56.96 t. The highest productivity was recorded during 2009–14, with a yield of 42.63 kg ha⁻¹ yr⁻¹ and production of 68.92 t.

Cooperative management and fisheries enhancement

There were 16 villages in and around Kodar Reservoir, of which four *viz.,* Tumsa, Odar, Jhilmila and Khatta, were associated with fishing activities. Approximately 230 registered fishers were associated with the reservoir, in addition to a variable number of migrant fishers from neighbouring states. Two major fish landing centres were located near Odar and Tumsa villages. The majority of the reservoir catch was landed at Odar. The reservoir is managed by Chhattisgarh Matsya Mahasangh Maryadit (CG Co-operative Fisheries Federation Ltd.), with fishing rights leased to Jai Patai Mata Primary Fisheries Cooperative Society Ltd. The society has held fishing rights since 2009. The cooperative comprises 28 members, including 15 women and 13 men, drawn from Tumsa, Navgaon, Jhogiripa and Jhilmila villages. Each member contributes an annual membership fee of ₹5,000. The cooperative implements mesh size restrictions, minimum legal size regulations and closed seasons. The reported annual stocking density was approximately 500 fingerlings ha⁻¹, with stocking generally undertaken in two operations between January and April, with pre-stocking nursery rearing also practised. Following stocking, a mesh size restriction of >5 inches is applied.

The cooperative undertakes stocking of IMCs and exotic carp fingerlings. The stocking target is approximately 10.25 lakh fingerlings, generally comprising IMCs and exotic carps, at a reported density of approximately 500 fingerlings ha⁻¹ yr⁻¹, with an average size of 70–100 mm. Stocking is generally carried out twice a year between January and April. In December 2020, approximately 10 lakh grass carp fingerlings were introduced into the reservoir for aquatic weed control. Pre-stocking management involved procurement of approximately 20 lakh fish spawn annually from hatcheries and their rearing in two village ponds

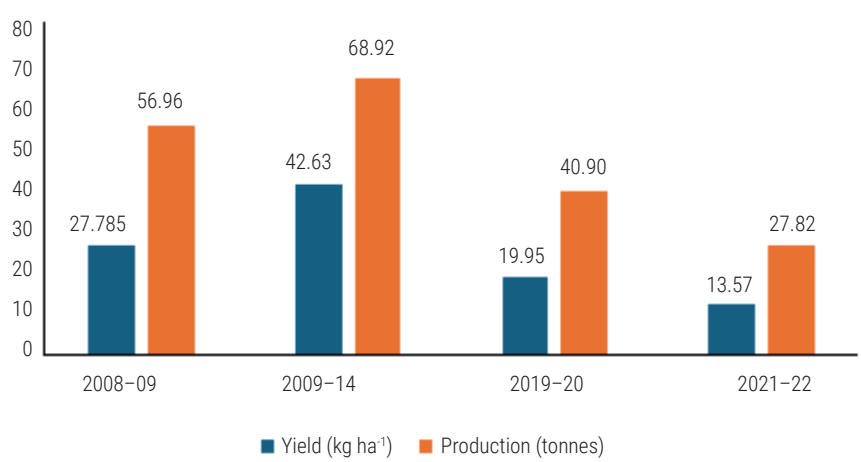

Fig. 6. Temporal changes in fish production and yield of Kodar Reservoir. The graph depicts variations in fish yield (kg ha⁻¹ yr⁻¹) and total production (t) across different periods (2008–09, 2009–14, 2019–20, and 2021–22)

of approximately 2 ha each. Spawn were stocked in August and reared for 4–5 months until December–January. Mustard oil cake and cow dung were used as supplementary feed. Reported survival at the end of the rearing period was approximately 50–60%, after which the fingerlings were stocked into the reservoir. Cage culture was also initiated in selected coves of the reservoir. Floating cages measuring 4×4×3 m were used for grow-out culture of Nile tilapia and *Pangasianodon hypophthalmus*. The cages were installed in sheltered areas, and pelleted commercial feed was used.

Stocking density estimation for IMCs

The natural annual potential yield (*P*) of Kodar Reservoir was estimated as 61.32 kg ha^{-1} using the MEI-based approach. Species-wise survival adjusted stocking densities for IMCs estimated following Welcomme's method are presented in Table 4.

The estimated stocking density for catla ranged from 29.41 to 149.40 individuals ha^{-1} across the applied mortality scenarios, while rohu and mrigal showed ranges of 44.10–224.20 and 44.12–224.10 individuals ha^{-1}, respectively.

Based on the selected mortality scenario, the recommended stocking densities were 150 individuals ha^{-1} for catla and 225 individuals ha^{-1} each for rohu and mrigal. With *q* values of 0.4 for catla and 0.3 each for rohu and mrigal, the resulting species composition was 40:30:30, giving a total recommended stocking density of 600 individuals ha^{-1}.

Livelihood contribution and marketing characteristics

The livelihood of fishers in Kodar Reservoir was supported by both fishing and agriculture. Paddy cultivation contributed approximately 60% of household income, while fishing contributed the remaining 40%. Fish were marketed through three major channels: fisher–consumer, fisher–retailer–consumer and fisher–auction–retailer–consumer. Fish were supplied to local periodic markets as well as distant urban markets.The daily income pattern recorded during September 2021 showed considerable variation (Fig. 7). Income was estimated using two approaches: the lessees' surplus rate and the MP FishFed rate. Peak earnings occurred on the first day after reopening of fishing, reaching nearly ₹1,400 under the lessees' surplus rate and approximately ₹1,000 under the FishFed rate. Thereafter, daily earnings generally ranged between ₹200 and 600. Throughout the observation period, income estimated using the lessees' surplus rate was higher than that estimated using the FishFed rate.

Discussion

The present assessment demonstrates that fishery performance in Kodar Reservoir needs to be understood through the interaction of environmental conditions, fish assemblage characteristics and management practices. The reservoir showed marked seasonal variation in its limno-chemical environment, while the fish assemblage comprised both commercially important fishes

Table 4. Stocking density estimates for IMCs in Kodar Reservoir

Species	q	P (kg ha^{-1})	W (kg)	(-Z) (per year)	tc−t_0 (year)	Survival adjusted stocking density (No. ha^{-1})	Recommended stocking density (No.ha^{-1})
Catla	0.40	61.32	2.0	0.7-2.0	1.75	29.41-149.4	150
Mrigal	0.30	61.32	1.0	0.7-2.0	0.75	44.12-224.10	225
Rohu	0.30	61.32	1.0	0.7-2.0	1.25	44.1-224.2	225

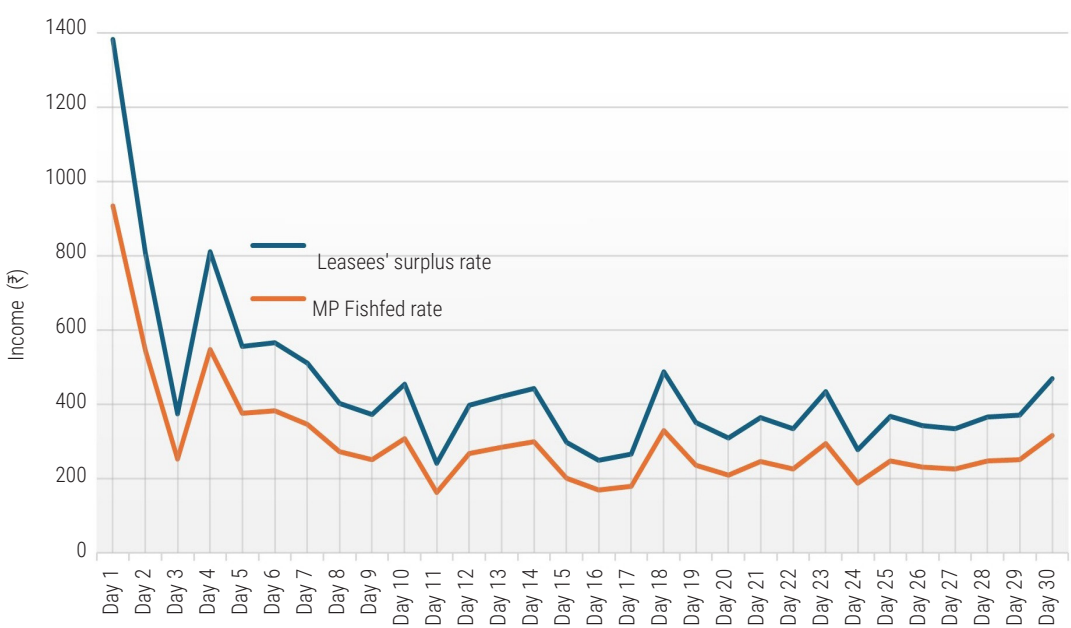

Fig. 7. Daily income trends of fishers in Kodar Reservoir during the monsoon season (September 2021)

and a substantial diversity of small indigenous species. These characteristics occurred alongside changes in catch composition, fish production, stocking practices and fishing regulations. Such an integrated perspective is particularly relevant for medium reservoirs, where fisheries productivity is influenced by the combined effects of morphometry, hydrology, nutrient conditions, fish assemblage and management interventions (Sugunan *et al*., 2013). Earlier information on the ichthyofauna of Kodar Reservoir was limited and fragmentary. Sugunan (1995) reported 16 fish species, with emphasis largely on commercially important fishes contributing to capture fisheries. Mishra *et al*. (2017) subsequently expanded the inventory to 44 species. The present study recorded 52 species and increased the cumulative species richness documented from the reservoir to 60 species. This increase may be associated with broader spatial coverage, seasonal sampling and improved taxonomic resolution, and highlights the importance of periodic systematic assessments of reservoir fish assemblages. The dominance of Cyprinidae, together with substantial representation of Danionidae and Bagridae, indicates the coexistence of commercially important and small-bodied indigenous fishes. The absence of some species reported previously, during the present sampling may reflect temporal variation in occurrence, habitat use, detectability or differences in taxonomic identification. Such differences therefore require further targeted investigation before being interpreted as evidence of local disappearance.

The environmental data provide an important context for interpreting this fish assemblage. PCA showed that the first three components accounted for 85.4% of the total variation in the standardised environmental dataset. PC1 was mainly associated with pH, alkalinity, total phosphorus and chlorophyll *a*, whereas PC2 was strongly associated with dissolved oxygen and water temperature; PC3 was associated particularly with water temperature and depth. The greater separation of seasonal groups than ecological zones in the score plot indicates that seasonal variability was a major component of environmental variation in the reservoir. Seasonal changes in water level, transparency, temperature, oxygen and nutrients can influence habitat conditions and biological processes in reservoirs (Thornton *et al*., 1990; Wetzel, 2001), and are therefore relevant when interpreting variation in fish assemblage and fisheries. The sediment characteristics provide an additional indication of the nutrient environment. The relatively low C:N ratios (~4.4–4.6) are consistent with relatively decomposable organic matter and may favour nitrogen mineralisation as low C:N ratios can facilitate nitrogen release from organic matter (Vass and Sugunan, 2009). In contrast, available phosphorus remained low (~1.16–1.28 mg 100 g^{-1} soil), below the range reported by Vass and Sugunan (2009) for highly productive conditions. The significant spatial variation observed for sediment pH, specific conductivity, total nitrogen and available phosphorus, together with the low available phosphorus concentrations, indicates spatial heterogeneity in the sediment environment despite the generally sandy character of the reservoir bed. The combination of relatively low phosphorus availability with seasonal variation in chlorophyll *a* and primary productivity suggests that nutrient availability may influence the productive base of the reservoir. However, the present study does not establish a direct causal relationship between sediment nutrient status and fish production.This environmental setting is relevant to the observed fishery because the reservoir supported a diverse assemblage, while the catch comprised several groups rather than being dominated exclusively by stocked IMCs. Small indigenous and other non-IMC fishes formed an important component of the catch, indicating that natural fish populations contribute substantially to fishery performance. Thus, enhancement through stocking needs to be considered alongside natural recruitment, food availability, habitat conditions and fishing practices. Culture based fisheries and other enhancement approaches have similarly been advocated for Indian reservoirs in relation to their ecological and fisheries characteristics (Sugunan, 2013; Sarkar *et al*., 2018).

The occurrence of exotic species, particularly *O. niloticus*, warrants continued attention because its effects on native fish assemblages and fisheries have been documented in other aquatic systems (Peng *et al*., 2021; Johnson *et al*., 2022). In Kodar, the present study establishes its occurrence but does not quantify its abundance, recruitment or ecological interactions. Its contribution to the observed production pattern therefore cannot be established from the present data. Continued monitoring of its abundance, size structure and contribution to catches would help determine its significance to the reservoir fishery. The historical production records showed a decline in reported yield from 42.63 kg ha^{-1} yr^{-1} during 2009–14 to 19.95 kg ha^{-1} yr^{-1} in 2019–20 and 13.57 kg ha^{-1} yr^{-1} in 2021–22. Although these records indicate reduced fishery output over the reported periods, the limited number of observation periods does not permit the decline to be attributed to any single environmental, biological or management factor. This is important in interpreting reservoir fisheries because changes in production may reflect the combined influence of recruitment, stocking, fishing effort, species composition, habitat conditions and management practices rather than a single driver. Stocking has long been used as an important fisheries enhancement strategy in reservoirs of developing countries. Successful stocking and culture-based fisheries programmes have been reported from India (Sugunan, 1995; 2000; 2013; Sarkar and Mishal, 2017; Sarkar *et al*., 2018), Sri Lanka (De Silva and Funge-Smith, 2005; Amarasinghe and Weerakoon, 2009; Amarasinghe and Nguyen, 2010; Chandrasoma *et al*., 2015; Pushpalatha *et al*., 2017) and China (De Silva, 2001, 2003; FBMA, 2006). These studies emphasise that stocking effectiveness depends on species selection, stocking density, survival, natural productivity and subsequent fishing management.

For Kodar, the estimated stocking requirement of 600 IMC fingerlings ha^{-1} yr^{-1}, comprising approximately 150 catla, 225 rohu and 225 mrigal ha^{-1}, provides a species specific basis for enhancement. The exponential survival model provides a quantitative means of incorporating species specific mortality and harvest parameters into stocking decisions, consistent with approaches used in culture-based reservoir fisheries (Welcomme and Bartley, 1998; Jayasinghe *et al*., 2006). The model-derived stocking density should, however, be regarded as an adaptive management estimate rather than a fixed optimum. Its effectiveness will depend on post-stocking survival, growth, fishing mortality, food availability, natural recruitment and prevailing environmental conditions. Therefore, the estimated density should be evaluated through subsequent monitoring of survival, growth and contribution to catches. The existing management system provides an institutional mechanism for implementing fisheries enhancement and regulating fishing activities. Mesh-size restrictions, minimum legalsize provisions and a closed fishing season are intended to regulate exploitation and protect fish during vulnerable periods. The identification of potential

breeding and spawning areas through PRA, followed by field observations and fish/plankton sampling, further demonstrates the value of integrating local ecological knowledge with scientific assessment. Protection of such areas during critical periods could complement existing seasonal and gear-based regulations. The cooperative also undertakes nursery rearing before reservoir stocking, with reported survival of 50–60%. Improving nursery management and seed survival could increase the efficiency of existing stocking efforts without necessarily increasing the number of fingerlings released. Similarly, the use of grass carp for aquatic weed control represents a management response to macrophyte proliferation, but large scale introduction of non-native or translocated fishes should be accompanied by ecological monitoring because of possible effects on native fish diversity and food-web interactions. The interaction between fisheries management and fishery performance is particularly important in Kodar because stocking, fishing regulation and cooperative management operate within the same reservoir ecosystem. The contribution of IMCs to the observed catch was 37% despite regular stocking, indicating that catch composition should be interpreted in relation to stocking as well as natural fish populations, environmental conditions, fishing effort and management practices. Community based management experiences such as the Tawa Matsya Sangh in Madhya Pradesh have demonstrated the importance of organised fisher institutions, secure fishing rights and technical support in strengthening inland fisheries (Jyothishi and Parthasarathy, 2007). For Kodar, strengthening cooperative participation and linking routine catch and effort records with scientific monitoring could similarly support adaptive fisheries management.

The socio-economic dimension further reinforces the importance of maintaining the reservoir fishery. Fishing contributed approximately 40% of household income, while paddy cultivation contributing about 60%. Similar dependence on diversified livelihood strategies has been reported among reservoir dependent communities in Central and Eastern India (Ekka *et al*., 2012). Thus, changes in fishery performance have implications beyond fish production itself, particularly for households combining fishing with agriculture and other seasonal occupations. The three identified marketing channels connect the reservoir fishery with local periodic markets as well as distant urban markets, while the observed variation in daily earnings indicates fluctuations in catch availability and market realization. Recent studies have also highlighted livelihood and market vulnerabilities in small-scale inland fisheries (Bassett *et al*., 2022; Das *et al*., 2022a; Rice *et al*., 2024).

Taken together, the findings suggest that management of Kodar Reservoir should not treat environmental monitoring, fish diversity, stocking, capture fisheries, cooperative regulation and livelihoods as independent components. Seasonal environmental variability shapes the ecological conditions supporting fish assemblage; which in turn determine the pool of fishes available to the fishery. Stocking influences the abundance of selected target species; while fishing regulations and cooperative institutions influence their exploitation, The resulting fishery contributes local livelihoods. This interconnected framework provides a stronger basis for interpreting fishery performance than any individual component considered separately. Accordingly, management should focus on continued seasonal monitoring of key environmental variables, periodic assessment of fish assemblage and catch composition, surveillance of exotic species, adaptive species specific stocking, improvement of nursery survival, protection of identified breeding habitats, and strengthening cooperative-based regulation as well as market support. The present study does not establish the relative contribution of each of these factors to production; rather, it identifies their interconnected roles and provides a baseline for evaluating these relationships through longer term monitoring. Such an adaptive, ecosystem based approach is particularly relevant for improving the sustainability of medium-reservoir fisheries and their contribution to local livelihoods.

Kodar Reservoir supports a diverse fish assemblage and an important livelihood based fishery, but its fishery operates within a system characterised by environmental variability, diverse fish assemblages, stocking practices and cooperative management. The study documented substantial seasonal variation in limno-chemical conditions, diverse fish assemblages including small indigenous fishes and exotic taxa, variation in fishery production and catch composition, and an established cooperative based management system. The estimated stocking requirement of 600 IMC fingerlings provides a species specific basis for fisheries enhancement, but its effectiveness should be evaluated through post-stocking monitoring rather than stocking numbers alone. The occurrence of exotic fishes, identified breeding and spawning areas, and existing fishing regulations further highlight the need for continued ecological and fisheries monitoring. Strengthening nursery management, improving compliance with fisheries regulations, protecting important breeding habitats and integrating local ecological knowledge with scientific assessment can support more adaptive management. The study demonstrates the value of linking environmental monitoring, fish assemblage assessment, fishery production, stocking and cooperative governance in the management of medium reservoirs. An adaptive approach that considers ecological conditions, fishery response and livelihood dependence, rather than focusing only on increasing yield, can provide a more sustainable basis for fisheries enhancement in Kodar Reservoir and contribute to the broader objectives of sustainable inland fisheries development.

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