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Is the Deccan Mahseer, *Tor khudree* (Sykes, 1839) (Pisces: Cyprinidae) fishery in the Western Ghats Hotspot sustainable? A participatory approach to stock assessment

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ABSTRACT

In this paper, we use a participatory approach, to assess the suitability of data provided by local fishers for determining the demography and harvest rates of endangered species, exploited in remotely located small-scale fisheries. We specifically focus on the Deccan Mahseer (*Tor khudree*) in the Western Ghats Hotspot of Peninsular India. Using catch data provided by local fishers, we assessed the dynamics of exploited populations of *T. khudree* from six major fishing sites having varying patterns of harvest (commercial vs. subsistence) and protection status (protected vs. non protected area). Based on annual length frequency data, growth parameters of *T. khudree* were worked out as $L_{\infty} = 383.25\text{--}1202.25\text{mm}$ total length and $K = 0.12\text{--}0.23\text{year}^{-1}$. The length frequency data of *T. khudree* individuals exploited from two fishing sites indicated that a high share of the catches throughout the year, are contributed by immature size classes. The total mortality coefficient (Z) was calculated to be between 0.35year^{-1} and 0.95year^{-1} and the fishing mortality coefficient (F) between 0.13year and 0.8year . The fishing mortality rate of *T. khudree* in Poringal Reservoir (0.8year) may probably be one of the highest for any species of Mahseer in India, and points to the targeted indiscriminate exploitation by local fishers. Exploitation rate (E) ($0.34\text{--}0.84\text{year}^{-1}$) was higher than the expected optimal level (0.5) at all, but one fishing sites revealing that *T. khudree* populations are over fished in the study region. Further, a comparison of the exploitation rate at various fishing sites revealed no significant differences between commercial and subsistence harvest, as well as inside and outside protected areas. In spite of its 'endangered' status, *T. khudree* receives no protection even in Biodiversity Hotspots like the Western Ghats, and its fishery is under threat of an imminent collapse. Management guidelines for sustainable Mahseer fishery in the region are suggested. © 2011 Elsevier B.V. All rights reserved.

1. Introduction

Inland fisheries engage more than 56 million people in the developing world (BNP, 2009), more than the estimated 50 million people who depend on the same activities in coastal areas (Welcomme et al., 2011). Majority of these inland fishers are known to be involved in the small-scale sector (Welcomme et al., 2011), which makes important but undervalued contributions to the economies of some of the world's poorest countries (Andrew et al., 2007).

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While no definitive statistics exist, nearly half of the world fish production, and most of the fish consumed in the developing world originate from small-scale fisheries (FAO, 2008–2010). Despite these big numbers, small-scale fisheries continue to be neglected, with very little research and monitoring. Of the various ecosystems where small-scale fisheries operate, freshwaters (including rivers, lakes and reservoirs) tend to be the least studied. Small-scale freshwater fisheries are seldom the focus of attention, because they are located in tropical developing countries where landings are made at many dispersed sites (DFID, 2002), often in physically remote locations, where local management agencies lack human resource or financial capacity for data collection (Mahon, 1997; Pauly, 1997; Arce-Ibbarra and Charles, 2008).

One of the few pragmatic solutions to overcome these constraints is to work directly with fishers, allowing them to collect and record data, and subsequently forwarding them to

scientists for detailed analyses (Bene et al., 2009). This method is not only cost effective but also lays the foundation for co-management (Bene et al., 2009). Several studies have examined engaging fishers and researchers together, for gathering socio-economic and trade data (Martin Smith et al., 2004; Jones et al., 2008; Castello et al., 2009; Wiber et al., 2009), as well as for monitoring, enforcement, education and advocacy (see Granek et al., 2008), but seldom as a basis for fish population assessments.

The Western Ghats (hence forth WG), extending along the west coast of India and covering an area of 180,000 km² (CEPF, 2007), is one of 34 global biodiversity Hotspots (<http://www.biodiversityhotspots.org/Pages/default.aspx>) and one of the two on the Indian subcontinent. Although the total area is less than 6% of the land area of India, the WG contains more than 30% of all plant, fish, herpetofauna, bird, and mammal species found in the country (CEPF, 2007). The streams and rivers flowing through southern part of the WG is a discrete freshwater eco-region (Abell et al., 2008) harbouring exceptional diversity of endemic freshwater fish (Kottelat and Whitten, 1996; Dahanukar et al., 2004).

Freshwater fish are intricately linked to the livelihoods of an unquantified number of marginalized tribes and forest dwelling communities in the Southern WG, providing a source of food and income. Freshwater fisheries in this region are however believed to be under increasing pressure, as evident from the anecdotal reports of declining populations of important species (Kurup et al., 2004; Raghavan et al., 2009). Nevertheless, dynamics of population and exploitation status of freshwater fishes are poorly known in the WG and, as such, it is an area where assessment of stocks is potentially useful.

The Deccan Mahseer, Tor khudree (Sykes, 1839), along lived and slow growing cyprinid (Froese and Pauly, 2010) is the single most important food fish exploited by forest dwelling communities living within the river basins of the Southern WG (Raghavan et al., 2008a). However, life history characters of *T. khudree* including high longevity and a population doubling time of 4.5–14 years (Froese and Pauly, 2010) makes them highly vulnerable to over exploitation. Local fishers in the region have indicated that catches of *T. khudree* have declined drastically in the last few years, and only smaller juveniles appear in the nets, compared to large adults that were frequently caught in 1980's (Minimol, 2000; Solomon, 2009). The IUCN has listed *T. khudree* as an "Endangered" species based on circumstantial evidence of their population decline (Devi and Boguskaya, 2007). In spite of this, there are no reliable estimates of the population parameters and stock assessment of the Deccan Mahseer in its native range.

The absence of scientific data on population status of *T. khudree* is in part attributed to the remote locations of fishery, lack of manpower for monitoring, and, the jurisdictional complexity over the control of freshwater fishing sites in the WG. For example, in the Southern Indian state of Kerala, where the present study is based, most of the Mahseer fishing sites are located in areas under the jurisdiction of the State Department of Forest and Wildlife (rivers and streams inside forest areas) and in some cases under the jurisdiction of the State Department of Power (reservoirs). The State Department of Fisheries seldom pay attention to riverine fisheries (Santha, 2007), and fisheries in remote areas such as those covered in the present study are sometimes even not recognized by these institutions. Therefore the only feasible way to record and monitor fish catches in such regions is by working with local fishers.

In this paper we use a participatory approach to assess the suitability of data provided by local fishers for determining

the demography and exploitation rates of *T. khudree*, exploited in remotely located small-scale fisheries. Based on the length and weight measurements of *T. khudree* caught at six major fishing sites in two of the most important river basins in Southern WG, we assess sustainability of the fishery, and determine whether demography and harvests are influenced by fishing location (inside vs. outside protected areas), fishing habitat (river vs. reservoir) and/or harvesting regimes (subsistence vs. commercial).

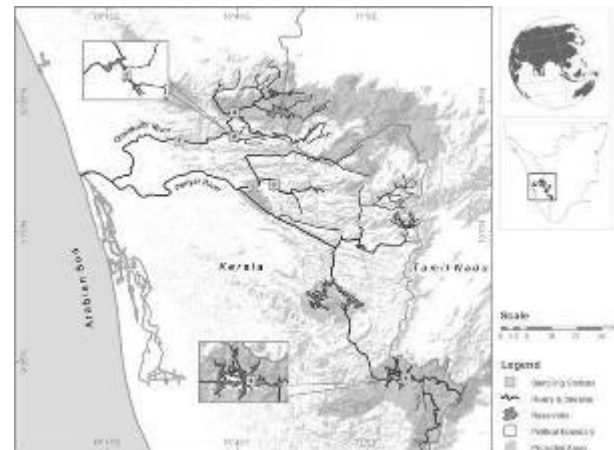


Fig. 1. Map of River Chalakudy and Periyar showing study sites

2. Materials and methods

2.1. Study area

We selected six fishing sites (Orukomban, Kuttampuzha, Pooyamkutty, Poringal, Thekkady and Vettilapara) located in two of the most important river basins, of the Southern WG – Periyar and Chalakudy (Fig. 1). Periyar has a total catchment area of 5243 km² and a length of about 300 km (Smakhtin et al., 2007). For a small-sized basin, Periyar never the less harbours a number of endemic and threatened species (CAMP, 2001; Kurup et al., 2004, 2006). Chalakudy (145 km) is considered to be one of the richest river systems in WG with regard to fish diversity and harbours as many as 98 species (Ajithkumar et al., 1999; Bijuet al., 2000) several of which are endemic and threatened (Raghavan et al., 2008a). However, the Chalakudy river basin is known to be highly threatened, as a result of extensive habitat alteration (Bachan, 2003), destructive fishing practices (Raghavan et al., 2008a) and alien invasive species (Raghavan et al., 2008b). The six fishing sites (Table 1 and Fig. 1) were selected based on the high occurrence of *T. khudree* in the daily catches of local fishers.

These six sites differed in their protection status (inside vs. outside protected areas), habitat (river vs. reservoir) as well as harvesting regime (subsistence fishery vs. commercial fishery). Two sites, Orukomban (site a) and Thekkady (site e) were located inside the boundaries of terrestrial protected areas where fishing rights are restricted to resident tribes through the issue of licenses, but without any restrictions on catch size or limits. At three sites, Orukomban (site a), Poringal (site b) and Thekkady (site e), the Mahseer fishery is commercial in nature with >95% of the catches sold at cooperative societies and markets; while in the remaining sites, Kuttampuzha (site b), Pooyamkutty (site c) and Vettilapara (site f), fishery was for subsistence, where local fishers harvested Mahseer for household consumption and only very rarely (<5%) for selling in the markets.

2.2. Data collection

We conducted a series of informal workshops and focus group discussions with local fishers at the six sites to gather information on Mahseer fishery (capture techniques, months, catch levels etc.), and introduce our project to them.

Table 1

Details of habitat, protection status and harvest regime of the fishing sites examined in the present study.

Site	Name	Elevation m ASL	Habitat	Protection	Harvest regime
a.	Orukomban	470	River	Protected/WLS	Commercial
b.	Kuttampuzha	50	River	Not Protected/RF	Subsistence
c.	Pooyamkutty	220	River	Not Protected/RF	Subsistence
d.	Poringal	418	Reservoir	Not Protected/RF	Commercial
e.	Thekkady	870	Reservoir	Protected/NP	Commercial
f.	Vettilapara	53	River	Not Protected	Subsistence

NP: National Park (IUCN Category II). RF: Reserved Forest. WLS: Wildlife Sanctuary (IUCN Category IV).

Subsequently, we selected 12 fishers (2 fishers \times 6 sites) and trained the min simple data collection relevant to fisheries such as measuring and recording length (total and standard length to a precision of 0.1mm) and weight (total weight to the nearest 1g). These 12 local fishers acted as our field assistants for a period of 1 year (January–December 2009) providing us with data on length and weight of *T. khudree* specimens ($n = 30/\text{month} \times 12 \text{ months}$) caught at their respective fishing sites. The 12 field assistants agreed to spend 4 h every month for helping us with data collection including recording length and weight on random days, and recording catch details. The sample size of 30 was the (average) number of fish that could be measured within this time frame. Each of these field assistants was paid a monthly honorarium. Random visits were made by the project team to the six fishing sites once a month to validate the data collection techniques, assess the quality of data entries (Ticheler et al., 1998) and provide any technical help, if required.

Monthly total catch data of *T. khudree* and co-occurring species harvested by local fishers at the six fishing sites were also collected with the help of the field assistants. Harvests from three fishing sites (Orukomban, Poringal and Thekkady) are sold through an eco-development society, which maintain landing records (numbers and weight). In addition, we provided additional data sheets, and weighing balance(s) to the society staff for recording catch details. At the sites where fishery was subsistence in nature, (Pooyamkutty, Vettilapara and Kuttampuzha), a log book and weighing balance was provided to each of the field assistants to record their catch details. These local assistants also visited households of the other major fishers operating in the area and recorded their catch details as well. At the end of the study, we compiled the information that were entered in the datasheets and log books by our local assistants, and determined the total monthly catch at each site.

2.3. Analyses

Data provided by the field assistants were arranged in a length frequency table with 5mm as the smallest mid length, and with a 10mm class interval. A contour plot was prepared using Microsoft Excel® 2003 to understand the distribution of length classes in relation to different months and different fishing sites. Growth and mortality parameters, as well as exploitation levels were then estimated from the length frequency data using Electronic Length Frequency Analysis I (ELEFANI) routine incorporated in the FAO- ICLARM Stock Assessment Tools II (FiSATII) software (Gayanilo and Pauly, 1997). As there was no strong influence of season in the study sites, we used von

Bertalanffy Growth Formula (vBGF) given by the formula, $L_t = L_\infty (1 - e^{-K(D(t-t_0))})$ where, L_∞ is the asymptotic length, K is the growth constant, t is the time, L_t is the length at time t , t_0 is the hypothetical time when the

length is zero and D is the positive constant (Pauly, 1984). A asymptotic length (L_∞) and growth constant (K) of vBGF were estimated using Shepherd's method embedded in ELEFANI routine of FiSATII (Pauly, 1984). The score (S) for Shepherd's method is defined by, $S = (s_A^2 + s_B^2) / 2$ where S_A and S_B are the goodness-of-fit scores (st_z) obtained with the origin of the vBGF in calendar time (t_z) set to 0 and 0.25, respectively. st_z is defined by, $st_z = \sum T_i \sqrt{N_i}$ where, N_i is frequency for length group i , $T_i = D \cdot \cos 2\pi (t-t_i)$, $D = (\sin \pi (\Delta t) / \pi (\Delta t))$, $t = \Delta t / 2$, $D_t = t_{max} - t_{min}$, $t_i - t_z = (1/K) \cdot \ln (1 - (L_i/L_\infty))$, and $t_z = (1/2\pi) \cdot \tan^{-1}(s_B/s_A)$. This generates a plot of S values (with S_{max} standardized to 1) for a range of K values ($0.1 - 10 \text{ year}^{-1}$) on a log scale, thus enabling the identification of the best value of K for a given value of L_∞ .

Based on L_∞ and K values, the growth performance index ($\phi = 2 \times \log L_\infty + \log K$) and potential longevity ($3/K$) of fish were estimated for different sites (Pauly and Munro, 1984). Total mortality (Z) was estimated using length converted catch curves (Pauly, 1984). Natural mortality (M) was determined using Pauly's Mequation, $\ln(M) = -0.0152 - 0.279 \cdot \ln(L_\infty) + 0.6543 \ln(K) + 0.463 \ln(T)$, where, T is the average annual temperature (24°C) of the site. Fishing mortality (F) was calculated as $F = Z - M$ and the exploitation level (E) was calculated as $E = F/Z$ (Gulland, 1970). Exploitation that retains 50% of the biomass (E_{50}) and maximum yield per recruit (E_{max}) were then predicted using relative yield per recruit (Y/R) and relative biomass per recruit (B/R) analysis using knife-edge selection method (Pauly, 1984).

To understand how different growth and mortality related parameters differed among study sites, a principle component analysis (PCA) was performed using correlation matrix between the variables. Correlation biplot was plotted to visualize PCA results (Legendre and Legendre, 1998). Further, we performed two-way cluster analysis to understand patterns in the weight of *T. khudree* in the total fish catch across different months and at different sites. Dendrograms were plotted using Euclidian distances based on Wards method for different months and different sites, based on the ratio of weight of *T. khudree* and the weight of total fish catch. In spite of the fact that this study did not have a truly factorial design with replicates, we carried out Mann–Whitney U test to understand whether protection status of the fishing location (inside vs. outside protected areas), fishing habitat (river vs. reservoir) and harvesting regimes (subsistence vs. commercial) influenced growth, mortality and exploitation rate of *T. khudree*.

3. Results

3.1. Length frequency distributions

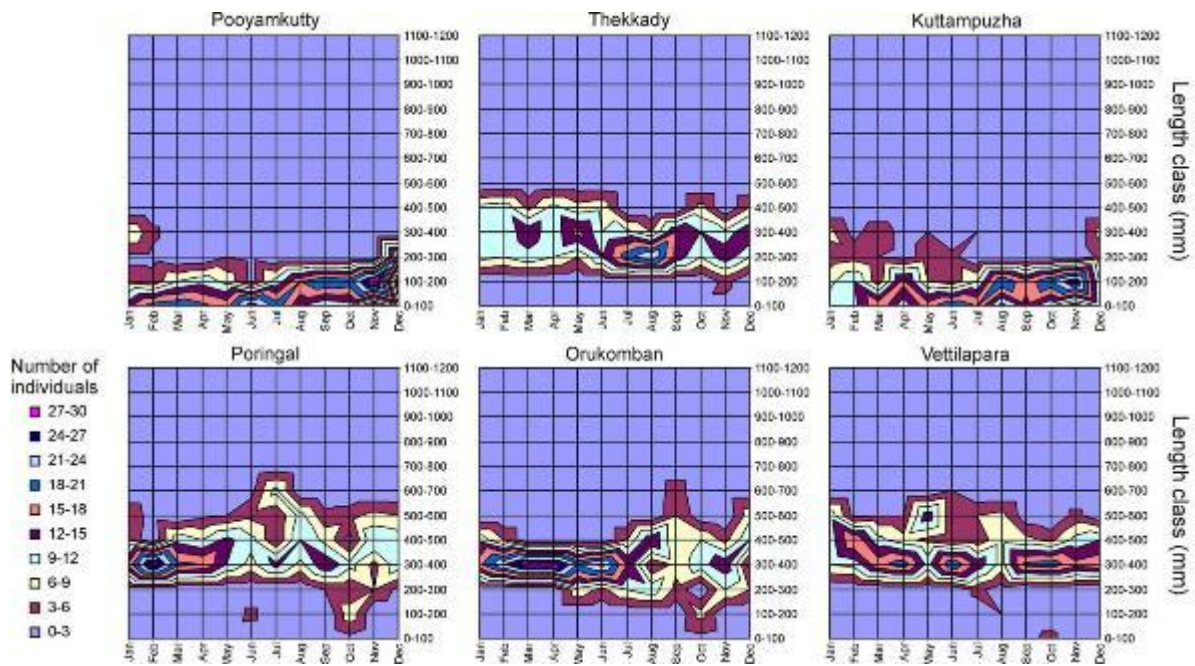


Fig. 2. Distribution of length frequencies of *T. khudree* across the six fishing sites in different months

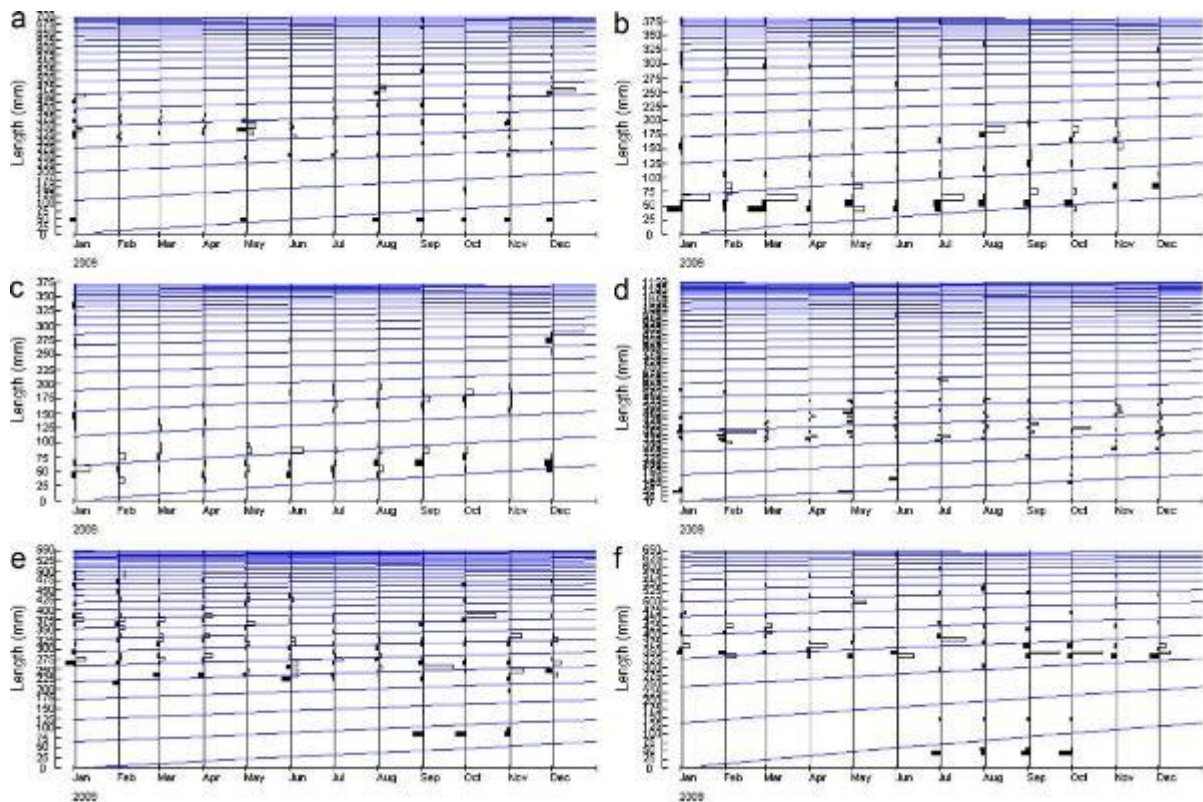


Fig.3. von-Bertalanffy growth curves for *T. khudree* from different fishing sites in the Western Ghats viz. (a) Orukomban, (b) Kuttampuzha, (c) Pooyamkutty, (d) Poringal, (e) Thekkady and (f) Vettilapara [Goodness of fit (R_n values) of the VBGF to the data was 0.129,0.151,0.152,0.123,0.135 and 0.139 respectively].

Table 2 Growth parameters of *T. kbudree* from different fishing sites in the Western Ghats.

Size	Asymptotic length (L_{∞}) mm	Growth coefficient (K) year^{-1}	Growth performance index (ϕ)	Potential longevity ($3/K$)
Orukomban	729.75	0.16	4.9305	18.75
Kuttampuzha	393.75	0.19	4.4692	15.7895
Pooyamkutty	383.25	0.17	4.3974	17.6471
Poringal	1202.25	0.12	5.2392	25
Thekkady	572.25	0.12	4.5944	25
Vettilapara	677.25	0.23	5.0232	13.0435

Table 3 Mortality rates (year^{-1}) and exploitation level of *T. kbudree* from six fishing sites in the Western Ghats.

Size	Total mortality Z	Natural mortality M	Fishing mortality $F=Z-M$	Exploitation rate $E=F/Z$
Orukomban	0.9	0.2	0.7	0.78
Kuttampuzha	0.69	0.27	0.42	0.6
Pooyamkutty	0.39	0.26	0.13	0.34
Poringal	0.95	2.15	0.8	0.84
Thekkady	0.35	0.17	0.18	0.51
Vettilapara	0.76	0.27	0.49	0.64

Frequency distributions of length classes (Fig. 2) reveal that the length range of *T. kbudree* populations in Pooyamkutty and Kuttampuzha are much smaller than other fishing sites. In Pooyamkutty and Kuttampuzha the maximum length of fish were recorded in the size class 300 - 400mm, and the maximum length recorded were 370mm and 374mm respectively. In Thekkady, the maximum length of *T. kbudree* was 545mm, while in Orukomban and Vettilapara the maximum length were 693mm and 644mm respectively. In Poringal, the maximum length recorded was 1142mm.

3.2. Growth and mortality parameters

Restructured form of the length frequency data of exploited *T. kbudree* populations from six fishing sites presented as output of ELEFAN I shows that the growth curves for different populations differ considerably (Fig. 3). Asymptotic length (L_{∞}) varied from 383.25mm (Pooyamkutty) to 1202.25mm (Poringal) while growth coefficient (K) varied from 0.12 year^{-1} (Poringal and Thekkady) to 0.23 year^{-1} (Vettilapara) (Table 2). Potential longevity of *T. kbudree* was the highest (25years) among Thekkady and Poringal populations (Table 2). Fishing mortality (F) was the highest in Poringal (0.8 year^{-1}) and the lowest in Pooyamkutty (0.13 year^{-1}), while natural mortality (M) was the lowest in Poringal (0.15 year^{-1}) and highest in Kuttampuzha and Vettilapara (0.27 year^{-1}) (Table 3). Exploitation level (E) at five of the six fishing sites was above the expected optimal exploitation level, $E_{opt} = 0.5$ (Table 3), and at three of the six fishing sites was above the E_{max} (Table 4; Fig. 4), indicating that these populations are severely overexploited.

A combined picture of growth and mortality related parameters for different sites is depicted in Fig. 5. PCA extracted two significant factors with Eigen value more than one. First factor explained 76.18% while second factor explained 20.08% of the total variation in the data. Variables such as asymptotic length (L_{∞}), growth performance index (ϕ^i), potential longevity ($3/K$), total mortality (Z), fishing mortality (F) and exploitation levels (E) had positive factor on the F1 axis while growth coefficient (K) and natural mortality (M) had negative factor loading on F1 axis. All the commercially exploited sites (Poringal, Orukomban and Thekkady) had

positive factor loading on F1 axis while all sites with subsistence level fishery (Vettilapara, Pooyamkutty and Kuttampuzha) had negative factor loading on the F1 axis. This indicated that all commercially exploited areas have relatively high values for L_{∞} , ϕ^i , $3/K$, Z , F and E and relatively low values for K and M , while it was vice versa in the case of sites with subsistence fishery.

3.3. Spatial patterns in catches

Ratio of weight of *T. kbudree* to total weight of catch which was plotted as two-way dendrograms showed that the ratio for Vettilapara, Pooyamkutty and Thekkady are similar and much lesser than the ratios for Kuttampuzha, Poringal and Orukomban (Fig. 6). Among the sites in latter cluster, Kuttampuzha is separated from the cluster of Poringal and Orukomban because of smaller ratio values. Month wise analysis suggests the presence of three clusters i.e. (1) June, July, August and September, (2) January, February, March, April and May, and (3) October, November and December. During June–September, the contribution of *T. kbudree* to total catch is very high, followed by January–May, and October–December. This clustering suggests that there are specific trends in the catches of *T. kbudree* in different months.

3.4. Effect of habitat type, protection status and harvesting regime on the dynamics of population

Growth, mortality and exploitation levels of *T. kbudree* were not significantly different in the fishing areas located inside and outside protected areas. Asymptotic length, growth performance index, total mortality, fishing mortality and exploitation levels of *T. kbudree* was not significantly different between populations in rivers and reservoirs. However, growth coefficient (one tailed Mann–Whitney $U=8$, $p = 0.05$) and mortality (one tailed Mann–Whitney $U=8$, $p = 0.05$) of *T. kbudree* in rivers was marginally more than that in reservoirs. Harvesting regimes had significant effects on the growth coefficient, potential longevity and natural mortality, but had no effect on the asymptotic length, growth performance index, total mortality and fishing mortality. The growth coefficient of *T. kbudree* populations subjected to subsistence fishery was more than those in commercial fishery (one tailed Mann–Whitney $U=9$, $p = 0.0385$). Potential longevity in *T. kbudree*

Size	Length at first capture (L_c)mm	E_{10}	E_{50}	E_{max}
Orukomban	308.54	0.516	0.342	0.610
Kuttampuzha	39.99	0.306	0.265	0.410
Pooyamkutty	41.94	0.309	0.263	0.408
Poringal	269.59	0.402	0.294	0.472
Thekkady	229.48	0.513	0.334	0.600
Vettilapara	335.64	0.553	0.363	0.675

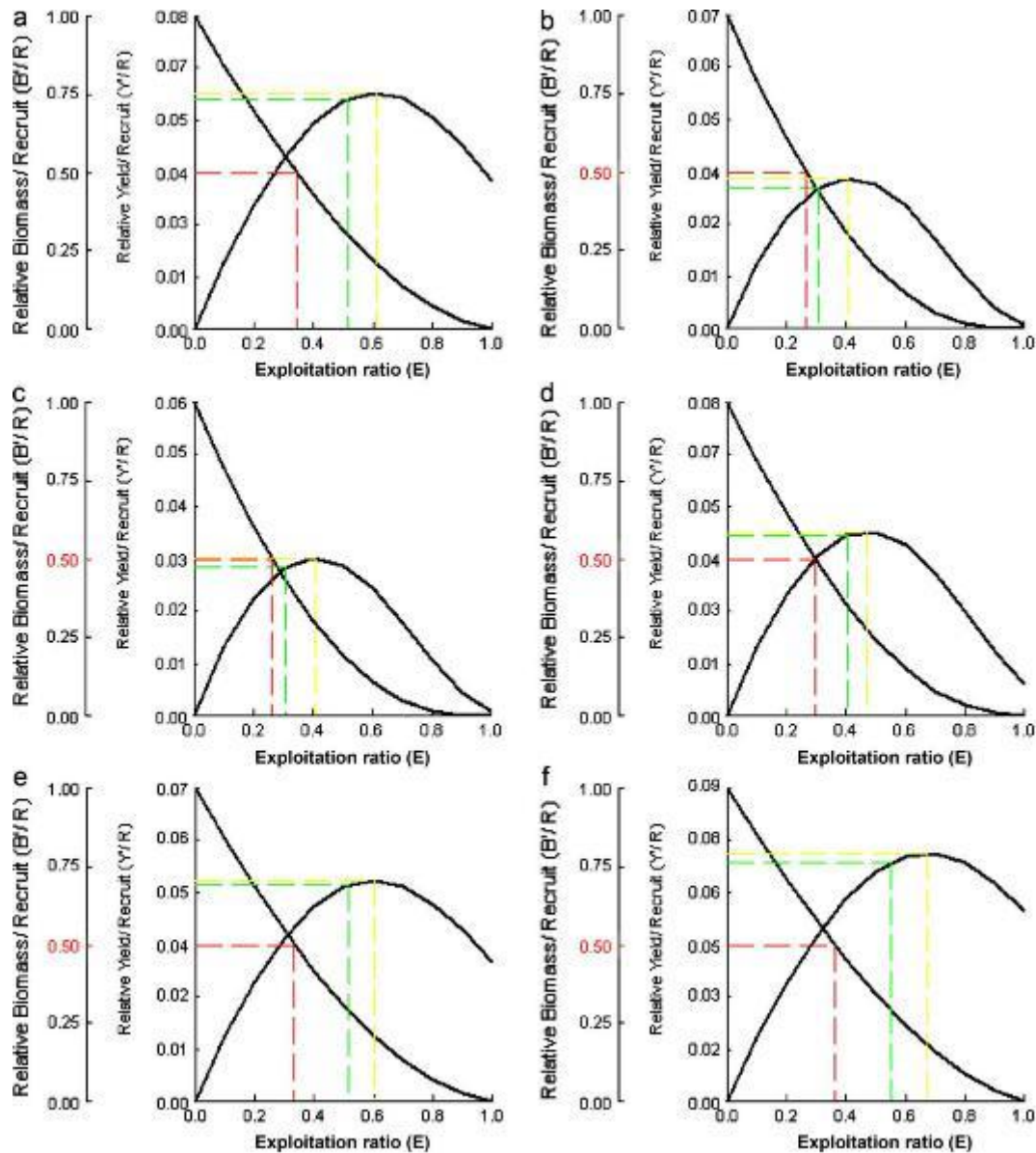


Fig. 4. Prediction of exploitation that retains 50% of the biomass E_{50} (shown by dashed arrow), and maximum yield per recruit E_{max} (shown by solid arrow) using relative yield per recruit (Y/R) and relative biomass per recruit (B/R) analysis with knife-edge selection method viz. (a) Orukomban, (b) Kuttampuzha, (c)

populations subjected to commercial fishery was higher than those populations subjected to subsistence fishery (one tailed Mann–Whitney $U=9$, $p = 0.0385$). Natural mortality of *T. khudree* in subsistence type of fishery, was more than that in commercial fishery (one tailed Mann–Whitney $U=0$, $p = 0.0385$).

4. Discussion

4.1. Fishery

Fishery for the Deccan Mahseer in the rivers and reservoirs of WG use similar gears as those used for Tor

Mahseer in Central India (Desai, 2003), and Golden Mahseer in the Himalayas (Joshi, 1988; Bhatt et al., 2000, 2004). However it was revealed from our results that, apart from cast nets and gill nets, which are the major gears used to target *T. khudree*, local fishers at some sites (Pooyamkutty and Kuttampuzha) are also resorting to destructive fishing practices. This was indicated by the presence of smaller sized fish in the landings, which normally do not entangle in either the gill nets or cast nets used by local fishers. Upon detailed enquiry, it was revealed that fishers use dynamite to catch Mahseer if they are unable to do so with the conventional gears. Dynamite fishing has been documented from the Southern WG since the early 1940s (Jones, 1946) and continues to be one of the most widely used

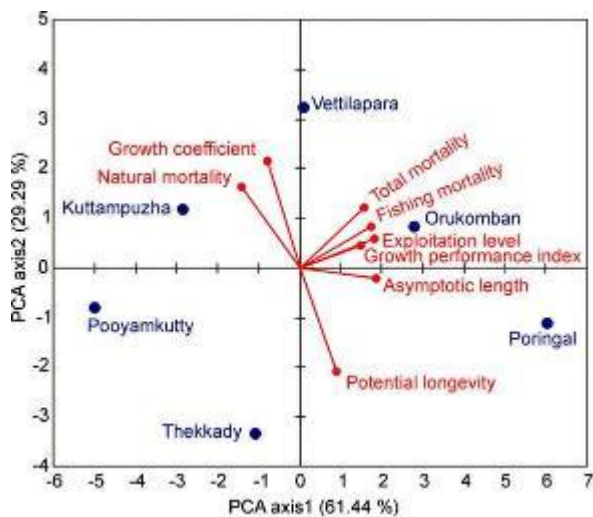


Fig. 5. Principle component analysis based on growth and mortality related parameters of *T. khudree* at various fishing sites (percentage in parentheses the percent variation explained by the factor).

destructive fishing techniques practiced in the region (Kurup et al., 2004; Raghavan et al., 2008a). Although dynamite fishing has been banned vide the Travancore Cochin Fisheries Act of 1950 (Government of Kerala, India) there is very little or no enforcement from the concerned authorities, and the practice continues to exist even inside protected areas of the region (Abraham et al., 2010).

4.2. Length frequency

Daniels (2002) reported that *T. khudree* grows to a maximum size of 1000mm, with specimens larger than 460mm rarely seen, while Talwar and Jhingran (1991) observed that this species grows to a maximum of 460mm in River Godavari and 130mm in Tamil Nadu. Our observation on an adult *T. khudree* measuring 1142mm caught from the Poringal reservoir therefore extends the maximum size of the species beyond 1000mm. From the length frequency distributions, it can be seen that *T. khudree* populations in Poringal, Thekkady, Orukomban and Vettilapara had large number of individuals >460mm, thought to be the average size of large *T. khudree* currently seen in rivers and reservoirs of WG (Daniels, 2002). The size at first maturity of *T. khudree* is known to be between 172mm and 220mm (Arun, 1999; Arunet al., 2001). The length frequency data of *T. khudree* individuals exploited from Pooyamkutty and Kuttampuzha indicate that a high share of the catches throughout the year, are contributed by immature size classes, thereby reducing the spawning stock and damaging the reproductive potential of the population.

4.3. Growth and mortality

Since there are no previous studies on the demography and population dynamics of *T. khudree*, our results, have been compared with other Mahseer species occurring in India. *T. khudree* has a higher growth coefficient ($K = 0.12–0.23$; mean of 0.19; $n = 6$) and lower asymptotic length ($L_{\infty} = 383.25–1202.25$ mm; mean of 659.75mm; $n = 6$) compared to the Golden/Himalayan Mahseer, *Tor putitora* ($K = 0.035–0.041$; mean of 0.038; $n=2$) ($L_{\infty} = 2160–2720$ mm; mean of 2440mm; $n = 2$), and a lower growth coefficient ($K = 0.12–0.23$; mean of 0.19; $n = 6$) and a mean lower asymptotic length ($L_{\infty} = 383.25–1202.25$ mm; mean of 659.75mm; $n = 6$) compared to the Tor Mahseer, *Tor tor* ($K = 0.50–0.78$; mean of 0.64; $n=2$) ($L_{\infty} = 787–946$ mm; mean of 866.5; $n=2$) (Nautiyal et al., 2008). The total mortality rate of *T. khudree* ($Z = 0.35–0.95$ year $^{-1}$; mean of

0.67 year $^{-1}$; $n = 6$) is higher than that of *T. putitora* ($Z = 0.366–0.58$ year $^{-1}$; mean of 0.473 year $^{-1}$; $n = 2$), but lower than that of *T. tor* ($Z = 4.08–5.57$ year $^{-1}$; mean of 4.825 year $^{-1}$; $n=2$) (Nautiyal et al., 2008). However, *T. khudree* has a comparable fishing mortality rate ($F = 0.13–0.8$ year $^{-1}$; mean of 0.45 year $^{-1}$; $n=6$) to *T. putitora* ($F = 0.312–0.517$ year $^{-1}$; mean of 0.414 year $^{-1}$; $n=2$) (Nautiyal et al., 2008). The fishing mortality rate of *T. khudree* in Poringal Reservoir ($F = 0.8$ year $^{-1}$) may probably be one of the highest for any species of Mahseer in India, and points to the targeted indiscriminate exploitation by the local fishers.

4.4. Exploitation rate

Over fishing is now considered to be a contributing factor to the decline of freshwater biodiversity (Allan et al., 2005). Although Mahseers are known to be threatened throughout its range countries (Nguyen et al., 2006), their exploitation continues unabated. Severe over fishing and population declines have been observed in many parts of India for Golden Mahseer, *T. putitora* (Bhatt et al., 2000, 2004; Nautiyal et al., 2008) and the Tor Mahseer, *T. tor* (Desai, 2003). Similarly, various South East Asian species of Mahseer including *Tor douronensis* and *Tor tambroides* are also known to be under severe fishing pressure (Nguyen et al., 2007).

In an optimally exploited stock, fishing mortality (F) should be about equal to natural mortality (M), resulting in an exploitation rate (E) of 0.5 year $^{-1}$ (Gulland, 1970). In the current study, exploitation rate of *T. khudree* at five of the six study sites were higher than ‘0.5’. The computed exploitation rates at three of the six sites were also more than the predicted E_{max} indicating that Mahseer populations in these areas are under excessive fishing pressure, and at some sites (Poringal and Orukomban) under the threat of an impending collapse. These results also validate the anecdotal information provided by local fishers that numbers, and size of the Mahseer caught are declining in the region (Minimol, 2000; Solomon, 2009).

4.5. Effect of habitat, protection status and harvesting regime

Dams are generally considered to be a threat to riverine fishes (Dudgeon, 2000; Dudgeon et al., 2006), especially to those making an upstream migration for spawning or breeding purposes. Mahseer perform seasonal migrations within a short distance mainly for breeding and feeding, with the limits of such movements determined by water temperature and flooding (Desai, 2003). Previous studies from the Chalakudy River basin indicate that dams have blocked spawning migration paths of *T. khudree* (Biju et al., 2000). However, our results indicate that there is no significant difference in the asymptotic length (L_{∞}), growth performance index (ϕ) and total mortality (Z) of *T. khudree* occurring in reservoirs (created as a result of large dams) compared to rivers, indicating that the species have now adapted to the altered environments and are doing well in the modified ecosystems. Similar observations have also been made from Central India where *T. khudree* and *Tor mussullah* have adjusted to the conditions in reservoirs and are maintaining breeding populations (Valsangkar, 1993). In addition, the potential longevity of *T. khudree* was found to be significantly higher in reservoirs when compared to rivers, and natural mortality significantly higher in rivers than in reservoirs, suggesting that reservoirs are also favourable habitats for growth and survival of *T. khudree* if fishing mortality is controlled through the regulation of harvests.

Worldwide, protected areas (with the exception of Ramsar Sites), are designed for the protection of terrestrial fauna, often viewing rivers and lakes as useful park boundaries rather than as targets for inclusion and protection in their own

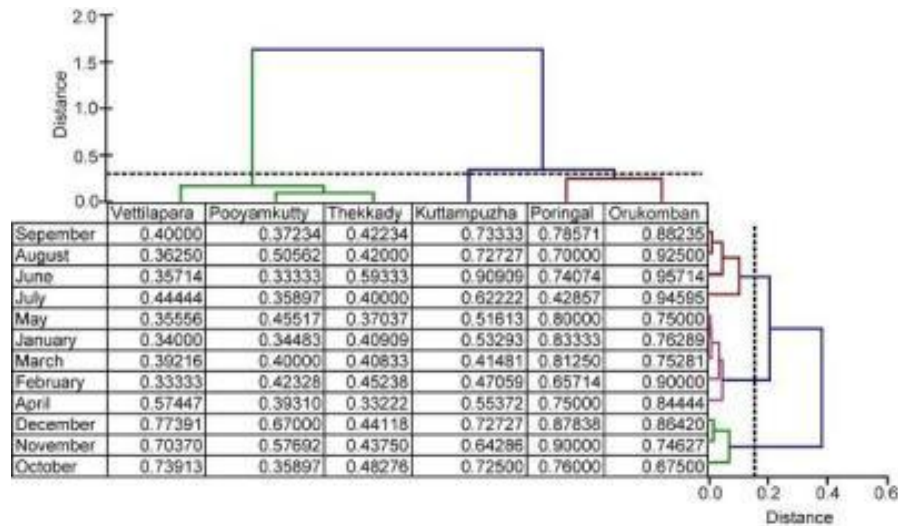


Fig. 6. Fraction of weight contributed by *T. kbudree* in the total weight of each catch for various fishing sites in Western Ghats. Dashed line gives cut-off for significant clusters.

right (Darwall et al., 2008). Nevertheless, some freshwater regions are also protected – but incidentally through their incorporation into terrestrial protected areas (Saunders et al., 2002). The Wildlife Protection Act of India (WLP), the highest legal instrument for the protection of flora and fauna in the country, provides protection to terrestrial and (some) marine mammals but little or no emphasis is placed on the conservation of freshwater biodiversity (Sarkar et al., 2008; Abraham et al., 2010). No freshwater fish species in India is listed in any of the appendices of the WLP (Raghavan, 2010). This laxity has hugely impacted the conservation and management of several endemic and threatened freshwater fish species in the country.

Recent studies from North India have indicated that water bodies located inside protected areas are important for conservation of the regional fish biodiversity, especially for endemic and endangered species (Sarkar et al., 2008). However this observation was based only on differences in species richness as well as size groups of selected species (Sarkar et al., 2008). Our results from the Southern WG have come out with a entirely different picture, suggesting that terrestrial protected areas may not help in conservation of freshwater fish species including the mighty Mahseer as there were no significant differences in their fishing mortality and exploitation rate within and outside protected areas. The exploitation rate of *T. kbudree* inside two major protected areas of the region—Periyar National Park (Thekkady) and Parambikulam Wildlife Sanctuary (Orukomban) are above the optimal limits indicating that the local populations may decline drastically if management plans are not urgently implemented.

4.6. Quality of participatory data

One of the main limitations in using data provided by local fishers for assessing population status is its quality. Most scientist perceive fishers as unreliable or biased, either intentionally, because it may serve their interest to under report their catch, or involuntarily as a consequence of limited education (Bene et al., 2009). The design of a fishery logbook—where data needed for the researcher is entered by the fishers is often considered to be a compromise between the desire of the researcher to obtain as much as information as possible, and the desire of fishers to spend as little time filling in information (King, 1995). Most fishers have an aversion to filling and entering data into forms and therefore a complicated questionnaire or logbook demanding too much information is

likely to be completed carelessly or even fictitiously (King, 1995). Taking these aspects into consideration, we asked fishers to enter only minimum data (length, weight and total catch) that was required for completing our analyses. This was based on King's (1995) suggestion that for a scientist, a small amount of accurate information is better than a large amount of suspect information.

During random visits to the fishing sites to validate the quality of data provided by field assistants and, subsequently during final analyses, we noticed that at certain sites (Pooyamkutty and Kuttampuzha), the size class of the catches that were recorded in the logbooks were much lower than the theoretical length which should have been obtained with the gears used. This indicated that fishers were resorting to fishing techniques other than those revealed to us during the initial workshop.

4.7. Management challenges

Small-scale fisheries have many features that make them vulnerable to collapse including over fishing, excess capacity (Andrew et al., 2007) and ineffective governance (Berkes et al., 2001). Traditional fishing communities in Kerala have often maintained a relationship of conflict or accommodation with state institutions (Santha, 2007), and there is a lack of mutual trust between formal institutions and traditional riverine fishing communities (Santha, 2007; Arunet al., 2001). Formal institutional arrangements in the region have also lacked the participation as well as representation of traditional riverine fishing communities (Santha, 2007). Man aging small-scale fisheries in such a region, especially in remote locations is therefore an immense challenge.

Nevertheless, as *T. kbudree* stocks in Kerala continue to be over- exploited and face an imminent collapse, there is need for urgent management intervention. Currently, the fishery for Mahseer in the protected areas of Kerala is not de facto open access, as fishing licenses are issued by the State Department o Forest (Arun et al., 2001; Solomon, 2009). However, there is no restriction on catch size or limits. Regulating total harvest could therefore be the single most important management strategy for protecting Mahseer stocks. However, implementation of a management plan to "reduce fishing effort" could prove to be unsuccessful as WG and Kerala are regions without any history of inland fisheries management.

A combination of different technical measures such as restrictions on gear size, catch size and closed seasons maybe ideally suited. In order to allow juvenile *T. khudree* to reach sexual maturity, before they are subjected to fishing mortality, a minimum size limit of 220mm should be enforced. Setting of minimum size limits should also be supplemented with restriction on the mesh size of the gill nets. If suitable gear restrictions are effectively implemented, there is little chance that the fishery will come in contact with the animals to be avoided (immature juveniles) (Charles, 2001). There is also a need for a ban on *T. khudree* fishing from October to December, when this species is known to breed in the waters of Kerala (Arun et al., 2001). During this time, the fishers can however turn their attention towards the harvest of more robust species such as the exotic Mozambique Tilapia, *Oreochromis mossambicus*, Common Carp, *Cyprinus carpio*, and transplanted Indian Major Carp *Gibelion catla*, all of which are available in the rivers and reservoirs from where *T. khudree* are caught. Through such selective harvesting, fisher livelihoods can be maintained without impacting the spawning stock of Mahseers.

Finally, a strict enforcement of the existing ban on dynamiting in the main Mahseer habitats of the region, following the Travancore Cochin Fisheries Act of 1950 and the recently proposed Kerala Inland Fisheries Act of 2010 should be carried out. Fishers who resort to dynamiting, and the owners of the quarries who supply dynamites to the fishers should be penalized strictly through appropriate measures such as payment of fines, cancellation of licenses and permits.

There is also a need to augment the Mahseer population through periodic stock enhancement and ranching of captive bred fry and fingerlings, similar to those carried out in the Central and Northern WG (Basavaraja, 2007; Ogale, 2002). However, this is a challenge as currently there is no hatchery for Mahseer in Kerala. Any plans to transport seeds from the nearest facilities located at Harangi Reservoir in Karnataka, or from the hatchery of the Tata Electric Company at Lonavala in Maharashtra may prove risky and resulting genetic contamination of stocks, as studies have indicated that *T. khudree* stocks in northern WG are different from those in southern WG (Kerala) and may even represent distinct species (Nguyen et al., 2008).

The biggest challenge for successful implementation of the above said management plan is the multiple ownership of the habitats of *T. khudree*. In Kerala, the state Ministry of Electricity and Power controls the reservoirs under hydro-electric power projects (for e.g. Poringal), while those reservoirs and streams located inside protected areas are under the jurisdiction of Ministry of Forest and Wildlife (for e.g. Thekkady). The Fisheries Department on the other hand has access only to a few irrigation reservoirs (Sugunan, 1995). The reservoirs under the Power and Forest Departments are currently not available for fish stocking (Harikumar and Rajendran, 2007) and therefore will require a great amount of bureaucratic interventions if plans to stock *T. khudree* are to be materialized in the immediate future. Even if management plans are designed, there are more questions that will need to be answered before the future of *T. khudree* is secured in the reservoirs of the region. These include (1) who will implement the stocking programs in the reservoirs? (2) Who will regulate the fishery of *T. khudree* in the reservoirs? (3) What legislations will be taken into account to prosecute fishers involved in illegal harvests?

5. Conclusions

Our study has revealed that the impact of small-scale fisheries is not always "small", and that populations targeted by such fisheries are susceptible to over fishing, as are large stock in oceans, and are in need of urgent management interventions. We have also successfully demonstrated the utility of participatory data collection in assessing the status of remotely located fisheries which can be replicated elsewhere in the tropics where such small-scale fisheries are seldom given attention, and are under threat. Lastly, our study on the demography and exploitation of *T. khudree* in the remote aquatic habitats of the WG is expected to provide valuable baseline data on which future conservation and management plans can be designed and implemented.

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References

- Abell, R., Thieme, M.L., Revenga, C., Bryer, M., Kottelat, M., et al., 2008. Freshwater eco regions of the World: a new map of biogeographic units for freshwater biodiversity conservation. *Bioscience* 58, 403–414.
- Abraham, R.K., Rajesh, R., Kelkar, N., 2010. Do protected areas of India's Western Ghats conserve fish diversity? Final Report Submitted to the Conservation Leadership Program (CLP Report 331409).
- Ajithkumar, C.R., Remadevi, K., Thomas, K.R., Biju, C.R., 1999. Fish fauna, abundance and distribution in Chalakudy river system, Kerala. *J. Bombay Nat. Hist. Soc.* 96 (2), 244–254.
- Allan, J.D., Abell, R., Hogan, Z., Ravenga, C., Taylor, B.W., Welcomme, R.L., Winemiller, K., 2005. Over fishing of inland waters. *Bioscience* 55 (12), 1041–1051.
- Andrew, N.L., Bene, C., Hall, S.J., Allison, E.H., Heck, S.S., Ratner, B.D., 2007. Diagnosis and management of small-scale fisheries in developing countries. *Fish. Fisheries* 8, 227–240.

- Arce-Ibbara, A.M., Charles, A.T., 2008. Inland fisheries of the Mayan Zone in Quintana Roo, Mexico: using a combined approach to fishery assessment for data-sparse fisheries. *Fish. Res.* 91(2–3), 151–159.
- Arun, L.K., 1999. Patterns and processes of fish assemblage in Periyar Lake-valley system of Southern Western Ghats. KFRI Research Report. Kerala Forest Research Institute, Peechi, Kerala, India.
- Arun, L.K., Jayasankar, B., Abraham, K.M., 2001. Biodiversity conservation and livelihood issues of tribe's folk: a case study of Periyar Tiger Reserve. Discussion Paper No 37. Kerala Research Program on Local Level Development (KRPLLD), Centre for Development Studies, Thiruvananthapuram, India, 79p.
- BNP, 2009. Big number program. Intermediate report. Food and Agriculture Organisation and World Fish Centre, Rome/Penang, Italy/Malaysia.
- Bachan, A.K.H., 2003. Riparian vegetation along the middle and lower zones of the Chalakudy River, Kerala, India. Report. Project 26/2000. Kerala Research Program on Local Level Development. Centre for Development Studies, Trivandrum, Kerala.
- Basavaraja, N., 2007. Freshwater fish seed resources of India, pp 267–327. In: Bondad-Reantaso, M.G. (Ed.), Assessment of Freshwater Seed Resources for Sustainable Aquaculture. FAO Fisheries Technical Paper No 501, FAO, Rome, 628 p.
- Bene, C., Abban, E.K., van Zwieten, P., Dankwa, H.R., Brummett, R., Ofori, J.K., Obirih-Opareh, N., Kolding, J., 2009. Engaging Local Communities in Aquatic Resources Research and Activities: A Technical Manual. World Fish Centre Technical Manual No.1951. The World Fish Centre, Penang, Malaysia, p.23.
- Berkes, F.R., Maho, P., McConney, R., Pollnac, Pomeroy, R., 2001. Managing Small-scale Fisheries: Alternative Directions and Methods. International Development Research Centre, Ottawa.
- Bhatt, J.P., Nautiyal, P., Singh, H.R., 2004. Status (1993-1994) of the endangered fish Himalayan Mahseer *Tor putitora* (Hamilton) (Cyprinidae) in the mountain reaches of the river Ganga. *J. Asian Fish. Soc.* 17, 341–355.
- Bhatt, J.P., Nautiyal, P., Singh, H.R., 2000. Population structure of Himalayan Mahseer, a large cyprinid
- Biju, C.R., Thomas, K.R., Ajithkumar, C.R., 2000. Ecology of hill streams of the Western Ghats with special reference to fish community. Final report 1996-1999 Project report submitted to Bombay Natural History Society, Bombay, India.
- CAMP, 2001. Conservation Assessment and Management Plan. In: Molur, S., Walker, S. (Eds.), Workshop Report by Zoo Outreach Organisation, Indian Edition. CBSG, 100 pp.
- CEPF, 2007. Ecosystem Profile: Western Ghats and Sri Lanka Biodiversity Hotspot – Western Ghats Region. Critical Ecosystem Partnership Fund, p.95.
- Castello, L., Viana, J.P., Watkins, G., Pinedo-Vasquez, M., Luzadis, V.A., 2009. Lessons from integrating fishers of Arapaima in small-scale fisheries management at the Mamirauá Reserve, Amazon. *Environ. Mgmt.* 43, 197–209.
- Charles, A., 2001. Sustainable Fishery Systems. Fish and Aquatic Resources Series 5, Blackwell Science, Oxford.
- DFID, 2002. Inland fisheries. Fact Sheet. Department for International Development, Rural Livelihoods Department.
- Dahanukar, N., Raut, R., Bhat, A., 2004. Distribution, endemism and threat status of freshwater fishes in the Western Ghats of India. *J. Biogeogr.* 31, 123–136.
- Daniels, R.J.R., 2002. Freshwater Fishes of Peninsular India. Universities Press (India) Private Limited.
- Darwall, W., Smith, K., Allen, D., Seddon, M., Reid, G.M., Clausnitzer, V., Kalkman, V., 2008. Freshwater Biodiversity – a hidden resource under threat. In: Vié, J.-C., Hilton-Taylor, C., Stuart, S.N. (Eds.), The 2008 Review of the IUCN Red List of Threatened Species. IUCN, Gland, Switzerland.
- Desai, V.R., 2003. Synopsis of biological data on the mahseer *Tor tor* (Hamilton, 1822). In: FAO Fisheries Synopsis. No. 158. FAO, Rome, 36pp.
- Devi, R., Boguskaya, N., 2007. *Tor kbudree*. In: IUCN 2010. IUCN Red List of Threatened Species, Version 2010.2 <http://www.iucnredlist.org/>. Accessed on 23 August 2010.
- Dudgeon, D., 2000. Riverine biodiversity in Asia: a challenge to conservation biology. *Hydrobiologia* 418, 1–13.
- Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z., Knowler, D., Lévêque, C., Naiman, R.J., Prieur-Richard, A.-H., Soto, D., Stiassny, M.L.J., Sullivan, C.A., 2006. Freshwater biodiversity: importance, status, and conservation challenges. *Biol. Rev.* 81, 163–182.
- FAO, 2008–2010. People and Communities. FAO Fisheries and Aquaculture Department [online], Rome. Updated 24 July 2008, <http://www.fao.org/fishery/ssf/people/en> accessed on 23rd August 2010.
- Froese, R., Pauly, D., 2010. Fish base. www.fishbase.org, cited June 18, 2009.
- Gayanilo, F.C., Pauly, D. (Eds.), 1997. FAO–ICLARM Stock Assessment Tools (FiSAT). Reference Manual. FAO Computerized Information Series (Fisheries) No.8. FAO, Rome, p.262.
- Granek, E.F., Madin, E.M.P., Brown, M.A., Figuiera, W., Cameron, D.S., Hogan, Z., Kristianson, G., DeVilliers, P., Williams, J.E., Post, J., Zahn, S., Arlinghaus, R., 2008. Engaging recreational fishers in management and conservation: global case studies. *Conserv. Biol.* 22(5), 1125–1134.
- Gulland, J.A., 1970. The fish resources of the ocean. FAO Fisheries Technical Paper No. 97, 425p.
- Harikumar, G., Rajendran, G., 2007. An Overview of Kerala Fisheries with Particular Emphasis on Aquaculture. Souvenir, Integrated Fisheries Project (IFP), Kochi, India, pp.1–19.
- Jones, J.P.G., Andriamarivololona, M.M., Hockley, N., Gibbons, J.M., Millner-Gulland, E.J., 2008. Testing the use of interviews as a tool for monitoring trends in the harvesting of wild species. *J. Appl. Ecol.* 45, 1205–1212.
- Jones, S., 1946. Destructive methods of fishing in the rivers of the hill ranges of Travancore. *J. Bombay Nat. Hist. Soc.* 46, 437–445.
- Joshi, C.B., 1988. Mahseer fishery of some hill streams in western Himalayas. *Indian J. Fish.* 35, 229–327.
- King, M., 1995. Fisheries Biology, Assessment and Management. Oxford Books.

- Kottelat, M., Whitten, T., 1996. Freshwater biodiversity in Asia with special reference to fish. World Bank technical paper 343. Washington, USA.
- Kurup, B.M., Manojkumar, T.G., Radhakrishnan, K.V., 2006. Fish and fisheries of Periyar Lake, Kerala. *Indian J. Fish.* 53, 153–166.
- Kurup, B.M., Radhakrishnan, K.V., Manojkumar, T.G., 2004. Biodiversity status of fishes inhabiting rivers of Kerala (S. India) with special reference to endemism, threats and conservation measures. In: Welcome, R.L., Petr, T. (Eds.), *Proceedings of LARS2. 2nd Large Rivers Symposium*. Mekong River Commission and Food and Agricultural Organization, pp.163–182.
- Legendre, P., Legendre, L., 1998. *Numerical Ecology*, 2nd Englished. Elsevier Science BV, Amsterdam, pp.xv+853.
- Martin Smith, K.M., Samoilys, M.A., Meeuwig, J.J., Vincent, A.C.J., 2004. Collaborative development of management options for an artisanal fishery for seahorses in the central Philippines. *Ocean. Coast. Mgmt.* 47, 165–193.
- Mahon, R., 1997. Does fisheries science serves the needs of managers of small stocks in developing countries? *Can. J. Fish. Aquat. Sci.* 54, 2207–2213.
- Minimol, K.C., 2000. Fishery management in Periyar Lake. PhD Thesis. Mahatma Gandhi University, Kottayam, India, 196p.
- Nautiyal, P., Rizvi, A.F., Dhasmanaa, P., 2008. Life History traits and decadal trends in the growth parameters of Golden Mahseer, *Tor putitora* (Hamilton 1822) from the Himalayan stretch of the Ganga River System. *Turk. J. Fish. Aquat. Sci.* 8, 125–132.
- Nguyen, T.T.T., Na-Nakorn, U., Sukmanomon, S., Ziming, C., 2008. A study on the phylogeny and biogeography of Masheer species (Pisces: Cyprinidae) using sequences of three mitochondrial DNA gene regions. *Mol. Phylogenet. Evol.* 48 (3), 1223–1231.
- Nguyen, T.T.T., Ingram, B., Sungan, S., Tinggi, D., Sim, S.Y., Gooley, G., DeSilva, S.S., 2007. Guidelines for Genetic Management and Conservation of two Mahseer species in Sarawak, Malaysia. *Network of Aquaculture Centres in Asia-Pacific (NACA)*, Bangkok, 21p.
- Nguyen, T.T.T., Ingram, B., Sungan, S., Gooley, G., Sim, S.Y., Tinggi, D., DeSilva, S.S., 2006. Mitochondrial DNA diversity of broodstock of two indigenous Mahseer species, *Tor tambroides* and *T. douronensis* (Cyprinidae) cultured in Sarawak, Malaysia. *Aquaculture* 253, 259–269.
- Ogale, S.N., 2002. Mahseer breeding and conservation, and possibilities for commercial culture: the Indian experience. In: Petr, T., Swar, S.B. (Eds.), *Coldwater Fisheries in the Trans Himalayan Countries*. FAO Fisheries Technical Paper 431, pp. 193–212.
- Pauly, D., 1997. Small-scale fisheries in the tropics: marginality, marginalization and some implication for fisheries management. In: Pikitch, E.K., Huppert, D.D., Sissenwine, M.P. (Eds.), *Global Trends: Fisheries Management*. American Fisheries Society Symposium 20. Bethesda, Maryland, pp.40–49.
- Pauly, D., 1984. Fish population dynamics in tropical waters: a manual for use with programmable calculators. *ICLARM Stud. Rev.* (8), 325p.
- Pauly, D., Munro, J.L., 1984. Once more on the comparison of growth in fish and invertebrate. *ICLARM Fish Byte* 2(1), 21.
- Raghavan, R., 2010. Ornamental fisheries and trade in Kerala. In: Benziger, L.A. (Ed.), *Fish Conservation in Kerala Sonnenschein*. World Aquariums and Oceans Federation, St. Louis, USA, pp. 169–197.
- Raghavan, R., Prasad, G., Ali, A., Pereira, B., Sujarittanonta, L., 2009. Damsel in distress – the tale of Miss Kerala, *Puntius denisonii* (Day) an endemic and endangered cyprinid of Western Ghats biodiversity hotspot, India. *Aquat. Cons. Mar. Fresh. Ecosyst.* 19(1), 67–74.
- Raghavan, R., Prasad, G., Ali, A., Pereira, B., 2008a. Fish fauna of River Chalakudy part of Western Ghats biodiversity hotspot (South India)- patterns of distribution, threats and conservation needs. *Biodivers. Conserv.* 17, 3119–3131.
- Raghavan, R., Prasad, G., Ali, A., Pereira, B., 2008b. Exotic fishes in a global biodiversity hotspot –a case study from River Chalakudy, part of Western Ghats, Kerala, India. *Biol Invasions* 10 (1), 37–40.
- Santha, S.D., 2007. State interventions and natural resource management: A study on social interfaces in a riverine fisheries setting in Kerala, India. *Nat. Res. Forum.* 31, 61–70.
- Sarkar, U.K., Pathak, A.K., Lakra, W.S., 2008. Conservation of freshwater fish resources of India: new approaches, assessments and challenges. *Biodivers. Conserv.* 17 (10), 2495–2511.
- Sunders, D.L., Meeuwig, J.J., Vincent, A.C.J., 2002. Freshwater protected areas: strategies for conservation. *Conserv. Biol.* 16 (1), 30–41.
- Smakhtin, V., Arunachalam, M., Behera, S., Chatterjee, A., Das, S., Gautam, P., Joshi, G.D., Sivaramakrishnan, K.G., Unni, K.S., 2007. Developing procedures for assessment of ecological status of Indian River Basins in the context of environmental water requirements. *Research Report 114*, International Water Management Institute (IWMI), Battaramulla, Sri Lanka.
- Solomon, S., 2009. Local knowledge, attitudes and perceptions of tribal's on the fish and fisheries of Poringalkuthu Reservoir, Kerala, India. BSc Dissertation submitted to the St. Albert's College, Mahatma Gandhi University, Kerala, India, 70 p. Sugunan, V.V., 1995. Reservoir fisheries of India. *FAO Fisheries Technical Paper* 345, 423 p.
- Talwar, P.K., Jhingran, A.G., 1991. *Inland Fishes of India and Adjacent Countries, I& II*. Oxford & IBH Publishing Co. Pvt. Ltd, New Delhi.
- Ticheler, H., Kolding, J., Chanda, B., 1998. Participation of local fishermen in scientific fisheries data collection: a case study from the Bangweulu swamps, Zambia. *Fish. Mgmt. Ecol.* 5, 81–92.
- Valsangkar, S.V., 1993. Mahseerin Bhandaradara reservoir resilient. *Fish. Chimes.* 13 (6), 43–49. Welcomme, R.L., Cowx, I.G., Coates, D., Bene, C., Funge-Smith, S., Halls, A., Lorenzen, K., 2011. Inland capture fisheries. *Phil. Trans. R. Soc.B.* 365, 2881–2896.
- Wiber, M., Charles, A., Kearney, J., Berkes, F., 2009. Enhancing community empowerment through participatory fisheries research. *Mar. Policy* 33,172–179.