Efficacy of angler catch data as a population and conservation monitoring tool for the flagship Mahseer fishes (Tor spp.) of Southern India

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Efficacy of angler catch data as a population and conservation monitoring tool for the flagship Mahseer fishes (*Tor* spp.) of Southern India

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ABSTRACT

1. Mahseer (*Tor* spp.) are flagship fishes in South Asian rivers. Their populations are threatened through poaching and habitat disturbance, yet they are highly prized game fishes due to their large size, appearance and sporting qualities. The international recreational angling community has been frequently cited as playing a vital role in conserving these fishes while also providing economic benefit to poor rural communities.

2. Due to a lack of scientific data and the considerable challenges associated with monitoring fish populations in large monsoonal rivers, efforts to determine the long-term trends in their populations has focused on sport-fishing catch records. Here, catch data collected between 1998 and 2012 from Galibore, a former fishing camp on the River Cauvery, Karnataka, India, were analysed to determine the catch per unit effort (CPUE - by number and weight) as an indicator of relative fish abundance, along with the size structure of catches. This fishery operated a mandatory catch-and-release (C&R) policy, and provided the fish community with protection from illegal fishing.

3. Between 1998 and 2012, 23,620 hours fishing effort were applied to catch and release 6,161 mahseer, ranging in size from 1 to 104 lbs (0.45 – 46.8 kg) in weight. Across the period, CPUE in number increased significantly over time with a concomitant decrease in CPUE by weight, revealing strong recruitment in the population and a shift in population size structure. This suggests a strong response to the C&R policy and the reduction in illegal fishing, indicating that conservation strategies focusing on the beneficial and negative aspects of exploitation can be successful in achieving positive outcomes.

4. These outputs from angler catch data provide insights into the mahseer population that were impossible to collect by any alternative method. They provide the most comprehensive analysis of a long-term dataset specific to any of the mahseer species across their entire geographical range and demonstrate the value of organised angling as a conservation-monitoring tool to enhance biological data, and inform conservation and fishery management actions.

KEY WORDS: angler logs; C&R; poaching; Western Ghats, stock protection, IUCN Red List; ecosystem services, population monitoring.

INTRODUCTION

Freshwater fishes comprise one of the most threatened taxa on earth (Cooke *et al*., 2012; Carrizo *et al*., 2013; Reid *et al*., 2013), with the extinction of approximately 60 species since 1500 and a further 1679 currently threatened with extinction (Carrizo *et al.,* 2013). Despite that, conservation attention on these fishes is limited, mostly attributable to issues relating to knowledge gaps on key life history traits, population and habitat requirements, and geographical distributions, all of which are crucial for developing and implementing effective conservation actions (Cooke *et al.,* 2012). Moreover, these knowledge gaps are increasing as taxonomists continue to discover and describe new species of freshwater fishes, many of them from habitats that are already facing high levels of anthropogenic disturbance.

Collection of inland fisheries data, particularly in biodiversity rich, tropical countries, can be extremely challenging as many of the sites are located in remote areas and extreme habitats which are often inaccessible for research, and where a lack of political will further limits both financial capacity and human resource (Mahon, 1997; Arce-Ibbara and Charles, 2008). Improving knowledge and understanding of freshwater fish and inland fisheries in these countries and regions therefore needs to consider the use of alternative, cost-effective approaches (Bene *et al*., 2009; Raghavan *et al*., 2011; de Graaf *et al.,* in press). Due to the often threatened status of the fish species concerned, allied with legislation that seeks to protect these species (even if management strategies are yet to be developed due to the knowledge gaps), these alternative approaches should also be non-destructive and have a strong ethical basis.

Mahseer (*Tor* spp; Cypriniformes: Cyprinidae) are large-bodied freshwater fishes that are endemic to the monsoonal rivers of Asia. They are popular throughout their range as flagship species of considerable economic, recreational and conservation interest (Siraj, 2007; Nguyen et al., 2008; Singh and Sharma, 1998). Of the 18 valid species of *Tor* mahseer (Eschmeyer, 2014; Kottelat, 2013), six species (*Tor ater*, *Tor khudree*, *Tor kulkarnii*, *Tor malabaricus*, *Tor putitora* and *Tor yunnanensis*) are 'Endangered', one is 'Near Threatened', and six species are 'Data Deficient' on the IUCN Red List (IUCN, 2013; www.iucnredlist.org). The remaining five species have not been assessed for their conservation status. Despite this, data on mahseer populations are severely limited, with even fundamental aspects such as taxonomy, autecology, and population demographics being unknown for many species Raghavan *et al.,* 2011; Pinder and Raghavan, 2013). For example, there are no population estimates available for the endangered species *T. khudree* and *T. malabaricus* (Raghavan, 2011; Raghavan and Ali, 2011). Nevertheless, they are internationally recognised for their large size, attractive appearance, and sporting qualities by recreational anglers; in India, they are known as the 'King of aquatic systems' (Langer *et al.,* 2001; Dhillon, 2004) and comprise one of the primary groups of fish targeted by recreational fishers (Cooke *et al*., in press). Indeed, the little information that is available on Indian mahseer populations has largely originated from, or is related to, the recreational angling community (e.g. Thomas, 1873; MacDonald, 1948; Trans World Fishing Team, 1984; Dhillon, 2004; Everard and Kataria, 2011; Pinder and Raghavan, 2013).

The recreational angling community offers a social group that positively supports fish conservation (Arlinghaus, 2006) and recreational fishers have engaged in various activities contributing to freshwater fish conservation such as monitoring, research, management, advocacy, and education (Granek *et al.,* 2008; Cooke *et al.,* in press). For example, in India, the recreational fishing sector has played an integral part in the conservation and management of mahseers through such activities as the implementation of compulsory catch-and-release (C&R), stock augmentation, stock protection and, in some cases, the maintenance of catch log books (Everard and Kataria, 2011; Pinder and Raghavan, 2013; Cooke *et al.,* in press). Nevertheless, despite recreational fishers and fishery managers having been previously identified as a potentially valuable source of data, there are, to date, no previous efforts to exploit these catch log-books. Consequently, in this study, catch log-book data from the Galibore Fishing Camp on the River Cauvery were assessed over a 15 year period (1998 to 2012). In this period, the fishery management objectives were the release of all rod-caught mahseers and the elimination of poaching throughout the controlled (~7km) length of river through enforcement. The study objectives were thus to: (i) determine the temporal trends in catch per unit effort (CPUE - by number and weight) of mahseer captured by recreational fishers; (ii) assess the extent to which the size structure of the mahseer population has changed over time and how this might be related to the fishery management objectives; and (iii) assess the implications of the outputs in relation to recreational fishery exploitation and species conservation.

MATERIALS AND METHODS

The Cauvery (basin area of 87900 km^2) (De Silva *et al*., 2007) is a major east flowing river draining the Western Ghats, an exceptional area of freshwater biodiversity and endemism in peninsular India (Molur *et al*., 2011). The Cauvery and its tributaries comprise one of the two (the other being the Himalayan Ganges) river systems where C&R angling for the mahseer has been practiced since the colonial times (Thomas, 1873; Dhu, 1923; MacDonald, 1948). Galibore Fishing Camp represents one of four former angling camps situated on the River Cauvery encompassed by the Cauvery Wildlife Sanctuary (an IUCN Category IV Protected Area) in the state of Karnataka, Southern India (Fig. 1). The Wildlife Association of South India (WASI) came into existence in 1972 with a mandate 'to conserve and preserve the wildlife of South India'. This Bangalore based Non-Governmental Organization was instrumental in the early development of the C&R fishery which encompassed the 7 km beat at Galibore and extended 22 km between Mutthatti and Mekedatu (Fig. 1). Due to the recognised revenue potential of the fishery, in 1999, Galibore along with two further camps (sited between Galibore and Shivasamudram Falls were developed into semi-permanent eco-tourism establishments by the state government-owned Jungle Lodges and Resorts (JLR). WASI's successful model of employing guards to man anti-poaching camps was maintained and supported by both WASI and JLR at Galibore until 2012, when the entire fishery was closed (see Pinder and Raghavan, 2013).

Despite current contention regarding the taxonomic identity of mahseer species present within this section of the Cauvery, there exist two well defined morphs which are known as blue finned mahseer and golden or hump-back mahseer. As works to resolve the exact identity of these 'species' are underway, this paper refers only to the phenotypic descriptions as 'blue-finned' and 'golden' mahseers so as to avoid risk of perpetuating erroneous scientific names.

The fishing season for mahseer typically extends from November to March, with fishery performance considered to peak, providing consistent sport quality (number and size of fish caught) between January and March when river flows are at their lowest and angling can be practised effectively.

Between mid-January and mid-March of 1998 to 2012, the mahseer fishery was subject to regulated angling pressure (maximum 10 rods/day), practicing a very strict C&R policy. Structured catch data collected during this period included daily records of individual angler identity (name); hours fished (effort); number of fish caught; weight of individual fish (the standard metric used by anglers was imperial lbs) and notes relating to mahseer phenotype. With the exception of two years (1999 and 2000), a sub-sample of catch returns spanning 1998 – 2012 were available from the fishery manager and complemented by additional returns retained by anglers over the same period. The resolution of the recovered data set is summarised in Table 1.

While all larger mahseer (>10 lbs (>4.5 kg)) were typically weighed to the nearest pound using spring loaded weighing scales, many weights of smaller individual fish were found to be restricted to estimates. Furthermore, where an angler recorded a large number of fish during a single (4 hour) fishing session, records were typically limited to the weight of the largest fish with the remaining catch enumerated, e.g. *six fish to 18 lbs*. Following consultation with the camp manager and a selection of the anglers, these data have been standardised by recording one fish at 18 lbs with all other individuals recorded as weighing 5 lbs (5 lbs representing the threshold at which most anglers were considered to neither weigh nor estimate the weight of their fish). Where the weight of the largest individual did not exceed 5 lbs (either estimated or weighed), e.g. *nine fish to 5 lbs*, data were standardised by applying a 50% weight reduction to the remaining eight fish for which weights were not recorded. In this example the adjusted record would account for one fish of 5 lbs and eight fish of 2.5 lbs. While the authors' acknowledge the inherent limitations of these standardised data, the allocation of arbitrary weights (as guided by the local angling community) has facilitated a valuable measure of the numbers of young fish recruiting to the population over the course of the study period.

The initial step in the data analyses was to determine catch per unit by number and weight for each year. These data were then analysed in linear mixed models where the final model used angler identity as the random variable (to account in the model for differences in their respective abilities, differences in fishing style etc., and in relation to their catches), year as the independent variable and catch per unit effort (either in number or weight) as the dependent variable. Outputs included estimated marginal means (i.e. mean adjusted CPUE by year) and the significance of their differences between years according to pairwise comparisons with Bonferroni adjustment for multiple comparisons. In addition, the mean weights of fish captured per year were tested using ANOVA with Tukey's post-hoc tests. All statistics were completed in SPSS v.21.0.

RESULTS

Annual median CPUE increased over the period, although the within-year variability of the data was considerable (Fig. 2). The linear mixed models were significant for both catch per unit effort by number ($F_{12,251} = 18.56$, $P < 0.01$) and weight ($F_{12,251} = 6.13$, $P < 0.01$), with pairwise comparisons revealing significantly higher CPUE by number between 2010 and 2012 compared to the highest CPUE by number recorded in the early 2000s (2001; $P < 0.01$; Fig. 3). There were, however, no significant differences in the mean adjusted catch per unit effort by weight per year ($P > 0.05$; Fig. 3).

Over the study period, the mean weight of fish captured by anglers significantly decreased (ANOVA, $F_{12,251} = 7.41$, $P < 0.01$), with Tukey's post-hoc tests revealing that the differences between the highest mean weight recorded in the study, 1998, and subsequent years were significant between 2007 and 2012 ($P < 0.05$; Fig. 4). The significant relationship between CPUE by number and mean weight of fish revealed that as catch rates increased over time they comprised of larger numbers of smaller fish (linear regression: $R^2 = 0.83$, $F_{1,11} = 22.93$, $P < 0.01$; Fig. 4). Indeed, by categorising the captured fish into weight categories of 20 to 39 lbs, 40 to 59 lbs and > 60 lbs, it was apparent that the contribution of the largest fish to catches significantly reduced between 2001 and 2012 (linear regression: $R^2 = 0.82$, $F_{1,10} = 18.81$, $P < 0.01$; Fig. 5), but not in the smaller weight classes (21 to 40 lbs: linear regression: $R^2 = 0.12$, $F_{1,10} = 1.21$, $P = 0.47$; 41 to 60 lbs: linear regression: $R^2 = 0.57$, $F_{1,10} = 0.57$, $P = 0.47$; Fig. 5).

DISCUSSION

The Indian Wildlife (Protection) Act 1972 (WPA) was enacted to provide much needed legal protection to flora and fauna. Although this piece of legislation prohibits the hunting of any 'wild animal' within areas set aside for protection (Protected Areas (PA)), the Act only specifies amphibians, birds, mammals, and reptiles as constituting the term 'wild animal' (Pinder and Raghavan, 2013). Lacking any formal amendment to recognise and include freshwater fish, recently revised governmental interpretation of the Act has resulted in the closure of the four former recreational mahseer fishing camps sited within the Cauvery Wildlife Sanctuary. The phased closure of these camps between 2010 and 2012 has left fish stocks previously afforded protection from poachers, once again vulnerable to the effects of illegal and highly destructive harvest methods including the use of dynamite (Pinder and

Raghavan, 2013). Lacking any scientifically derived survey data, the daily catches recorded by anglers at the Galibore Camp between 1998 and 2012 represent the only available data to examine the temporal performance of the mahseer stock leading up to the implementation of the angling ban and to explore any potential effects that the C&R fishery may have had on the health of the population.

The outputs of the analyses of the catch data from the Galibore fishery revealed some marked changes in catch composition over the study period, with increased numbers of smaller fish appearing in catches that was allied with increased CPUE by number. This successful use of recreational catch data to obtain insights into the mahseer population mirror other examples of using recreational angler catch data as a tool to monitor freshwater fish stocks and inform population management strategies (see Cowx, 1991; Granek *et al*., 2008). As a consequence of historic overexploitation, examples in many cases relate to species of high economic value, either as food and/or sport fishes, which are now facing global and/or localised population threats e.g. Atlantic salmon *Salmo salar* (Gee and Milner, 1980) and white sturgeon *Acipenser transmontanus* (Inglis and Rosenau, 1994). In the case of 'Endangered' species which are endemic to developing countries (e.g. Eurasian taimen *Hucho taimen* (Jensen *et al.,* 2009); mahseer *Tor* spp. (Pinder and Raghavan, 2013)), resources available to monitor and manage fish populations are typically highly constrained, thus limiting the development of effective management strategies which are urgently required to foster a balance between exploitation and species conservation (Jensen *et al*., 2009). Thus, angler catch data can provide a very cost effective alternative in collating temporal and spatial information on the fish stock that can provide information on long-term population patterns and trends in that component of the stock that is being exploited (Cooke *et al*., in press).

While bait selection and angling method can be highly selective with respect to species and sizes of fish captured (Mezzera and Largiadèr, 2001; Ussi-Heikkila *et al*., 2008), such bias were considered to be minimal here due to the very large mouth gape of even the smallest mahseers. Despite some limited effort being applied by anglers to catch fish using artificial lures, the primary method of capture was based on using large balls (~8cm diameter) of cereal (Ragi, *Eleusine coracana*) derived paste as bait that appeared to randomly capture fish of between 1 lb and 104 lbs (0.45 – 46.8 kg) in weight. This was thus likely to have reduced the potential for variability in the data occurring through use of different methodologies. As any inherent variance in individual angler ability in the dataset was also accounted for in the analyses, the increased appearance of smaller fish in catches suggests this was due to their greater availability to anglers. The data highlight an apparent threshold between 2007 and 2008, when CPUE by fish number and total weight demonstrated a marked increase. Given that anecdotal evidence has suggested minimal stock augmentation in the river (S. Chakrabarti, Wildlife Association of South India, pers. com.), the increased abundance of smaller mahseer has been interpreted as occurring through elevated natural recruitment success. The mechanisms responsible for the observed sudden increase in numbers are not yet understood, but the strong year classes observed since 2008 could potentially be explained by several years of more favourable environmental conditions (e.g. flows) being temporally synchronised with key life history functions (e.g. spawning and early development).

When considering the abundance of fish recorded within weight categories, fish smaller than 20lbs (<9 kg) were omitted from the analysis to guarantee the exclusion of all weights derived by the standardised assumptions detailed within the methods section. Focusing only on fish with individually angler assigned weights, it was apparent that the contribution of the largest fish (greater than 60lbs (>27 kg)) to catches significantly reduced between 2001 and 2012 (Fig. 5). While this will have contributed to the overall decrease in mean weight over the same period, it is important to note that these larger specimens were represented by a distinct phenotype and referred to by anglers as 'golden' mahseer or the ambiguous '*Tor mussullah*' (Pinder and Raghavan, 2013; Cooke *et al.,* 2014; also see Knight *et al*., 2013). Establishing the true species identity and conservation status of these larger specimens lies beyond the scope of the current study; however the notes associated with the current dataset indicate the recent (post-2005) failure in recruitment of this golden phenotype. The resolution of data collected by anglers between 1998 and 2012 therefore go beyond the provision of just numbers and weights and might also contribute a better understanding of conservation ecology in defining the temporal genetic composition of mahseer within this part of the River Cauvery.

Environmental factors also require consideration in influencing catch statistics. Potential drivers of catch success include river temperature (McMichael and Kaya, 1991), flow (North, 1980), and turbidity (Lehtonen *et al.,* 2009; Drenner *et al.,* 1997); all of which can vary in response to natural climatic conditions and/or in response to river regulation and the anthropogenic manipulation of flows from upstream dams and reservoirs (Barillier *et al.,* 1993; North and Hickley, 1977). Although environmental data are not available to complement the current dataset, it is considered that due to the limited intra-annual timeframes of focus (January – March), when weather and river conditions were typically stable as it is outside of the monsoon season, that environmental factors were likely to have played only a minimal role in influencing angling success over the study period.

In a recent review, Cooke *et al.* (in press) highlighted a global interest in targeting endangered fish by recreational anglers and proposed a dichotomous decision tree of indicators to inform whether the practice of C&R angling constitutes a conservation problem or conservation action. The data recorded from the Galibore Camp between 1998 and 2012 clearly demonstrate a natural and indeed significant increase in mahseer population size. However, qualifying the efficacy of the C&R management and stock protection programme in driving the observed increase in fish biomass remains constrained by a lack comparative empirical data from control sites, which were not afforded protection over the same period. There are many references specifically documenting the long term efforts of the Cauvery fishing camps and the role of the Wildlife Association of Southern India (WASI) in protecting fish stocks by forcing poaching activities beyond the boundaries of the fishery (Nair, 2010; Pinder and Raghavan, 2013; Pinder, 2013). Despite the largely anecdotal nature of this information, the data presented within the present study, coupled with the fact that recreational fishing interest for these highly prized fish has not since shifted beyond the boundaries of the closed fishery, strengthens the evidence to support the effective conservation benefits of the former management model practiced within the wildlife sanctuary.

In light of the consistent fishery management practice applied across all four former camps and throughout the entire controlled reach, it is considered that the Galibore catch data provides representation of the performance of the mahseer population throughout the 22 km between Mutthatti and Mekedatu Gorge (see Fig 1). Within the broader contexts of catchment management (Nguyen *et al.*, 2008) and associated ecosystem services (Everard, 2013), the population growth and high biomass of mahseer shown to be present until 2012 may also have been significant at the catchment level. Indeed, in addition to the natural dispersal behaviour typically exhibited by rheophilic cyprinids (Robinson *et al.,* 1998; Reichard *et al.,* 2004), annual monsoon river flows are likely to have been highly effective in delivering larvae and juveniles to the downstream reaches where annual augmentation of the stock would have contributed to maintaining local populations and/or enhance the harvest potential for sustenance fishers in downstream rural communities.

In summary, this structured catch dataset collected by recreational anglers visiting Galibore between 1998 and 2012 represents the most comprehensive long term dataset specific to any of the mahseers across their entire geographical range in Asia) and demonstrates the value of organised angling as a monitoring tool to enhance biological data and inform conservation and fishery management actions. Not only do these data demonstrate the conservation benefits realised over a 15 year period, but also provide a unique baseline against which the population response (either positive or negative) to the recent and radical change in management policy, the closure of the catch and release fishery, could be qualified, quantified, and considered against future conservation targets.

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Table 1. Temporal resolution of data recovered to inform CPUE. Individual angler numbers/year (1998 – 2012) and hours fished (effort) between January and March in each year.

	No. hours fished			Total No.	Total No. hours
Year	Jan	Feb	March	anglers	fished
1998		580		6	580
1999					0
2000					0
2001			820	9	820
2002			1080	10	1080
2003		1920		19	1920
2004		1868	772	25	2640
2005	848		1756	28	2604
2006	264	1344		17	1608
2007	976	1656		27	2632
2008	736	2028	424	33	3188
2009	692	504		11	1196
2010	848	1136		29	1984
2011	984	976	428	35	2388
2012	980			10	980

Figure captions

Figure 1. Location of the River Cauvery and the study area. Solid line represents the 7 km Galibore fishery. The dashed line represents the 22 km C&R fishery formerly controlled by WASI. Locations are coded: SF: Shivasamudram Falls, MU: Mutthattii, G: Galibore, MT: Mekedatu.

Figure 2. Box plot of year versus catch per unit effort (CPUE) of: *a*: number of fish per angler per hour, and *b*: weight (lbs) of fish per angler per hour, where the median, 25^{th} and 75^{th} percentile, and 10^{th} and 90^{th} percentile are displayed.

Figure 3: Mean adjusted catch per unit effort by number (*a*) and weight (*b*) by year, where the random effects of individual anglers in the data set have been accounted for in the model. * = Difference in catch per unit effort is significantly different from the highest value recorded in the early 2000s ($P < 0.01$). Error bars represent standard error.

Figure 4. *a*: Mean weight of fish captured per year; * Difference in mean weight significantly different from highest values in the early 2000s ($P < 0.01$). *b*: Relationship of mean adjusted catch per unit effort per year and the mean weight of fish captured in that year. In all cases, error bars represent standard error.

Figure 5. Plot of proportion of weight class of fish to total catch per unit effort by number according to year, where white boxes = 20 to 39 lbs, grey = 40 to 59 lbs, and black = > 60 lbs (1 lb = 0.45 kg).

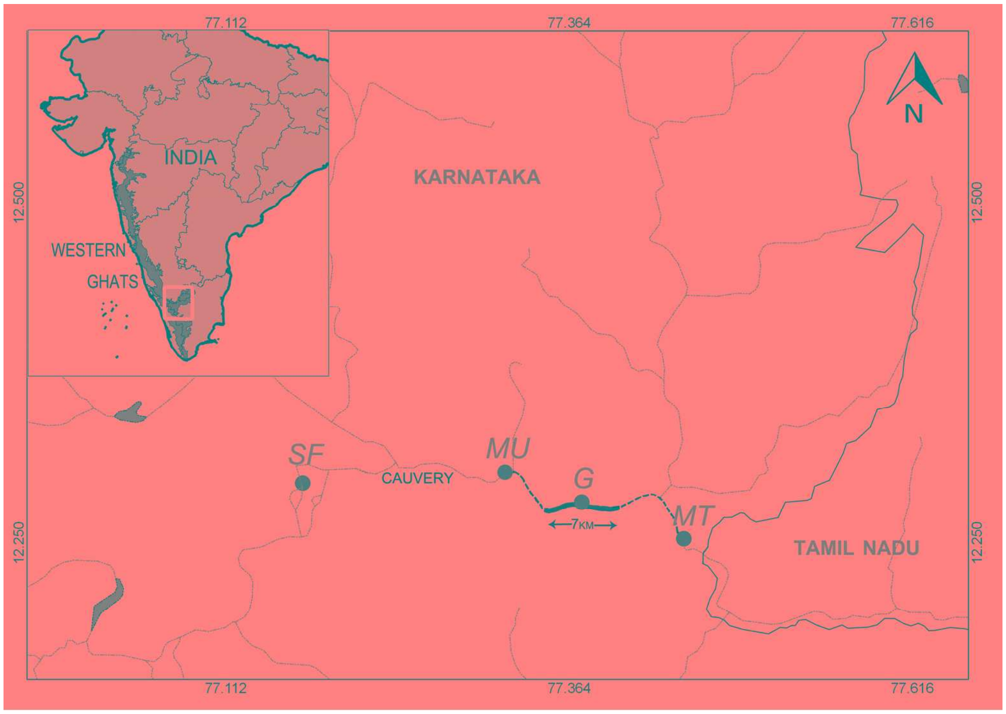

Figure 1. Location of the River Cauvery and the study area. Solid line represents the 7 km Galibore fishery. The dashed line represents the 22 km C&R fishery formerly controlled by WASI. Locations are coded: SF: Shivasamudram Falls, MU: Mutthattii, G: Galibore, MT: Mekedatu.
209x148mm (300 x 300 DPI)

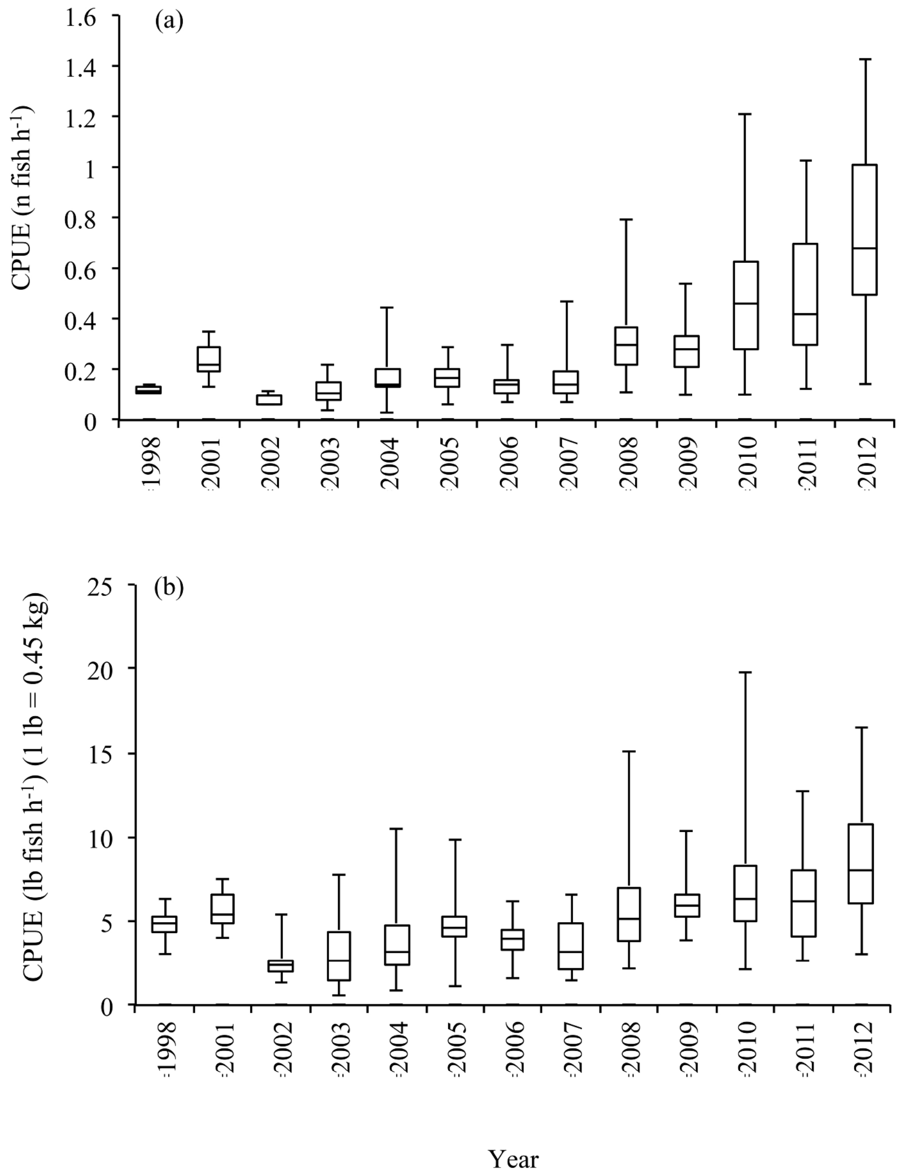

Figure 2. Box plot of year versus catch per unit effort (CPUE) of: a: number of fish per angler per hour, and b: weight (lbs) of fish per angler per hour, where the median, 25th and 75th percentile, and 10th and 90th percentile are displayed.
242x316mm (300 x 300 DPI)

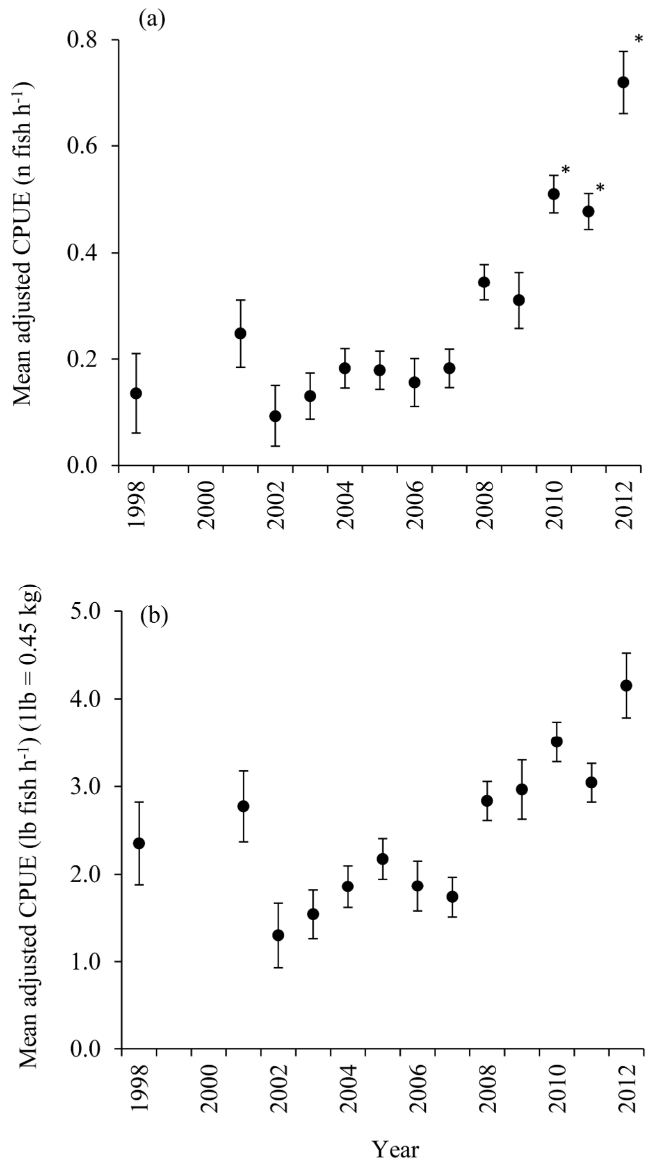

Figure 3: Mean adjusted catch per unit effort by number (a) and weight (b) by year, where the random effects of individual anglers in the data set have been accounted for in the model. * = Difference in catch per unit effort is significantly different from the highest value recorded in the early 2000s (P < 0.01). Error bars represent standard error.
205x349mm (300 x 300 DPI)

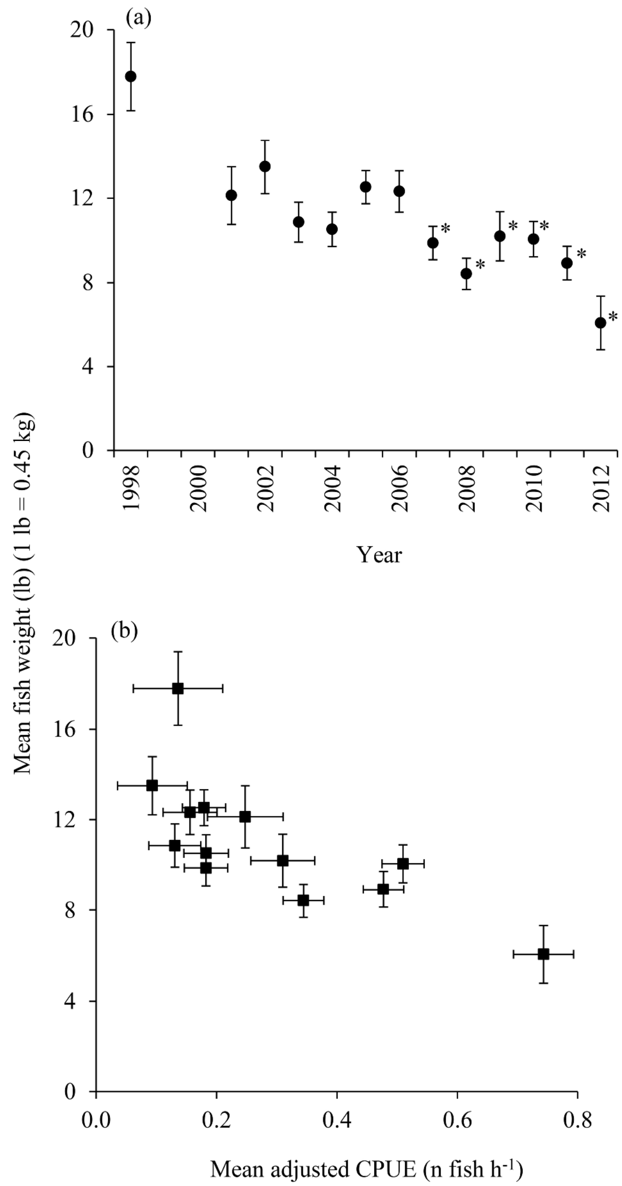

Figure 4. a: Mean weight of fish captured per year; * Difference in mean weight significantly different from highest values in the early 2000s (P < 0.01). b: Relationship of mean adjusted catch per unit effort per year and the mean weight of fish captured in that year. In all cases, error bars represent standard error.
212x404mm (300 x 300 DPI)

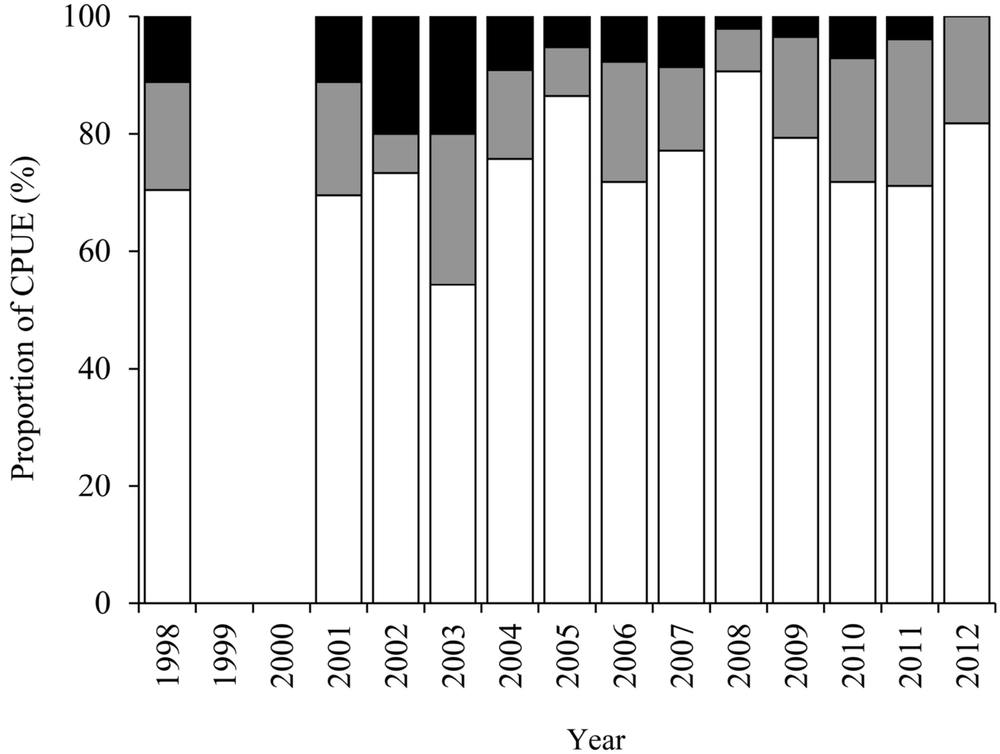

Figure 5. Plot of proportion of weight class of fish to total catch per unit effort by number according to year, where white boxes = 20 to 39 lbs, grey = 40 to 59 lbs, and black = > 60 lbs (1 lb = 0.45 kg).
149x114mm (300 x 300 DPI)