CONSERVING THE ICONIC AND HIGHLY THREATENED MAHSEER FISHES OF SOUTH AND SOUTHEAST ASIA

ADRIAN C. PINDER

A Thesis submitted in partial fulfilment of the requirements of Bournemouth University for the Degree of Doctor of Philosophy

Bournemouth University
March 2020

CONSERVING THE ICONIC AND HIGHLY THREATENED MAHSEER FISHES OF SOUTH AND SOUTHEAST ASIA

Adrian C. Pinder

ABSTRACT

This thesis and supporting papers constitute the submission for an award of a PhD research degree by publication and consists of a cohesive synthesis linking a total of eight published papers across seven peer review journals and an IUCN Red List assessment.

The mahseers (*Tor* spp.) represent an iconic group of large-bodied cyprinid fishes found throughout the fast-flowing rivers of South and Southeast Asia. Due to the considerable religious, cultural and recreational significance of these fishes, and the anthropogenic pressures they face, they are of high conservation concern and represent flagship and umbrella focal species for the sustainable management of river systems throughout their biogeographic range.

Based on research conducted since 2012, considerable advances in the taxonomic and human dimension aspects of mahseer conservation have been acheived. Engagement with the recreational angling community has demonstrated the high value, and future potential for this rapidly expanding stakeholder group to impact positively on the conservation of mahseer and rivers more generally. This has been evidenced through the development of economic incentivised community habitat protection initiatives. Specifically, community level recognition that a live fish captured and released by paying anglers has a renewable value over the single revenue value of a harvested fish, has been shown to offer employment opportunities and support the sustainable stewardship of aquatic ecosystems. Where such

incentives are lacking however, fisheries continue to be subject to high levels of exploitation, due to limited alternative livelihood opportunities available within impoverished rural communities. Further, and due to a combined lack of political will and the difficulties associated with sampling large fishes in large and remote monsoonal rivers, records from catch-and-release angler logs have provided the only available insight to the temporal performance of mahseer populations. Over a 12 year period, angler derived data not only revealed a collapse (>90% reduction) in the River Cauvery's endemic mahseer population, but also evidenced the establishment and rapid invasion of the non-indigenous blue-finned mahseer, thus highlighting the previously under-appreciated risks of stocking mahseer species into novel systems beyond their natural distribution range.

With particular focus on the mahseers of South India's River Cauvery, this work has afforded the largest of all mahseer species, the hump-backed mahseer, with a valid scientific name (*Tor remadevii*) and, through extensive analysis of angler catch data, has highlighted its high extinction risk, with it now assessed as 'Critically Endangered' on the IUCN Red List of Threatened Species. This has in turn impacted on regional and national fishery and wildlife policy and affected a concerted international effort to apply a multidisciplinary and multiple stakeholder approach to saving this iconic species of megafauna from extinction. In the absence of these works, it is highly probable that the species would have remained on a trajectory towards rapid extinction. Instead, the first major steps to safeguarding its future have been taken.

In achieving these research highlights, this work has also resulted in an extensive gap analyses to identify and address some of the many knowledge gaps which have been constraining the effective direction and efficacy of international efforts to conserve species across the genus. With specific reference to previous taxonomic uncertainties, a comprehensive synthesises and critique of species descriptions and subsequent morphological and molecular focused literature, has resulted in the previously listed 24 species of *Tor*, being revised to just 16 valid species. Additional collation of available data to inform distribution ranges, population trends and threats across the genus, has facilitated the revision of IUCN Red List assessments, with one species now 'Critically Endangered', three as 'Endangered' one as 'Vulnerable', three as 'Near Threatened', and eight remaining 'Data Deficient'.

In discussing residual uncertainties, population threats, conservation prospects and the role of stakeholders across the region, this submission concludes with an overarching synthesis of the current knowledge base pertaining to the genus *Tor*. In discussing taxonomic clarifications, emerging research priorities and potential mechanisms to effect species conservation, this also represents a first point of reference for researchers, while encouraging further research to challenge and enhance the knowledge base necessary to conserve and promote these freshwater icons as focal species to support the ecological integrity of South Asian rivers.

Acknowledgements

In addition to the many names and organisations acknowledged within the ten papers which constitute this thesis, there are a few unsung heroes worthy of special mention. Rewinding to the beginning of my career, I remain indebted to Dr RHK Mann for the opportunity to work as his assistant and for nurturing my early enthusiasm for fisheries research. Working with Rudy Gozlan in the early 2000's was a pivotal time in my career and I thank him for his encouragement to publish my first papers and for the many laughs we've had along the way. In recent years my colleague Dr Andy Harrison has been a constant source of sound technical advice and provided the day-to-day cover which has allowed me to undertake multiple trips to India during work time. My supervisor Professor Rob Britton has been a great source of inspiration and I am incredibly grateful for his support and encouragement.

With specific reference to my mahseer research journey, I thank my main partner in crime Dr Rajeev Raghavan and other members of Team Mahseer not already mentioned above; Shannon Bower, Steve Cooke, Steve Lockett, Sascha Clarke-Danylchuk, Andy Danylchuk, Derek D'souza and Unmesh Katwate. Working with these incredibly talented professionals has not only been an education, but also exceptional fun, despite some of the challenging environments and circumstances that we have had to work together. I thank the growing numbers of global supporters of the Mahseer Trust who have attended our conferences, assisted our research, facilitated site access, provided hospitality or just shown an intereser and support for mahseer conservation.

Closer to home, my family have all had a role in making this happen. I'm indebted to my Mum and Dad for their ongoing support and encouragement since day one. Furthermore, the extensive travel required to complete this submission would not have been possible without the full support of my wife Claire and our kids Jasmine, Harry and Rudi. I dedicate this body of work to my family. x

Contents

1. Chapter 1: THESIS OVERVIEW 1
   1.1 Rationale 1
   1.2 Main Research Themes 1
   1.3 Publications Submitted for Examination 2
   1.4 The Structure of the Supporting Document 5
2. CHAPTER 2: A VERY FISHY CAREER 7
   2.1 Centre for Ecology and Hydrology 7
   2.2 Consultancy 9
   2.3 The Mahseer Trust 11
3. CHAPTER 3: INTRODUCTION 13
   3.1 Cultural significance of mahseer 13
   3.2 My introduction to India and the mahseer 16
   3.3 Specific research objectives 18
   3.4 References 19
4. CHAPTER 4: EXPLORING THE ROLE OF RECREATIONAL ANGLERS IN MAHSEER CONSERVATION 22
   4.1 Prelude to Submission 1 22
      4.1.1 References 25
   4.2 Submission 1 27
5. CHAPTER 5: STAKEHOLDER ENGAGEMENT 40
   5.1 Prelude to Submissions 2 & 3: 40
      5.1.1 References 44
   5.2 Submission 2 47
   5.3 Submission 3 67
6. CHAPTER 6: EXPLORING THE VALUE OF ANGLER LOG BOOKS 88
   6.1 Prelude to Submissions 4 and 5 88
      6.1.1 References 92
   6.2 Submission 4 95
   6.3 Submission 5 117
7. CHAPTER 7: SUSTAINABILITY CONSIDERATIONS OF C&R ANGLING FOR ENDANGERED FISH 135
   7.1 Prelude to Submissions 6: 135

7.1.1 References 140
7.2 Submission 6 142
8. CHAPTER 8: RESOLVING THE TAXONOMY AND CONSERVATION STATUS OF THE WORLD'S LARGEST SPECIES OF MAHSEER 164
8.1 Prelude to Submissions 7 and 8: 164
8.1.1 References 169
8.2 Submission 7 171
8.3 Submission 8 198
9. CHAPTER 9: FINAL SYNTHESIS - MAHSEER (*TOR* spp.) FISHES OF THE WORLD: STATUS, CHALLENGES AND OPPORTUNITIES FOR CONSERVATION 207
9.1 Prelude to Submission 9: 207
9.1.1 References 213
9.2 Submission 9 215
10. CHAPTER 10: CONCLUDING SUMMARY 292
10.1 Scientific obscurity: the unknown mahseers of the River Cauvery 292
10.2 Invasive mahseer 295
10.3 The importance of taxonomic classification 298
10.4 The importance to conservation of the IUCN Red List 299
10.5 Red List assessment of *Tor remadevii* 300
10.6 Contextualising the imperilment of hump-backed mahseer at the genus level 301
10.7 Conservation impact 302
10.7.1 Government and industry level impacts 302
10.7.2 Stakeholder level conservation impacts 303
10.8 Concluding remarks 304
10.9 References 305
11. APPENDIX I - Co-authorship statements 311
12. APPENDIX II - Full list of scientific publications (exclusive of commercial reports) 315

Table of Figures

Figure 3.2.1. Hindu god Vishnu's first incarnation as 'Matsya' – half man/half mahseer? Image created by Anant Shivaji Desai and sourced from Wikimedia Commons 14

Figure 3.2.2. A young family feeding mahseer at a temple pool on the River Cauvery in South India. Photo: A. Pinder, January 2017. 15

Figure 3.3.1. The legendary orange finned hump-backed mahseer that had initially drawn me to the Cauvery (left), and my first mahseer with 'blue fins' which left me scratching my head (right). 17

Figure 4.2.1. Large Mahseer, Galibore Fishing Camp, River Cauvery (February 2010). 29

Figure 5.2.1. A heat map showing the States/Union Territories of India predominantly fished in by anglers. 52

Figure 5.3.1. Participants in the South India (Bannerghatta) workshop pose for a photo at the conclusion of Day 1. 75

Figure 5.3.2. Participants in the North India (Byasi) workshop during breakout discussions on Day 1. 75

Figure 6.1.1. An example of one of the catch record sheets kept by the head angling guide at Galibore Fishing Camp and used to inform Submisisons 4 and 5. 90

Figure 6.1.2. The earliest record of stocking I was able to find was in in the Wildlife Association of South India's (WASI) annual journal WILD LIFE, published in 1976 (left). This details the source, recipient site and numbers of mahseer stocked (right). 91

Figure 6.2.1. 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. 99

Figure 6.2.2. 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. 103

Figure 6.2.3. 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. 104

Figure 6.2.4. *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. 105

Figure 6.2.5. 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). 106

Figure 6.3.1. Location of the River Cauvery and the study area. Solid line represents the 7 km Galibore fishery (G). The dashed line represents the 22 km extent of the former C&R mahseer fishery. 121

Figure 6.3.2. (a) Comparison of the number of each mahseer phenotype captured per year (×), where the solid line represents the fitted relationship (linear regression) and dashed line represents the null hypothesis that equal numbers of each phenotype were captured each year. (b) Annual catch per unit effort (CPUE) of the blue-finned (●) and (c) hump-backed (○) mahseer across the study period. Error bars are not displayed for brevity. 125

Figure 6.3.3. Box plots of the weight of individual fish captured per year for (a) hump-backed mahseer, and (b) blue-finned mahseer). Filled circles represent mean annual weight, horizontal lines represent the 25th, 50th and 75th percentile and the error bars represent the 10th and 90th percentiles. 126

Figure 7.1.1. Decision tree for determining when angling for endangered fish should be allowed/encouraged vs. dissuaded/prohibited – from Cooke et al. (2014). 139

Figure 7.2.1. Location of the Cauvery River in India and the rapid assessment sampling area in Valnur, Kodagu (inset). 146

Figure 7.2.2. Blue-finned mahseer (Tor sp.) during analysis. Photo credit: 147

Figure 7.2.3. (a) Ragi ball affixed to a single, barbed hook; a traditional bait used in the mahseer recreational fisheries of south India. (b) Volunteer anglers fish from a coracle, a traditional round-bottomed boat used for fishing activities in south India. Photo credits: Shannon Bower. 148

Figure 7.2.4. Proportional contributions of individual indicators to RAMP 154

Figure 8.1.1. The author and the elusive hump-backed mahseer acquainted for the first time in December 2015. 167

Figure 8.2.1. Adult Cauvery hump-backed mahseer, *Tor remadevii* captured by Martin Clark, 1978 [Photo Credit: Trans World Fishing Team]. 174

Figure 8.2.2. Maximum likelihood phylogenetic tree based on cox1 sequences of mahseer species occurring in India (*Tor* sp 1 represent individuals not matching any of the described species from India and could potentially comprise new species, *Tor* sp. 2 are sequences available in

GenBank with uncertain identities, i.e. under different species names). Species of *Neolissochilius* are used as outgroup. Values along the nodes are percentage bootstraps for 1000 iterations. 180

Figure 8.2.3. Discriminant analysis of the four peninsular Indian *Tor* species. Fisher's distances between clusters (blue cells) and associated p values (red cells) are provided in inset. Values in parenthesis are the percentage variation explained by each discriminant axis. 182

Figure 8.2.4. Lateral (A), dorsal (B) and ventral (C) view of *Tor remadevii* (ZSI F-9150, 487 mm SL) collected from the River Moyar, India. 183

Figure 8.2.5. Lateral (A), ventral (B) and dorsal (C) view of the head region of *Tor remadevii* (ZSI F-9150, 487 mm SL) collected from the River Moyar, India. 184

Figure 8.2.6. Freshly caught adult *Tor remadevii* from the River Moyar, India, showing the characteristic orange coloured fins 185

Figure 8.2.7. Collection locations of *Tor remadevii* from the tributaries of the River Cauvery, India 188

Figure 8.2.8. Typical habitat of *Tor remadevii* in the River Moyar, India 189

Figure 8.3.1. Distribution of *Tor remadevii* 201

Figure 9.2.1. Cumulative publications by subject area from 1950 to 2017. Based on a Google Scholar search ["tor mahseer", all words, anywhere in article]. First 1,000 search results manually filtered to remove duplicates and retain relevant publications only (n=591). Each publication was categorised into one of five subject areas (Biology and Aquaculture, Molecular/Taxonomy, Population, Ecology or Other [including Review, Recreation and Conservation]), based on the main theme of the publication. 219

Figure 9.2.2. Distribution of *Tor ater.* Inset image: *T. ater* holotype (308 mm) from the Nam Theun at Ban Talang, Laos. With kind permission of T. Roberts. 231

Figure 9.2.3. Distribution of *Tor barakae.* Inset image: *T. barakae* (405 mm) from the Barak River, Manipur, India. With kind permission B. Amin-Laskar. 232

Figure 9.2.4. Distribution of *Tor dongnaiensis.* Inset image: *T. dongnaiensis* (240 mm) from the Đồng Nai River, Vietnam. With kind permission of Huy Đuc Hoang. 233

Figure 9.2.5. Distribution of *Tor khudree.* Inset image: *T. khudree* (520 mm) from the River Cauvery and believed to be the progeny of hatchery stocks introduced from Lonavla, Maharashtra, India. Note: delineation of ‘introduced, established’ and ‘introduced, not established’ is approximate only. 235

Figure 9.2.6. Distribution of *Tor kulkarnii.* Inset image: *T. kulkarnii* holotype (208 mm) from the museum collection of Zoological Survey of India (ZSI), Kolkata. 236

Figure 9.2.7. Distribution of *Tor laterivitattus.* Inset image: adult *T. laterivitattus* collected from a fish market at Louang Prabang, River Mekong basin, Laos. With kind permission Muséum National d'Histoire Naturelle , Paris, France. 237

Figure 9.2.8. Distribution of *Tor malabaricus.* Inset image: *T. malabaricus* (260 mm) from the Chaliyar River in Northern Kerala, India. 238

Figure 9.2.9. Distribution of *Tor mosal*. Inset image: *T. mosal* from the Brahmaputra Basin. With kind permission B. Amin-Laskar. Note: until collected from the type locality, data are lacking to validate the genetic authenticity and physical appearance of *T. mosal* collected from other river systems. 240

Figure 9.2.10. Distribution of *Tor polylepis.* Inset image: adult *T. polylepis* (Holotype KIZ863563) collected from the Lancang Jiang in Yunnan, China and deposited in the Kunming Institute of Zoology, China. 241

Figure 9.2.11. Distribution of *Tor putitora*. Inset image: *T. putitora* photographed by Tristan Tan/Shutterstock.com. 243

Figure 9.2.12. Distribution of *Tor remadevii.* Inset image: *T. remadevii* (487 mm) from the River Moyar, Tamil Nadu, India........ 244

Figure 9.2.13. Distribution of *Tor sinensis.* Inset image: *T. sinensis* (465 mm) from the River Mekong, Laos. With kind permission T. Roberts. 245

Figure 9.2.14. Distribution of *Tor tambra and Tor tambroides.* Inset image: *T. tambra* (560 mm) from the Serayu River basin South-central Java, Indonesia. 247

Figure 9.2.15. Distribution of *Tor tor.* Inset image: *T. tor* (410 mm) from the Choral River in the Narmada River basin, Madhya Pradesh, India. Note: until collected from the type locality, data are lacking to validate the genetic authenticity and physical appearance of *T. tor* collected from other river systems. 248

Figure 9.2.16. Distribution of *Tor yingjiangensis.* 249

Figure 9.2.17. The yellow mahseer of Sri Lanka currently recorded in literature as *Tor khudree longispinnis.* 250

Figure 10.1.1. Map of River Cauvery basin and key sites of interest. Locations are coded: A: Galibore Fishing Camp, B: collection site of *T. remadevii* on Moyar River, C: type locality of *T. remadevii* on Pambar River, D: upper River Cauvery, Kodagu District (Coorg). The dashed line represents tidal reach of River Cauvery. 294

Figure 10.2.1. The non-indigenous blue-finned (AKA silver) mahseer, since confirmed as *Tor khudree* (top) and endemic hump-backed (AKA golden) mahseer, since confirmed as *Tor remadevii* (bottom), both contributed to angler catches during the study period 1998 – 2012. 296

Figure 10.2.2. Catch per unit effort (n/h^{-1}) of blue-finned mahseer (filled circles) and hump-backed mahseer (clear circles) recorded at Galibore Fishing Camp between 1998 and 2012 (from Pinder et al., 2015b). 297

Chapter 1: THESIS OVERVIEW

1.1 Rationale

This document presents the case for support for the submission for an award of a PhD research degree by publication. The author has worked in the field of fisheries science since 1988 and over this time has published on a broad range of related disciplines, including fish migration, early development and invasive species. This submission however focuses on research conducted since 2012 and presents a selection of papers on the theme of mahseer (*Tor* spp.) conservation and associated human dimensions. Although much work has been focused on the River Cauvery catchment in South India, this research has been instrumental in advancing the taxonomic knowledge base and opportunities for conservation action across the genus *Tor*, throughout their biogeographic range which extends over much of South and Southeast Asia.

This supporting document is designed to fulfil the requirement of a synthesis to highlight and critically evaluate the contributions these works have made towards the advancement of knowledge both within the field of mahseer conservation and within the discipline of fisheries and conservation science more generally.

1.2 Main Research Themes

This submission is based on publications that draw upon research skills and experience gained throughout the author's professional career. These fall into the following four broad disciplines of fisheries research and are frequently interwoven for context throughout many of the individual papers which form this submission:

1. Societal/stakeholder interaction with the biological resource
    - Comprehensive desk-based and stakeholder interview derived syntheses of individual and cumulative anthropogenic pressures

which threaten mahseer populations, attitudes towards conservation, recreational fisheries, rural livelihoods, government policy and industrial level conservation efforts;

2. Population dynamics
   - Working with angler catch data to define population community structure and establish temporal trends in population size and age demographics;
3. Taxonomy
   - Application of a multidisciplinary study approach to elucidate the species identity of the world's largest mahseer;
4. Conservation
   - IUCN Red List assessment of the hump-backed mahseer as 'Critically Endangered' and state of the art synthesis of current knowledge and conservation prospects across the genus *Tor*.

1.3 Publications Submitted for Examination

The collection of nine publications submitted for consideration represent a focused collection of works embodied within a broader range of papers published by the author over his research career. The rationale for selection was that:

1. All works have been published within the last 6 years;
2. These publications form the product of a strategic vision to raise awareness of aquatic biodiversity in South and Southeast Asia and effect change to support biological conservation and associated links with the livelihood prospects of poor rural communities.
3. They provide evidence of a dynamic multidisciplinary research approach to navigate logical stepping stones within achieving the overarching vision above.
4. They culminate in evidencing considerable advancement in the subject area and by impacting and changing policy across various stakeholder levels.

5. Collectively, they demonstrate strength in the author's ability for capacity building and effective international scientific collaboration.

Eight published papers across seven peer review journals and an IUCN Red List assessment have been selected to demonstrate my research contribution. Although I have led the authorship of six of these outputs, I have included a further three papers that I have contributed to, which form important links within my own strategy for contextualising, engaging and communicating my research across the diverse stakeholder groups needed to affect future conservation efforts. The multi-disciplinary approach required to bring many of these studies to publication has required a collaborative approach and the input of a number of specialists; my own contribution to each paper in relation to that of my co-authors is defined in Appendix 1.
The publications below are listed in chronological order of study and not necessarily year of publication:

Submission 1. Pinder, A.C., Raghavan, R., 2013. Conserving the endangered mahseers (*Tor* spp.) of India: the positive role of recreational fisheries. *Current Science* 104, 1472-1474.

Submission 2. Gupta, N., Raghavan, R., Sivakumar, K., Mathur, V., **Pinder, A.C**., 2015. Assessing recreational fisheries in an emerging economy: Knowledge, perceptions and attitudes of catch-and-release anglers in India. *Fisheries Research*, 165, 79-84.

Submission 3. Bower, S.D., Danylchuk, A.J., Raghavan, R., Clark-Danylchuk, S., **Pinder, A**.**C**., Alter, A., Cooke, S.J., 2017. Involving recreational fisheries stakeholders in development of research and conservation priorities for mahseer (*Tor* spp.) of India through collaborative workshops. *Fisheries Research* 186, 665-671.

Submission 4. Pinder, A. C., Raghavan, R., Britton, J. R., 2015. Efficacy of angler catch data as a population and conservation monitoring tool for the flagship Mahseer fishes (Tor spp.) of Southern India. *Aquatic Conservation: Marine and Freshwater Ecosystems* 25, 829-838.

Submission 5. Pinder, A. C., Raghavan, R., Britton, J. R., 2015. The legendary hump-backed mahseer Tor sp. of India's River Cauvery: an endemic fish swimming towards extinction? *Endangered Species Research* 28, 11-17.

Submission 6. Bower, S.D., Danylchuk, A.J., Raghavan, R., Clark-Danylchuk. S., **Pinder, A.C**., Cooke, S.J., 2016. Rapid assessment of the physiological impacts caused by catch-and-release angling on blue-finned mahseer (*Tor* sp.) of the Cauvery River, India. *Fisheries Management and Ecology* 23, 208-217.

Submission 7. Pinder A.C, Manimekalan, A., Knight, J.D.M, Krishnankutty, P., Britton, J.R., Philip, S., Dahanukar, N., Raghavan, R., 2018. Resolving the taxonomic enigma of the iconic game fish, the hump-backed mahseer from the Western Ghats biodiversity hotspot, India. *PLoS ONE* 13(6): e0199328.

Submission 8. Pinder A.C., Katwate, U., Dahanukar, N., Harrison, A.J., 2018. *Tor remadevii*. The IUCN Red List of Threatened Species v2018-2.

Submission 9. Pinder A.C, Britton, J.R., Harrison, A.J., Nautiyal, P., Bower, S.D., Cooke, S,J., Lockett, S., Everard,M., Katwate, U., Ranjeet, K., Walton, S., Danylchuk, A.J. & Raghavan, R., 2019. Mahseer (*Tor* spp.) fishes of the world: status, challenges and opportunities for conservation. *Reviews in Fish Biology and Fisheries* 29, 417-452.

1.4 The Structure of the Supporting Document

The main commentary and publications supporting this submission for PhD by publication are contained within Chapters 2 to 10. For professional context Chapter 2 provides a brief synopsis of my entire career and the background research skills gathered in leading up to my relatively recent (>2012) research on mahseer conservation. A general introduction is provided in Chapter 3, and in subsequent chapters I present a supporting commentary (prelude) for each of my selected publications, either as stand-alone chapters or by grouping themed papers within a single chapter. In each chapter I discuss the developments and events which triggered the subsequent direction of research and how these papers have contributed as a) stand-alone contributions to the research field, and b) address their cumulative relevance and impact as the chapters progress. Chapters 9 and 10 present a comprehensive synthesis of these works, embodied in a published review of the current state of knowledge and conservation prospects across the entire genus *Tor* (Chapter 9) and a final concluding summary (Chapter 10).

The multi-disciplinary approach required to bring many of these studies to publication has required a collaborative approach and the input of a number of specialists; my own contribution to each paper in relation to that of my co-authors is defined in Appendix 1. Two of the papers included in this thesis (Submissions 3 and 6), represent works that have been previously submitted for the award of PhD by the lead author. Accordingly, these have not been included to claim personal credit, but due to ther importance in building the evidence base and guiding the strategic direction of my own research journey.

In addition to the traditional bibliography giving details of all the references cited in the text, Appendix 2 lists all my publications under the categories of journal articles, books, chapters in books, other ISBN outputs (e.g. IUCN Red List assessments) and subject relevant popular articles. Due to much of my career being dedicated to consultancy and the high volume (>400) and diversity of commercial reports I have authored, I have purposely omitted these outputs from Appendix 2.

CHAPTER 2: A VERY FISHY CAREER

My entry into the world of academia is probably best described as 'unconventional', as I made my exit from secondary school at the age of 16. Having been a fanatical angler from the age of four and spending my early teens working Saturdays as a fish monger's assistant, enrolling on the Youth Training Scheme (YTS) to study Fish Farming and Fisheries Management, with a view to progressing to a Diploma course at Sparsholt College, seemed at the time, the only available option to position myself for a career which involved working with fish. The format of this foundation course was largely work-placement based with one month residential periods at college during each term. Being based at the former Dorset Springs trout farm and fisheries provided me the opportunity to develop a broad range of practical fish husbandry skills (inclusive of retail, while managing the farm shop) and allowed me to focus for the first time academically, on a subject I was extremely passionate about. Despite my enjoyment and enthusiasm for completing the course, six months into my studies I became aware of a full-time job opportunity which was too good to ignore and subsequently secured my next 19 years of employment.

2.1 Centre for Ecology and Hydrology

My career at the Centre for Ecology and Hydrology (CEH) began in 1988, when as a 17 year-old, I was recruited as an Assistant Scientific Officer under the supervision of Dr Richard Mann to assist with a long-term study into the factors affecting the recruitment success of coarse fish populations in the River Great Ouse in Cambridgeshire. Despite an illustrious research career in the biology and ecology of freshwater fish, the practicalities of sampling and identifying eggs and larval fishes for recruitment studies was as novel a challenge to Dr Mann as it was to me. This afforded me a degree of autonomy at a very early stage in my career, with my boss providing me with the time and encouragement required to research and develop the unique skills needed to support the project. As these skills developed I was fortunate to also assist various post-doctoral positions which included working closely with Dr Gordon Copp in researching the role of early ontogeny in determining microhabitat selection and dietary resource partitioning in lowland river fish communities.

In 1992 the offer of relocating to set up a new field base and spend the next four years collecting and analysing predominantly water chemistry samples for the Land Ocean Interaction Project (LOIS), had limited attraction due to the departure from fisheries research. Fortunately however, by this time, my field and taxonomic skills were in demand and my day-to-day responsibilities were frequently interrupted with the need to support other national CEH fisheries teams with commercially funded projects on various rivers throughout England and Wales. This along with the incentive of a promotion to Scientific Officer, saw me based at York University until 1997, where in addition to the routine collection and analysis of water samples, I also gained considerable experience in setting up and running an extensive network of automatic data sondes, and telemetered depth/turbidity triggered auto-water samplers.

Commensurate with the LOIS project coming to an end in 1997, my reposting to Dorset's River Laboratory was met with considerably more enthusiasm as I was born and raised in the area and had already worked with the Dorset based fisheries team on a number of previous projects. Prior to the move I had secured my first consultancy project and had been commissioned over the following three years to develop and produce illustrated identification keys to the larval and juvenile stages of the coarse fishes of the British Isles. Working on this project was interspersed with a vast array of fishery investigations and the acquisition of new skills required tostudy the spatial ecology of fish populations using automated fish counters and biotelemetry tools. With the exception of ongoing work on the identification keys, this also represented a shift in focus from coarse fish communities to salmonid research.

Despite continuing to use the River Laboratory as a field base throughout my time at CEH, in 2001, an organisation restructure saw all staff relocated a short distance away to Winfrith Technology Centre. This coincided with our team recruiting Dr Rudy Gozlan who had undertaken his PhD under the supervision of Dr Copp on the subject of the early ontogeny of cyprinid fishes. This common interest very quickly led to a productive collaboration and the publication of a number of papers (including my first papers as first author) on the subjects of early ontogeny and non-native fishes. With my fish identification keys also being published as a book in 2001, I now reflect on this period as a threshold in my career during which I transitioned from a research assistant to a semi-independent researcher gaining recognition for the first time among international peers.

As mentioned previously, salmonid research was also a key theme of my work at this time and in forging a specific interest in the phenomenon of autumn seaward migration of salmon parr, and based on my growing publication record, I was offered the opportunity to undertake a part-time PhD at Southampton University. The news of another major CEH restructuring exercise and closure of the CEH Dorset base in 2007 came as a bitter disappointment. Due to my domestic situation ruling out my ability to relocate to Oxfordshire, this not only marked the end of my career with CEH but also forced the termination of my PhD programme after only a single years' study.

2.2 Consultancy

Despite having developed some experience in the delivery of consultancy projects and people management at CEH, my move to the private consultancy APEM Ltd. in 2007, represented a new and exciting challenge. Recruited as a Principal Fisheries Scientist with the responsibility of establishing and managing a new regional office, required the rapid acquisition of new knowledge and skills, particularly with regard to business acquisition, tendering, competitor analysis and strategic recruitment. With a remit of expanding the company's capacity to delivery projects across a broad range of aquatic science disciplines, by 2013 I had built a highly profitable multidisciplinary team of 15 consultants with expertise spanning marine and freshwater taxonomy, ornithology, fisheries, remote sensing and geomorphology.

This role provided the opportunity to expand my professional network and engage with both industrial and environmental regulatory clients across a broad array of project disciplines, from small-scale local issues to overseeing the environmental elements of major national infrastructure builds and proposed developments such as the Tyne Tunnel and Hinkley Point nuclear power station. In addition to continuing to keep abreast with the scientific literature and collaborating with former colleagues in bringing earlier fisheries research to publication, occasional opportunity also arose to undertake competitively acquired novel research (e.g. the migratory behaviour of glass eel), which resulted in additional publications in peer reviewed journals during this appointment. Leaving APEM in 2013 with established recognition on the international fisheries research stage, experience in the commercial application of research skills and business management, provided the ideal skillset to join Bournemouth University as an Associate Director with a remit of establishing a new environmental consultancy business within the Department of Life and Environmental Sciences. Within three months of my appointment at BU, I had established Bournemouth University Global Environmental Solutions (BUG) www.bournemouth.ac.uk/bug and was already engaged in the delivery of my first competitively won consultancy project. Provided with a free reign to develop BUG into a financially self–sustaining enterprise, the business model I developed was to use the consultancy as a 'shop window' to promote the breadth of expertise within the department and encourage academic staff to engage with the commercial sector. To date, BUG has delivered in excess of 100 projects which have engaged 80 percent of academics within the department.

My desire to continue and expand my own academic research portfolio has been strongly encouraged and supported by BU and in addition to my papers on mahseer, which constitute this submission for PhD by publication (see also Section 2.4), I have also published papers (several as first author) on the subjects of lamprey conservation, the consequences of angling on marine fish species, the genetics of Malaysian mahseers, water security in semi-arid landscapes, temperature effects on the recovery of recreationally angled fish and the global biodiversity threat posed by the practice of Buddhist Live Release. For a full list of publications see Appendix II.

2.3 The Mahseer Trust

Prior to joining Bournemouth University and following my initial forays to South India, I had started to feel my career was becoming a treadmill and was lacking new challenges and excitement. Having recently familiarised myself with the River Cauvery in South India, the prospect of directing some of my professional skills and enthusiasm towards mahseer and their associated ecosystems became my primary focus; however, what was lacking was an organisational vehicle to make this aspiration a reality.

Although registered as a Charitable Trust in 2008 by a small group of British anglers, the Mahseer Trust had only existed on paper. On contacting the trustees and pointing this out, I was recruited (in a voluntary capacity) as Director in April 2013. Following a few late nights of web-based self-tuition in web design and hosting, the first Mahseer Trust website www.mahseertrust.org was launched, establishing the Trust with the following aims:

- To advance scientific knowledge of mahseer taxonomy, biology and ecology;
- To provide an interactive online resource for scientists, conservationists and anglers;
- To seek funding to support international research and conservation programmes relating to mahseer;
- To promote awareness of the conservation, and socio-economic benefits of sport angling;

- To engage with all stakeholders and provide regular reporting of the activities of the Trust.

Following the strategic recruitment of a Chairman and board of trustees, in 2016, the Mahseer Trust was established as a UK Registered Charity, allowing me to adopt a more focused role as a trustee and Director of Research. Within this role I have travelled extensively and established a global network of mahseer researchers, organised and hosted several conferences and workshops, including the International Workshop on Mahseer Conservation in Kochi 2017, and secured funding from Tata Power to support the conservation of the hump-backed mahseer. In December 2018 I was invited to deliver the opening keynote at the International Mahseer Conference in Paro, Bhutan, which assisted in establishing formal partnerships with major conservation organisations, including WWF, and further funding to support the Trust's work in conserving all mahseer species across their full biogeographical range.

CHAPTER 3: INTRODUCTION

The mahseers represent an iconic group of cyprinid fishes found throughout the fast-flowing rivers of South and Southeast Asia. Characterised by their very large scales, the name mahseer is often applied to fishes within the genera *Neolissocheilus*, *Nazaritor* and *Tor*. However, it is only species within this latter genus '*Tor'* which are typically considered to be the 'true' mahseers (Desai 2003; Nguyen et al. 2008) and often referred to as 'the tiger of the water' due to their reputation as the hardest fighting freshwater fish in the world (TWFT, 1984; Nautiyal 2006); and thus affording their iconic status amongst the international recreational angling community.

3.1 Cultural significance of mahseer

Mahseers have long been afforded saintly status as God's fishes and revered amongst isolated tribal societies across India and beyond (Gupta et al. 2016). Paintings depicting large-scaled fish on Nal pottery, from Pakistan, indicate an interest in 'large-scaled' fishes as early as 3,000BC (Hora 1956) and references describing sacred and masculine figures of 'mahseer-like' fish can also be found in Hindu religious scriptures, symbols, motifs and sculptures (Jadhav 2009). The first avatar/incarnation of the Hindu god Vishnu took the form of 'Matsya', symbolised as half-man/half-fish (Figure 3.1.1), with sculptures commonly found in ancient temples throughout India and a mythology with much in common with the Noah's Ark narrative (Pinder 2017).

Figure 3.1.1. Hindu god Vishnu's first incarnation as 'Matsya' – half man/half mahseer? Image created by Anant Shivaji Desai and sourced from Wikimedia Commons

This religious connection has led to the establishment of mahseer sanctuaries where huge numbers of fish congregate in pools adjacent to temples and are fed daily with puffed rice by worshipers (Dandekar 2011) (Figure 3.1.2). Some of these sanctuaries have been in existence for centuries and are safeguarded from exploitation through the social beliefs and sentiments of devotees from associated villages and temple authorities (Sen & Jayaram 1982; Bhagwat & Rutte 2006; Katwate et al. 2014).

Figure 3.1.2. A young family feeding mahseer at a temple pool on the River Cauvery in South India. Photo: A. Pinder, January 2017.

Within India, eight species of *Tor* are currently known to share the country's natural resources with a human population of >1.3 billion. This makes India the second most populated country in the world, accommodating approximately 18% of the world's population. This number is forecast to continue to grow and to overtake China by 2022. Not surprisingly, India's rivers, from the Himalayas in the North to the tropical rivers of the south, are under unprecedented anthropogenic pressure (Saunders et al. 2002). Indeed, extensive deforestation in headwater drainages, massive abstractions to service rapidly growing mega-cities, and the construction of mega dams to create storage reservoirs and power generation, have left some catchments with plummeting and contaminated ground water resources (Everard et al. 2018). Exacerbating existing pressures, climate change is now presenting a direct threat to human life across large parts of India, through a combination of extended periods of drought and flash-flooding. In addition to the loss of hundreds of human lives during the devastating floods and land-slides across Kerala and Karnataka during the summer of 2018, large areas of forests in the Western Ghats were also destroyed, thus, further compromising natural hydrological process and reducing the resilience of these systems to the more extreme weather patterns projected (INCCA 2010).

3.2 My introduction to India and the mahseer

The name mahseer first came to my attention in the late 1970's when as a young boy I stumbled across a photograph in the Angling Times, the image of which is still etched in my mind, of a Western angler standing chest deep in a majestic river with an Indian guide assisting him in cradling a gigantic humpbacked fish with bright orange fins and scales the size of the palm of an adult hand. Along with inspirations closer to home, I have no doubt that this image contributed to igniting my obsessive fascination in fishes, which defined my career path and in 2010 eventually lured me to undertake my first trip to South India's River Cauvery to acquaint myself with the mighty mahseer.

In both 2010 and 2011, I travelled as an angling tourist to the Galibore Fishing Camp which had become famous for the giant fish captured by international anglers adopting catch-and-release (C&R) practises. Galibore Fishing Camp represents one of four former camps situated in the middle reaches of the River Cauvery, Karnataka. These camps accommodated paying recreational anglers from around the globe, operated a strict C&R policy and provided a classic example of how a natural biological resource can provide alternative livelihoods in terms of employment for poor rural communities (Chapter 4). Here I learned first hand about livelihood dependence, the complex dynamics of socio-ecological systems and the fragility of the ecological balance between tourism and conservation.

Prior to my initial trip, my knowledge of the genus *Tor* was somewhat limited due to a paucity of publications since the early literary works published during British rule of India. The authors of these pioneering books were essentially anglers, but they were also amateur natural historians; the works of Thomas (1873), Dhu (1923) and MacDonald

(1948), still provide some of the most valuable information on the biology and ecology of mahseers found in the rivers of the southern Western Ghats, the Himalayas and Burma (now Myanmar). Back in 2010, these books also provided me with advanced knowledge over my angling peers and the local guides, whom many had fallen into the misconception that 'the mahseer' was a single species. However, they also provided me with sufficient information to become extremely confused during my initial visits to India about the taxonomy of the fish I observed. The first mahseer I had ever seen in the flesh was a fish I caught during my first evening on the River Cauvery, a photograph of which hangs on my dining room wall at home to remind me of where this journey began. This was clearly a mahseer, but quite different in appearance to the fish that I had seen in historic pictures from the River Cauvery (Figure 3.2.1). Indeed over the course of the first week only two fish (both large specimens in excess of 30 kg) matched the hump-backed fish with orange fins which had made the River Cauvery famous. All other mahseer caught by anglers exhibited various shades of blue fins, which when quizzed upon, the local guides shook their heads and suggested they were all the same.

Figure 3.2.1. The legendary orange finned hump-backed mahseer that had initially drawn me to the Cauvery (left), and my first mahseer with 'blue fins' which left me scratching my head (right).

A thorough literature search on my return to the UK resulted in further confusion which led me to write to the Zoological Survey of India (ZSI) to seek the expertise of renowned Indian Ichthyologist Dr K Rema Devi.

Despite not having any definitive answers to my question, Dr Rema Devi suggested that I contacted Dr Rajeev Raghavan who was at the time based at St Albert's College in Kochi, Kerala. Raghavan had been studying and recently published a paper on the mahseer of the western drainage of the Western Ghats, but after discussing my photographs via email, we made little progress in determining the species of mahseer present at the Galibore Fishing Camp of the mid River Cauvery.

NOTE: the assistance of Dr Rema Devi represents a pivotal moment in this journey, as Raghavan has since become an active collaborator and co-author. In an unforeseen twist of fate, the name 'Rema Devi' re-enters this narrative in Chapter 8.

3.3 Specific research objectives

While my initial trips to India had stimulated a strong personal interest in masheer, the development of my research direction has been a dynamic process, which has evolved to focus on the following key research objectives:

1. To qualify the potential for the global recreational angling community to contribute to mahseer conservation efforts;
2. To quantify the scale of participation of recreational angling in India and the levels of knowledge, attitudes and willingness within this community of stakeholders to actively engage in conservation efforts;
3. To examine the efficacy of angler-catch-data as a sampling tool to monitor the temporal and spatial trends in population dynamics of mahseer throughout the region;
4. To clarify the taxonomy of the River Cauvery's hump-backed mahseer, using a combination of molecular and morphometric techniques. This was a pivotal step and required to enable formal

conservation assessment of this species on the IUCN Red List of Threatened Species;

5. To synthesise the current state of taxonomic knowledge, population threats, emerging research priorities and conservation prospects across the entire genus *Tor*.

3.4 References

Bhagwat, S.A., Rutte, C., 2006. Sacred groves: potential for biodiversity management. *Front Ecol Environ* 4, 519−524.

Desai, V.R., 2003. Synopsis of biological data on the Tor mahseer, Tor tor (Hamilton, 1822) *Food and Agriculture Org*. (No. 158)**.**

Dandekar, P., 2011b. Temple fish sanctuaries: Last bastions of native fish and pristine river stretches - A report, http://www.indiawaterportal.org/articles/temple-fish-sanctuaries-last-bastions-native-fish-and-pristine-river-stretches-report [Accessed: Sept 2018].

Dhu S., 1923. *The angler in India or the mighty mahseer*. Natraj Publishers: Dehra Dun.

Everard, M., Sharma, O. P., Vishwakarma, V. K., Khandal, D., Sahu, Y. K., Bhatnagar, R., Pinder, A.C., 2018. Assessing the feasibility of integrating ecosystem-based with engineered water resource governance and management for water security in semi-arid landscapes: A case study in the Banas catchment, Rajasthan, India. *Science of the Total Environment* 612, 1249-1265.

Gupta, N., Kanagavel, A., Dandekar, P., Dahanukar, N., Sivakumar, K., Mathur, V.B., Raghavan. R., 2016. 'God's fishes: religion, culture and freshwater fish conservation in India' *Oryx* 50, 244–249.

Hora, S.L., 1956. Fish paintings of the third millennium B.C. from Nal (Baluchistan) and their zoogeographical significance. *Memoirs of the Indian Museum, Kolkata* 14, 78–84.

Jadhav, U., 2009. Aquaculture technology and environment. PHI Learning Pvt. Ltd., 21–22.

Katwate, C., Pawar, R., Shinde, V., Apte, D., Katwate, U., 2014. How long will social beliefs protect the pride of River Savitri? *MIN*: The Newsletter of the IUCN SSC/WI Freshwater Fish Specialist Group (South Asia) 2, 21−24.

MacDonald, A.S.J., 1948. *Circumventing the Mahseer*. Natraj Publishers: Dehra Dun.

INCCA (Indian Network for Climate Change Assessment), 2010. Climate Change and India: A 4 × 4 Assessment. New Delhi, India: Ministry of Environment and Forests, Government of India. 160pp.

Nautiyal. P., 2006. Rising awareness and efforts to conserve the Indian mahseers. Current Science 91, 1604.

Nguyen, T.T., Na-Nakorn, U., Sukmanomon, S., ZiMing, C., 2008. A study on phylogeny and biogeography of mahseer species (Pisces: Cyprinidae) using sequences of three mitochondrial DNA gene regions. *Molecular Phylogenetics and Evolution* 48, 1223-1231.

Pinder, A.C., 2017. Of mahseer and men: India's changing landscape of rivers and fisheries. FISH magazine 127, 8-12.

Saunders, D.L., Meeuwig, J.J., & Vincent, A.C.J., 2002. Freshwater protected areas: strategies for conservation. *Conservation Biology* 16(1), 30-41.

Sen, T.K., Jayaram K.C., 1982. Mahseer fishes of India: a review. *Records of the Zoological Survey of India*, Occasional Paper 39, 1–34.

Thomas H.S., 1873. *The rod in India*. Stolz, Mangalore, 319 p.

TWFT, 1984. *Trans*-world fishing team*: Quest for a Legendary Fish*. International Book Distributors: Dehra Dun.

CHAPTER 4: EXPLORING THE ROLE OF RECREATIONAL ANGLERS IN MAHSEER CONSERVATION

4.1 Prelude to Submission 1

Pinder, A.C and Raghavan, R., 2013. Conserving the endangered mahseers (*Tor* spp.) of India: the positive role of recreational fisheries. *Current Science* 104, 1472-1474.

Global participation in recreational fisheries (the practice of catching fish with rod and line for non-commercial gain) has been estimated at C.700 million (Cooke & Cowx 2004). The activity represents the primary use of wild freshwater fish stocks in all industrialised countries (Arlinghaus et al. 2017; FAO 2012), with participatory growth also now evident in many developing countries (FAO 2012; Freire et al. 2012; Bower et al. 2014).
The motivations driving this activity range from the necessitated supplementation of nutritional needs through to entirely non-consumptive leisure purposes (Cooke et al. 2018). Estimates suggest that more than 60 % of the global recreational catch of 47 billion fish per annum is purposely released alive following capture (Cooke & Cowx 2004). Despite some national policies (e.g. Germany) prohibiting the release of recreationally angled fish on ethical grounds (see Chapter 7) and further geographical and cultural differences influencing the proportion of release to harvest ratios across the world (Cooke et al. 2018), the conservation benefits of catch-and-release (C&R) angling are typically being increasingly implemented as a management strategy to promote the sustainability of the recreational resource (Arlinghaus et al. 2017). This model of fisheries management is now gaining traction in developing countries, particularly at the local scale, where communities have recognised angling tourism as having the potential to provide additional or alternate forms of livelihood (Barnett et al. 2016).

The former mahseer fishery of the mid River Cauvery provides a classic example of an entirely harvest fishery which transitioned to 100% C&R in the late 1970's. Indeed, the realisation that a live fish has a renewable value which can be capitalised multiple times, has rehabilitated former local poachers to protect fish stocks with their lives, in defence of their lucrative employment as angling guides and auxiliary support roles (e.g. drivers, chefs, bait makers etc.). During my time at Galibore Camp I spent many hours in conversation with the staff and learned that their salaries, supplemented by tips over several decades, have represented the main source of income to their villages, thus elevating their personal social status and garnering community respect, and further protection for the biological resource on which their employment relied.

Following my trips in 2010 and 2011 and witnessing the level of illegal exploitation of fish by highly destructive methods (e.g. dynamite) which has had very obvious deleterious effects on fish stocks and associated aquatic fauna beyond the boundaries of river sections protected under this model, I realised the vital importance of these fisheries to the mahseer and the exceptionally rich aquatic biodiversity and endemism associated with the river drainages of the Western Ghats (Molur et al. 2011). I had also become aware that the daily angling logs kept by the camp may offer a valuable source of data with which to monitor the temporal performance of the mahseer stocks. It was therefore a considerable shock to hear in November 2012, that the Supreme Court had passed a ruling which immediately outlawed any form of fishing throughout the former angling camps. The potential implications of the fishery closure dominated my thoughts for days and manifested into the following concerns:

1. There was no longer any incentive to protect fish stocks from illegal fishing (e.g. dynamite);
2. The loss of employment and thus food security would result in camp staff returning to their former profession as poachers, resulting in depletion of the resource they had until then protected;
3. Without angling activity, there was no method remaining in place to monitor population status;
4. How would it be possible to resolve the taxonomy of the two distinct mahseer phenotypes I had observed?; and

5. Perhaps the officials responsible for this sudden policy change were unaware of the conservation benefits and economic dependence within the region?

With the exception of some of the Northeast states of India, the ban on angling within Protected Areas (PA's), still extends across much of India, with the rationale for this policy being discussed in Submission 1. It was this abrupt change in policy that was the catalyst which saw my angling interest shift into research mode and the onset of my research journey.

With a busy day job as a consultant at this time, my evenings became swallowed up by the production of a report to provide stakeholders (the recreational angling community) with the scientific evidence they had requested of me, to support a legal challenge to the angling ban.
Although never published in full, this encouraged me to re-establish contact with Raghavan. Following some discussion, it was decided that the best strategy to get my message to policy makers was to publish a stripped down and succinct commentary paper in India's most read scientific journal, Current Science. While Submission 1 identifies many positive aspects of the conservation benefits of recreational angling, it was also important to acknowledge that negative impacts of the activity (e.g. fish welfare and ethical considerations) would require further investigation (See Chapter 7). In May 2018 this paper was cited in the Indian National Academy of Agricultural Sciences Strategy Paper 8 on conservation policies for hilsa and mahseer (NAAS 2018). This document acknowledges the difficulties associated with monitoring fish populations in dynamic monsoonal rivers using conventional fisheries assessment tools. Accordingly, it highlights the positive role of C&R fisheries in monitoring mahseer populations and recommends that a science led angling protocol should be developed to reinstate the monitoring of mahseer populations on the River Cauvery and within Protected Areas throughout India.

4.1.1 **References**

Arlinghaus, R., Alós, J., Beardmore, B., Daedlow, K., Dorow, M., Fujitani, M., Huhn, D., Haider, W., Hunt, L.M., Johnson, B.B., Johnston, F., Klefoth, T., Matsumura, s., Monk, C., Pagel, T., Post, J.R., Rapp, T., Riepe, C., Ward, H., Wolter, C., 2017. Understanding and managing freshwater recreational fisheries as complex adaptive social-ecological systems. *Rev. Fish. Sci. Aquac*. 25, 1-41

Barnett, A., Abrantes, K. G., Baker, R., Diedrich, A. S., Farr, M., Kuilboer, A., Mahony, T., McLeod, I., Moscardo, G., Prideaux, M., Stoeckl, N., van Luyn, A. and Sheaves, M., 2016. Sportfisheries, conservation and sustainable livelihoods: a multidisciplinary guide to developing best practice. *Fish and Fisheries*, 17(3), 696-713.

Bower S.D., Nguyen V.M., Danylchuk A.J., Beard Jr. T.D., and Cooke S.J., 2014. Inter-sectoral conflict and recreational fisheries of the developing world: Opportunities and challenges for co-operation. In McConney, P., Medeiros, R., and Pena, M. (Eds.) *Enhancing Stewardship in Small-Scale Fisheries: Practices and Perspectives*. Too Big to Ignore (TBTI) and Centre for Resource Management and Environmental Studies, The University of the West Indies, Cave Hill Campus, Barbados. CERMES Technical Report No. 73, 88-97.

Cooke, S.J. and Cowx, I.G., 2004. The role of recreational fishing in global fish crises. *BioScience.* 54, 857-859.

Cooke, S.J., Twardek, W.M., Lennox, R.J., Zolderdo, A.J., Bower, S.D., Gutowsky, L.F., Danylchuk, A.J., Arlinghaus, R., Beard, D., 2018. The nexus of fun and nutrition: Recreational fishing is also about food. *Fish and Fisheries* 19(2), 201-224.

FAO, 2012. *Technical Guidelines for Responsible Recreational Fisheries*. Food and Agriculture Organization, Rome. 176 pp

Freire, K.M., Machado, M.L., Crepaldi, D., 2012. Overview of inland recreational fisheries in Brazil. *Fisheries* 37, 484-494.

Molur, S., Smith, K.G., Daniel, B.A., Darwall, W.R.T., 2011. The status and distribution of freshwater biodiversity in the Western Ghats, India. *Cambridge, UK and Gland, Switzerland: IUCN, and Coimbatore, India: Zoo Outreach Organisation*.

NAAS, 2018. Conservation policis for hilsa and mahseer. Strategy paper #8. *National Academy of Agricultural Sciences, New Delhi*, 28 pp.

4.2 Submission 1

CURRENT SCIENCE, VOL. 104, NO. 11 (2013)

Conserving the endangered Mahseers (Tor spp.) of India: the positive role of recreational fisheries

Adrian C. Pinder [a,b] and Rajeev Raghavan[b,c]

[a]Faculty of Science and Technology, Bournemouth University, Poole, UK
[b]Mahseer Trust, Freshwater Biological Association, Wareham, Dorset, UK
[c]Conservation Research Group (CRG), St. Albert's College, Kochi, India

A third of all freshwater fishes globally are threatened with extinction (Dudgeon 2012; Gray 2011) making them one of the most important vertebrate groups in need of urgent conservation attention. Freshwater fishes are increasingly threatened by a range of factors, including habitat loss, overexploitation and biological invasions (Dudgeon 2012; Gozlan et al. 2005). Conserving freshwater fishes is therefore a complex challenge requiring a combination of proactive strategies, on a continuous and sustained basis (Dahanukar et al. 2011; Dudgeon et al. 2006). To be successful, conservation measures also require the political will of national and regional authorities, and the participation of local communities (Kottelat et al. 2012).

Many countries, especially those in the tropics where much of the freshwater fish diversity is concentrated, invest little time and effort on their conservation. For example, in India, freshwater fishes have been 'out of sight' and 'out of mind' of the policy makers and general public (Gadgil et al. 2001). This is in spite of the fact that the country harbours the greatest number of endemic freshwater fishes in continental Asia (De Silva et al. 2007), many of which are threatened (Dahanukar et al. 2011; Vishwanath et al. 2011) and some probably extinct (Raghavan & Ali 2011, 2012).

Mahseers of the genus *Tor* are large cyprinids endemic to continental Asia, and popular cultural icons of economic, recreational and conservation interest in their native range (Siraj et al. 2007; Nguyen et al. 2008). Due to the large sizes they attain, mahseers find a place among the 20 'mega fishes' of the world (Stone 2007), and have often been called the 'tiger of the water' (Nautiyal 2006), and the world's hardest fighting fish (Trans World Fishing Team 1984). There are no reliable estimates of the number of *Tor* species found in Indian waters, mainly due to the taxonomic uncertainties within this genus (Siraj et al. 2007). However, they comprise one of the most threatened groups of freshwater fish in the country. Of the currently valid species, five are listed as 'Endangered' (*Tor khudree*, *T. kulkarni*, *T. malabaricus*, *T. mussullah* (see Note 1) and *T. putitora*) and two as 'Near Threatened' (*T. tor* and *T. progenius*) in the IUCN Red List of Threatened Species (IUCN 2012).

The report of the National Commission on Agriculture (NCA) in 1976 was probably the first to highlight the plight of the mahseers and the need for their conservation (National Commission on Agriculture 1976). Several studies have since revealed that overfishing and habitat alteration have resulted in severe population decline of different *Tor* species, including the golden mahseer, *T. putitora* and the tor mahseer, *T. tor* in the Himalayan rivers (Bhatt et al. 2004; Bhatt et al. 2000) and the Deccan mahseer, *T. khudree* in the Western Ghats (Raghavan et al. 2011). More recently, the escalating list of anthropogenic threats to mahseer populations has been synthesized to include a broad range of individual and combined effects such as catchment fragmentation, water and aggregate abstraction, and the prevalence of illegal and highly destructive fishing methods such as small mesh nets, plant-derived toxins, electricity and dynamite (WWF 2013).

The Wildlife association of South India (WASI), an NGO based in Bangalore, Karnataka, came into existence in 1972 with a mandate 'to conserve and preserve the wildlife of South India'. The association also obtained a lease of a 22 km reach of the River Cauvery with the aim to conserve native mahseer populations. While this initiative lacked influence over catchment-scale developments impacting either directly or indirectly on habitat quality and longitudinal and lateral connectivity, the focus of the WASI effort was to control illegal fishing and replenish wild stocks using captive bred fish (Sehgal 1999). The WASI also set up small seasonal fishing camps to promote responsible 'catch and release' mahseer fisheries. The success of WASI encouraged other NGOs such as the Coorg Wildlife Society (Sehgal 1999)., private individuals (Jung 2012), and the State Government-owned Jungle Lodges and Resorts (JLR 2013) to set up both seasonal and full-time angling camps on the River Cauvery during the 1980s and 1990s. The income generated from recreational fisheries effectively controlled illegal fishing of mahseer through the establishment of anti-poaching camps, as well as rehabilitation of former poachers as 'Ghillies' or fishing guides, thus providing alternative employment and associated societal benefits. Catch records maintained at these fishing camps show that between 1989 and 1996, the large sized mahseer captured by anglers ranged from 21.6 to 48.1 kg (Sehgal 1999) (Figure 4.2.1).

Figure 4.2.1. Large Mahseer, Galibore Fishing Camp, River Cauvery (February 2010).

Such success was to later capture the attention of international tour operators, and in 2006 a British-based angling tourism specialist, Angling Direct Holidays (ADH), secured an agreement with JLR for a block booking at the Galibore Camp between mid-January and mid- March of each year. Activity during this period has been restricted to a maximum of ten anglers practising a strict ‘catch and release’ policy. Catch data from Galibore (number, weight, phenotype notes, etc.) and fishing effort (time) were recorded in daily logs. Preliminary analyses of data collected between 1996 and 2012 demonstrate a dramatic increase in the total number of fish caught over time along with a reducing trend in individual mean weights. These data form the basis of a manuscript in preparation, but indicate elevated levels of recruitment in response to the reduction/ elimination of poaching activities (Dinesh et al. 2010) and possibly assisted through stocking (Ogale 2002).

While the main focus of mahseer angling in South India has been on the River Cauvery, there is also considerable interest in recreational fisheries and conservation of golden mahseer, *T. putitora* in the rivers draining south from the Himalayan watershed (Dinesh et al. 2010; Everard & Kataria 2011). Since 2007, Adventure Expedition Travels Pvt Ltd, through its subsidiary, India Angling (www.india-angling.com) adapted an ‘integrated catchment value systems’ model (Everard et al. 2009) and applied it for angling tourism in the Ramganga River at Bikhyasen in the Himalayan foothills. Local people were employed as helpers for the anglers, and the local temple at Sarna benefitted financially for providing accommodation. Furthermore, in association with the temple, fishing prohibition signboards were erected on the two prime pools holding large specimens of mahseer (Everard & Kataria 2011). This model which provides incentives to local people to protect rivers through economic benefits acquired from recreational services has helped improve the conservation of *T. putitora* in the region (Everard & Kataria 2011).

Apart from the positive role played by recreational fishing, the success of these efforts also demonstrated the importance of engaging local communities in the conservation of endemic and threatened freshwater fish species. Recreational fishers constitute a social group that offers unique potential to enhance fish conservation. They have a vested interest in preserving or enhancing the resources they depend on and there is ample evidence to demonstrate that anglers work proactively to conserve, and where possible enhance, aquatic biodiversity (Granek et al. 2008), as well as motivating others to do so (Parkkila et al. 2010). In addition, anglers have also been known to participate in developing pro-environmental legislations, and in taking legal action to oppose developments likely to be environmentally damaging (Bate 2002; Kirchhofer 2002).

The Indian Wildlife (Protection) Act 1972 (IWPA) was enacted to provide the much needed legal protection to flora and fauna within areas set aside for protection (Protected Areas (PA)). While this item of legislation affords little attention to freshwater fish (Dahanukar et al. 2011; Sarkar et al. 2008), the Act clearly states that 'No person shall hunt any "wild animal" specified in Schedule, I, II, III and IV, except under the provisions defined in Sections 11 and 12'. Despite fishes being included within the definition of 'wildlife', under Section 2(1), the Act does not explicitly draw attention to fish under the definition of 'wild animal', which is defined as including amphibians, birds, mammals, and reptiles, and their young, and in the case of birds and reptiles, their eggs. The only specific reference to protected fish species is restricted to Part IIA of Schedule I, which includes the following marine species, whale shark (*Rhinocodon typus*), shark and ray (all *lasmobranchii*), sea horse (all *Sygnathidians*) and giant grouper (*Epinephelus lanceolatus*).

Despite this lack of clarity, the IWPA has previously been highlighted as a major factor constraining the effective conservation of declining mahseer populations throughout India due of the constraints placed on the development of recreational fisheries being managed to harmonize with conservation objectives (Johnsingh et al. 2006). Perhaps ironically, the Act has also been implicated in seriously impeding the access of scientists to conduct scientific research within the PAs (Madhusudan et al. 2006).

Despite the effective participation based conservation model practised on the River Cauvery, on 17 April 2009, a legal notice was issued under Section 55 of the IWPA. It questioned the construction(albeit temporary) of the privately owned Bush Betta fishing camp (Jung 2012) within the Cauvery Wildlife Sanctuary, without prior approval from the National Wildlife Board (NWB) and the Supreme Court. This was followed by the issue of a further legal notice to the Central Empowerment Committee (CEC) of the Supreme Court, drawing attention to the further violation of the IWPA by permitting angling within the boundaries of the Cauvery Wildlife Sanctuary. Under Section 2(16a) of the IWPA, the Ministry of Environment and Forests (MoEF), New Delhi has considered angling to be aligned with hunting; an activity which is prohibited within protected areas. As a result, all angling activity has recently been prohibited throughout the Cauvery Wildlife Sanctuary.

In spite of several decades of research on mahseers, there remain significant knowledge gaps in our understanding of basic biology and population dynamics of important species in Indian waters. Uncertainties exist on even the total number of mahseer species that occur in India, and also on the exact species status of the *Tor* found in the Cauvery. A recent gathering of experts agreed that these were immediate research priorities (WWF 2013).

Due to the fact that many of the areas where mahseers are distributed are either physically remote or dispersed, often falling within protected forest areas, the involvement of local communities and other relevant stakeholders is vital for advancing both science and conservation. Engaging community and stakeholder participation in research is not only cost effective, but also lays the foundation for co-management (Bene et al. 2009). For example, with regard to recreational fisheries of mahseers, collaboration between scientists and anglers can provide valuable data that can inform future conservation actions. This has been successfully demonstrated in the case of the world's largest salmonid, the threatened Eurasian giant trout or the taimen, *Hucho taimen* in Mongolia (Granek et al. 2008).

Monitoring population performance of mahseers in monsoonal rivers is problematic due to the logistical difficulties in sampling such large fishes in challenging environments. Thus, there is a paucity of available data to assess the current status and vulnerability of stocks within the Cauvery and other rivers. The value of catch data collected by the Galibore angling camp on the River Cauvery has only recently been realized (manuscript in prep.). Despite potential sampling biases, these data provide temporal and spatial information on fish numbers, weights and phenotypes over a period of 15+ years. Within-year sample size can also be substantial, thus enhancing statistical validity of observations. For example, considering that the Cauvery angling season typically extends between October and April, in any one week, a group of ten anglers would typically amass a sample of 500 hours fishing.

While the promotion of 'catch and release' fisheries may assist in effecting conservation objectives, consideration should also be afforded to the potentially damaging influence of poorly informed fisheries management actions such as stocking to artificially enhance and maintain populations. In the case of the Cauvery, no baseline exists to describe the original mahseer community prior to the advancement of mahseer culture methods pioneered by Tata Electric Company (Ogale 2002) and the implications for future genetic integrity of populations. There also remain a host of anthropogenic catchment pressures which impact on stocks less directly by influencing fish movement, habitat and water quality. Until practising ichthyologists are in a position to quantify these impacts, there remains an urgent need to focus on the collection and collation of biological data to determine the current gene pool, and improve understanding of the biology and ecological requirements of these fishes.

Despite the current contentions of whether 'catch and release' angling constitutes 'hunting', provision exists within the IWPA to override the prohibition of hunting in PA's. Under Section 12, Chief Wildlife Wardens have the authority to grant hunting permits for specified animals animals, provided their capture is for the purpose of (a) education; 4(b) scientific research; (bb) scientific management. The ‘Act’ further defines clause (bb), the expression, ‘scientific management’ means (i) translocation of any wild animal to an alternative suitable habitat; or (ii) population management of wildlife, without killing or poisoning or destroying any wild animals.

In light of the perilous status of mahseer stocks and the evidence presented to support the positive role of recreational fisheries, it is recommended that ‘catch and release’ angling be actively encouraged throughout India. Furthermore, within well-managed fisheries, such as the Cauvery Wildlife Sanctuary, structured data collection programmes should constitute a condition of angling permits being issued to advance scientific research. A further recommendation is that all stocking activity within the Cauvery Wildlife Sanctuary and elsewhere in peninsular Indian river systems should be strictly prohibited until the current gene pool has been defined and an understanding of stock/wild fish interactions gained.

While there is little doubt that ‘catch and release’ practices are less likely to limit population performance than indiscriminate fishing methods such as dynamite fishing, a number of researchers have highlighted a range of risks which may be associated with recreational fishing methods. Risks have been synthesized to include a range of impacts from delayed post-release mortality (Arlinghaus et al. 2007; Cooke & Cowx 2004) through to subtle physiological and behavioural effects (Arlinghaus et al. 2009) which could potentially impair predator avoidance capabilities of released fish, particularly in the presence of other apex predators such as crocodile (*Crocodylus palustris* and *Gavialis gangeticus*) and otter (*Lutrogale perspicillata*). In balancing the perceived benefits of ‘catch and release’ angling, there also remains a requirement to quantify any such factors which have the potential to impair conservation objectives. **Note** 1. Although the species status of *T. mussullah* is ambiguous, for the sake of the present commentary, we consider ‘mussullah’ as a species of *Tor*.

REFERENCES

Arlinghaus, R., Cooke, S.J., Lyman, J., Policansky, D., Schwab, A., Suski, C., Thorstad, E.B., 2007. Understanding the complexity of catch-and-release in recreational fishing: an integrative synthesis of global knowledge from historical, ethical, social, and biological perspectives. *Reviews in Fisheries Science* 15(1-2), 75-167.

Arlinghaus, R., Klefoth, T., Cooke, S.J., Gingerich, A., & Suski, C., 2009. Physiological and behavioural consequences of catch-and-release angling on northern pike (Esox lucius L.). *Fisheries Research* 97(3), 223-233.

Bate, R., 2002. Saving Our Streams: The Role of the Anglers' Conservation Association in Protecting English and Welsh Rivers. *Fordham Envtl. LJ*, *14*, 375.

Bene, C., 2009, World Fish Center Technical Manual No. 1951, The World Fish Center, Penang, Malaysia, p. 23.

Bhatt, J.P., Nautiyal, P., & Singh, H.R., 2000. Population structure of Himalayan mahseer, a large cyprinid fish in the regulated foothill section of the river Ganga. *Fisheries Research* 44(3), 267-271.

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. *Asian Fisheries Science* 17, 341-355.

Cooke, S.J., & Cowx, I.G., 2004. The role of recreational fishing in global fish crises. *AIBS Bulletin* 54(9), 857-859.

Dahanukar, N. Raghavan, R., Anvar, A., Abraham, R., Shaji, C.P., 2011. In *The Status and Distribution of Freshwater Biodiversity of the Western Ghats* (compilers: Molur, S. *et al*.), IUCN, Cambridge, UK and Gland, Switzerland and Zoo Outreach Organization, Coimbatore, 2011, p. 116.

De Silva, S.S., Abery, N.W., & Nguyen, T.T., 2007. Endemic freshwater finfish of Asia: distribution and conservation status. *Diversity and Distributions* 13(2), 172-184.

Dinesh, K., Nandeesha, M.C., Nautiyal, P., & Aiyappa, P., 2010. Mahseers in India: A review with focus on conservation and management. *Indian Journal of Animal Sciences (India)*.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.I., Knowler, D.J., Lévêque, C. & Sullivan, C.A., 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological reviews* 81(2), 163-182.

Dudgeon, D., 2012. Threats to freshwater biodiversity globally and in the Indo-Burma Biodiversity Hotspot. *The Status and Distribution of Freshwater Biodiversity in Indo-Burma* 1-28.

Everard, M., Colvin, J., Mander, M., Dickens, C., & Chimbuya, S., 2009. Integrated catchment value systems. *Journal of Water Resource and Protection* 1(03), 174.

Everard, M., & Kataria, G., 2011. Recreational angling markets to advance the conservation of a reach of the Western Ramganga River, India. *Aquatic Conservation: Marine and Freshwater Ecosystems* 21(1), 101-108.

Gadgil, M., Chandrashekahariah, H.N. and Bhat, A., 2001. *The Hindu Survey of the Environment*, pp. 137–142.

Gozlan, R.E., St-Hilaire, S., Feist, S.W., Martin, P., & Kent, M.L., 2005. Biodiversity: disease threat to European fish. *Nature* 435(7045), 1046.

Granek, E.F., Madin, E.M., Brown, M.A., Figueira, W., Cameron, D.S., Hogan, Z., Zahn, S., 2008. Engaging recreational fishers in management and conservation: global case studies. *Conservation Biology* 22(5), 1125-1134.

Gray, R., *The Telegraph*, 30 July 2011;
http://www.telegraph.co.uk/earth/wildlife/

8672417/Third-of-freshwater-fish-threatened-with-extinction.html (accessed 10 February 2013).

IUCN, 2012. The IUCN Red List of Threatened Species, Version 2012.2; http://www.iucnredlist.org [Accessed: Oct 2012].

JLR, 2013. www.junglelodges.com [Accessed: Feb 2013].

Johnsingh, A.J.T., Negi, A.S., & Mohan, D., 2006. Golden mahseer conservation in Uttaranchal. *Cheetal* 43(1), 9-17.

Jung, S.B., 2012. *Subhan and I: My Adventures with the Angling Legend of India*, Roli Books, p. 223.

Kirchhofer, A., 2002. The role of legislation, institutions and policy making in fi sh conservation in Switzerland: past, present and future challenges. In Conservation of Freshwater Fish: Options for the Future, eds. M.J. Collares-Pereira, I.G. Cowx & M.M. Coelho, pp. 389–401. Blackwell Science, Oxford

Kottelat, M., Bairdz, I.G., Kullanderg, S.O., Ng, H.H., Parenti, L.R., Rainboth, W.J., & Vidthayanon, C., 2012. In *The Status and Distribution of Freshwater Biodiversity in Indo-Burma* (compilers: Allen, D. J. *et al*.), IUCN, Cambridge, UK and Gland, Switzerland, 2012, p. 158.

Madhusudan, M.D., Shanker, K., Kumar, A., Mishra, C., Sinha, A., Arthur, R., Rangarajan, M., 2006. Science in the wilderness: the predicament of scientific research in India's wildlife reserves. *Current Science* 91(8), 1015-1019.

National Commission on Agriculture, 1976. Report on Fisheries, Government of India, Vol. 8, p. 270.

Nautiyal, P., 2006. Rising awareness and efforts to conserve the Indian mahseers. *Current Science* 91(12), 1604.

Nguyen, T.T., Na-Nakorn, U., Sukmanomon, S., & ZiMing, C., 2008. A study on phylogeny and biogeography of mahseer species (Pisces:

Cyprinidae) using sequences of three mitochondrial DNA gene regions. *Molecular Phylogenetics and Evolution* 48(3), 1223-1231.

Ogale, S.N., 2002. Mahseer breeding and conservation and possibilities of commercial culture. The Indian experience. *FAO Fisheries Technical Paper*, 193-212.

Parkkila, K., Arlinghaus, R., Artell, J., Gentner, B., Haider, W., Aas, Ø., Barton, D., Roth, E., Sipponen, M., Hickley, P., 2010. "Methodologies for assessing socio-economic benefits of European inland recreational fisheries." *EIFAAC Occasional Paper* 46: I.

Raghavan, R., Ali, A., Dahanukar, N., & Rosser, A., 2011. Is the Deccan Mahseer, Tor khudree (Sykes, 1839)(Pisces: Cyprinidae) fishery in the Western Ghats Hotspot sustainable? A participatory approach to stock assessment. *Fisheries Research* 110(1), 29-38.

Raghavan, R. & Ali, A., 2011. *Hypselobarbus lithopidos*. *The IUCN Red List of Threatened Species* 2011: e.T172483A6901473. http://dx.doi.org/10.2305/IUCN.UK.2011-

Raghavan, R. & Ali, A., 2012. *Puntius deccanensis*. In IUCN Red List of Threatened Species. Version 2012.2; www. iucnredlist.org [Accessed: Feb 2013].

Sarkar, U.K., Pathak, A.K., & Lakra, W.S., 2008. Conservation of freshwater fish resources of India: new approaches, assessment and challenges. *Biodiversity and conservation* 17(10), 2495-2511.

Sehgal, K.L., 1999. Coldwater fish and fisheries in the Indian Himalayas: rivers and streams. *Fish and fisheries at higher altitudes: Asia. Food and Agriculture Organization of the United Nations Technical Paper* 385, 41-63.

Siraj, S.S., 2007. (eds), *Mahseer: The Biology, Culture and Conservation*, Malaysian Fisheries Society, Serdang, Malaysia, 2007, p. 235.

Stone, R., 2007. The last of the leviathans. *Science* 316(5832), 1684-1688.

Trans World Fishing Team, 1984. *Quest for a Legendary Fish*, International Book Distributors, Dehra Dun, India, 1984, p. 154.

Vishwanath, W., Ng, H.H., Britz, R., Singh, L.K., Chaudry, S., Conway, K.W., 2011. In *The Status and Distribution of Freshwater Biodiversity in the Eastern Himalaya* (compilers: Allen,D. *et al*.), IUCN, Cambridge, UK and Gland, Switzerland and Zoo Outreach Organization, Coimbatore, 2011, p. 88.

WWF, 2013. http://www.mahseerconservancy.org/blog/2012/09/26/wwf-workshop-indelhi-mahseer-conservancy-program/ [Accessed: Feb 2013].

CHAPTER 5: STAKEHOLDER ENGAGEMENT

5.1 Prelude to Submissions 2 & 3:

Gupta, N., Raghavan, R., Sivakumar, K., Mathur, V., **Pinder, A.C**., 2015. Assessing recreational fisheries in an emerging economy: Knowledge, perceptions and attitudes of catch-and-release anglers in India. *Fisheries Research*, 165, 79-84.

*Bower, S.D., Danylchuk, A.J., Raghavan, R., Clark-Danylchuk, S., **Pinder, A.C**., Alter, A., Cooke, S.J., 2017. Involving recreational fisheries stakeholders in development of research and conservation priorities for mahseer (*Tor* spp.) of India through collaborative workshops. *Fisheries Research* 186, 665-671.

* Previously submitted for the award of PhD by the lead author. This paper has not been included to claim personal credit, but to demonstrate how I have contributed towards advancing the knowledge base and the importance of this work in guiding the strategic direction of my own research journey.

The status and emergence of a recreational fisheries sector in India

As well as supporting many examples of conservation success stories and driving major national and local economies around the world (see Chapter 4), recreational fishing has also been demonstrated to generate associated health benefits to individuals and communities through encouraging increased exercise, social interaction, reduced stress, and improved well-being (Cowx et al. 2010; Griffiths et al. 2017). Quantification of these holistic benefits therefore provides the potential to attract the attention and positive support of policy makers in achieving both positive conservation and societal outcomes (Brownscombe et al. 2019).

To qualify any potential conservation benefits of any recreational fishery, the monitoring of participation rates (Arlinghaus et al. 2015) and angler behaviours (Hunt et al. 2011) are vital to understand how anglers interact with fish and their environment and, ultimately, their collective impact on the sustainability of the exploited biological resource (Brownscombe et al. 2019). Research into the human dimensions of recreational fisheries is, therefore, a fundamental component of sustainable fisheries management development (Hunt et al. 2013). Yet, knowledge of this type remains poorly understood or completely lacking in some developing countries (Bower et al. 2014). Despite some challenges associated with collecting and interpreting data, stakeholder questionnaires have been demonstrated as a rapid and cost-effective mechanism to collate the views of recreational anglers on fishery management options (Oh et al. 2005; Carlin et al. 2012), their willingness to support conservation initiatives (Oh & Ditton 2008; Drymon & Scyphers 2017), opinions on fish stocking (Arlinghaus et al. 2014; von Linden & Mosler 2014), habitat protection (Hutt & Bettoli 2007) and the assessment of stakeholder activity, demographics and economic value (Armstrong et al. 2018).

Shortly after the publication of Submission 1 (Chapter 4), I was contacted by Nishikant Gupta, a PhD student at Kings College London. Gupta was co-supervised by academics at the Wildlife Institute of India and was studying the potential role of mahseer in protecting the Indian Himalayan Rivers, with a particular focus on the role of recreational fisheries. Pooling our knowledge of the Himalayan and South Indian mahseer fisheries was enlightening but highlighted a complete lack of knowledge across the majority of Indian states, many supporting major river drainages (e.g. Narmada, Krishna, Godavavi) where mahseer species were known to be present, indicating potential for recreational fishery activity. Following some meetings and remote communications, we co-designed a questionnaire to explore temporal and spatial participation and compare the knowledge, perceptions and attitudes of recreational angers across India.

While internet angler forums and the international angling press were at the time identified as the optimal means to recruit participants, the number of participating anglers has since increased substantially across India. This has driven the establishment of a national representative body of anglers, the All

India Game Fishing Association (AIGFA) http://www.aigfa.org/ and the participation of large numbers of domestic anglers on social media platforms, such as state/regional Facebook angling pages (e.g. Kerala, Rajasthan, Nagaland, Pune, Bangalore etc.). While this demonstrates a rapid expansion of angling interest, it also highlights a need to reassess the current status and future trajectory of the recreational fisheries sector in India, and its associated impacts on natural resources. This growth, new visibility and accessibility to the sector via social media platforms provides considerable opportunity for constructive conservation focused communication and the opportunity to engage anglers in securing the future sustainability of the resource for recreation, aquatic ecosystem integrity and associated ecosystem services.

Uniting stakeholders

Social-ecological systems (SES's) can be most succinctly defined as independent yet linked systems of people and nature across bio-geo-physical scales (Folke 2006; Ostrom 2009). Recreational fisheries are being increasingly considered within the context of SES frameworks in recognition of the complexity of ecosystem functions and anthropogenic players which combine to complicate their effective management (Hunt et al. 2013). Irrespective of considerations of sustainable fishery exploitation, in rapidly developing countries like India, the impacts of local communities on aquatic resources are frequently eclipsed by government policies enacted to support the rapid development of urban and economic demands for water and power. For example, the construction of dams for power generation and the over-abstraction of water from India's rivers are resulting in the destruction of key functional habitats, pollution and the drying of river beds (Everard et al. 2018). Stakeholder interests which may be expected to be more closely aligned also reveal conflict. For example, the current policy of India's State Fishery Departments is to stock all dam impounded river sections with non-native fishes to fulfil their remit in food security (Sunil 2007). This is in direct conflict with the interests of conservation and wildlife organisations via potential deleterious impacts on endemic biodiversity, including the decline of native mahseer populations (see MoEFCC 2017).

With multiple and complex demands on aquatic resources (e.g. recreation, sustenance fisheries, power generation, sewerage, agriculture etc.), it is perhaps not surprising that individual stakeholders tend to work in isolation, with limited or no appreciation for the intrinsic links which function to provide their individual ecosystem services of interest. The engagement of stakeholders has, therefore, been effectively incorporated as a central feature of many biodiversity conservation and natural resource management projects globally (Sterling et al. 2017). This also explains why many researchers argue that fisheries management is as much about people management as it is about stock management (Arlinghaus 2004; Hilborn 2007). Instilling self-ownership, pride and encouraging the participation of recreational anglers in conservation planning has been shown to contribute positively to aquatic stewardship (Cowx et al. 2010; Granek et al. 2008; Tufts et al. 2015). However, without appropriate knowledge transfer, the potential naivety of anglers regarding their awareness of the complexity of ecological interactions and associated issues has been identified as a potential weakness of anglers in their collective contribution to conservation planning (Cowx et al. 2010).

The results presented in Submission 2 revealed some important differences in the target species, regulation, participation rates and angling methods employed between North and South Indian fisheries. For example, angling had recently been banned within the Protected Area which encompasses the former Cauvery Fishing Camps (see Submission 1, Chapter 4) and while bait fishing was the favoured angling method for *Tor remadevii* and *Tor khudree* in South India, fly and lure fishing dominated the methods to target *Tor putitora* in the Himalayan states. Accordingly, it was considered that stakeholder engagement should target these two geographical locations separately, given their contrasts and the different challenges they present for developing research and conservation priorities for mahseer. The key aims of these workshops were to disseminate current scientific knowledge and seek the input of researchers, industry and stakeholder partners to identify regional specific knowledge gaps, threats and priorities for strategic future research and conservation action.

5.1.1 References

Arlinghaus, R., 2004. *A human dimensions approach towards sustainable recreational fisheries management*. Turnshare Ltd.-Publisher.

Arlinghaus, R., Beardmore, B., Riepe, C., Meyerhoffl, J., Pagel, T., 2014. Species-specific preferences of German recreational anglers for freshwater fishing experiences, with emphasis on the intrinsic utilities of fish stocking and wild fishes. *J Fish Biol* 85, 1843–1867

Armstrong, M., Brown, A., Hargreaves, J., Hyder, K., Pilgrim-Morrison, S., Munday, M., & Williamson, K., 2013. Sea angling 2012—a survey of recreational sea angling activity and economic value in England. *Department for Environment Food and Rural Affairs, London* 13.

Bower, S.D., Nguyen, V.M., Danylchuk, A.J., Beard Jr, T.D., & Cooke, S.J., 2014. Inter-sectoral conflict and recreational fisheries of the developing world: Opportunities and challenges for co-operation. *Enhancing Stewardship in Small-Scale Fisheries: Practices and Perspectives, ed. P. McConney, R. Medeiros, and M. Pena. Too Big To Ignore (TBTI) and Centre for Resource Management and Environmental Studies, Technical Report*, (73).

Brownscombe, J.W., Hyder, K., Potts, W., Wilson, K.L., Pope, K.L., Danylchuk, A.J., Cooke, S.J., Clarke, A., Arlinghaus, R. and Post, J.R., 2019. The future of recreational fisheries: Advances in science, monitoring, management, and practice. *Fisheries Research* 211, 247-255.

Carlin, C.S., Schroeder, S.A., & Fulton, D.C., 2012. Site choice among Minnesota walleye anglers: the influence of resource conditions, regulations and catch orientation on lake preference. *North Am J Fish Manag* 32, 299–312.

Cowx, I.G., Arlinghaus, R., & Cooke, S.J., 2010. Harmonizing recreational fisheries and conservation objectives for aquatic biodiversity in inland waters. *Journal of Fish Biology* 76(9), 2194-2215.

Drymon, J.M., & Scyphers, S.B., 2017. Attitudes and perceptions influence recreational angler support for shark conservation and fisheries sustainability. *Marine Policy* 81, 153-159.

Everard, M., Sharma, O.P., Vishwakarma, V.K., Khandal, D., Sahu, Y.K., Bhatnagar, R., Kumar, V. & Pinder, A.C., 2018. Assessing the feasibility of integrating ecosystem-based with engineered water resource governance and management for water security in semi-arid landscapes: A case study in the Banas catchment, Rajasthan, India. *Science of the Total Environment* 612, 1249-1265.

Folke, C., 2006. Resilience: the emergence of a perspective for social-ecological systems analyses. *Global Environmental Change* 16(3), 253-267. http://dx.doi.org/10.1016/j.gloenvcha.2006.04.002

Granek, E.F., Madin, E.M., Brown, M.A., Figueira, W., Cameron, D.S., Hogan, Z., Kristianson, G., De Villiers, P., Williams, J.E., Zahn, S., Arlinghaus, R., 2008. Engaging recreational fishers in management and conservation: global case studies. *Cons. Biol*. 22 (5), 1125–1134.

Griffiths, S.P., Bryant, J., Raymond, H.F., & Newcombe, P.A., 2017. Quantifying subjective human dimensions of recreational fishing: does good health come to those who bait?. *Fish and Fisheries* 18(1), 171-184.

Hilborn, R., 2007. Managing fisheries is managing people: what has been learned?. *Fish and Fisheries* 8(4), 285-296.

Hunt, L.M., Arlinghaus, R., Lester, N., & Kushneriuk, R., 2011. The effects of regional angling effort, angler behavior, and harvesting efficiency on landscape patterns of overfishing. *Ecological Applications* 21(7), 2555-2575.

Hunt, L.M., Sutton, S.G., & Arlinghaus, R., 2013. Illustrating the critical role of human dimensions research for understanding and managing recreational fisheries within a social-ecological system framework. *Fisheries Management and Ecology* 20 (2-3), 111-124.

Hutt, C.P. & Bettoli, P.W., 2007. Preferences, specialization, and management attitudes of trout anglers fishing in Tennessee tailwaters. North *Am J Fish Manag* 27, 1257–1267

MoEFCC, 2017. India's National Wildlife Action Plan 2017-31. Ministry of Environment Forests and Climate Change, Government of India. 160 pp. http://www.indiaenvironmentportal.org.in/files/file/nwap_2017_31.pdf). [Accessed May 2019].

Oh, C.O, Ditton, R.B., Gentner, B., Riechers, R., 2005. A stated preference choice approach to understanding angler preferences for management options. *Human Dimens Wildl* 10,173–186

Oh, C.O. & Ditton, R.B., 2008. Using recreation specialization to understand conservation support. *J Leis Res* 40, 556–573

Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. *Science* 325 (5939):419-422. http://dx.doi.org/10.1126/science.1172133

Sterling, E.J., Betley, E., Sigouin, A., Gomez, A., Toomey, A., Cullman, G. & Filardi, C., 2017. Assessing the evidence for stakeholder engagement in biodiversity conservation. *Biological Conservation* 209, 159-171.

Sunil, D.S., 2007. State interventions and natural resource management: A study on social interfaces in a riverine fisheries setting in Kerala, India. *Natural Resources Forum* 31, 61-70).

Tufts, B.L., Holden, J., DeMille, M., 2015. Benefits arising from sustainable use of North America's fishery resources: economic and conservation impacts of recreational angling. *Int. J. Environ. Stud* 72(5), 850–868.

von Lindern, E. & Mosler, H.J., 2014. Insights into fisheries management practices: using the theory of planned behavior to explain fish stocking among a sample of Swiss anglers. *PLoS ONE* 9 (12),1–20

5.2 Submission 2

FISHERIES RESEARCH, VOL. 165, 79-84. (2015)

Assessing recreational fisheries in an emerging economy: knowledge, perceptions and attitudes of catch-and-release anglers in India

Nishikant Gupta[a,c], Rajeev Raghavan[c,d,e], Kuppusamy Sivakumar[b], Vinod Mathur[b], **Adrian C. Pinder**[c,f]

a Department of Geography, King's College London, Strand, London, United Kingdom
bWildlife Institute of India (WII), Chandrabani, Dehradun, India
cMahseer Trust, c/o The Freshwater Biological Association, East Stoke River Laboratory, Wareham, Dorset, United Kingdom
dConservation Research Group (CRG), St. Albert's College, Kochi, India
eLaboratory of Systematics, Conservation and Ecology, Zoo Outreach Organization (ZOO),
Coimbatore, India
fFaculty of Science & Technology, Bournemouth University, Poole, Dorset, United Kingdom

ABSTRACT

Across the globe, catch-and-release (C&R) angling represents a leisure activity indulged by millions. The practice of C&R is commonly advocated by conservation managers because of its potential to protect local fish populations from a range of anthropogenic threats, including over-fishing. In India, C&R angling in freshwaters has a history dating back to colonial times. Despite this, little is known about the current state of the sector. To address this, an online web-based survey was conducted to target C&R anglers who fish in Indian rivers to assess their knowledge, attitudes and perceptions relating to the national status of India's freshwater C&R fisheries. From a total of 148 responses, factors such as angling quality (score of 4.6/5.0); aesthetics of surroundings (4.6/5.0), presence of other wildlife (4.4/5.0), fishery management practices (4.6/5.0) and socioeconomic benefits (4.4/5.0) were evaluated. Over 65% (n=148) of the anglers reported an observed decrease in the quality of fishing (e.g. a reduction in the size and/or numbers of fish available for capture). Respondents also considered deforestation (score of 4.2/5.0), water abstraction (4.4/5.0), pollution (4.4/5.0), hydropower projects (4.2/5.0) and destructive fishing techniques (4.7/5.0) as factors which threaten both the habitat and species they target. C&R practitioners were largely united regarding the benefits and willingness to contribute both their time and financial input to support conservation initiatives (score of 4.7/5.0). The current study provides the first overview of the status of C&R angling in India and explores challenges, opportunities, and priorities for future resource management.

Keywords: mahseer, conservation**,** Asia, developing country, freshwater, sport fishing

INTRODUCTION

Apart from being an important protein source and facilitating vital ecosystem functions (Dugan et al. 2006; Welcomme et al. 2010; Brummet et al. 2013), freshwater fish also provide recreational benefits (Pinder & Raghavan 2013). Recreational (catch-and-release (henceforth C&R)) fishing, defined as "a non-commercial activity that captures fishes for purposes other than nutritional needs" (Granek et al. 2008; Cowx et al. 2010) is a highly indulged pastime, both in developed and developing countries. C&R has a very high participation rate (Cooke & Cowx 2004; Granek et al. 2008; Cowx et al. 2010) and its popularity is expected to grow in developing countries and emerging economies owing to increased wealth of their societies (FAO 2012). For example, despite the popularity of recreational angling in India during colonial times, it is only in the past two decades that C&R angling has gained national popularity, and now represents a fast expanding market (see Everard & Kataria 2011). Indeed, an increasing number of tour operators are offering angling as part of their wildlife and tourism packages to two of the nation‟s biodiversity hotspots, the Himalayas and the Western Ghats (Everard & Kataria 2011). Of particular attraction to international anglers are the mahseers (*Tor* spp.); often considered to be the world‟s hardest fighting fish (TWFT 1984), both foreign and domestic anglers frequent the upper Ganges catchment (in the Himalayas) and the Cauvery (in the Western Ghats) in pursuit of these fish.

Despite contributing a multitude of key ecological functions and societal benefits (WWF 2006; Collen et al. 2014), freshwater ecosystems, especially rivers, comprise one of the most endangered and poorly protected ecosystems on earth (Dudgeon 2011; Cooke et al. 2012). Multiple interacting threats including habitat alteration/loss, alien species, overexploitation, pollution and climate change (Xenopoulos et al. 2005; Dudgeon et al. 2006; Strayer & Dudgeon 2010; Vörösmarty et al. 2010; McDonald et al. 2011) are widely cited as contributing to the precarious state of global freshwater biodiversity. Since freshwater fishes are integral to ecosystem function and are also a source of food and livelihood to millions (Dugan et al. 2006; Welcomme et al. 2010; Brummet et al. 2013; Reid et al. 2013), they are considered a critical component of freshwater biodiversity. Freshwater fishes are nevertheless one of the most threatened vertebrate taxa on earth (Reid et al. 2013), with more than 36% (of the 5785 species assessed by the IUCN) at the risk of extinction and over 60 species having already gone extinct since 1500 (Carrizo et al. 2013).

Despite varying levels of threat as a result of escalating anthropogenic pressures (Vishwanath et al. 2010; Dahanukar et al. 2011), India supports notably high levels of freshwater fish diversity and endemism. National fishery focused conservation and management policies have often suffered from setbacks due to jurisdictional issues, oversights, and implementation of top-down approaches (Raghavan et al. 2011); poor enforcement of existing laws (Raghavan et al. 2013) and community-based conservation initiatives often failing to protect river stretches outside their own jurisdiction (Gupta 2013). Furthermore, the Indian Wildlife (Protection) Act, 1972, the highest legal instrument for wildlife conservation in the country (Dahanukar et al. 2011; Raghavan et al. 2013), affords no mention of freshwater fish. Additionally, very few studies on C&R angling and its potential benefits are available from India (Everard & Kataria 2011; Pinder & Raghavan 2013). This paper seeks to enhance current understanding of the status of recreational angling by assessing the knowledge, attitudes and perceptions of both international and domestic anglers practicing C&R angling in India.

METHODS

Prior to any data collection a pilot survey was carried out. The questions formulated were based on the concerns and opinions of C&R anglers fishing in India (N. Gupta, pers. comm. with C&R anglers). Randomly selected international and domestic respondents (n=25) from India-specific angling forums were requested to complete the survey and pinpoint any problems with its content (Andrews et al. 2003). A web-based survey was used (running for six months from November 2013 to April 2014) to facilitate quicker response times, increased response rates, and reduced costs (Oppermann 1995; Lazar & Preece 1999; Andrews et al. 2003). The survey design was based on a series of 23 questions (see supplementary material). Information on the fishing locations and target fish species of interest to anglers was first determined. Further, (a) preferred fishing techniques; (b) factors influencing the angling experience; (c) changes in quality of the angling experience over of the course of angling at a particular location; (d) threats to target species and fishing locations; (e) awareness of the anglers on the conservation status (International Union for Conservation of

Nature/IUCN Red List of Threatened Species) of target species; (f) various conservation strategies which the C&R anglers felt was needed for the protection of target species; (g) economics of C&R angling through the amount of money spent (in US$) annually by the anglers on angling and related activities; (h) perception on the benefit of C&R angling as a conservation strategy; (i) willingness to pay for, and get involved in a conservation initiative; and (j) anglers willingness to contribute time and money towards such initiatives was also ascertained. An option for additional comments was also provided at the end of the survey to obtain views and opinions of anglers fishing in Indian waters. The respondents scored each criterion on a scale of 1-5, in ascending order of preference, and the mean score calculated and represented in a tabular form.

To assess international participation, the survey was advertised globally to target anglers spanning different method disciplines. The notification of the survey was posted on global/domestic conservation and angling websites and forums, published in international/national fishing and angling magazines/newsletters, and posted on social media (Facebook, Twitter) sites. All known India-specific angling forums were also targeted. The survey was advertised every fortnight to maintain interest. No changes were made to the survey questions during the course of data collection (Zhang 2000) and care was taken to allow only one response per individual angler to avoid dual submission (Hasler et al. 2011) by thoroughly reviewing the responses to spot any duplicate submissions.

Angling quality/experience was defined as the availability of fish (numbers/size) available for capture. The aesthetics of surroundings denoted the environment of the angling location. The presence of other wildlife refers to the visual presence of flora and fauna during angling activities. Fishery management practice considers effort applied by local fisheries/forest department towards the protection and conservation of fish communities. Local stakeholders' involvement and transparent sharing of C&R angling revenue dealt with the engagement of and financial benefits to local communities. Camp infrastructure considers the accommodation available to C&R anglers.

RESULTS AND DISCUSSION

A total of 148 responses were obtained and analysed from anglers specifically targeting fishing locations in India, (i.e., United Kingdom/UK + India) (see Figure 5.2.1). In comparison to
anglers from the UK, Indian/domestic anglers chose highly diverse and multiple fishing sites distributed across the country (see Figure 5.2.1).

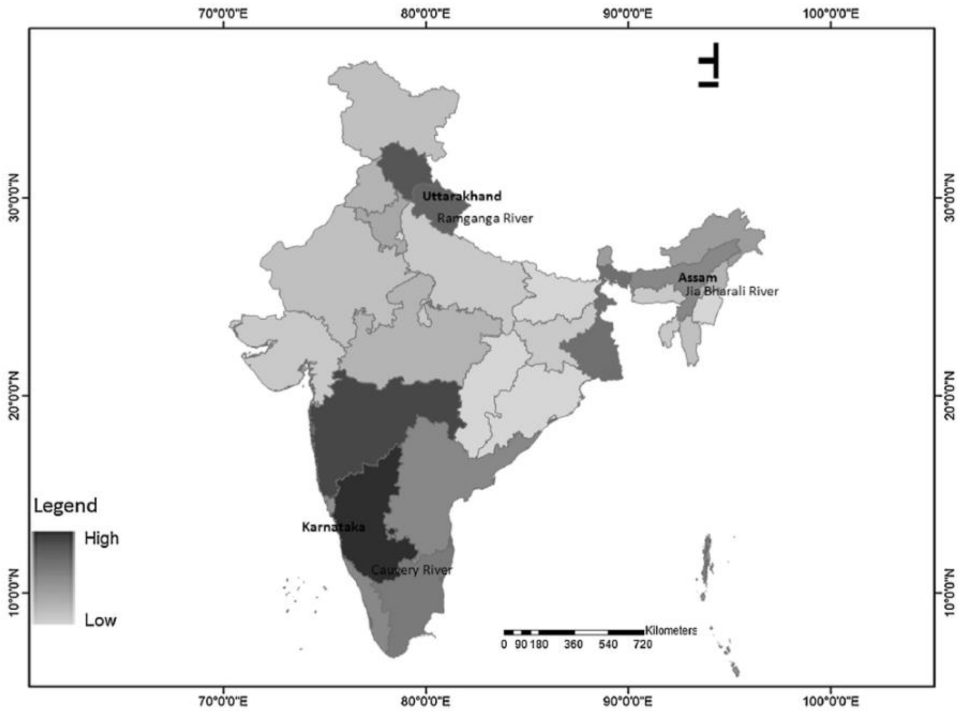


Figure 5.2.1. A heat map showing the States/Union Territories of India predominantly fished in by anglers.

Many species targeted by C&R anglers in India have shown a declining trend of population and are listed as threatened in the IUCN Red List, (e.g. *Tor khudree*, *T. malabaricus* and *T. putitora*, all assessed as 'Endangered'; the goonch catfish, *Bagarius bagarius* assessed as 'Near Threatened'; and *Schizothorax richardsonii* assessed as 'Vulnerable'), for none of these species has recreational C&R angling so far been mentioned as a threat (see species specific accounts in the IUCN Red List of Threatened Species). This has also been the case with most threatened fish species targeted by recreational anglers around the world (see Cooke et al. in press).

Apart from angling quality, aesthetics of surroundings and camp infrastructure (all directly related to C&R angling experience), ecological factors such as presence of other wildlife, fishery management practices, and the inclusion of, and financial benefits to local communities were valued by C&R anglers (see Table 1). This not only highlights the ecological and social awareness among C&R anglers, but demonstrates alignment with the current objectives of river and fish conservation policies in the region. Such awareness has the potential to assist in the co-engagement of key stakeholders (Everard & Kataria 2011) and bridge the gap between social, economic and biological dimensions of river ecosystem conservation (Cowx & Portocarrero-Aya 2011). Indeed, an opportunity could exist where C&R anglers could become involved in future conservation programmes, and possibly assist in monitoring, data collection, enforcement and lobbying at local levels (Granek et al. 2008; Cowx et al. 2010).

'Angling quality and experience' is a key driving force for any C&R angler (Arlinghaus 2006; Granek et al. 2008). The responses obtained regarding decrease in this experience and quality is a cause of concern not only for ecology and conservation, but also for the human dimensions of the fishery (Hunt et al. 2013). It has been suggested that any conservation assistance from anglers could rely heavily on the satisfactory fulfilment of an angler's leisure experience (Granek et al. 2008), and that a C&R angler's 'angling experience' depends on the well-being of the fishes they primarily target

(Arlinghaus 2006; Granek et al. 2008). Therefore, a decline in stocks is likely to have a profound effect on the quality of this personal experience, and subsequently impact the overall socioeconomic viability of the fishery (Danylchuk & Cooke 2011).

The perceptions of UK anglers on the major anthropogenic threats to angling quality (see Table 5.2.1) were consistent with those recorded in the scientific literature (Vishwanath et al. 2010; Dahanukar et al. 2011). However, 7% of domestic anglers disagreed with some of the identified threats. There could be many possible reasons for this (see Arlinghaus et al. 2007; Hunt et al. 2013) including a) international anglers being more environmentally conscious than domestic anglers, or b) domestic anglers being conditioned to accepting such threats as normal and therefore do not classify them to be such major issues.

A substantial proportion (26%) of anglers from both groups (n=148) were unaware of the conservation status (IUCN Red List) of target fish species. Strict environmental guidelines for C&R angling, including those that deal with threatened species (see Cooke et al., in press) need to be enforced by the Department of Fisheries and/or the Department of Forest and Wildlife, and also by the angling associations who can influence the behaviour of their members and guests. In addition, voluntary regulations and informal institutions could also play a pivotal role in enforcing guidelines (Cooke et al. 2013).

Both UK and domestic anglers highlighted the top three strategies required for conserving the target species as education; effective anti-poaching patrol and improved legislation (see Table 5.2.1). Despite only 16% of anglers highlighting education as important, the ‘spirit of the river’ initiative developed to educate anglers in Mongolia about best-practice catch-and-release techniques for the Taimen (*Hucho taimen*) is an example of how education can also support conservation of threatened species targeted in recreational fisheries (Bailey 2012). Although there is some legislation (Indian Fisheries Act and various State inland fisheries acts) to protect freshwater fishes in India, effective enforcement is considered to be limited (see Raghavan et al., 2011). The interest of anglers in conserving their target habitats and fish species opens up opportunities for developing participatory enforcement mechanisms based on existing legislations (see Pinder & Raghavan 2013).

In considering the value of ‘stocking’ as a potential conservation tool, domestic anglers scored this more highly (4.2/5.0) than UK anglers (3.5/5.0). The comments associated with this question were of particular interest as UK anglers expressed awareness of the potential for genetic pollution and the need for decisions on stocking policy to be informed by the historical and current population status of a species within catchments (Hickley & Chare 2004; Everard & Kataria 2011; Pinder & Raghavan 2013). Stocking for angling species has been carried out in major river systems of India (Pinder & Raghavan 2013), and this could have influenced the responses of domestic anglers. However, comparatively higher awareness among UK anglers could be another reason, as the spread of knowledge regarding the associated issues with stocking of fish species is still in its infancy in India. Indeed, the IUCN Guidelines for Reintroductions and other Conservation Translocations explicitly suggests that reintroduction should be beneficial to the species in question and the ecosystem it occupies, and should only be carried out after focused scientific research (IUCN/SSC 2013). Hence, stock augmentation for the sole purpose of increasing angler catches (numbers and/or size of fish) should be avoided. This is particularly true of the mahseers for which satisfactory knowledge pertaining to population genetics across India (and beyond) is still lacking (Pinder & Raghavan 2013).

Table 5.2.1. Summary of responses obtained from recreational anglers fishing in the Indian rivers

Criteria	**UK anglers (n= 40)**	**Domestic anglers (n=108)**
Preferred fishing locations (rivers)	(a) Cauvery: 75% (b) Kali: 6% (c) Ramganga: 19%	Assi Ganga, Barak, Beas, Bhadra, Bhagirathi, Bhakra, Bhatsa, Bhavani, Bhilangana, Bhima, Cauvery, Damodar, Gambur, Ganga, Giri, Godavari, Indrayani, Jaldhaka, Jia Bharali, Kali, Kallada, Kamini, Kosi, Krishna, Manjira, Mula, Narmada, Nira, Pavana, Ramganga, Rangeet, Ravi, Saryu, Shimsha, Subansiri, Sutlej, Teesta, Tirthan, Tons, Tungabhadra, Ulhas, Wardha, Warna and Yamuna
Preferred target fish species	(a) *Tor* spp: 82% (b) *Bagarius bagarius*: 18%	(a) *Barbodes carnaticus, Ctenopharyngodon idella, Gibelion catla, Hypselobarbus* spp, *Oncorhynchus mykiss, Salmo trutta, Schizothorax richardsonii, Labeo calbasu, Labeo rohita, Channa marulius, C. striata, Etroplus suratensis, Oreochromis* spp, *and Wallago attu*: 61% (b) *Tor* spp: 26% (c) *Bagarius bagarius*: 13%
Fishing techniques (score from 1-5, where 5 = most preferred; mean score)	(a) Bait (live/dead): 3.6 (b) Lure/spinner: 3.6 (c) Fly fishing: 3.2	(a) Bait (live/dead): 3.6 (b) Lure/spinner: 4.1 (c) Fly fishing: 2.2
Factors influencing angling experience (score from 1-5, where 5 = strongly agree; mean score)	(a) Angling quality: 4.8 (b) Aesthetics of surroundings: 4.7 (c) Presence of other wildlife: 4.5 (d) Fishery management practices: 4.8 (e) Inclusion of, and financial benefit to local communities: 4.6 (f) Camp infrastructure: 3.6	(a) Angling quality: 4.4 (b) Aesthetics of surroundings: 4.4 (c) Presence of other wildlife: 4.2 (d) Fishery management practices: 4.4 (e) Inclusion of, and financial benefit to local communities: 4.1 (f) Camp infrastructure: 3.7

Criteria	UK anglers (n=40)	Domestic anglers (n=108)
Changes in quality of angling experience at the angling locations	(a) Negative change: 75% (b) Positive change: 25%	(a) Negative change: 65% (b) Positive change: 35%
Threats to target fish species and fishing locations (score from 1-5, where 5 = strongly agree; mean score)	(a) Deforestation: 4.2 (b) Water abstraction: 4.6 (c) Hydropower projects: 4.3 (d) Water pollution: 4.3 (e) Destructive fishing techniques: 4.8	(a) Deforestation: 4.2 (b) Water abstraction: 4.2 (c) Hydropower projects: 4.1 (d) Water pollution: 4.5 (e) Destructive fishing techniques: 4.6
Awareness regarding conservation status of target species (score from 1-5, where 5 = strongly aware; mean score)	3.3	3.4
Conservation strategies for target species (score from 1-5, where 5 = strongly agree; mean score)	(a) Afforestation: 4.1 (b) Legislation: 4.7 (c) Scientific research: 4.0 (d) Anti-poaching patrol: 4.8 (e) Harsher fines: 4.5 (f) Education: 5.0 (g) Stocking: 3.5	(a) Afforestation: 4.0 (b) Legislation: 4.5 (c) Scientific research: 4.6 (d) Anti-poaching patrol: 4.8 (e) Harsher fines: 4.6 (f) Education: 4.8 (g) Stocking: 4.2
Perceptions on angling as a conservation strategy	(a) Yes: 100% (b) No: 0%	(a) Yes: 97% (b) No: 3%
Willingness to pay for and support conservation action (score from 1-5, where 5 = very interested; mean score)	4.5	4.8

Table 5.2.2. Dominant responses obtained from C&R anglers (UK + Indian; n=148) regarding the benefits of angling as a tool for conservation of threatened fish species in India

Activity during C&R angling	Benefits to threatened fish species	Reasons
Monitoring	(a) Protection against poachers (b) Helps build recognition for the species (c) Helps raise conservation awareness among the wider C&R angling community (d) Keeps track of fish counts, species diversity and habitat status (e) Helps assess the health and quality of the fishery, if applicable	(a) Discourages poaching activities (b) Limits poaching (c) Provides more eyes on the water
Prolonged presence along rivers	(a) Effective bankside protection (b) A source of first-hand information on natural and anthropogenic factors affecting fish species	(a) Deterrent to poachers (b) More easily accessible information regarding fish species
Revenue generation	(a) Future conservation work (b) Formation of local anti-poaching patrol parties	(a) Local availability of funds (b) Economic influence by financially supporting local communities
Involvement of local stakeholders	(a) Formation of local groups targeting the conservation of fish species	(b) Creation of local job opportunities and training (c) Local awareness and education (d) Spreading understanding of the high value of protecting fish species for sustainable recreational purposes (e) Resulting political influence

Along with socio-economic benefits, the efficacy of C&R fishery management in conserving fish populations has been demonstrated in many regions of the world (Arlinghaus 2006; Granek et al. 2008). Therefore, the high agreement rate (99%; n=148) of anglers that C&R fisheries have the potential to form effective conservation measures was not surprising (see Table 5.2.2). Hence, both groups (UK and domestic) expressed personal willingness to contribute
their own time and money to support conservation initiatives within the rivers they fish. Willingness to pay (WTP) represents a successful model of protecting fish populations (Gozlan et al. 2013; Rogers 2013) and enhance recreational fishery performance (Kenter et al. 2013). Added protection of river reaches can also enhance biodiversity and associated ecosystem services (Kenter et al. 2013). There is also potential for the revenue generated through C&R angling initiatives to feedback to local communities, and further strengthen societal support for future river and fish conservation strategies (Everard & Kataria 2011).

CONCLUSIONS

Both UK and domestic anglers fishing in India have demonstrated conservation awareness and a willingness to support local conservation initiatives. This is important as the industry is in an expansion phase in the country, and such collaborative opportunities could assist ongoing and future river and fish conservation strategies. However, there are concerns among C&R anglers that biodiversity managers and policy makers would initiate strict management of C&R angling activities in Indian rivers. This is because there are serious concerns that some C&R anglers cause more risk than benefits to the fish species they target, especially threatened species (Gupta et al. in press). Further, domestic anglers were comparatively unaware of the genetic risks of stocking (see Table 5.2.1). This highlights the importance of spreading awareness through education. This can be facilitated by the existing angling organizations among its members through angling workshops and literature. Additionally, Indian anglers are interested in a much greater diversity of rivers and fish species (see Table 5.2.1). This is a positive sign from a national perspective and demonstrates that C&R benefits beyond mahseer, the Cauvery and Ganges.

Apart from having a current global value in billions (in US$) (FAO 2012) C&R angling has also generated substantial income for national economies (Cooke & Suski 2005; Cowx et al. 2010; Danylchuk & Cooke 2011; Everard & Kataria 2011). Economic benefits in the year 2005 alone were estimated at US$2 billion in Canada, US$800 million in New Zealand, US$150 million in Argentina, and US$10-15 million in Chile (Arismendi & Nahuelhual 2007). The amount of money spent by anglers fishing Indian rivers represents an emerging economy, and could play a decisive role for fish conservation by bringing both social and economic benefits for local communities and associated stakeholders. Everard & Kataria (2011) noted that a single 5-day angling tour for three anglers on the Ramganga River in 2007 generated US$ 1,220; and in 2010 (February-April), US$ 7,800 was spent by anglers in this region on purchases and accommodation alone (Everard & Kataria 2011). Such monetary incentives could motivate local people to participate voluntarily in fish tourism, and assist in the protection of threatened species from illegal fishing techniques (Everard & Kataria 2011; Pinder & Raghavan 2013). As the industry expands, there remains a need to maintain transparency during the profit sharing stages, and ensure the marginalization of any particular group of stakeholders is avoided. C&R anglers frequenting the Indian rivers have expressed concern over the acceptable distribution of angling derived revenue by some angling tourism operators (see Gupta at al. in review). One way to overcome this would be to set up community conservation units (CCUs) within local villages, the members of whom could interact with local angling associations and ensure that appropriate dividends reach their communities. With the current perilous state of Indian rivers and their associated biodiversity, there is an urgent need for alternate conservation strategies, and C&R anglers as a local stakeholder group could potentially provide such an opportunity.

ACKNOWLEDGEMENTS

Nishikant Gupta is funded by King's College London, UK. Rajeev Raghavan is supported by the Mohammed Bin Zayed Species Conservation Fund. The authors thank Steven Lockett for his valuable suggestions to the manuscript, anglers from around the world who participated in this survey through numerous angling forums and social media; and Navneet Singh and the Mahseer Trust for their support.

REFERENCES

Andrews, D., Nonnecke, B., Preece, J., 2003. Electronic survey methodology: A case study in reaching hard to involve Internet Users. *Int. J. Hum. Comput. Interact* 16, 185–210.

Arismendi, I., Nahuelhual, L., 2007. Non-native Salmon and Trout Recreational Fishing in Lake Llanquihue, Southern Chile: Economic Benefits and Management Implications. *Rev. Fish. Sci* 15, 311–325.

Arlinghaus, R., 2006. Overcoming 307 human obstacles to conservation of recreational fishery resources, with emphasis on central Europe. *Environ. Conserv* 33, 46–59.

Arlinghaus, R., Cooke, S.J., Lyman, J., Policansky, D., Schwab, A., Suski, C., Sutton, S.G.,Thorstad, E.B., 2007. Understanding the Complexity of Catch-and-Release in Recreational Fishing: An Integrative Synthesis of Global Knowledge from Historical, Ethical, Social, and Biological Perspectives. *Rev. Fish. Sci* 15, 75–167.

Bailey, D.H., 2012. Collaborative Conservation of Taimen (*Hucho taimen*) Through Education and Awareness Khovsgol Aimag Mongolia. Theses, Diss. Prof. Pap. Pap. 203.

Brummet, R.E., Beveridge, M.C.M., Cowx, I.G., 2013. Functional aquatic ecosystems, inland fisheries and the Millennium Development Goals. *Fish Fish*. 14, 312–324.

Carrizo, S.F., Smith, K.G., Darwall, W.R.T., 2013. Progress towards a global assessment of the status of freshwater fishes (Pisces) for the IUCN Red List: application to conservation programmes in zoos and aquariums. Int. *Zoo Yearb*. 47, 46–64.

Collen, B., Whitton, F., Dyer, E.E., Baillie, J.E.M., Cumberlidge, M., Darwall, W.R.T., Pollock, C., Richman, N.I., Soulsby, A.M., Bohm, M., 2014. Global patterns of freshwater species diversity, threat and endemism. *Glob. Ecol. Biogeogr*. 23, 40-51.

Cooke, S.J., Paukert, C., Hogan, Z., 2012. Endangered river fish: factors hindering conservation and restoration. *Endanger. Species Res*. 17, 179–191.

Cooke, S.J., Cowx, I.G., 2004. The Role of Recreational Fishing in Global Fish Crises. *Biosci* 54, 857

Cooke, S.J., Hogan, Z.S., Butcher, P.A, Stokesbury, M.J.W., Raghavan, R., Gallagher, A.J., Hammerschlag, N., Danylchuk, A.J., in press. Angling for endangered fish: conservation problem or conservation action? *Fish Fish*. doi: 10.1111/faf.12076

Cooke, S.J., Suski, C.D., 2005. Do we need species-specific guidelines for catch-and-release recreational angling to effectively conserve diverse fishery resources? *Biodivers. Conserv*. 14, 1195–1209.

Cooke, S. J., Suski, C. D., Arlinghaus, R., Danylchuk, A.J., 2013. Voluntary institutions and behaviours as alternatives to formal regulations in recreational fisheries management. *Fish Fish*. 14, 439–457.

Cowx, I.G., Arlinghaus, R., Cooke, S.J., 2010. Harmonizing recreational fisheries and conservation objectives for aquatic biodiversity in inland waters. *J. Fish Biol*. 76, 2194– 215.

Cowx, I.G., Portocarrero Aya, M., 2011. Paradigm shifts in fish conservation: moving to the ecosystem services concept. *J. Fish Biol*. 79, 1663–80.

Dahanukar, N., Raghavan, R., Ali, A., Abraham, R., Shaji, C.P., 2011. The status and distribution of freshwater fishes of the Western Ghats. In: Molur, S., Smith, K.G., Daniel, B.A., Darwall, W.R. (compilers) The status and distribution of freshwater biodiversity in the Western Ghats, India. IUCN Cambridge and Zoo Outreach Organization. Coimbatore. 116p.

Danylchuk, A.J., Cooke, S.J., 2011. Engaging the recreational angling community to implement and manage aquatic protected areas. *Conserv. Biol*. 25, 458–64.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.-I., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A.-H., Soto, D., Stiassny, M.L.J., Sullivan, C.A., 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biol. Rev. Camb. Philos. Soc*. 81, 163–82.

Dudgeon, D., 2011. Asian river fishes in the Anthropocene: threats and conservation challenges in an era of rapid environmental change. *J. Fish Biol.* 79, 1487–1524.

Dugan, P., Dey, M.M., Sugunan, V.V., 2006. Fisheries and water productivity in tropical river basins: Enhancing food security and livelihoods by managing water for fish. *Agric. Water Manag*. 80, 262–275.

Everard, M., Kataria, G., 2011. Recreational angling markets to advance the conservation of a reach of the Western Ramganga River, India. *Aquat. Conserv. Mar. Freshw. Ecosyst*. 21, 101–108.

FAO., 2012. Recreational fisheries. FAO Technical Guidelines for Responsible Fisheries, No 13. Food and Agricultural Organization of the United Nations, Rome. 176p.

Gozlan, R.E., Burnard, D., Andreou, D., Britton, J.R., 2013. Understanding the threats posed by non-native species: public vs. conservation managers. *PLoS One* 8, e53200.

Granek, E.F., Madin, E.M.P., Brown, M. A., Figueira, W., Cameron, D.S., Hogan, Z., Kristianson, G., de Villiers, P., Williams, J.E., Post, J., Zahn, S., Arlinghaus, R., 2008. Engaging recreational fishers in management and conservation: global case studies. *Conserv. Biol*. 22, 1125–34.

Hasler, C.T., Colotelo, A.H., Rapp, T., Jamieson, E., Bellehumeur, K., Arlinghaus, R., Cooke, S.J., 2011. Opinions of Fisheries Researchers, Managers, and Anglers towards Recreational Fishing Issues: An Exploratory Analysis for North America. Am. Fish. Soc. Symp. 75, 51–74.

Hickley, P., Chare, S., 2004. Fisheries for non-native species in England and Wales: angling or the environment? *Fish. Manag. Ecol*. 11, 203–212.

Hunt, L.M., Sutton, S.G., Arlinghaus, R., 2013. Illustrating the critical role of human dimensions research for understanding and managing recreational fisheries within a social-ecological system framework. *Fish. Manag. Ecol*. 20, 111–124.

IUCN/SSC, 2013. Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0. Gland, Switzerland: IUCN Species Survival Commission, viiii + 57 pp.

Kenter, J.O., Bryce, R., 380 Davies, A., Jobstvogt, N., Watson, V., Ranger, S., Solandt, J.L., Duncan, C., Christie, M., Crump, H., Irvine, K.N., Pinard, M., Reed, M.S., 2013. The value of potential marine protected areas in the UK to divers and sea anglers. UNEP WCMC, Cambridge, UK.

Lazar, J., Preece, J., 1999. Designing and implementing Web-based surveys. *J. Comput. Inf. Syst*. 39, 63–67.

McDonald, R.I., Green, P., Balk, D., Fekete, B.M., Revenga, C., Todd, M., Montgomery, M., 2011. Urban growth, climate change, and freshwater availability. *Proc. Natl. Acad. Sci. U. S. A.* 108, 6312–7.

Oppermann, M., 1995. E-mail surveys: Potentials and pitfalls. *Mark. Res*. 7, 28.

Pinder, A.C., Raghavan, R., 2013. Conserving the endangered Mahseers (*Tor* spp.) of India: the positive role of recreational fisheries. *Curr. Sci*. 104, 1472–1475.

Raghavan, R., Ali, A., Dahanukar, N., Rosser, A., 2011. Is the Deccan Mahseer, *Tor khudree* (Sykes 1839) (Pisces: Cyprinidae) fishery in the Western Ghats Hotspot sustainable? A participatory approach to stock assesment. *Fish. Res*. 110, 29-38.

Raghavan, R., Dahanukar, N., Tlusty, M.F., Rhyne, A.L., Kumar, K.K., Molur, S., Rosser, A.M., 2013. Uncovering an obscure trade: Threatened freshwater fishes and the aquarium pet markets. *Biol. Conserv*. 164, 158–169.

Reid, G.M., MacBeath, T.C., Csatadi, K., 2013. Global challenges in freshwater-fish conservation related to public aquariums and the aquarium industry. *Int. Zoo Yearb*. 47, 6–45.

Rogers, A.A., 2013. Social Welfare and Marine Reserves: Is Willingness to Pay for Conservation Dependent on Management Process? A Discrete Choice Experiment of the Ningaloo Marine Park in Australia. *Can. J. Agric. Econ*. 61, 217–238.

Strayer, D.L., Dudgeon, D., 2010. Freshwater biodiversity conservation: recent progress and future challenges. *J. North Am. Benthol. Soc*. 29, 344–358.

TWFT, 1984. The quest for the legendary fish. Trans World Fishing Team. International Book Distributors. 160p.

Vishwanath, W., Ng, H.H., Britz, R., Singh, L.K., Chaudhry, S., Conway, K.W., 2010. The status and distribution of freshwater fishes of the Eastern Himalaya region. In: Allen, D.J., Molur, S., Daniel, B.A. (Compilers). The Status and Distribution of Freshwater Biodiversity in the Eastern Himalaya.

Cambridge, UK and Gland, Switzerland: IUCN, and Coimbatore, India: Zoo Outreach Organisation. 90p.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, S.A., Liermann, C.R., Davies, P.M., 2010. Global threats to human water security and river biodiversity. *Nature* 467, 555–61.

Welcomme, R.L., Cowx, I.G., Coates, D., Béné, C 416 ., Funge-Smith, S., Halls, A., Lorenzen, K., 2010. Inland capture fisheries. Philos. *Trans. R. Soc. Lond. B. Biol. Sci*. 365, 2881–96.

WWF, 2006. Free-flowing rivers Economic luxury or ecological necessity? World Wildlife Fund, 44p.

Xenopoulos, M.A., Lodge, D.M., Alcamo, J., Märker, M., Schulze, K., Van Vuuren, D.P., 2005. Scenarios of freshwater fish extinctions from climate change and water withdrawal. *Glob. Chang. Biol*. 11, 1557–1564.

Zhang, Y., 2000. Using the internet for survey research: A case study. *J. Am. Soc. Inf. Sci.* 51, 57–68.

5.3 Submission 3

FISHERIES RESEARCH, VOL. 186, 665-671 (2017)

Involving recreational fisheries stakeholders in development of research and conservation priorities for mahseer (Tor spp.) of India through collaborative workshops

Shannon D. Bower[a], Andy J. Danylchuk[b], Rajeev Raghavan[c,d], Sascha Clark Danylchuk[e], **Adrian C. Pinder**[d,f], Aaron M. Alter[g], Steven J. Cooke[a]

[a]Fish Ecology and Conservation Physiology Laboratory, Department of Biology, Carleton University, 1125 Colonel By Dr., Ottawa, ON K1S 5B6, Canada

[b]Department of Environmental Conservation, University of Massachusetts Amherst, 160 Holdsworth Way, Amherst, MA, 01003, USA

[c]Department of Fisheries Resource Management, Kerala University of Fisheries and Ocean Studies, Kochi, 682 506, Kerala, India

[d]Mahseer Trust, c/o The Freshwater Biological Association, East Stoke River Laboratory, Wareham, Dorset, BH20 6BB, United Kingdom

[e]Fish Mission, 11 Kingman Rd., Amherst, MA, 01002, USA

[f]Faculty of Science and Technology, Bournemouth University, Fern Barrow, Poole, Dorset, BH12 5BB, United Kingdom

[g]Fishery Promotion and Conservation, Baobab Educational Adventures, 49 Seahorse Ln., Christchurch, VA, 23031, USA

ABSTRACT

The mahseer (Tor spp.) of India are a group of potamodromous cyprinids currently facing numerous challenges in their native ranges including overfishing, pollution, and hydropower development. As a result of such challenges, four of the seven Indian species of *Tor* have been listed as 'Endangered' on the IUCN Red List, including two of the most popular recreationally fished species, *Tor khudree* and *Tor putitora*. Stakeholders in the mahseer recreational fishery may serve as an ally for this group of iconic fishes, fostering aquatic stewardship and providing livelihood alternatives for poachers. Yet, information regarding species-specific responses to recreational fishing practices is lacking and a 2009 decree equating fishing with hunting in the Indian Wildlife Protection Act (1972) has since 2011 effectively banned angling within protected areas and rendered the future of mahseer recreational fisheries elsewhere uncertain. In 2014, our team collaborated with local organizations, fisheries professionals, non-governmental organizations (NGOs), and anglers to conduct two stakeholder workshops designed to develop a research agenda for various species of Indian mahseer. General knowledge gaps identified in the two workshops were very similar and included biological, sociological, and economic considerations. The resulting research priorities in both locations strongly highlighted local context, indicating that while opportunities for addressing knowledge gaps through collaboration exist at the national scale, there is a need for regional-or fishery-specific governance strategies and approaches to mahseer research and conservation.

INTRODUCTION

Stakeholder engagement, the active participation of individuals in planning, research, or management processes that impact them (Sloan 2009), has become a popular topic in fisheries research (e.g., in the US, Feeney et al. 2010; in the UK, Hartley & Robertson 2008; in Europe, Mackinson et al. 2011; for spatial planning, Pomeroy & Douvere 2008). A number of concerns associated with the incorporation of stakeholder engagement into research have been identified (e.g., negative impacts on scientific integrity, Abbot & Guijt 1997; the potential exclusion of already marginalized groups from the engagement process, Kothari 2001; Prell et al. 2008; potential consequences of negative trust relationships, Smith et al. 2013). Other studies, however, have noted that incorporating local context led to improved research outcomes as a result of access to more relevant information (e.g., anticipating problems or conflict, Koontz & Thomas 2006; facilitating social learning, promoting trust among collaborators, Yochum et al. 2011).These benefits may be critical for developing sound management strategies for data deficient recreational fisheries. For example, Arlinghaus & Krause (2013) suggested that under certain conditions stakeholder estimates of population size could be as reliable as more traditional stock assessment methods. Other benefits associated with the stakeholder engagement process include improved relationships between researchers and the public, the development of ongoing partnerships, and acceptance and self-enforcement of management decisions based on research outcomes (Reed 2008; Steyaert et al. 2007). Recreational fisheries have been recognized as a complex social-ecological system, where changes to either component results in changes to the other (Mora et al. 2009). In these systems, wicked problems, or problems that by their nature are difficult to solve due to a combination of complexity and stochasticity, can arise which require extensive communication and efforts among numerous disciplines to tackle effectively (Jentoft & Chuenpagdee 2009). Stakeholder engagement and partnership strategies have proven successful in recreational fisheries research and conservation efforts by incorporating multiple viewpoints and facilitating angler participation to engender cooperation and support (e.g. see Armitage et al. 2008; Granek et al. 2008; Hartley & Robertson 2006). Indeed, when consultation and participatory conditions are met, harnessing the support of freshwater and marine anglers can contribute greatly to aquatic stewardship (Cowx et al. 2010; Granek et al. 2008; Tufts et al. 2015; but see also Danylchuk & Cooke 2011). An example of this potential can be found in the management and conservation challenges surrounding the mahseer (*Tor* spp.) recreational fishery of India.

Mahseer are a group of large-bodied potamodromous cyprinids targeted by commercial, subsistence and recreational fishers in Asia. Despite the fact that four of the seven *Tor* species in India have been listed as endangered (an additional species is listed as ‘Near Threatened’, IUCN, 2015), very little information is currently available describing the ecology of these species (but see Bhatt et al. 2004; Bhatt & Pandit 2016; Nautiyal et al. 2008; Nautiyal 2014 describing migration behaviours and ecology of *Tor putitora*). Catch and release (C&R) was advocated as an angling ethic in the 1970s in an effort to control poaching activities after anglers noted a decline in the body size and rate of catch (Gupta et al. 2015a). In an effort to mitigate concerns surrounding the state of the fishery, anglers developed ‘coalitions’ and leased property along river reaches, developing training programs for guides and monitoring river activities to reduce poaching (Everard & Kataria 2011; Gupta et al. 2015[b]; Pinder & Raghavan, 2013). Angler catch data collected from a former angling camp on the Cauvery River has demonstrated an increase in catch rate (along with concomitant decreases in body size), indicating strong recruitment has occurred since this type of fisheries management model was established (Pinder et al. 2015[b]). However, in 2009, a legislative decree equating C&R fishing with hunting effectively shut down the recreational fishery in protected areas, while leaving other locales virtually unaffected. This uneven application of regulations has since resulted in anecdotal reports of elevated poaching and illegal fishing activity within the Cauvery Wildlife Sanctuary (Pinder et al. 2015[a,b]). In 2013, WWF India issued a report detailing the current status and challenges surrounding mahseer conservation (see WWF-India 2013). A key report finding was the need to develop an evidence based research agenda to support mahseer conservation. In 2014, our team collaborated with local organizations, fisheries professionals, NGOs, and anglers in two regions to conduct stakeholder workshops designed to meet this need by facilitating discussions to clarify the current state of mahseer research, identify key knowledge gaps constraining mahseer conservation, and to develop a research agenda based on the outcomes of these discussions.

METHODS

The goal of both stakeholder workshops was to collaborate with researchers, industry and stakeholder partners to identify key knowledge gaps and develop a research agenda for mahseer that addresses these knowledge gaps and supports current and future research and conservation efforts. The unique characteristics of each location, and associated fisheries, threats, and focal species necessitated different approaches for each workshop. In both cases, preparation consisted of identifying local experts in the target areas to seek their partnership in facilitating workshops through planning and participation (as per Reed et al. 2006). These facilitators populated a balanced list of key stakeholders from multiple arenas, including fisheries and forestry managers (Karnataka Department of Fisheries, Uttarakhand Department of Forests and Ecotourism), representatives from fishing associations (including the Coorg Wildlife Society, the Wildlife Association of South India, Jungle Lodges, The Himalayan Outback, Baobab Educational Adventures), lodge and homestay owners, anglers, and representatives from conservation NGOs (WWF India and Zoo Outreach Organization).The South India workshop took place at Jungle Lodges and Resorts, Bannerghatta Nature Camp, Bangalore, Karnataka on March 28 and 29, 2014, with 30 people in attendance. Mahseer recreational fishing is firmly established in the southern states, including Karnataka (Gupta et al. 2015[b]; Sehgal 1999). Participants in this workshop were interested in discussing developments in the recreational fishery, including rules and regulations governing fishing activity, and the angling ban in protected areas. The North India workshop took place on April 5, 2014 at the Byasi Beach Camp, Rishikesh, Uttarakhand, on the banks of the Ganges River, and on April 6, 2014 at Atali Ganga, Rishikesh, Uttarakhand, with18 people in attendance. Mahseer recreational fishing is growing as a tourism industry in the northern states (including Uttarakhand), though it is not known to be a popular activity undertaken by many domestic recreational anglers. Participants of this workshop were interested in discussions regarding the role of tourism in promoting the sport, and strategies for achieving balance between tourism- and locally-based activities (e.g., small-scale commercial and subsistence fishing).The nature and type of both workshops was developed in response to the preferences of participants and partners. For example, the workshop held in South India (Bannerghatta) was very structured, with specific time frames allotted for presentations and discussion. In North India (Byasi/Atali Ganaga), the workshop process was more flexible, leaving more time for ad hoc discussions and deviations from planned topics. Time frames were estimated for individual topics and were adjusted according to how much/how little participants had to contribute. Both workshops were scheduled over two days, with different goals set for each day. We opted to provide numerous opportunities for relationship-building and conversation prior to initiating discussion regarding the research agenda (as per Allen et al. 2011; Reed 2008). For example, on Day 1, participants identified local and regional-scale issues impacting mahseer, discussed the management and conservation context for these issues, and background topics associated with the research (i.e., current state of recreational fisheries research, C&R research and associated best practices; Table 5.3.1 and Figure 5.3.2). This method transformed the process from a top-down scenario to a bottom-up process in accordance with Reed's (2008) best practices for stakeholder engagement, and afforded the opportunity to discuss any potential flashpoint issues in an open atmosphere. These flashpoint issues were aired, but not considered an essential part of the research agenda by any attendees. The list of knowledge gaps was populated at the end of Day 1in both workshops. The second day (Day 2) was devoted to developing a research agenda for mahseer based on knowledge gaps and discussion from Day 1.

Table 5.3.1. Priority knowledge gaps constraining mahseer conservation identified by participants of stakeholder workshops in South India (Bannerghatta) and North India (Byasi/Atali Ganga). Knowledge gaps have been separated into categories according to primary concern: biological, sociological, and economic. Where identical knowledge gaps were identified, identical descriptors have been used. Where similar knowledge gaps were identified, descriptors highlight specificities according to each location.

	Bannerghatta Workshop	**Byasi/Atali Ganga Workshop**
Biological	Insufficient knowledge of: • Taxonomy and diversity of mahseer (and other freshwater fishes) • Natural history and ecology of mahseer, including differences among age/size classes re: physical habitat, habitat use, major life events, e.g., spawning, migration • Amount and impacts of illegal fishing activity, including use of small mesh nets, dynamiting, poisoning, and electrocution • Impacts of invasive species introductions, stocking, and C&R on mahseer, bycatch species (e.g., snakehead; *Channa* spp.), and compare potential tools for improving survivorship of released fishes • Impacts of hydropower development and pollution on mahseer populations and behaviour, e.g. impacts of reduced connectivity, shifting habitat types (lentic to lotic)	Insufficient knowledge of: • Diversity of mahseer (and other freshwater fishes) • Natural history and ecology of mahseer, including differences among age/size classes re: physical habitat, habitat use, major life events, e.g., spawning, migration • Amount and impacts of illegal fishing activity, including use of small mesh nets, dynamiting, poisoning, and electrocution • Impacts on mahseer populations arising from invasive species introductions and stocking • Impacts of hydropower development and pollution on mahseer populations and behaviour, e.g. impacts of reduced connectivity, shifting habitat types (lentic to lotic) • Suitable levels of combined (i.e., among fisheries) harvest
Sociological	Insufficient knowledge of: • Identifiable cross-cutting and cross-jurisdictional issues • Identify effective methods for raising awareness of mahseer conservation, e.g., mahseer as umbrella species to promote freshwater conservation • Collaboration potential among managing entities • Impacts of angling behaviours on mahseer behaviour (e.g., bait use, ground-baiting)	Insufficient knowledge of: • Identifiable cross-cutting and cross-jurisdictional issues • Identify effective methods for raising awareness of mahseer conservation, e.g., mahseer as umbrella species to promote freshwater conservation • Collaboration potential for addressing community needs in the fisheries management context • Benefits and constraints of recreational fishing activity to local

		communities • Enforcement efficacy, and alternative strategies that promote safety and compliance • Suitable methods for generating community support for recreational fishing activities, including recruitment of young, female anglers • Suitable management toolbox for integrating different fishery types
Economic	Insufficient knowledge of: • Economic expenditures associated with all fishery types • Suitable access fees for recreational fishing activities • Efficacy of fees as enforcement for rule violations, suitable fine amounts	Insufficient knowledge of: • Economic expenditures associated with all fishery types • Suitable strategies for sharing benefits arising from recreational fishing activities with local communities

Figure 5.3.1. Participants in the South India (Bannerghatta) workshop pose for a photo at the conclusion of Day 1.

Figure 5.3.2. Participants in the North India (Byasi) workshop during breakout discussions on Day 1.

RESULTS

Stakeholder workshop participants identified knowledge gaps across disciplines (e.g., biological, sociological, economic). While similar points were recognized in both workshops, location-specific knowledge gaps were also identified (Table 5.3.1). Twelve knowledge gaps were identified by Bannerghatta workshop participants (5 biological; 4 sociological; 3 economic). Fifteen knowledge gaps were identified by Byasi/Atali Ganga workshop participants (6 biological; 7 sociological; 2 economic). Both locations shared similarities among five biological knowledge gaps, three sociological knowledge gaps, and one economic knowledge gap. In both workshops, participants developed the list of top six research priorities from the established knowledge gaps. These identified priorities were also multi-disciplinary but exhibited fewer similarities than occurred through developing the list of knowledge gaps (Table 5.3.2). Both groups retained three of the shared knowledge gaps, but on refining them into more detailed research priorities differentiated greatly on focus (Table 5.3.2).

Table 5.3.2. Priority research agenda items identified by participants of stakeholder workshops in South India (Bannerghatta) and North India (Byasi/Atali Ganga). Research agenda items have been separated into categories according to primary concern: biological, sociological, and economic. Where identical research priorities were identified, identical descriptors have been used. Where similar research priorities were identified, descriptors highlight specificities according to each area.

	Bannerghatta Workshop	**Byasi/Atali Ganga Workshop**
Biological	Clarify the taxonomy and systematics of mahseer (and other endemic freshwater fishes)	Clarify the taxonomy of mahseer (and other freshwater fishes), confirm identification, and examine local adaptations (e.g., dietary overlap and competition among freshwater fishes)
	Quantify trends in natural history and ecology of mahseer, including: differences among age/size classes re: physical habitat; habitat use; major life events, e.g., spawning, migration; and mahseer population dynamics, including age, growth, reproduction, mortality (natural mortality rates and external sources such as angling)	Identify impacts of hydropower development and pollution on mahseer populations and behaviour, e.g. impacts of reduced connectivity, shifting habitat types (lentic to lotic)
	Determine impacts of invasive species introductions, stocking, and C&R on mahseer, bycatch species (e.g., snakehead; *Channa* spp.), and compare potential tools for improving survivorship of released fishes	
Sociological	Determine the suitability of mahseer to act as an umbrella species for freshwater conservation in India by determining the value of mahseer (and C&R) to the public, and identify other routes of knowledge mobilization	Determine the suitability of mahseer to act as an umbrella species for freshwater conservation in India and identify other mechanisms for encouraging conservation-oriented behavior
		Measure collaboration potential for addressing community needs in the fisheries management context, including determining the carrying capacity of local social systems for ecotourism and angling activities and identifying suitable models for facilitating social conflict resolution
Economic	Develop an estimate of the economic expenditures generated by recreational angling, trade-off/offsets	Develop an estimate of the economic expenditures generated by recreational angling, and estimates for the degree of local dependence on mahseer for livelihood/food
	Evaluate efficacy of fees as enforcement for rule violations, and identify alternate methods for regulation enforcement (e.g., discouraging the sale of mahseer at market)	Evaluate suitable strategies for sharing benefits arising from recreational fishing activities with local communities , including the likelihood of success of alternative livelihood strategies

DISCUSSION

The knowledge gaps and research priorities identified in both workshops highlight the need to establish research programs that acknowledge the integrated nature of fisheries, including multi-disciplinary approaches in research (a need also identified in Europe, Arlinghaus 2006), and addressing the requirements of location-specific stakeholders and sectors (e.g., balancing participation among different forms of tourism and fisheries). Indeed, workshop participants identified a greater number of sociological and economic knowledge gaps than biological knowledge gaps constraining mahseer conservation. The shared identified knowledge gaps indicate that there are opportunities to collaborate among states/regions to establish an evidence base for mahseer biology, ecology, and behaviour, in addition to opportunities for research studying the biological, social, and economic impacts of recreational (and other sector) fisheries. Both groups prioritized the research agenda items based on local issues and concerns (i.e., context mattered) and no individuals or groups disagreed with any included items. For example, both groups identified impacts of invasive species and hydropower development as knowledge gaps, but on prioritizing issues for the research agenda, participants in the Bannerghatta workshop prioritized invasive species concerns over hydropower development, while participants in the Byasi/Atali Ganga workshop prioritized issues arising from hydropower development over invasive species. Bannerghatta workshop participants were interested in partnering with management entities to explore enforcement options and alternatives in an already established fishery, while Byasi/AtaliGanga workshop participants identified community engagement and benefit-sharing as a priority management strategy to build the mahseer fishery. These differences in priority setting highlight the need for multi-scale approaches (i.e., national and state) to fisheries research and management. Shared knowledge gaps (including impacts to mahseer by invasive species, hydropower development, illegal fishing methods, and the use of mahseer as an umbrella species to promote freshwater conservation) could be studied at the national level, while adopting management strategies based on research outcomes may benefit from a state- or location-level focus. Regional-level differences in dominant mahseer species and ecology further support the need for multi-level mahseer research and management strategies. Recent research by Everard & Kataria (2011) and Gupta et al. (2014) suggests that the golden mahseer (*T. putitora*) may be useful as a flagship species for promoting freshwater conservation throughout the Himalayan rivers in Northern India, where this species is found (Nautiyal 2014). *Tor khudree*, while endangered in its native waters (IUCN 2015), has been artificially cultured and since the 1970's been periodically introduced to the Cauvery. This intended augmentation of the stock is now strongly suspected to have played a role in the decline of the yet to be described humpback mahseer endemic to the Cauvery River in the South (Pinder et al. 2015[a]). These nuances indicate that while priorities for mahseer research (as identified by workshop participants) may be similar, there will be a need for species-specific approaches in order to sufficiently address the identified knowledge gaps. The occurrence of mahseer species in different countries in Asia (e.g., *T. putitora*, Nguyen et al. 2008) suggests collaboration and cooperation may also be possible at the international level. Current research efforts examining the behavioural ecology of *T. putitora* in Bhutan (Claussen 2015) for example, could offer valuable insights for the same species in the Himalayan watershed across the border in India. Similarly, ongoing research efforts in India may be useful in supporting the development of research priorities for mahseer in other countries (e.g., in Malaysia, Nguyen 2008). As such, we suggest that international collaboration of mahseer researchers maybe beneficial for aligning goals and strategies to identify synergies in research priorities and opportunities for collaboration. The involvement of stakeholders in the research agenda development process was integral to identifying priority focal points that may have otherwise been missed, or possibly discounted. Through stakeholder participation, we were not only able to benefit from the varied perspectives and expertise of workshop participants, but incorporate regional and local priorities into goal setting in a manner that may not have been possible at a more formalized national meeting. It is essential to note that while we took care to invite individuals representing as many viewpoints as possible, a strong majority of the invitees viewed recreational fisheries positively, and none of the attendees were subsistence fishers, or members of migrant communities. As such, priorities of these communities may not be adequately represented in the respective research agendas (see Kothari 2001; Prell et al. 2008). The views of local communities and stakeholders vary among fisheries (for e.g., see Gupta et al. 2016). As such, we recommend that any future efforts to adopt research outcomes into management strategies include consultation with these stakeholder groups also. This workshop process is an example of the overall value of stakeholder engagement for addressing data deficiencies in global recreational fisheries. Stakeholder engagement affords the opportunity to gather many perspectives together, thereby bringing more information to the table through which to develop a knowledge base (Hartley & Robertson 2008; Reed et al. 2008). Many recreational fisheries around the world are data deficient, and many managing bodies may be constrained in supporting fisheries research by limited expertise and funding (Mahon 1997). Creative approaches will be essential in addressing deficiencies effectively as we move towards improving global fisheries management and conservation using best available science. Several tools have been developed and used as a way of addressing such data deficiencies in recreational fisheries to ensure that we are not 'managing blind' (rapid assessments, Bower et al. 2016[a,b], Lennox et al. 2015; species-specific C&R research, see examples in Cooke & Schramm 2007, Cooke & Suski 2005), but to date these approaches have heavily favoured the biological responses of species to fisheries processes. There continues to be a dearth of suitable tools available for rapidly and thoroughly incorporating sociological and economic considerations in fisheries research (Arlinghaus 2005), though strategies for incorporating adaptive management and co-management processes are increasing in other fields (e.g., see Armitage et al. 2008; Mackinson et al. 2011; Pomeroy & Douvere 2008). Using effective methods of stakeholder engagement can help researchers to address data deficiencies by allowing researchers to incorporate local knowledge into priority and goal setting, and better understand the socio-economic context of specific fisheries.

ACKNOWLEDGEMENTS

Bower is supported by the Ontario Graduate Scholarship Fund and Too Big to Ignore. Cooke is supported by the Canada Research Chairs Program and the Natural Sciences and Engineering Research Council of Canada. Danylchuk is supported by the National Institute of Food & Agriculture, U.S. Department of Agriculture, the Massachusetts Agricultural Experiment Station, Department of Environmental Conservation and the Whiting Foundation. Raghavan is supported by the Mohammed Bin Zayed Species Conservation Fund. Pinder is supported by the Mahseer Trust. All coordinators were supported by the Fisheries Society of the British Isles Small Research Grant Program with additional sponsorship received from Lotek and Smith Root. We appreciate logistic support provided by CWS, WASI and our many volunteer anglers, and permission for the study (through CWS) from Dr. Ramakrishna, Joint Director of Fisheries, Government of Karnataka. Special thanks go to Steve Lockett, Neethi Mahesh, Dr. Ambily Nair, Shyam Aiyappa, Aiyappa C.P., Dr. Dayan Mandappa, Sandeep Chakrabarti, Shine Sathvik, Naren Sreenivasan, Dr. A.J.T. JohnSingh, Dr. Sanjay Molur, Dr. Romulus Whitaker, Misty Dhillon and Suman Panwar. Thanks also go out to all of the individuals and organizations who participated in the workshops and shared their time and expertise.

REFERENCES

Abbot, J., Guijt, I., 1997. Changing Views on Change: A Working Paper on Participatory Monitoring of the Environment. International Institute for Environment and Development (IIED), London, UK, 96p.

Allen, W., Fenemor, A., Kilvington, M., Harmsworth, G., Young, R.G., Deans, N., Horn, C., Phillips, C., Montes de Oca, O., Ataria, J., Smith, R., 2011. Building collaboration and learning in integrated catchment management: the importance of social process and multiple engagement approaches. *N. Z. J. Mar. Freshwater Res*. 45 (3), 525–539.

Arlinghaus, R., Krause, J., 2013. Wisdom of the crowd and natural resource management. *Trends Ecol. Evol*. 28 (1), 8–11.

Arlinghaus, R., 2005. A conceptual framework to identify and understand conflicts in recreational fisheries systems, with implications for sustainable management. *Aquat. Resour. Cult. Dev*. 1 (2), 145–174.

Arlinghaus, R., 2006. Overcoming human obstacles to conservation of recreational fishery resources, with emphasis on central Europe. *Environ. Conserv*. 33 (01), 46–59.

Armitage, D.R., Plummer, R., Berkes, F., Arthur, R.I., Charles, A.T., Davidson-Hunt, I.J., Diduck, A.P., Doubleday, N.C., Johnson, D.S., Marschke, M., McConney, P., Pinkerton, E.W., Wollenberg, E.K., 2008. Adaptive co-management for social-ecological complexity. *Front. Ecol. Environ*. 7 (2), 95–102.

Bhatt, J.P., Pandit, M.K., 2016. Endangered Golden mahseer *Tor putitora* Hamilton: a review of natural history. *Rev. Fish Biol. Fish*. 26 (1), 25–38.

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. *Asian Fish. Sci*. 17, 341–355.

Bower, S.D., Danylchuk, A.J., Raghavan, R., Clark Danylchuk, S., Pinder, A., Cooke, S.J., 2016a. Rapid assessment of the physiological impacts caused bycatch-and-release angling on blue-finned mahseer (Tor sp.) of the Cauvery River, India. *Fish. Manage. Ecol.* (in press).

Bower, S.D., Danylchuk, A.J., Brownscombe, J.W., Thiem, J.D., Cooke, S.J., 2016b. Evaluating effects of catch-and-release angling on peacock bass (Cichlaocellaris) in a Puerto Rican reservoir: a rapid assessment approach. *Fish. Res.*175, 95–102.

Claussen, J., 2015. The Bhutan telemetry project: tracking golden mahaseer in the Manas watershed. In: In 145th Annual Meeting of the American Fisheries Society, AFS, Bethesda, Maryland, USA, August.

Cooke, S.J., Schramm, H.L., 2007. Catch-and-release science and its application to conservation and management of recreational fisheries. *Fish. Manage. Ecol*. 14(2), 73–79.

Cooke, S.J., Suski, C.D., 2005. Do we need species-specific guidelines for catch-and-release recreational angling to effectively conserve diverse fishery resources? *Biodivers. Conserv*. 14 (5), 1195–1209.

Cowx, I.G., Arlinghaus, R., Cooke, S.J., 2010. Harmonizing recreational fisheries and conservation objectives for aquatic biodiversity in inland waters. *J. Fish Biol*. 76(9), 2194–2215.

Danylchuk, A.J., Cooke, S.J., 2011. Engaging the recreational angling community to implement and manage aquatic protected areas. *Conserv. Biol.* 25 (3), 458–464.

Everard, M., Kataria, G., 2011. Recreational angling markets to advance the conservation of a reach of the Western Ramganga River, India. *Aquat. Conserv. Mar. Freshwater Ecosyst.* 21 (1), 101–108.

Feeney, R.G., La Valley, K.J., Hall-Arber, M., 2010. Assessing stakeholder perspectives on the impacts of a decade of collaborative fisheries research in the Gulf of Maine and Georges Bank. *Mar. Coastal Fish*. 2 (1), 205–216.

Granek, E.F., Madin, E.M., Brown, M.A., Figueira, W., Cameron, D.S., Hogan, Z., Kristianson, G., De Villiers, P., Williams, J.E., Zahn, S., Arlinghaus, R., 2008. Engaging recreational fishers in management and conservation: global case studies. *Cons. Biol*. 22 (5), 1125–1134.

Gupta, N., Sivakumar, K., Mathur, V.B., Chadwick, M.A., 2014. The ‘tiger of Indian rivers’: stakeholders’ perspectives on the golden mahseer as a flagship fish species. *Area* 46 (4), 389–397.

Gupta, N., Nautiyal, P., Borgohain, A., Sivakumar, K., Mathur, V.B., Chadwick, M.A., 2016. Catch-and-release angling as a management tool for freshwater fish conservation in India. *Oryx* 50 (2), 250–256, http://dx.doi.org/10.1017/S0030605314000787.

Gupta, N., Raghavan, R., Sivakumar, K., Mathur, V., Pinder, A.C., 2015a. Assessing recreational fisheries in an emerging economy: knowledge, perceptions and attitudes of catch-and-release anglers in India. *Fish. Res.* 165, 79–84.

Gupta, N., Bower, S.D., Raghavan, R., Danylchuk, A.J., Cooke, S.J., 2015b. Status of recreational fisheries in India: development, issues and opportunities. *Rev. Fish. Sci. Aquacult.* 23 (3), 291–301.

Hartley, T.W., Robertson, R.A., 2006. Stakeholder engagement, cooperative fisheries research and democratic science: the case of the Northeast Consortium. *Hum. Ecol. Rev*. 13 (2), 161.

Hartley, T.W., Robertson, R.A., 2008. Stakeholder collaboration in fisheries research: integrating knowledge among fishing leaders and science partners in northern New England. *Soc. Nat. Resour*. 22 (1), 42–55.

IUCN, 2015. The IUCN Red List of Threatened Species. Version 2015-4. <http://www.iucnredlist.org> [Accessed: Nov 2015].

Jentoft, S., Chuenpagdee, R., 2009. Fisheries and coastal governance as a wicked problem. *Mar. Policy* 33 (4), 553–560.

Koontz, T.M., Thomas, C.W., 2006. What do we know and need to know about the environmental outcomes of collaborative management. *Public Adm. Rev*.,111–121.

Kothari, U., 2001. Power, knowledge and social control in participatory development. In: Kothari, U., Cooke, B. (Eds.), Participation: The New Tyranny? Zed Books, London, UK, pp. 139–152.

Lennox, R.J., Brownscombe, J.W., Cooke, S.J., Danylchuk, A.J., Moro, P.S., Sanches,E.A., Garrone-Neto, D., 2015. Evaluation of catch-and-release angling practices for the fat snook Centropomus parallelus in a Brazilian estuary. *Ocean Coastal Manage*. 113, 1–7.

Mackinson, S., Wilson, D.C., Galiay, P., Deas, B., 2011. Engaging stakeholders in fisheries and marine research. *Mar. Policy* 35 (1), 18–24.

Mahon, R., 1997. Does fisheries science serve the needs of managers of small stocks in developing countries. *Can. J. Fish. Aquat. Sci*. 54 (9), 2207–2213.

Mora, C., Myers, R.A., Coll, M., Libralato, S., Pitcher, T., Sumaila, R., Zeller, D., Watson, R., Gaston, K.J., Worm, B., 2009. Management effectiveness of the world's marine resources. *PLoS Biol*. 7 (6), e1000131.

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.

Nautiyal, P., 2014. Review of the art and science of Indian mahseer (Game fish) from nineteenth to twentieth century: road to extinction or conservation? *Proc. Natl. Acad. Sci. India Sect. B: Biol. Sci.* 84 (2), 215–236.

Nguyen, T.T., 2008. Population structure in the highly fragmented range of *Tor douronensis* (Cyprinidae) in Sarawak, Malaysia revealed by microsatellite DNA markers. *Freshwater Biology* 53 (5), 924–934.

Nguyen, T.T., Na-Nakorn, U., Sukmanomon, S., ZiMing, C., 2008. A study on phylogeny and biogeography of mahseer species (Pisces: Cyprinidae) using sequences of three mitochondrial DNA gene regions. *Mol. Phylogenet. Evol*. 48(3), 1223–1231.

Pinder, A.C., Raghavan, R., 2013. Conserving the endangered Mahseers (Tor spp.) of India: the positive role of recreational fisheries. *Curr. Sci*. 104 (11), 1472–1475.

Pinder, A.C., Raghavan, R., Britton, J.R., 2015a. The legendary hump-backed mahseer Tor sp. of India's River Cauvery: an endemic fish swimming towards extinction? *Endanger. Species Res*. 28, 11–17.

Pinder, A.C., Raghavan, R., Britton, J.R., 2015b. Efficacy of angler catch data as a population and conservation monitoring tool for the flagship

Mahseer fishes (Tor spp.) of Southern India. A*quat. Conserv. Mar. Freshwater Ecosyst.* 25 (6),829–838.

Pomeroy, R., Douvere, F., 2008. The engagement of stakeholders in the marine spatial planning process. *Mar. Policy* 32 (5), 816–822.

Prell, C., Hubacek, K., Quinn, C., Reed, M., 2008. 'Who's in the network?' When stakeholders influence data analysis. *Syst. Pract. Action Res*. 21 (6), 443–458.

Reed, M.S., Fraser, E.D., Dougill, A.J., 2006. An adaptive learning process for developing and applying sustainability indicators with local communities. *Ecol. Econ*. 59 (4), 406–418.

Reed, M.S., Dougill, A.J., Baker, T.R., 2008. Participatory indicator development: what can ecologists and local communities learn from each other. *Ecol. Appl*.18 (5), 1253–1269.

Reed, M.S., 2008. Stakeholder participation for environmental management: a literature review. *Biol. Conserv*. 141 (10), 2417–2431.

Sehgal, K., 1999. Coldwater fish and fisheries in the Western Ghats, India. In: Petr, T. (Ed.), Fish and Fisheries at Higher Altitudes: Asia. FAO, Rome, pp. 41–64 (FAO Fisheries Technical Paper 385).

Sloan, P., 2009. Redefining stakeholder engagement. *J. Corp. Citizsh*. 2009 (36), 25–40.

Smith, J.W., Leahy, J.E., Anderson, D.H., Davenport, M.A., 2013. Community/agency trust and public involvement in resource planning. *Soc. Nat. Resour*. 26 (4),452–471.

Steyaert, P., Barzman, M., Billaud, J.P., Brives, H., Hubert, B., Ollivier, G., Roche, B., 2007. The role of knowledge and research in facilitating social learning among stakeholders in natural resources management in the French Atlantic coastal wetlands. *Environ. Sci. Policy* 10 (6), 537–550.

Tufts, B.L., Holden, J., DeMille, M., 2015. Benefits arising from sustainable use of North America's fishery resources: economic and conservation impacts of recreational angling. *Int. J. Environ. Stud*. 72 (5), 850–868.

WWF-India, 2013. Mahseer Conservation in India: Status, Challenges and the Way Forward. In: Nautiyal, P., Babu, S., Behera, S. (Eds.). WWF-India, New Delhi,India, 38p.

Yochum, N., Starr, R.M., Wendt, D.E., 2011. Utilizing fishermen knowledge and expertise: keys to success for collaborative fisheries research. *Fisheries* 36 (12), 593–605.

CHAPTER 6: EXPLORING THE VALUE OF ANGLER LOG BOOKS

6.1 Prelude to Submissions 4 and 5

Pinder, A. C., Raghavan, R., & Britton, J. R., 2015. Efficacy of angler catch data as a population and conservation monitoring tool for the flagship Mahseer fishes (Tor spp.) of Southern India. *Aquatic Conservation: Marine and Freshwater Ecosystems* 25, 829-838.

Pinder, A. C., Raghavan, R., & Britton, J. R., 2015. The legendary hump-backed mahseer Tor sp. of India's River Cauvery: an endemic fish swimming towards extinction? *Endangered Species Research* 28, 11-17.

The effective assessment of fish populations in large river systems presents researchers with multiple challenges (Casselman et al. 1990). These challenges become considerably magnified in tropical monsoonal systems where high flows, deep water and high habitat heterogeneity combine to preclude the use of conventional scientific sampling gears (i.e. fishery independent monitoring tools such as netting and electric fishing). Consider further, the large potential body size (50 kg +) of mahseers, the remoteness of the rivers which support them and the wildlife associated with these jungle environs, then it is perhaps not surprising that the combination of poor sampling efficacy and potential dangers to operatives mean that, to date, there is not a single example of a robust 'fishery-independent' assessment of mahseer population abundance across the entire genus *Tor* and its biogeographic range. This is indeed in fitting with the discussions of Cooke et al. (2012) which highlighted that sampling difficulties represent a key factor in constraining a general lack of information on the abundance, assemblages and trends in endangered riverine fish species and their conservation.

In addition to the widespread use of commercial fisheries data to monitor and manage fisheries resources in both marine and freshwater environments, temporal and spatial records of angler catch-per-unit-effort (CPUE) have also been widely applied as proxies for fish population densities (e.g. Jansen et al. 2013). Due to a broad range of potentially influencing factors (e.g. abiotic environmental changes, evolution of fishing gears and fashions, changing fish community structure, inconsistencies in record keeping and self-bias), there is widespread recognition that angler derived data need to be interpreted with caution (Cooke et al. 2000; Dorrow & Arlinghaus 2011). Despite the challenges involved in accounting for bias, angler log books have been used extensively to provide information on catch and harvest rates (Cooke et al. 2000, 2018), assess inter-annual recruitment success (Lehtonen et al. 2009), elucidate temporal shifts in body size and migration timings (Quinn et al. 2006), evaluate stocking success (Champigneulle & Cachera 2003) and inform conservation management planning (Environment Agency 2018). Hence, there is a general consensus amongst researchers that in the absence of fishery independent data, angler records can provide a valuable and cost-effective sampling alternative for indexing long-term trends in the relative abundance and population dynamics of target species (Sztramko et al. 1991).

It was during my first trips to South India's River Cauvery as an angler in 2010 and 2011 that I became aware of the detailed catch records compiled by the head angling guide and subsequently realised the potential value of these records (see Figure 6.1.1). Motivated by the recent ban on angling within this section of river (see Chapter 4), I was keen to explore the response of the mahseer population to the C&R management regime and to raise awareness, specifically with policy makers, that the recreational angling community had previously contributed a much needed scientific monitoring service in the absence of any other fisheries data within one of the major river systems of the western Ghats biodiversity hotspot.

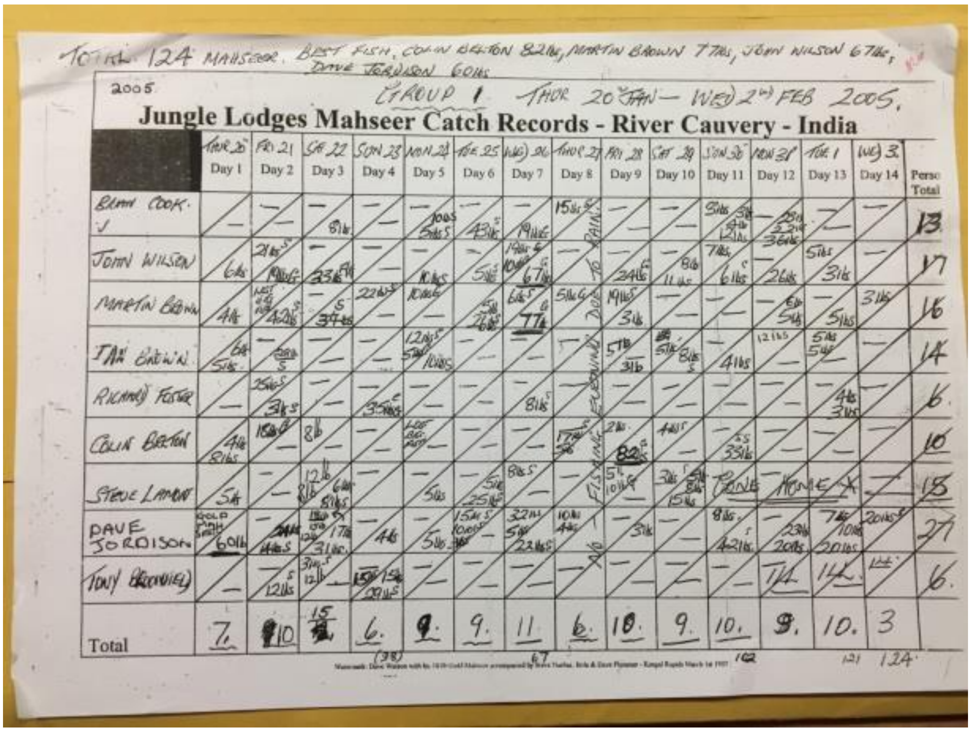


Figure 6.1.1. An example of one of the catch record sheets kept by the head angling guide at Galibore Fishing Camp and used to inform Submisisons 4 and 5.

In considering the broad range of potential biases in angler logs, many of these concerns were reduced by the consistent method of record collation and recording coordinated by the head angling guide. Consistency in angling methods was also evident, with the dominant use of large cereal paste baits not seeming to bias the size of captures and producing mahseer ranging between one and over 100 lbs in weight. Despite the availability of earlier catch returns, dating back to 1974, the style of record keeping shown in Figure 6.1.1, was only available from 1998 to 2012, thus providing the 15 year dataset used to produce Submission 4 (Section 6.2) and conclude the positive role of the C&R fishery on the mahseer population.

During the production of Submission 4, the same dataset revealed the potential to examine trends in the relative abundance of the two mahseer phenotypes (later to be confirmed as different species) which had been apparent since my first evening on the River Cauvery (see Section My introduction to India and the mahseer). Isolating these two species and revisiting the CPUE analysis was the basis of Submission 5 (Section 6.3), which revealed a comprehensive shift in the community structure of the two species resulting in the rapid expansion of the blue-finned mahseer. This was coincident with a substantial decline in the hump-backed mahseer. This posed new questions regarding which species was endemic to the River Cauvery: a question which was resolved by investigating previous stocking records. This parallel investigation revealed that Tata Electric Company (TEC) had donated large numbers (> 10,000) of blue-finned mahseer fingerlings to the Wildlife Association of South India (WASI). These fingerlings had been produced at Tata's Lonavla hatchery in Maharashtra and been stocked into the WASI controlled angling sections of the River Cauvery since 1976 (Wildlife, 1976) (Figure 6.1.2).

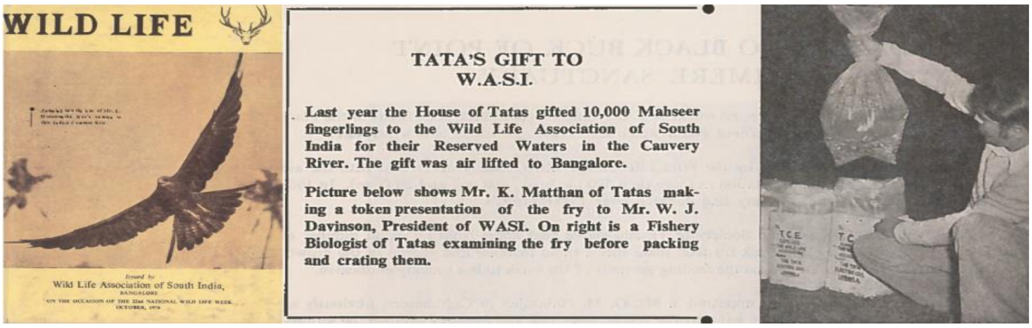


Figure 6.1.2. The earliest record of stocking I was able to find was in in the Wildlife Association of South India's (WASI) annual journal WILD LIFE, published in 1976 (left). This details the source, recipient site and numbers of mahseer stocked (right).

This led me to a number of publications published by employees of TEC which confirmed the identity of the stocked fish as *Tor khudree*. Brood fish of this species had been procured from the River Krishna River Basin and, by 2002, hatchery produced fingerlings had been stocked to waters in the majority of states in India, and even shipped outside India to Laos (Ogale 2002). As anglers had been photographing their mahseer catches on the Cauvery over many decades, I was able to recover many hundreds of photographs dating back to as early as 1919. Combining these data with interview feedback from domestic and international anglers, including the surviving members of the Trans World Fishing Team, who were the first foreigners to fish the Cauvery since independence (TWFT 1985), revealed that *T. khudree* did not feature in angler catches until 1993. This provided corroborating evidence that the hump-backed mahseer was endemic to the Cauvery and *T. khudree* was an introduced non-indigenous species that had become invasive and was potentially involved in the process driving the hump-backed mahseer to the edge of extinction.

The publication of Submission 5 resulted in high coverage in the popular press, including in India. This resulted in the invited production and publication of another popular article which summarised this situation in Sanctuary Asia (Pinder 2015). This article attracted the attention of Tata Power and initially resulted in some conflicts between us. However, these were resolved through a number of meetings and the eventual launch of a Tata funded collaborative effort to save the hump-backed mahseer from extinction. However, until the publication of Submission 8 (See Chapter 8), conservation efforts were constrained due to the hump-backed mahseer lacking a scientific name and thus preventing its qualification for global conservation assessments, such as the IUCN Red List of Threatened Species (IUCN 2019).

6.1.1 **References**

Casselman, J.M., Penczak, T., Carl, L., Mann, R.H.K., Holcik, J. & Woitowich, W.A., 1990. An evaluation of fish sampling methodologies for large river systems. *Pol. Arch. Hydrobiol* 37(4), 521-551.

Champigneulle, A., & Cachera, S., 2003. Evaluation of large-scale stocking of early stages of brown trout, Salmo trutta, to angler catches in the French–Swiss part of the River Doubs. *Fisheries Management and Ecology* 10(2), 79-85.

Cooke, S.J., Dunlop, W.I., Macclennan, D., & Power, G., 2000. Applications and characteristics of angler diary programmes in Ontario, Canada. *Fisheries Management and Ecology* 7(6), 473-487.

Cooke, S.J., Paukert, C., & Hogan, Z., 2012. Endangered river fish: factors hindering conservation and restoration. *Endangered Species Research* 17(2), 179-191.

Cooke, S.J., Twardek, W.M., Lennox, R.J., Zolderdo, A.J., Bower, S.D., Gutowsky, L.F., Danylchuk, A., Arlinghaus, R. & Beard, D., 2018. The nexus of fun and nutrition: Recreational fishing is also about food. *Fish and Fisheries* 19(2), 201-224.

Dorow, M., & Arlinghaus, R., 2011. A telephone-diary-mail approach to survey recreational fisheries on large geographic scales, with a note on annual landings estimates by anglers in northern Germany. In *American Fisheries Society Symposium* (Vol. 75, No. 1, p. 13).

Environment Agency, 2018. Salmonid and Freshwater Fisheries Statistics for England and Wales, 2017. Environment Agency, Bristol, 37pp.

IUCN, 2019. The IUCN Red List of Threatened Species. Version 2019-1. https://www.iucnredlist.org/ [Accessed May 2019].

Jansen, T., Arlinghaus, R., Als, T.D., & Skov, C., 2013. Voluntary angler logbooks reveal long-term changes in a lentic pike, E sox lucius, population. *Fisheries Management and Ecology* 20(2-3), 125-136.

Lehtonen, H., Leskinen, E., Selén, R., & Reinikainen, M., 2009. Potential reasons for the changes in the abundance of pike, Esox lucius, in the western Gulf of Finland, 1939–2007. *Fisheries Management and Ecology* 16(6), 484-491.

Ogale, S.N, 2002. Mahseer breeding and conservation and possibilities of commercial culture. The Indian experience. In: Cold water fisheries in the trans-Himalayan countries. FAO Fisheries Technical Paper 431:193–212.

Pinder, A.C., 2015. Icon of the Cauvery. *Sanctuary Asia*, October 2015:50–53.

Quinn, T.P., McGinnity, P., & Cross, T.F., 2006. Long-term declines in body size and shifts in run timing of Atlantic salmon in Ireland. *Journal of Fish Biology* 68(6), 1713-1730.

Sztramko, L.K., Dunlop, W.I., Powell, S.W., & Sutherland, R.G., 1991. Applications and benefits of an angler diary program on Lake Erie. In *D. Guthrie, JM Hoenig, M. Holliday, CM Jones, MJ Mills, SA Moberly, KH Pollock, and DR Talhelm, editiors. Creel and angler surveys in fisheries management. American Fisheries Society, Symposium* (Vol. 12, pp. 520-520).

Trans World Fishing Team, 1984. *Quest for a legendary fish*. International Book Distributors: Dehra Dun.

Wildlife, 1977. The monsters of Karnataka. W*ildlife Journal of the Wildlife Association of South India (WASI)*1977: 1–8.

6.2 Submission 4

AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS, VOL. 25, 829-838 (2015)

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

Adrian C. Pinder [a,b], Rajeev Raghavan [c,d], J. Robert Britton [b]

[a]Mahseer Trust, c/o The Freshwater Biological Association, East Stoke River Laboratory, Wareham, Dorset, BH20 6BB, UK

[b]Faculty of Science and Technology, Bournemouth University, Fern Barrow, Poole, Dorset, BH12 5BB, UK

[c]Conservation Research Group (CRG), St Albert's College, Kochi, Kerala, 682 018, Kerala, India

[d]Laboratory of Systematics, Ecology and Conservation, Zoo Outreach Organization (ZOO), Coimbatore, 641 035, Tamil Nadu, India

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 & 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 & 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 & Raghavan 2013). For example, there are no population estimates available for the endangered species *T. khudree* and *T. malabaricus* (Raghavan 2011; Raghavan & 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 & Kataria 2011; Pinder & 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 & Kataria 2011; Pinder & 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 (Figure 6.2.1).

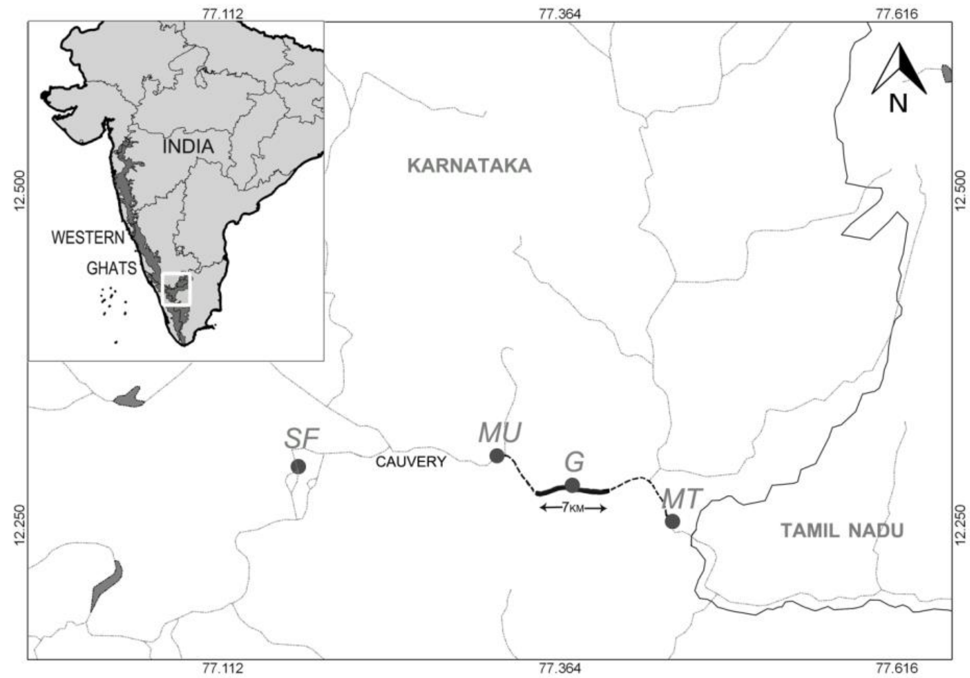


Figure 6.2.1. Location of the River Cauvery and the study area. Solid line represents the 7 km Galibore fishery. The dashed line represents the 22 km

C&R fishery formerly controlled by WASI. Locations are coded: SF: Shivasamudram Falls, MU: Mutthattii, G: Galibore, MT: Mekedatu.

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 (Figure 6.2.1). 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 & 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 6.2.1.

Table 6.2.1. 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.
Year	Jan	Feb	March	Anglers	hours 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

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 (Figure 6.2.2). 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; $P < 0.01$; Figure 6.2.3). There were, however, no significant differences in the mean adjusted catch per unit effort by weight per year ($P > 0.05$; Figure 6.2.3).

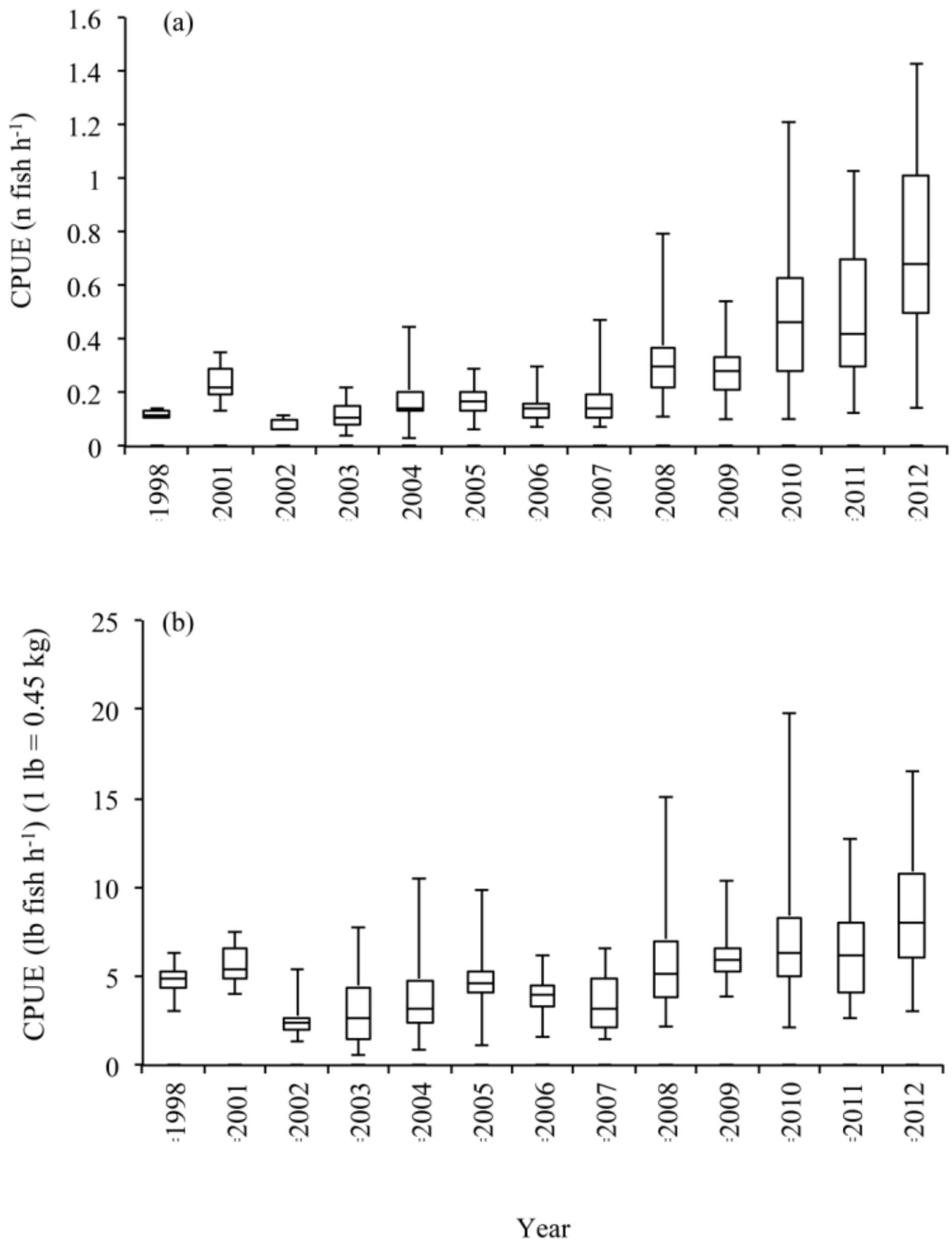


Figure 6.2.2. Box plot of year versus catch per unit effort (CPUE) of: *a*: number of fish per angler per hour, and *b*: weight (lbs) of fish per angler per hour, where the median, 25th and 75th percentile, and 10th and 90th percentile are displayed.

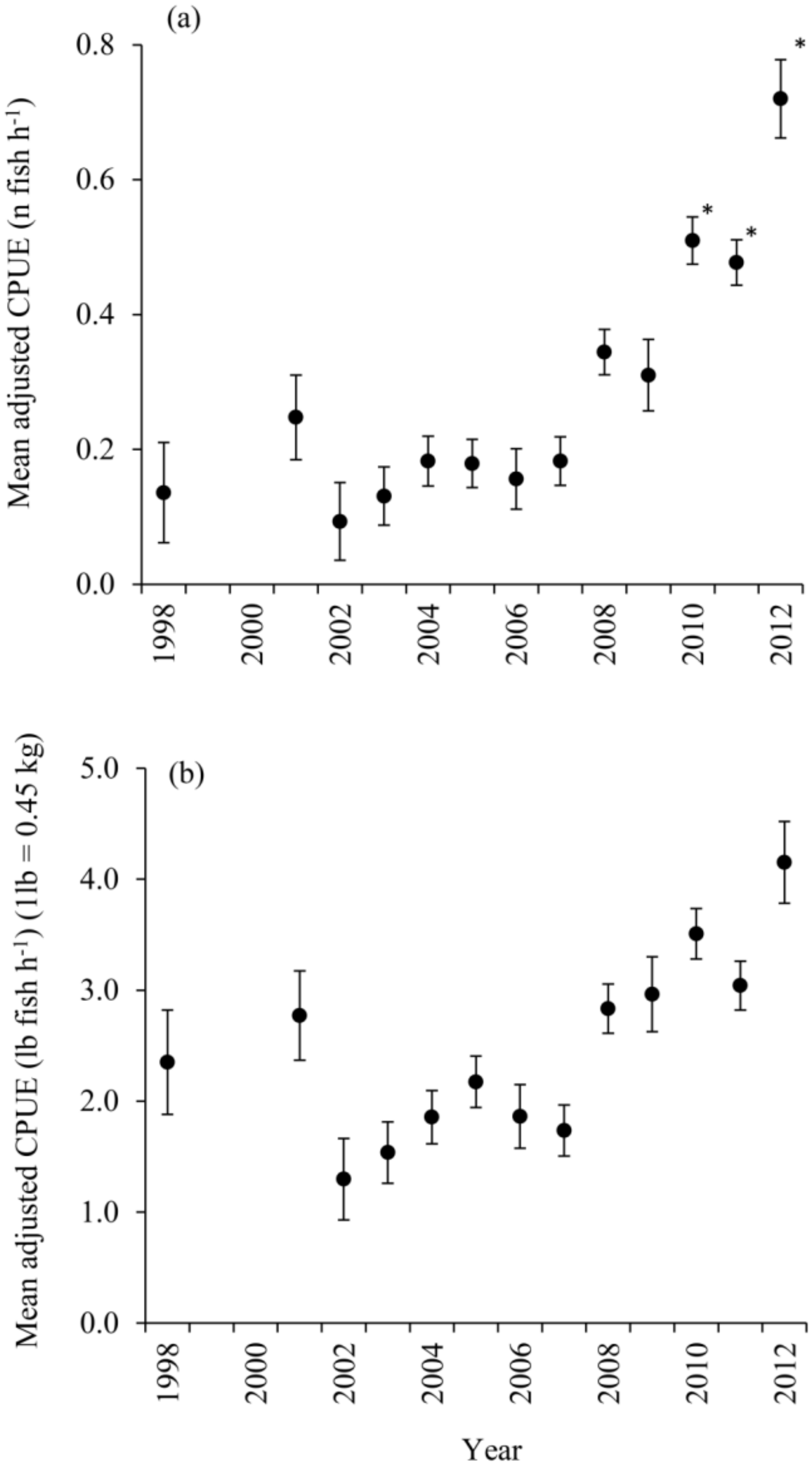


Figure 6.2.3. Mean adjusted catch per unit effort by number (*a*) and weight (*b*) by year, where the random effects of individual anglers in the data set have been accounted for in the model. * = Difference in catch per unit effort is significantly different from the highest value recorded in the early 2000s ($P < 0.01$). Error bars represent standard error.

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 ($P < 0.05$; Figure 6.2.4).

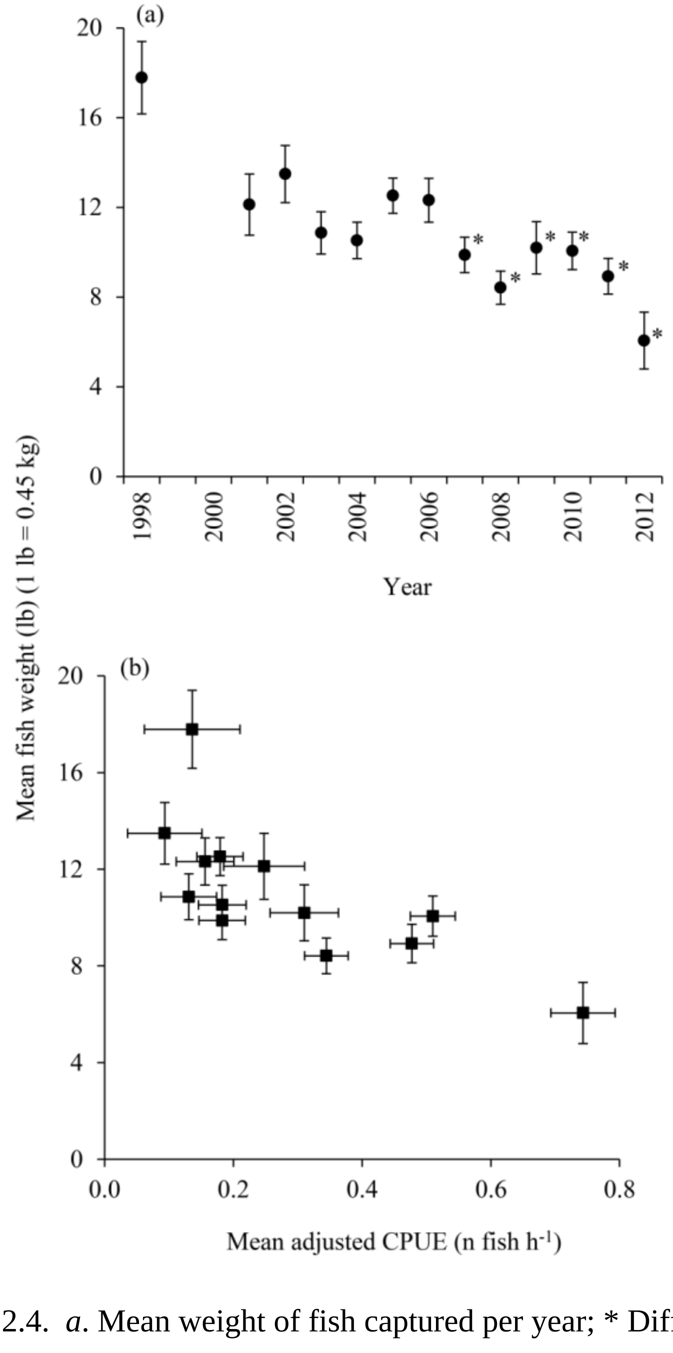


Figure 6.2.4. *a*. Mean weight of fish captured per year; * Difference in mean weight significantly different from highest values in the early 2000s (P < 0.01). *b*: Relationship of mean adjusted catch per unit effort per year and the mean weight of fish captured in that year. In all cases, error bars represent standard error.

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: $R^2 = 0.83$, $F_{1,11} = 22.93$, $P < 0.01$; Figure 6.2.4). 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: $R^2 = 0.82$, $F_{1,10} = 18.81$, $P < 0.01$; Figure 6.2.5), 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: $R^2 = 0.57$, $F_{1,10} = 0.57$, $P = 0.47$; Figure 6.2.5).

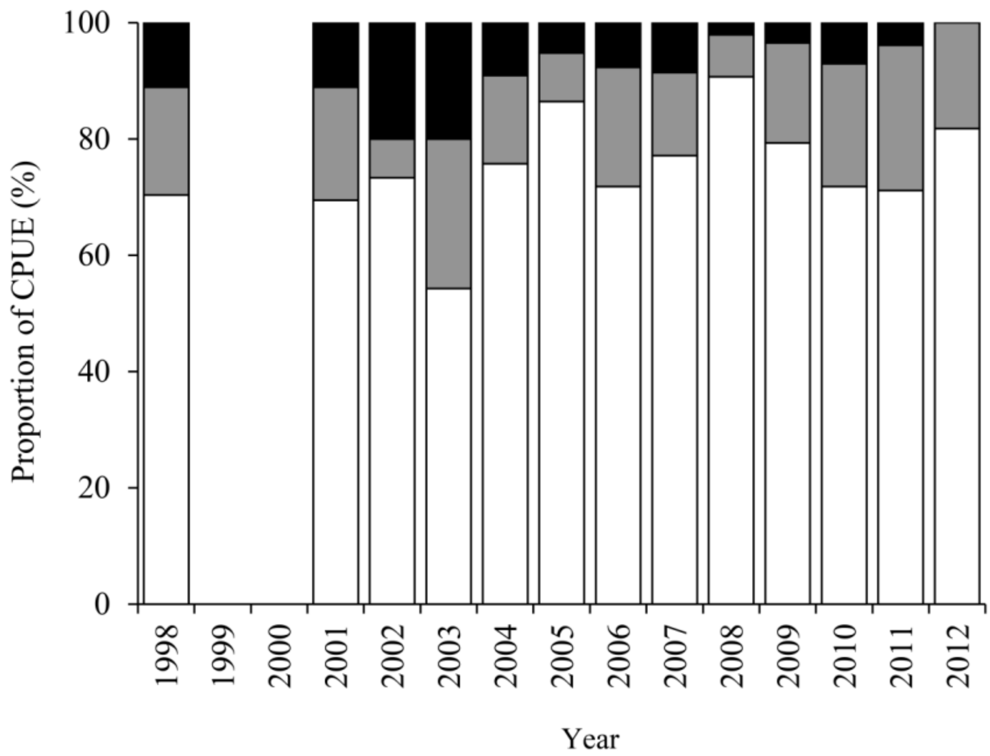


Figure 6.2.5. Plot of proportion of weight class of fish to total catch per unit effort by number according to year, where white boxes = 20 to 39 lbs, grey = 40 to 59 lbs, and black = > 60 lbs (1 lb = 0.45 kg).

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 & 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 & 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 & Milner 1980) and white sturgeon *Acipenser transmontanus* (Inglis & 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 & 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 & 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 & 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 & 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 & 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 & 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 Figure 6.2.1). 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.

ACKNOWLEDGEMENTS

The authors wish to thank Sportquest Holidays Ltd, D. Plummer and M. Brown for the provision of catch records. Maps and historical insight to the fishery were provided by S. Chakrabarti and S. Raj. We are also grateful to A. Kanagavel for assisting in the production of Figure 1. This research was supported by the Mahseer Trust.

REFERENCES

Arce-Ibarra, 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. *Fisheries Research* 91, 151–159.

Arlinghaus, R., 2006. Overcoming human obstacles to conservation of recreational fishery resources, with emphasis on central Europe. *Environmental Conservation* 33, 46–59.

Barillier, A., Garnier, J., & Coste, M., 1993. Experimental reservoir water release: Impact on the water quality on a river 60 km downstream (upper Seine river, France). *Water Research* 27, 635-643.

Bene, C., Abban, E.K., 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*. WorldFish Center Technical Manual. Penang; Malaysia, WorldFish Center.

Carrizo, S.F., Smith, K.G., & Darwall, W.R.T., 2013. Progress towards a global assessment of the status of freshwater fishes (Pisces) for the IUCN Red List: application to conservation programmes in zoos and aquariums. *International Zoo Yearbook* 47, 46–64.

Cooke, S.J., Paukert, C., & Hogan, Z., 2012. Endangered river fish: factors hindering conservation and restoration. *Endangered Species Research* 17, 171-191.

Cooke, S.J., Hogan, Z.S., Butcher, P.A., Stokesbury, M.J.W., Raghavan, R., Gallagher, A.J., Hammerschlag, N., & Danylchuk, A.J. in press. Angling for endangered fish: conservation problem or conservation action? *Fish and Fisheries*. doi: 10.1111/faf.12076

Cowx, I.G., 1991. *Catch Effort sampling Strategies: their application in freshwater fisheries management*. Fishing News Books, Blackwell, Oxford. 420pp.

de Graaf, G., Bartley, D., Jorgensen, J., Marmulla, G., in press. The scale of inland fisheries, can we do better? Alternative approaches for assessment. *Fisheries Management and Ecology*. doi: 10.1111/j.1365-2400.2011.00844.x

De Silva, S.S., Abery, N.W., & Nguyen, T.T.T., 2007. Endemic freshwater finfish of Asia: distribution and conservation status. *Diversity and Distributions* 13, 172-184.

Dhillon, M., 2004. The mahseer of India Himalayas. *Rackelhanen Flyfishing Magazine*. Available at: www.rackelhanen.se/eng/10273.htm [Accessed: April 2014].

Dhu, S., 1923. *The angler in India or the mighty mahseer*. Natraj Publishers: Dehra Dun.

Drenner, R.W., Gallo, K.L., Edwards, C.M., Rieger, K.E., & Dibble, E.D., 1997. Common carp affect turbidity and angler catch rates of largemouth bass in ponds. *North American Journal of Fisheries Management* 17, 1010-1013.

Everard, M., Kataria, G., 2011. Recreational angling markets to advance the conservation of a reach of the Western Ramganga River, India. *Aquatic Consevation: Marine and Freshwater Ecosystems* 21, 101-108.

Everard, M., 2013. Safeguarding the provision of ecosystem services in catchment systems. *Integrated Environmental Assessment and Management* 9, 252–259.

Eschmeyer, W.N. (ed)., 2014. Catalog of Fishes. http://research.calacademy.org/research/ichthyology/catalog/fishcatmain.asp [Accessed: April 2014].

Gee, A.S., & Milner, N.J., 1980. Analysis of 70-year catch statistics for Atlantic salmon *Salmo salar* in the River Wye and implications for management of stocks. *Journal of Applied Ecology* 17, 41-57.

Granek, E.F., Madin, E.M.P., Brown, M.A., Figueira, W., Cameron, D.S., Hogan, Z., Kristianson, G., De Villiers, P., Williams, J.E., Post, J., Zahn, S,. & Arlinghaus, R., 2008. Engaging recreational fishers in management and conservation: global case studies. *Conservation biology* 22, 1125–34.

Inglis, S.D., & Rosenau, M.L., 1994. Non-tidal sturgeon angler fishery of the lower Fraser River – angler card analysis. Ministry of Environment, Lands and Parks Regional Fisheries Report No. 241, Surrey, BC.

IUCN, 2013. IUCN Red List of Threatened Species. Version 2013.2. www.iucnredlist.org [Accessed: April 2014].

Jensen, O.P., Gilroy, D.J., Hogan, Z., Allen, B.C., Hrabikm, T.R., Weidel, BC., & Vander Zanden, M.J., 2009. Evaluating recreational fisheries for an endangered species: a case study of taimen, *Hucho taimen*, in Mongolia. *Canadian Journal of Fisheries and Aquatic Sciences* 66, 1707-1718.

Knight, J.D., Rai, A., & D'Souza, R.K.P., 2013. On the identities of *Barbus mussullah* Sykes and *Cyprinus curmuca* Hamilton with notes on the status of *Gobio canarensis* Jerdon (Teleostei: Cyprinidae). *Zootaxa* 3750, 201-215.

Kottelat, M., 2013. The fishes of the inland waters of southeast Asia: a catalogue and core bibiography of the fishes known to occur in freshwaters, mangroves and estuaries. *The Raffles Bulletin of Zoology* Supplement No. 27, 1-663.

Langer, R.K., Ogale, S.N., & Ayyappan, S., 2001. *Mahseer in Indian Subcontinent-a Bibliography*. Central Institute of Fisheries Education (CIFE), Mumbai, India, 109pp.

Lehtonen, H., Leskinen, E., Sele´, N.R., & Reinikainen, M., 2009. Potential reasons for the changes in the abundance of pike, *Esox lucius*, in the western Gulf of Finland, 1939–2007. *Fisheries Management and Ecology* 16, 484–491.

MacDonald, A.S.J., 1948. *Circumventing the Mahseer*. Natraj Publishers: Dehra Dun.

Mahon, R., 1997. Does fisheries science serve the needs of managers of small stocks in developing countries. *Canadian Journal of Fisheries and Aquatic Sciences* 54, 2207-2213.

McMichael, G.A., & Kaya, C.M., 1991. Relations among stream temperature, angling success for rainbow trout and brown trout, and fisherman satisfaction. *North American Journal of Fisheries Management* 11, 190-199.

Mezzera, M., & Largiadèr, C.R., 2001. Evidence for selective angling of introduced trout and their hybrids in a stocked brown trout population. *Journal of Fish Biology* 59, 287–301.

Molur, S., Smith, K.G., Daniel, B.A., & Darwall, W.R.T. (compilers)., 2011. *The status of freshwater biodiversity in the Western Ghats*. International Union for Conservation of Nature (IUCN) Gland, Switzerland, & Zoo Outreach Organization (ZOO) Coimbatore, India, 116p

Nair, S., 2010. Karnataka, *Where the Mahseer is Safe*. Available at: www.deccanherald.com/content/77977/where-mahseer-safe.html. [Accessed: April 2014].

Nguyen, T.T.T., Na-Nakorn, U., Sukmanomon, S., & Ziming, C., 2008. A study on phylogeny and biogeography of mahseer species (Pisces: Cyprinidae) using sequences of three mitochondrial DNA gene regions. *Molecular Phylogenetics and Evolution* 48, 1223-1231.

North, E., & Hickley, P., 1977. The effects of reservoir releases upon angling success in the River Severn. *Aquaculture Research* 8, 86-91.

North E. 1980. The effects of water temperature and flow upon angling success in the River Severn. *Aquaculture Research* **11**: 1–9.

Pinder, A.C., & Raghavan, R., 2013. Conserving the endangered mahseers (Tor spp.) of India: the positive role of recreational fisheries. *Current Science* 104,1472–1475.

Pinder, A.C., 2013. Conserving the mighty mahseer of South India. *FISH magazine* 111, 24-28.

Raghavan, R., Ali, A., Dahanukar, N., & Rosser, A., 2011. Is the Deccan Mahseer, *Tor khudree* (Sykes, 1839) (Pisces: Cyprinidae) fishery in the Western Ghats Hotspot sustainable? A participatory approach to stock assessment. *Fisheries Research* 110, 29-38.

Raghavan, R., 2011. *Tor khudree*. In: IUCN 2013. IUCN Red List of Threatened Species. Version 2013.2. <www.iucnredlist.org>. [Accessed: April 2014].

Raghavan, R., & Ali, A., 2011. *Tor malabaricus*. In: IUCN 2013. IUCN Red List of Threatened Species. Version 2013.2. <www.iucnredlist.org>. [Accessed: April 2014].

Reichard, M., Jurajda. P., & Smith, C., 2004. Spatial distribution of drifting cyprinid fishes in a shallow lowland river. *Archiv für Hydrobiologie* 159, 395-407.

Reid, G.M., MacBeath, T.C., & Csatadi, K., 2013. Global challenges in freshwater-fish conservation related to public aquariums and the aquarium industry. *International Zoo Yearbook* 47, 6–45.

Robinson, A.T., Clarkson, R.W., & Forrest, R.E., 1998. Dispersal of larval fishes in a regulated river tributary. *Transactions of the American Fisheries Society* 127, 772-786.

Singh, D., & Sharma, R.C., 1998. Biodiversity, ecological status and conservation priority of the fish of the River Alaknanda, a parent stream of the River Ganges (India). *Aquatic Conservation: Marine and Freshwater Ecosystems* 8, 761-772.

Siraj, S.S., Christianus, A., Kiat, N.C., & de Silva, S.S. (eds)., 2007. *Mahseer, the biology, culture and conservation*: Proceedings of the International Symposium on the Mahseer, 29–30 March 2006, Kuala Lumpur, Malaysia. Malaysian Fisheries Society, Serdang, Malaysia.

Thomas, H.S., 1873. *The rod in India*. 8vo: Mangalore.

Trans World Fishing Team, 1984. *Quest for a legendary fish*. International Book Distributors: Dehra Dun.

Ussi-Heikkila, S., Wolter, C., Klefoth, T., & Arlinghaus, R., 2008. A behavioural perspective on fishing-induced evolution. *Trends in Ecology and Evolution* 23, 419-421.

6.3 Submission 5

ENDANGERED SPECIES RESEARCH, VOL. 28, 11-17 (2015)

The legendary hump-back mahseer (Tor spp.) of India's River Cauvery: an endemic fish swimming towards extinction?

Adrian C. Pinder[1,2], Rajeev Raghavan[1,3,4] & J. Robert Britton[2]

[1]Mahseer Trust, c/o The Freshwater Biological Association, East Stoke River Laboratory, Wareham, Dorset, BH20 6BB, UK

[2]Faculty of Science and Technology, Bournemouth University, Fern Barrow, Poole, Dorset, BH12 5BB, UK

[3]Conservation Research Group (CRG), St Albert's College, Kochi, Kerala, 682 018, Kerala, India

[4]Laboratory of Systematics, Ecology and Conservation, Zoo Outreach Organization (ZOO), Coimbatore, 641 035, Tamil Nadu, India

ABSTRACT

The Western Ghats of India is an exceptional area of freshwater biodiversity and endemism. Mahseer fishes of the genus *Tor* have acquired a legendary status in the region, famed for their sporting qualities and cultural significance, but nevertheless are threatened as a result of increasing anthropogenic stressors. In the River Cauvery, the mahseer community comprises a 'blue-finned' and an orange-finned, 'hump-backed' fish. Whilst it is not yet known if these are distinct species or two different phenotypes, evidence suggests that the hump-backed phenotype is endemic to the river, whereas the blue-finned phenotype was introduced in the 1980s. Angler-catch data from a managed fishery on the Cauvery, gathered between 1998 and 2012 and comprising 23,620 hours of fishing effort, revealed that captured individuals ranged in size from 1 to 104 lbs (0.45 – 46.8 kg), with the blue-finned phenotype comprising of 95 % of all captured fish and the remainder being ‘hump-backed’. The catch per unit effort (CPUE) of the blue-finned phenotype significantly increased over the study period, while the mean weight of individual fish significantly declined. By contrast, the CPUE of the hump-backed phenotype declined significantly over the period, with individual mean weights significantly increasing. These data suggest a recent recruitment collapse in the hump-backed phenotype resulting in an ageing population spiralling towards extinction. The introduced blue-finned phenotype, however, continues to recruit strongly, suggesting that the mahseer community of the River Cauvery has undergone considerable shifts in the last 30 years.

INTRODUCTION

Freshwater ecosystems and their biodiversity remain one of the most endangered and poorly protected resources on Earth (Millenium Ecosystem Assessment 2005; Dudgeon 2011; Cooke et al. 2012), with almost one in three freshwater species facing a high risk of extinction (Collen et al. 2014). Of the 5785 species of freshwater fish assessed for their conservation status by the IUCN, more than 36% are threatened, and over 60 species have gone extinct since 1500 (Carrizo et al. 2013).

The Western Ghats region of India, part of the Western Ghats-Sri Lanka Biodiversity Hotspot, is an exceptional area of freshwater biodiversity and endemism (Dahanukar et al. 2011; Raghavan et al. 2014). Nevertheless, approximately half of the region’s endemic fish species are threatened with extinction (Dahanukar et al. 2011), a result of escalating anthropogenic pressures and threats, lack of governmental support for freshwater fish conservation, jurisdictional issues and oversights, poor enforcement of existing laws, and implementation of top-down approaches (Dahanukar et al. 2011; Raghavan et al. 2011; Pinder & Raghavan 2013; Raghavan et al. 2013). In the region, no freshwater fish has garnered attention from the public as much as the mahseer (*Tor* spp.), a group of large-bodied fishes of the Cyprinidae family. For example, they were represented in the ancient Indian literature (Nautiyal 2014), are revered as gods (Dandekar 2011) and have been globally recognised as premier game fishes since colonial times (Thomas 1873; Dhu 1923; MacDonald 1948). They are, however, one of the most threatened groups of freshwater fish species in the Western Ghats, impacted by habitat loss and destructive fishing, yet with many knowledge gaps regarding their taxonomy, natural histories and population statuses (Pinder & Raghavan 2013). Of particular concern is their systematics and taxonomy, with continuing ambiguity about the identity and distribution of species; the increasing volume of information in the peer-reviewed literature has also been relatively unhelpful to date as it often provides contrasting perspectives on these subjects (*cf.* Knight et al. 2013; Khare et al. 2014).

Whilst in British colonial times, the mahseer of the River Cauvery in the Western Ghats were premier sport fishes, interest in their fishery diminished following Indian independence in 1947, leading many to assume the fish had become extinct. In 1978, however, a small team of British explorers were successful in catching mahseer to 42 kg (TWFT 1984), reigniting global interest in the river as a premier freshwater sport fishing destination and launching a new era of Indian angling ecotourism (Everard & Kataria 2011). The fishery developed on strict catch-and-release (C&R) principles that realised tangible river conservation and societal benefits (Pinder & Raghavan 2013). Despite these benefits, governmental reinterpretation of the Indian Wildlife Protection Act (1972) resulted in a shutdown of the angling camps from 2012, exposing aquatic biodiversity generally and mahseer specifically to elevated levels of illegal and destructive levels of exploitation (e.g. dynamite fishing) in the river.

A recent study on the mahseer fishery of the River Cauvery highlighted the value of angler catch returns in monitoring temporal population trends in mahseer numbers and weight (Pinder et al. in press), and highlighted a marked shift in the weight of individual fish being captured despite a relatively consistent methodology used across the time series, with increasingly smaller fish being captured over time. Although speculated as relating to a change in the mahseer community structure from the endemic hump-backed (orange-finned) phenotype (that grows to over 50 kg) to a distinct blue-finned, smaller phenotype, this was not tested. Consequently, through further interrogation of the dataset of Pinder et al. (in press), the objectives of this study were to a) quantify any shift in mahseer community structure and the current status of both phenotypes; b) identify the vulnerability to extinction of the hump-backed phenotype in the River Cauvery and the conservation implications of the presence of the blue-finned phenotype; and c) to present the urgency associated with defining the true scientific identity of the 'hump-backed mahseer' to advance the ecological knowledge required to inform species-specific conservation action. Note that whilst these two mahseer phenotypes have been previously referenced respectively as *Tor mussullah* and *Tor khudree*, their taxonomic classifications are currently under scrutiny and to avoid perpetuating erroneous scientific names, they are referred to here as only phenotypes, i.e. as 'hump-backed' and 'blue-finned' respectively. Note that the hump-backed phenotype has, historically, only been recorded from the River Cauvery basin (Thomas 1873), including its tributaries, the Kabini (TWFT 2004), Bhavani (Hora 1943) and the Moyar (Jayaram 1997); and thus, based on its restricted distribution alone, it may be considered as highly vulnerable to extinction (Helfman 2007; Giam et al. 2011). By contrast, the blue-finned phenotype was not recorded in the river prior to 1993 and is believed to have originated from artificially propagated stock (Desai 2003).

METHODS

The study area on the River Cauvery was the Galibore Fishing Camp, 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, part of the Western Ghats in Southern India (Figure 6.3.1).

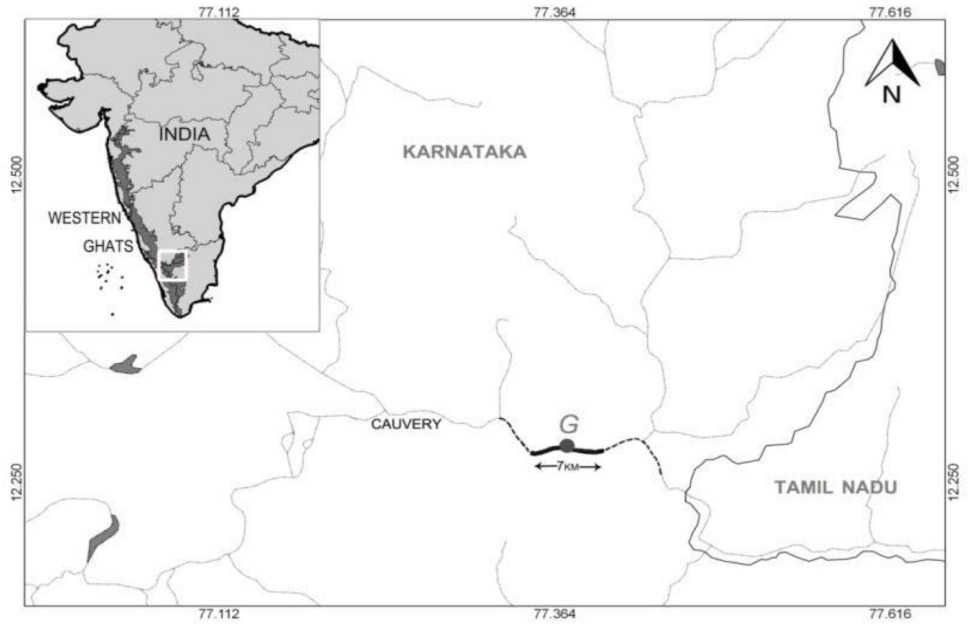


Figure 6.3.1. Location of the River Cauvery and the study area. Solid line represents the 7 km Galibore fishery (G). The dashed line represents the 22 km extent of the former C&R mahseer fishery.

Between mid-January and mid-March of 1998 to 2012, the Galibore fishery was subject to regulated angling pressure (maximum 10 rods/day), practising 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, where 1 lb = 0.45 kg) and notes relating to mahseer phenotype (denoted as hump-backed (H) and blue-finned (B)). With the exception of two years (1999 and 2000), a sub-sample of catch returns spanning 1998 to 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 6.3.1.

Table 6.3.1. 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.

Year	Total number of anglers	Total hours fished	Number of mahseer captured	
			Hump-backed	Blue-finned
1998	6	580	14	59
2001	9	820	38	153
2002	10	1080	6	81
2003	19	1920	80	148
2004	25	2640	95	342
2005	28	2604	25	407
2006	17	1608	6	228
2007	27	2632	3	452
2008	33	3188	5	1022
2009	11	1196	4	346
2010	29	1984	9	887
2011	35	2388	1	1095
2012	10	980	3	653

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 (4h) 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, and as per Pinder et al. (in press), these data have been standardised by recording one fish at 18 lbs with all other individuals recorded as weighing 5 lbs (5 lbs (or 2.25 kg) 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.

Catch returns were initially sorted into the respective phenotypes and enumerated as annual totals. To identify whether the number of blue-finned mahseer captured each year was a good predictor of the number of hump-backed mahseer captured, their relationship was tested using linear regression. To assess whether the differences in the number of each phenotype captured per year were significantly different, the gradient of the regression line (b) was used to test the null hypothesis that equal numbers of the phenotypes were captured each year; with this accepted when b was not significantly different to 1.0 and vice-versa, based on its 95 % confidence limits (Keith et al. 2009). The catch per unit effort (CPUE) of each phenotype was then determined for each year and expressed as the number of each phenotype captured per hour per year. Differences in CPUE value between of the two phenotypes was tested using ANOVA. The temporal pattern in the CPUE of each phenotype was tested for significance using linear regression where the independent variable was the number of years since the study commenced and the dependent variable was the annual CPUE of the mahseer phenotype. To identify whether there was a relationship between the temporal patterns in the CPUE of the hump-backed mahseer and the CPUE of the blue-finned mahseer, Pearson's correlation coefficient was used in cross-correlation, using time 0 (i.e. testing of CPUE data from the same year) and at time lags of -1 to -3 years.

For the weight of individual fish, differences between the phenotypes were tested using a Mann Whitney U test due to the data not being normally distributed. The temporal pattern in the mean weights of each phenotype was then tested for significance using linear regression where the independent variable was the number of years since the study commenced and the dependent variable was the mean annual weight of the mahseer phenotype. This was also repeated for all the fish captured, i.e. by combining data from both phenotypes.

Throughout the study, where error was expressed around the mean, it denoted standard error.

RESULTS

Over the study period, 23,620 hours fishing effort were applied to catch-and-release 6,162 mahseer, ranging in size from 1 to 104 lbs (0.45 – 46.8 kg) in weight. Of these mahseer, 95 % comprised the blue-finned phenotype with the remainder being hump-backed (Table 6.3.1). The number of blue-finned and hump-backed mahseer captured per year were not significantly related ($R^2 = 0.14$, $F_{1,11} = 1.73$, $P > 0.05$; Figure 6.3.2a) and gradient of this regression line (*b*) indicated that significantly more blue-finned mahseer were captured per year than hump-backed (95% confidence intervals: -0.09 to 0.02; Figure 6.3.2a). The annual catch per unit effort of the blue-finned phenotype was also significantly higher than the hump-backed phenotype (ANOVA: $F_{1,22} = 21.78$, $P < 0.01$), with the mean CPUE of the blue-finned phenotype being 0.248 ± 0.050 n h^{-1} and the hump-backed phenotype 0.014 ± 0.005n h^{-1} (Figure 6.3.2b). Across the study period, CPUE of the blue-finned phenotype significantly increased with time ($R^2 = 0.70$, $F_{1,11} = 25.65$, $P < 0.01$), whereas it significantly decreased in the hump-backed phenotype ($R^2 = 0.68$, $F_{1,11} = 9.54$, $P < 0.01$) (Figure 6.3.2b). The cross-correlation revealed that the relationship of the annual CPUE of the hump-backed phenotypes was not significantly correlated to the CPUE of the blue-finned mahseer at time 0, -2 and -3 years (r = -0.49, -0.30 and -0.25 respectively, $P > 0.05$ in all cases), but was significant at time -1 year (-0.58, $P < 0.05$) (Figure 6.3.2b).

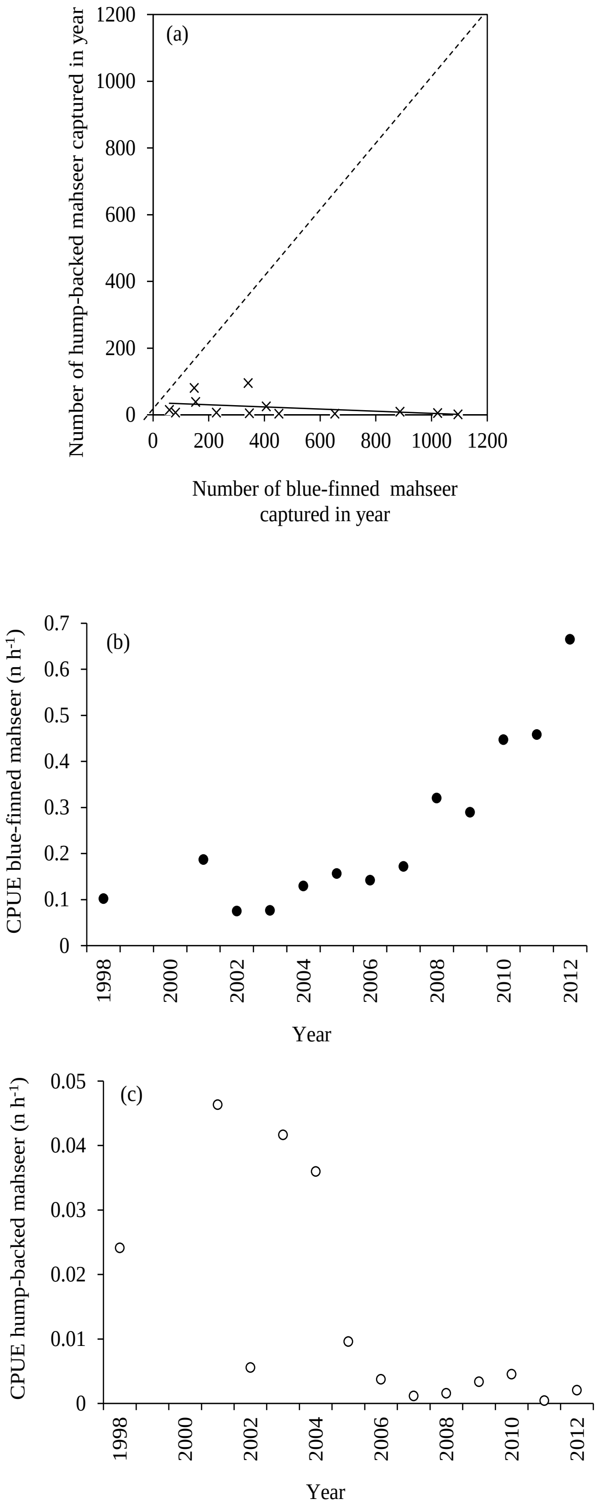


Figure 6.3.2. (a) Comparison of the number of each mahseer phenotype captured per year (×), where the solid line represents the fitted relationship (linear regression) and dashed line represents the null hypothesis that equal numbers of each phenotype were captured each year. (b) Annual catch per unit effort (CPUE) of the blue-finned (●) and (c) hump-backed (○) mahseer across the study period. Error bars are not displayed for brevity.

Across the study period, the mean weight of the hump-backed mahseer was 24.3 ± 1.5 lb (range 1 to 104 lb (0.45 to 46.8 kg)) and the blue-finned 7.8 ± 0.1 lb (range 1 to 62 lb (0.45 to 27.9 kg)), with this difference significant (Mann Whitney U test: Z = -14.37, $P < 0.01$; Figure 6.3.3).

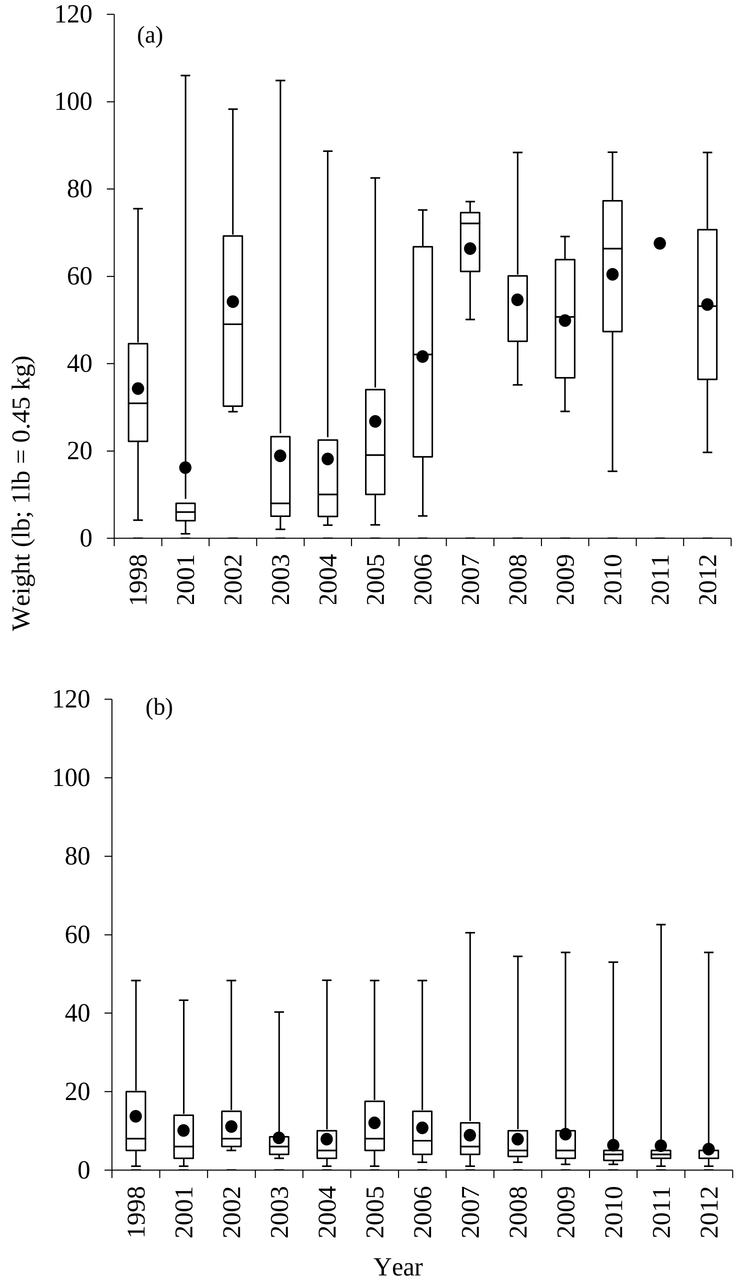


Figure 6.3.3. Box plots of the weight of individual fish captured per year for (a) hump-backed mahseer, and (b) blue-finned mahseer). Filled circles represent mean annual weight, horizontal lines represent the 25th, 50th and 75th percentile and the error bars represent the 10th and 90th percentiles.

For the hump-backed phenotype, their mean weights per year significantly increased over the study period (R^2 = 0.45, $F_{1,11}$ = 8.82, $P < 0.02$), ranging between from 16 lb (7.2 kg) in 2001 and 67.5 lb (30.4 kg) in 2011 (Figure 6.3.2a). In contrast, the mean weight of the blue-finned phenotype significantly decreased over the study period (R^2 = 0.63, $F_{1,11}$ = 18.60, $P <$ 0.01), ranging between 13.8 lb (6.2 kg) in 1998 and 5.4 lb (2.4 kg) in 2012 (Figure 6.3.2b). Indeed, across the study period, 42 % of the captured blue-finned phenotype were below 5 lb (<2.25 kg) in weight. When the data for both phenotypes were combined, the highest mean weight of captured fish was recorded in 1998 (17.7 ± 2.0 lb) and lowest was in 2012 (5.6 ± 0.3 lb), with a significant temporal decline in mean weight also evident (R^2 = 0.83, $F_{1,11}$ = 51.71, $P < 0.01$).

DISCUSSION

The angler catch data revealed some distinct patterns in the composition of the mahseer catches over time, with a significantly increasing catch rate of blue-finned phenotype and a significant decline in catch rates of the hump-backed phenotype. Despite considerable technological advances in recreational fishing gears (e.g. development of braided lines), the challenging environmental conditions and presence of sharp submerged rocks in the Cauvery has dictated that angling techniques remained consistent over the period and provided a representative catch rate of all mahseer between 1 and 104 lbs (Pinder et al. in press). Hence, these outputs indicate that the mahseer community of the river is primarily currently comprised of the blue-finned phenotype whose mean weight is substantially lower than the hump-backed phenotype. The combination of the significant decline in catch rate of the hump-backed phenotype and the significant increase in the sizes of individual fish being captured suggests that there has been a relatively recent issue with their recruitment in the river, with this not evident in the blue-finned phenotype.

The recruitment collapse of the hump-backed phenotype does not appear to be associated with antagonistic interactions between the two phenotypes, given the output of the cross-correlation. It does correspond with anecdotal reports of the failure of the 2004 monsoon, which dramatically reduced river discharge during the 2005 fishing season and resulted in the observed mortality of several large hump-backed mahseer (M. Brown pers. com.). Their overall decline was also coincident with an increase in angling pressure and although catch and release was practised, it could be speculated that the capture and subsequent handling of some of the large hump-backed individuals resulted in their post-release mortality and thus loss from the spawning stock, although there is no supporting anecdotal evidence of this. Irrespective, without action to remediate or mitigate this population decline and recruitment collapse in the hump-backed phenotype then their population in the River Cauvery appears to be increasingly unsustainable and heading towards extinction.

Historical information, including photographs, is critical to understand status of species and populations (see McClenachan 2009; McClenachan et al. 2011) and reveal that only the hump-backed phenotype was captured and photographed during the colonial times. Indeed, photographs of the hump-backed phenotype, as typified by its golden body and orange fins, are distributed throughout angling literature and were all captured in the Cauvery River system, suggesting the absence of this phenotype in other rivers (Thomas 1873; Dhu 1923; MacDonald 1948; Shanmukha 1996). Moreover, until 1993, it was the only mahseer phenotype captured by anglers in the Cauvery, suggesting in all probability that they are endemic. The appearance of the blue-finned phenotype is likely to relate to fish movements and hatchery-reared fish that were initiated in the 1970s. In response to the realisation that a combination of anthropogenic threats were causing a rapid decline in mahseer stocks across India, the Tata Electric Companies (TEC) fish-seed hatchery at Lonavla, Maharashtra, began the large scale breeding and culture of mahseer species (*Tor khudree*, *T. tor*, *T. putitora* and the ambiguous '*Tor mussullah*') for national distribution of fingerlings to augment stocks (Shanmukha 1996; Sehgal 1999; Ogale 2002; Desai 2003). The dates and geographical details of where brood-stock was acquired and the seed distribution of the exact species are scarce, although activities included the experimental hybridisation between mahseer species (Ogale & Kulkarni 1987) and the translocation of species beyond their endemic geographical ranges (including outside the country) have been documented (Ogale 2002; Desai 2003). In 1978, the Trans World Fishing Team (TWFT) visited the TEC hatchery and provided the first record of blue-finned mahseer, describing the culture of *'a strikingly blue finned fish'*; which were targeted for release in the nearby rivers and reservoirs (TWFT 1984). Sehgal (1999) and Desai (2003) have since reported the release of 150,000 advanced fry/fingerlings of *T. khudree* to the River Cauvery by the Department of Fisheries of the State of Karnataka, with further documentation that stocking activity on the Cauvery included 30,000 mahseer by the Fish Farmers Development Agency, Mysore (Shanmukha 1996), 15,000 mahseer fingerlings to the Coorg Wildlife Society and 10,000 to the Wildlife Association of South India (Ogale 2002).

The dataset used in the present study reveals that the blue-finned phenotype was sufficiently well established in the River Cauvery by 1998 to enable them to be already be captured in greater numbers than the hump-backed phenotype, with individual specimens attaining weights to 48 lbs (21.6 kg). Also, whereas the catch data suggest declines in the hump-backed phenotype associated with poor recruitment due to the declining catch rate and increasing individual fish size, data from the blue-finned phenotype suggests sufficient recruitment occurred that enabled large numbers of smaller fish to be captured by anglers, as 42 % of all blue-finned mahseer captured in the study period were below 5 lbs (<2.25 kg) in weight. Due to the lack of detailed catch data prior to 1998, records on the blue-finned phenotype are limited to articles in the popular press and media. The earliest record communicating their presence was in 1993 during the mahseer world angling championships when a fish of approximately 5 kg was captured (A. Clark, pers. com.). Based on current knowledge of the growth rates of blue-finned phenotype and the demographic structure of the population by 1998 (see Pinder et al. in press), it seems highly probable that the blue-finned phenotype originated from the TEC hatchery and was introduced during the late 1980s. Understanding the ecological mechanisms responsible for the high population expansion of the blue-finned phenotype at the expense of the hump-backed phenotype in recent years is currently constrained by insufficient knowledge pertaining to the autecology and genetics of both phenotypes. However, life history traits, such as growth, age at maturity and fecundity are considered to be likely factors, with increased plasticity in the successful utilisation of key function habitats (e.g. spawning media, feeding) potentially providing the blue-finned mahseer with greater niche capacity to exploit and thus facilitating competitive displacement. In addition, direct predation and hybridisation have also been frequently cited as factors increasing the threat to endemic fishes through the introduction of new species (Crivelli 1995).

Since the Galibore fishery was closed in 2012, the fish community has been reported to have been subjected to elevated poaching pressure, but there are currently no means of measuring and tracking community and population metrics against the baseline data established from the current dataset. Accordingly, there is an immediate urgency to establish the status of the hump-backed mahseer throughout the Cauvery basin and acquire genetic material to secure the true taxonomic identity of this animal as a precursor to exploring potential species survival planning.

ACKNOWLEDGEMENTS

The authors wish to thank Sportquest Holidays Ltd, D. Plummer and M. Brown for the provision of catch records. We are grateful to A. Clarke and M. Clarke of the Trans World Fishing Team for historical insight to the fishery and thank A. Kanagavel for assisting in the production of Figure 1. This research was supported by the Mahseer Trust.

REFERENCES

Carrizo, S.F., Smith, K.G., & Darwall, W.R.T., 2013. Progress towards a global assessment of the status of freshwater fishes (Pisces) for the IUCN

Red List: application to conservation programmes in zoos and aquariums. *Int Zoo Yearbook* 47, 46–64.

Collen, B., Whitton, F., Dyer, E.E., Baillie, J.E.M., Cumberlidge, M., Darwall, W.R.T., Pollock, C., Richman, N.I., Soulsby, A.M., & Bohm, M., 2014. Global patterns of freshwater species diversity, threat and endemism. *Global Ecol Biogeogr* 23, 40-51.

Cooke, S.J., Paukert, C., & Hogan, Z., 2012. Endangered river fish: factors hindering conservation and restoration. *Endanger Species Res* 17, 179–191.

Crivelli, A.J., 1995. Are fish introductions a threat to endemic freshwater fishes in the northern Mediterranean region? *Biol Conserv* 72, 311-319.

Dahanukar, N., Raghavan, R., Ali, A., Abraham, R., & Shaji, C.P., 2011. The status and distribution of freshwater fishes of the Western Ghats. In: Molur S., Smith K.G., Daniel B.A., Darwall W.R.T. (compilers) The status and distribution of freshwater biodiversity in the Western Ghats, India. IUCN Cambridge and Zoo Outreach Organization. Coimbatore, 116p

Dandekar, P., 2011. India's Community Fish Sanctuaries Protect Wild Fish and Rivers. *World Riv. Rev* 26, 1-7.

Desai, V.R., 2003. Synopsis of biological data on the tor mahseer *Tor tor* (Hamilton, 1822). FAO Fisheries Synopsis. No. 158. FAO, Rome. 36p

Dhu, S. 1923. The angler in India or the mighty mahseer. Natraj Publishers, Dehra Dun, India

Dudgeon, D., 2011. Asian river fishes in the Anthropocene: threats and conservation challenges in an era of rapid environmental change. *J Fish Biol* 79, 1487–1524.

Everard, M., & Kataria, G., 2011. Recreational angling markets to advance the conservation of a reach of the Western Ramganga River, India. *Aquat Conserv: Mar & FW Ecosyst* 21, 101-108.

Gadgil, M., Chandrashekahariah, H.N., & Bhat, A., 2001. Freshwater fish: out of sight, out of mind. *The Hindu Survey of the* Environment, 137-142

Giam, X., Ng, T.H., Lok, A.F., & Ng, H.H., 2011. Local geographic range predicts freshwater fish extinctions in Singapore. *J Appl Ecol* 48, 356-363

Helfman, G., 2007. Fish Conservation. Island Press. 584p.

Hora, S.L., 1943. The game fishes of India. XVI. The mahseers or the large-scaled barbels of India. 9. Further observations on mahseers from the Deccan. *J Bom Nat Hist Soc* 44, 1-8.

Jayaram, K.C., 1997. Nomenclatural and systematic status of *Barbus mussullah* Sykes, 1839. J Bom Nat Hist *Soc* 94, 48–55.

Khare, P., Mohindra, V., Barman, A.S., Singh, R.K., & Lal, K.K., 2014. Molecular evidence to reconcile taxonomic instability in mahseer species (Pisces: Cyprinidae) of India. *Org Divers Evol* 14, 307-326.

Knight, J.D.M., Rai, A., & D'souza, R.K.P., 2013. On the identities of *Barbus mussullah* Sykes and *Cyprinus curmuca* Hamilton, with notes on the status of *Gobio canarensis* Jerdon (Teleostei: Cyprinidae). *Zootaxa* 3750, 201-215.

MacDonald, A.S.J., 1948. Circumventing the Mahseer. Natraj Publishers, Dehra Dun, India

McClenachan, L., 2009. Documenting loss of large trophy fish from the Florida Keys with historical photographs. *Conserv Biol* 23(3), 636-644.

McClenachan, L., Ferretti, F., & Baum, J.K., 2012. From archives to conservation: why historical data are needed to set baselines for marine animals and ecosystems. *Conserv. Lett* 5, 349-359.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Wetlands and Water Synthesis. World Resources Institute, Washington, DC.

Nautiyal, P., 2014. Review of the Art and Science of Indian Mahseer (Game Fish) from Nineteenth to Twentieth Century: Road to Extinction or Conservation? *P Natl Acad Sci India: Part B: Biological Sciences* 84, 215-236.

Ogale, S.N., & Kulkarni, C.V., 1987. Breeding of pond-raised hybrids of mahseer fish, *Tor khudree* (Sykes) and *Tor tor* (Ham.). *J Bom Nat Hist Soc* 84, 332-335

Ogale, S.N., 2002. Mahseer breeding and conservation and possibilities of commercial culture. The Indian experience. In: Petr, T., Swar, D.B. (Eds) Cold Water Fisheries in the Trans Himalayan Countries, *FAO Fisheries Technical Paper* 431, 193-212

Pinder, A.C., & Raghavan, R., 2013. Conserving the endangered Mahseers (*Tor* spp.) of India: the positive role of recreational fisheries. *Curr Sci* 104, 1472–1475

Pinder, A.C., Raghavan, R., & Britton, J.R., in press. Efficacy of angler catch data as a population and conservation monitoring tool for the flagship Mahseer fishes (*Tor* spp.) of Southern India. *Aquat Conserv: Mar & FW Ecosyst*

Raghavan, R., Dahanukar, N., Philip, S., Iyer, P., Kumar, B., Daniel, B.A., & Molur, S., In press. Conservation status of freshwater decapod crustaceans in the Western Ghats of India: an exceptional region of freshwater biodiversity. *Aquat Conserv*: Mar & FW Ecosyst

Raghavan, R., Dahanukar, N., Tlusty, M.F., Rhyne, A.L., Krishna Kumar, K., Molur, S., & Rosser, A.M., 2013. Uncovering an obscure trade: Threatened freshwater fishes and the aquarium pet markets. *Biol Conserv* 164, 158–169

Raghavan, R., Ali, A., Dahanukar, N., & Rosser, A., 2011. Is the Deccan Mahseer, *Tor khudree* (Sykes 1839) (Pisces: Cyprinidae) fishery in the Western Ghats Hotspot sustainable? a participatory approach to stock assesement. *Fish Res* 110, 29-38

Sehgal, K., 1999. Coldwater fish and fisheries in the Western Ghats, India. In: Petr T (ed) *Fish and Fisheries at Higher Altitudes: Asia*, FAO Fisheries Technical Paper 385, 304p

Shanmukha, S.N., 1996. Status of mahseer fishery in Karnataka. *Fishing Chimes* 15, 26-29

Thomas, H.S., 1873. The rod in India. 8vol: Mangalore, India

Trans World Fishing Team (TWFT), 1984. Quest for a legendary fish. International Book Distributors: Dehra Dun.

CHAPTER 7: SUSTAINABILITY CONSIDERATIONS OF C&R ANGLING FOR ENDANGERED FISH

7.1 Prelude to Submissions 6:

*Bower, S.D., Danylchuk, A.J., Raghavan, R., Clark-Danylchuk. S., **Pinder, A.C**., & Cooke, S.J., 2016. Rapid assessment of the physiological impacts caused by catch-and-release angling on blue-finned mahseer (*Tor* sp.) of the Cauvery River, India. *Fisheries Management and Ecology* 23, 208-217.

* Previously submitted for the award of PhD by the lead author. This paper has not been included to claim personal credit, but to demonstrate how I have contributed towards advancing the knowledge base and the importance of this work in guiding the strategic direction of my own research journey.

Despite considerable research and discussion on fish welfare in recent years, the specific question of whether fish feel cognitive pain remains contentious and inconclusive (Rose et al. 2014). It was therefore never my intention to enter into discussion in this area, but to ensure I was suitably informed to provide an evidence based response to policy makers asking whether C&R angling for endangered fish constitutes a conservation problem or conservation action? This was a question recently posed and explored by Cooke et al. (2014) via a number of case studies focused on several well-known iconic (but also endangered) recreationally targeted fish species. Regardless of the cognitive pain dilemma, all schools of thought agree that any fish subject to C&R will, as a minimum, experience some level of physical injury via the mechanics of hook penetration and be subject to some degree of physiological stress (Cooke & Sneddon 2007). These factors have been demonstrated to elicit a relative scale of risk of post-release-mortality (PRM) or sub lethal effects that can impact on fitness (Arlinghaus et al. 2007).

The conservation benefits of C&R are, therefore, fundamentally dependent on a high proportion of the released fish surviving (Cooke & Schramm, 2007), with impacts on physiological and behavioural performance not compromising the reproductive potential of individual fish (Bartholomew & Bohnsack, 2005). In recent years, there has been considerable attention directed towards studying the stress response and subsequent survival and performance of a broad range of C&R angled marine, freshwater and estuarine sport fishes (e.g. bonefish (*Albula vulpes*) Danylchuk et al. 2007; Atlantic cod (*Gadus morhua*) Weltersbach & Strehlow 2013; peackock bass (*Chichla ocellaris*) Bower et al. 2016). This has facilitated the development of species-specific best angling practice guidelines and informed fishery management decisions designed to maximise the survival prospects of released fish and the sustainability of the fishery (Cooke & Suski 2005). Understanding the resilience of mahseer to C&R is, therefore, vital to inform expected rates of mortality, and determine whether the practice and risks posed by the practice of C&R outweigh the benefits of alternative management strategies, including fishery closure. These issues were briefly touched upon in Submission 1 (Chapter 4) which acknowledged that potential negative impacts of C&R (e.g. fish welfare considerations) would require further investigation.

Prior to the workshops which formed the basis of Submission 3 (see Section 5.3), I teamed up with Raghavan who introduced me to Dr Steven Cooke of Carleton University, Canada, with whom he was in the process of co-authoring the previously cited paper on recreational angling for endangered fish (Cooke et al. 2014). Following several teleconferences with Cooke and his research team to design a study and resolve a series of logistical challenges, the opportunity arose to collaborate with Dr Shannon Bower on the application of novel and rapid assessment tools to assess C&R impacts on fishes.

Using blue-finned mahseer (now known to be *Tor khudree*) as a model species for the genus *Tor*, Submission 6 concluded that, providing appropriate care is applied (e.g. limiting air exposure), mahseer are particularly robust to C&R, with the risks of PRM and sub-lethal effects (e.g. predation risk and reproductive fitness) considered to be negligible at the population level. However, since conducting this study, the hump-backed mahseer, *Tor remadevii,* which represents the endemic *Tor* of the Cauvery system, has been assessed as ‘Critically Endangered’ on the IUCN Red List of Threatened Species (see Submission 8, Section 8.3). This raises the question once more as to whether C&R angling is acceptable for exploiting critically endangered species? If robust protection from poaching was realistically achievable then the answer is, arguably, ‘no’. However, as evidenced throughout this thesis, until the closure of the Cauvery fishery in 2012, recreational angling played a vital role in protecting the fish of the Cauvery Wildlife Sanctuary from illegal fishing using indiscriminate and highly destructive methods such as dynamite and poisons, which had a deleterious impacted on all aquatic fauna and respective life-stages. Since the closure of the fishery, anecdotal evidence suggests that illegal fishing is now high within this 27 km section of river, that is now known to be one of the remaining habitats of the hump-backed mahseer (see Section 6, Submission 4). Furthermore, recreational anglers have proved highly effective in collecting quality data to monitor mahseer populations. Without their contribution of long term data, the critical status of the hump-backed mahseer would not have been apparent, with a high risk of this species going extinct before being afforded a valid scientific name. While Cooke et al. (2014) provide the following decision tree as guidance for determining the circumstances when angling for endangered fish should be allowed/encouraged vs. dissuaded/prohibited (Figure 7.1.1), one must also consider and evaluate site specific holistic threats versus resources to mitigate these threats and base such challenging decisions on informed and balanced appraisal of evidence to maximise conservation benefits.

My own contribution to Submission 6 has since enabled me to adapt and apply these newly acquired skills to both marine and freshwater recreational fisheries research in the UK (Pinder et al. 2016, 2019). Specifically, the Pinder et al (2019) study was designed to examined the effects of water temperature on the C&R resilience of a model coldwater fish species in the UK and has produced important evidence to support sustainable levels of recreational exploitation through best practice fishery management and angler behaviour. Furthermore, these findings also have important ramifications for recreationally exploited fish populations globally. Specifically within the context of climate change and rivers subject to accelerated warming due to high levels of abstraction, such as South India's River Cauvery.

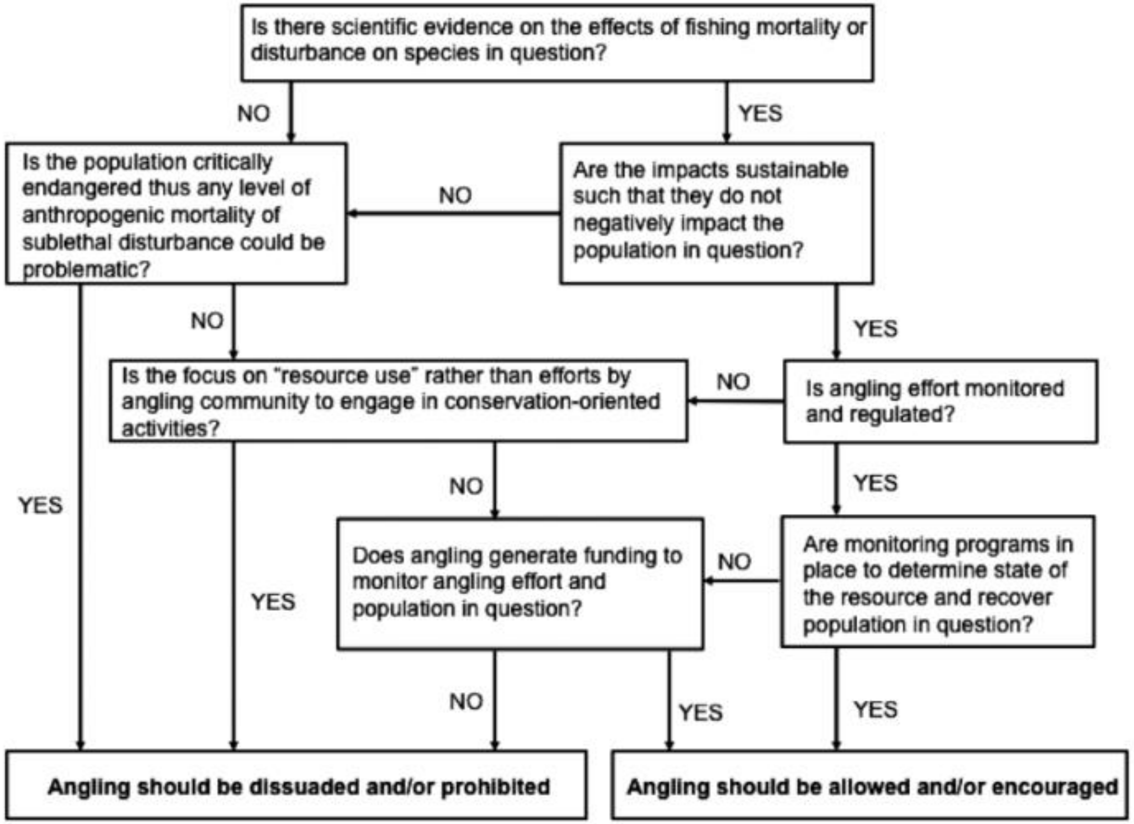


Figure 7.1.1. Decision tree for determining when angling for endangered fish should be allowed/encouraged vs. dissuaded/prohibited – from Cooke et al. (2014).

7.1.1 **References**

Arlinghaus, R., Cooke, S.J., Lyman, J., Policansky, D., Schwab, A., Suski, C., Sutton, G. & Thorstad, E.B., 2007. Understanding the complexity of catch-and-release in recreational fishing: an integrative synthesis of global knowledge from historical, ethical, social, and biological perspectives. *Reviews in Fisheries Science* 15(1-2), 75-167.

Bartholomew, A., Bohnsack, J.A., 2005. A review of catch-and-release angling mortality with implications for no-take reserves. *Rev. Fish. Biol. Fish.* 15, 129-154.

Bower, S.D., Danylchuk, A.J., Brownscombe, J.W., Thiem, J.D., & Cooke, S.J., 2016. Evaluating effects of catch-and-release angling on peacock bass (Cichla ocellaris) in a Puerto Rican reservoir: a rapid assessment approach. *Fisheries research* 175, 95-102.

Cooke, S.J., & Suski, C.D., 2005. Do we need species-specific guidelines for catch-and-release recreational angling to effectively conserve fishery resources? *Biodivers. Conserv*. 14, 1195-1209. DOI 10.1007/s10531-004-7845-0

Cooke, S.J., & Sneddon, L.U., 2007. Animal welfare perspectives on recreational angling. *Applied Animal Behaviour Science* 104(3-4), 176-198.

Cooke, S.J., & Schramm, H.,L. 2007. Catch-and-release science and its application to conservation and management of recreational fisheries. *Fisheries Management and Ecology* 14(2), 73-79.

Cooke, S.J., Hogan, Z.S., Butcher, P.A., Stokesbury, M.J., Raghavan, R., Gallagher, A.J., & Danylchuk, A.J., 2016. Angling for endangered fish: conservation problem or conservation action?. *Fish and Fisheries* 17(1), 249-265.

Danylchuk, A.J., Danylchuk, S.E., Cooke, S.J., Goldberg, T.L., Koppelman, J.B., & Philipp, D.P., 2007. Post-release mortality of bonefish, *Albula* *vulpes*, exposed to different handling practices during catch-and-release angling in Eleuthera, The Bahamas. *Fish. Manag. Ecol.* 14, 149-154.

Pinder, A.C., Velterop, R., Cooke, S.J., & Britton, J.R., 2016. Consequences of catch-and-release angling for black bream Spondyliosoma cantharus, during the parental care period: implications for management. *ICES Journal of Marine Science* 74(1), 254-262.

Pinder, A.C., Harrison, A.J., & Britton, J.R., 2019. Temperature effects on the physiological status and reflex impairment in European grayling Thymallus thymallus from catch-and release angling. *Fisheries Research* 211, 169-175.

Rose, J.D., Arlinghaus, R., Cooke, S.J., Diggles, B.K., Sawynok, W., Stevens, E.D., & Wynne, C.D.L., 2014. Can fish really feel pain?. *Fish and Fisheries* 15(1), 97-133.

Pinder, A.C., Harrison, A. J. & Britton, J.R., 2019. Temperature effects of the physiological status and reflex impairment in European grayling *Thymallus thymallus* from catch-and-release angling. Fisheries Research 211, 169-175.

Weltersbach, M.S., & Strehlow, H.V., 2013. Dead or alive - estimating post-release mortality of Atlantic cod in the recreational fishery. *ICES J. Mar. Sci.* 70, 864-872.

7.2 Submission 6

FISHERIES MANAGEMENT AND ECOLOGY, VOL. 23, 208-217 (2016)

Rapid assessment of the physiological impacts caused by catch-and-release angling on blue-finned mahseer (Tor sp.) of the Cauvery River, India

S.D. Bower[1], A.J. Danylchuk[2], R. Raghavan[3,4,5], S .E. Clark-Danylchuk[6], **A .C. Pinder**[4,7], S.J. Cooke[1]

[1]Fish Ecology and Conservation Physiology Laboratory, Department of Biology, Carleton University, Ottawa, ON, Canada
[2]Department of Environmental Conservation, University of Massachusetts Amherst, Amherst, MA, USA
[3]Conservation Research Group (CRG), St. Albert’s College, Kochi, India
[4]Mahseer Trust, Freshwater Biological Association, Wareham, Dorset, UK
[5]Laboratory of Systematics, Ecology and Conservation, Zoo Outreach Organization (ZOO), Coimbatore, India
[6]Fish Mission, Amherst, MA, USA
[7]Faculty of Science and Technology, Bournemouth University, Poole, UK

ABSTRACT

Forty-nine blue-finned mahseer (Tor sp.; mean total length 458 ± 20 mm) were angled using a range of bait/lure types, angling and air exposure times in water that averaged 27 ± 2 °C over the course of the assessment. No cases of mortality were observed, and rates of moderate and major injury were

low, with 91% of mahseer hooked in the mouth. More extreme physiological disturbances (i.e. blood lactate, glucose, pH) in mahseer were associated with longer angling times. Sixteen fish (33%) exhibited at least one form of reflex impairment. Moreover, longer air exposures and angling times resulted in significant likelihood of reflex impairment. Findings suggest that blue-finned mahseer are robust to catch-and-release, but that anglers should avoid unnecessarily long fight times and minimise air exposure to decrease the likelihood of sub-lethal effects that could contribute to post-release mortality.

INTRODUCTION

Recreational fisheries are increasingly recognised as an important fisheries sector around the globe (FAO 2012). Although anglers harvest some fish, catch-and release (C&R; i.e. the act of returning a fish to water after landing, presumably unharmed; Arlinghaus et al. 2007) is common; it can be voluntary due to the conservation ethic of the anglers or a result of compliance with regulations that require fish to be released. The extent to which C&R behaviours practiced by anglers can act as a conservation tool in any particular fishery is a complex one, particularly when targeting endangered species (Cooke et al. In Press). Target species exhibit a wide-range of outcomes associated with C&R (i.e. various species respond differently to the same angling practices), suggesting research should be conducted on individual species to assess the suitability of C&R as a management strategy (Cooke & Suski 2005). For example, some species may demonstrate sensitivity to air exposure or exhibit high post-release mortality rates (see numerous examples in reviews by Muoneke & Childress 1994; Bartholomew & Bohnsack 2005; Arlinghaus et al. 2007). Even if data are available for species known to exhibit similar physiologies, findings may not be transferable to target species occupying different habitat types, life-history stages or targeted using different angling behaviours (Cooke & Suski 2005).

Fishery-specific research can be challenging when resources for fisheries management or data availability are limited; an issue that may be of particular concern in developing recreational fisheries in low-to middle income countries (LMICs; Bower et al. 2014) or for endangered species (Cooke et al. In Press). Rapid C&R assessment protocols that combine injury and mortality observations with assessments of physiological state (see Cooke et al. 2013) and reflex impairment (see Davis 2010) have been developed as a way of generating data on such key response attributes in a swift and cost-effective manner. In a C&R rapid assessment, researchers first interact with stakeholders to identify likely areas to focus research efforts based on specific elements of a fishery (e.g. gear type, angler behaviour, environmental conditions) and then use a combination of simple endpoints to obtain a snapshot of the extent to which behaviours practiced in a given C&R fishery may be sustainable. By combining these approaches (i.e. injury and mortality assessment, physiological analyses, reflex indicators) into a single study to generate essential baseline data for species-specific responses to C&R practices, rapid assessments can also serve as a tool to triage future research priorities. For example, a rapid assessment could identify the need for a larger scale assessment across multiple seasons if there is evidence of a thermal stress component or perhaps looking at different lure, bait or hook types should there be evidence of deep hooking. Essentially, a rapid assessment is a first step towards ensuring that C&R fisheries are sustainable and that angling practices are optimised to maintain the welfare status of fish that will be released.

Mahseer (Tor spp.) is a group of potamodromous cyprinids endemic to Asia. The mahseer of India are currently declining as a result of a multitude of pressures including changes in land use, agricultural run-off, hydropower projects, invasive species, overexploitation and use of damaging fishing gears (Everard & Kataria 2011; Raghavan et al. 2011; WWF 2013). Indian populations of the Tor mahseer consist of seven species as yet identified in scientific literature, although there is still much confusion surrounding their taxonomy. Four known species are currently listed as ‘Endangered’ on the IUCN RedList (IUCN 2014), including the two most popular game species

Tor khudree Sykes (blue-finned or the Deccan mahseer), and Tor putitora Hamilton (Golden mahseer). In India, these species are primarily targeted by subsistence and recreational fishers (Everard & Kataria 2011; Raghavan et al. 2011). In the 1970s, recreational fishers first noted a decline in mahseer size and numbers and took action to address the problem, forming angling conservation groups and coalitions [e.g. Wildlife Association of South India (WASI)]. These groups established angling camps based on strict C&R principles, employed guards to protect stocks from poaching and began collecting catch data (Pinder & Raghavan 2013).

Despite the lengthy history of recreational fishing for mahseer in India, little is known about the responses of the species to common angling practices. Indeed, there are currently no known studies that have evaluated any elements of C&R practices (spanning injury, mortality or stress) for any mahseer species in India or anywhere within their range. To address these knowledge gaps, working in partnership with local anglers and river managers, a rapid assessment was used to evaluate C&R practices for angled blue-finned mahseer (which will be referred to as Tor sp. to reflect current taxonomic uncertainty; also see Pinder et al. In Press) in the Cauvery River, India. Results of this study can be used to support evidence-based decision making in mahseer recreational fisheries, and the rapid assessment process can support the development of species-specific best practices for recreational fisheries in data-poor LMICs that can be communicated to anglers and other relevant stakeholders.

METHODS

Study site

Angling and sampling took place along the Cauvery (Kaveri) River (Ammangala Village, Valnur; 12.457494°N, 75.960549°E; Figure 7.2.1) in Kodagu District (Coorg), Karnataka State, India in March, 2014. Angling on much of this stretch of river (exceptions include temple sanctuary waters and the Nisargadhama Reserve) is managed by the Coorg Wildlife Society (CWS), an NGO that coordinates C&R angling in the area. The river in the

study site also supports a variety of other users and purposes, including local and farming use (i.e. irrigation
source), subsistence fishing, religious use (i.e. temple sanctuaries) and tourism (i.e. rafting). Sand-mining operations also occur on this stretch of the Cauvery (S. Bower personal observation). Water temperatures during the rapid assessment averaged 27 ± 2 °C.

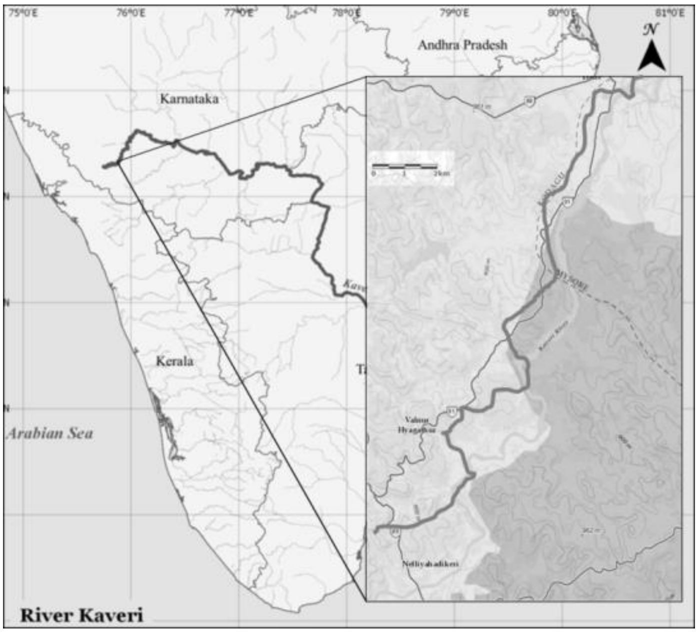


Figure 7.2.1. Location of the Cauvery River in India and the rapid assessment sampling area in Valnur, Kodagu (inset).

Angling practices

Angling and sampling was conducted over the course of 3 days along a 20-km stretch of the Cauvery by two assessment teams, each consisting of between three to six anglers and an individual responsible for processing samples and recording data. Rather than simulating fisheries, local anglers and river managers were engaged to ensure that C&R practices studied reflected actual practices used for blue-finned mahseer (Cooke et al. 2013; Figure 7.2.2). To account for differences in angler expertise (anglers varied in experience from novice anglers with little fishing experience overall to expert anglers with decades of fishing experience in the study area), each angler spent time collecting fish for both groups over the course of the rapid assessment.

Figure 7.2.2. Blue-finned mahseer (Tor sp.) during analysis. Photo credit: Steve Lockett.

All anglers used light- to mid-weight spinning gear and adopted a variety of terminal tackle (hereafter collectively referred to as lure types), all of which are commonly employed in the recreational fishery, including: spoons, spinners, plugs, soft baits and a traditional flour-based dough bait locally referred to as ragi (see Figure 7.2.3). Ragi recipes use a variety of spices and flavours, but are universally fashioned into a balled shape around a single barbed or barbless hook. Pellet floats were also used to target mahseer, a technique less commonly employed in the area. Angling took place from shore, from a dinghy and from a coracle (a traditional round-bottomed boat; Figure 7.2.3).

Figure 7.2.3. (a) Ragi ball affixed to a single, barbed hook; a traditional bait used in the mahseer recreational fisheries of south India. (b) Volunteer anglers fish from a coracle, a traditional round-bottomed boat used for fishing activities in south India. Photo credits: Shannon Bower.

Rapid assessment protocols

Over the course of the rapid assessment, 49 blue-finned mahseer were angled and processed. Prior to angling, the lure type, number of hooks and hook type (barbed or barbless) were recorded. Processing began by recording the time taken to land the fish (angling time in sec), beginning from the initial setting of the hook by the angler and terminating at landing. Once landed, the anatomical hooking location for each fish was recorded and each fish was measured (total length in mm; TL). Fish were scored for the presence of injury using a standardised objective scoring system, where a score of 0 indicated no discernible injury; a score of 1 indicated a minor injury such as minor tearing of tissue (i.e. <5 mm in length, including any visible tissue tear or abrasion resulting from hooking); a score of 2 indicated moderate injury such as the presence of bleeding, bruising or a tissue tear >5 mm in length; and a score of 3 indicated major injury, such as ocular or gill damage with significant pulsatile bleeding (as per Gutowsky et al. 2011). A standardised scoring system was also applied to describe the ease of hook removal, where a score of 0 referred to a hook that was removed easily and immediately (i.e. in <10 s); a score of 1 referred to a hook that required between 10 and 20 s to remove; and a score of 2 was assigned when hooks required >20 s to remove (a time based variation on hook removal scores used in Cooke et al. 2001). To standardise scoring methods, only those fish scored for injury and hook removal by the assessment teams were included in analysis for these variables. Landed fish processed for non-score variables (length, lure type, hook type, angling time) by team members without a prior training in scoring standards were not included in analysis of scored variables (injury, ease of hook removal). The cumulative amount of air exposure time (s) accrued during handling was recorded by all participants.

A 'whole body' stress response in fish can take the form of immediate (e.g. inhibition of reflex behaviours) and/or delayed responses, such as decreased reproductive outputs or growth (Pankhurst & Van Der Kraak 1997). Immediate reflex responses may be measured during a rapid assessment using reflex action mortality predictors (RAMP), indicators developed by Davis (2010). The use of indicators to measure reflex responses as proxies for physiological stress and as predictors for post-release mortality and behavioural impairment have been used in a variety of teleost fish studies (for e.g. *Oncorhynchus kisutch* Walbaum, Raby et al. 2012; *Albula vulpes* Linnaeus, Brownscombe et al. 2013). With the fish submerged, RAMP indicators were measured prior to release. Four reflex indicators were used in this rapid assessment, including: 'tail grab' (fish exhibits burst swimming reflex when grabbed by the tail); 'body flex' (fish flexes torso when held along the dorsoventral axis); 'head complex' (fish exhibits steady operculum beats during handling); and, 'equilibrium' (fish rights itself within 3 s after being placed upside-down in water) (Davis 2010). Binary RAMP scores of 0 (reflex present) or 1 (reflex absent) were assigned to each indicator measurement, resulting in a total score ranging from 0–4. These individual RAMP indicator scores were then combined to produce a proportional impairment score ranging from 0–1 for each fish, where 0 indicated no overall impairment and 1 indicated total impairment.

Blood sampling

In addition to measuring reflex responses, non-lethal blood samples were obtained from a subset of fish (n = 36) to quantify the physiological stress response of mahseer to C&R angling. These responses may be measured in a rapid assessment by obtaining a non-lethal blood sample from the caudal vasculature (Barton 2002) and processed quickly in the field using point-of-care devices and techniques validated on fish and other species (as reviewed by Stoot et al. 2014). Prior to sampling, these fish were subject to the same measurements as described above. Following these measurements, fish in the blood-sampled subgroup were sampled immediately (i.e. in <30 s; as per Meka & McCormick 2005).

Non-lethal blood samples were obtained by temporarily inverting fish in the water column while <1 mL of blood was drawn from the caudal vasculature with a 22G needle (BD Vacutainer Multi-sample Needles and 4.0 mL lithium heparin collection tubes, 75 USP, Becton, Dickson and Company (BD), Franklin Lakes, NJ, USA). Blood was analysed onsite immediately after withdrawal for blood lactate (mmol L_1, Lactate Pro LT-1710, Arkray Inc., Kyoto, Japan), glucose (mmol L_1, Accu-Chek Compact Plus, Roche Diagnostics, Basel, Switzerland) and pH (HI-99161, Hanna Instruments, Woonsocket, RI, USA). Fish that were blood sampled were released immediately after sampling was completed. All experimental manipulations performed during this study were conducted in accordance with Canadian Council of Animal Care regulations under permit number B13-02 (file # 100105).

Statistical analyses

To determine whether angling variables such as lure type, angling time, air exposure and difficulty of hook removal influenced differences in injury score (mortality rate was not included as no cases of mortality were observed), Chi-Square (lure type, difficulty of hook removal) and Kruskal–Wallis tests (angling time, air exposure time) were employed. Tukey’s HSD tests were applied as post hoc testing for all Kruskal–Wallis tests. To evaluate stress response in blood-sampled mahseer, general linear models were applied to measure the relationship between blood values (glucose, lactate and pH) and angling variables (angling time, air exposure).To normalise residuals in the model examining angling variable contributions to blood glucose values, blood glucose values were log-transformed but predictor variables were not (as recommended in Zuur et al. 2009). Contributions from uncontrolled independent variables (i.e. water temperature, °C; TL, mm), were accounted for by including these variables in analysis. Models were chosen based on a combination of parsimony (i.e. fewest variables explaining the most variation) and minimum Akaike Information Criterion (AIC) value.

Chi-square analyses (lure type, injury score) and Kruskal–Wallis analyses (angling time, air exposure time) were performed to compare reflex impairment responses among mahseer subject to different angling times, air exposure times, lure type and injury score. RAMP scores were treated as objective measurements during analysis (RAMP scores were converted to ordinal variables; 0.0, 0.25, 0.5, 0.75, 1), a common assumption in studies using RAMP scoring (see Raby et al. 2012; Brownscombe et al. 2013; Nguyen et al. 2014 for examples). However, the low numbers of non-zero RAMP scores prevented formal statistical analysis by individual score category. Thus, non-zero RAMP scores were binned into a single category and the contributions of angling time, air exposure, lure type and injury score to non-zero RAMP scores were measured.

The dataset's compliance with assumptions of homogeneity of variance and normality of distribution were assessed using Levene and Shapiro–Wilk tests on each variable prior to analysis. Variables found to meet assumptions were treated with general linear models, while the remainder were subject to the non-parametric analyses described above. Unless otherwise noted, all data are presented as mean _ standard error. All analyses were conducted using R (version 3.1.0, © 2014, The R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Injury and mortality

Of the 44 angled blue-finned mahseer assessed for hooking location, most (91%) were hooked in the mouth, specifically in the corner of the mouth (n = 16), lower jaw (n = 12) or upper jaw (n = 12). Four fish (9%) were foul-hooked, and each instance of foul-hooking was also categorised as a minor, moderate or major injury, according to the degree of resulting tissue damage. Of the 39 fish assessed for injury, 23 were classified as having minor (n = 18, including two instances of foul-hooking) or moderate (n = 5, including one instance of foul-hooking) injury, and one fish exhibited major injury in the form of a loss of perfusion to fins and damage to the 2nd gill arch after being foul-hooked in the gills. Increases in injury score were not associated with gear-related variables such as lure type (χ^2 = 6.49, d.f. = 8, P = 0.59), or hooking location (χ^2 = 5.60, d.f. = 8, P = 0.69). Increased difficulty in hook removal (χ^2 = 5.66, d.f. = 6, P = 0.07), extended angling times (χ^2 = 1.13, d.f. = 2, P = 0.57) or extended air exposures (χ^2 = 2.34, d.f. = 2, P = 0.31) also did not significantly increase injury score. Finally, there were no observed instances of mortality during the course of this study, although one highly impaired and injured fish (see above) was not expected to survive over the short term.

Blood chemistry

Mean length of mahseer angled for the rapid assessment was 458 ± 20 mm TL (n = 49; range 200–700 mm TL), while fish in the blood-sampled subset (n = 36) averaged 443 ± 24 mm TL. Mean values for blood glucose, lactate and pH in this sampled subset were 2.5 ± 0.2 mmol L^{-1}, 5.7 _ 0.4 mmol $L^{-1}$and 7.30 ± 0.16 respectively. GLM models identified which angling variables (angling time, air exposure time, TL and water temperature) contributed most to variability in physiological parameters. In the model analysing factors contributing to blood lactate values, the lowest AIC value occurred when all independent variables (angling variables above) were included in the model. However, when all independent variables but angling time (the only statistically significant predictor) were removed from the model, AIC value remained low and the adjusted R-squared value remained stable (Adj. R^2 for full model = 0.47, Adj. R^2 for reduced model=0.46). As such, the latter model was chosen on the basis of parsimony and revealed that elevated blood lactate values in mahseer were significantly, although weakly, correlated with longer angling times (Adj. R^2 = 0.46, F = 31.37, d.f. = 34, P < 0.001). The lowest AIC values in the model analysing angler variable contributions to log transformed blood glucose occurred when all variables were retained. This model revealed that lengthened air exposure times (t = 2.73, P = 0.01), longer angling times (t = 3.39, P = 0.002), and shorter fish lengths (t = -4.4, P < 0.001) all correlated with increased blood glucose values (Adj. I^2 = 0.42, F = 5.13, d.f. = 28, P = 0.001). Finally, angling time was also identified as being the variable contributing most to changes in blood pH of sampled mahseer, with the lowest AIC value and most parsimonious model occurring when all variables but angling time were removed. Extended angling times were correlated with significant decreases in mahseer blood pH (Adj. I^2 = 0.55, F = 7.94, d.f. = 33, P < 0.001).

Reflex impairment

Mean RAMP score for the total number of fish measured for reflex impairment (N = 49) was 0.20. Sixteen mahseer (33%) tested positive for impairment for at least one of the four RAMP indicators tested. Seven of these 16 mahseer scored 0.25, indicating impairment of a single reflex behaviour. Four mahseer scored 0.50, indicating impairment of two reflex behaviours, and four mahseer scored 0.75, indicating impairment of three reflex behaviours. Lastly, one mahseer scored 1.00, indicating that all four reflexes were impaired. Among the indicators measured, equilibrium, and tail grab were most commonly impaired, followed by body flex, and head complex (Figure 7.2.4).

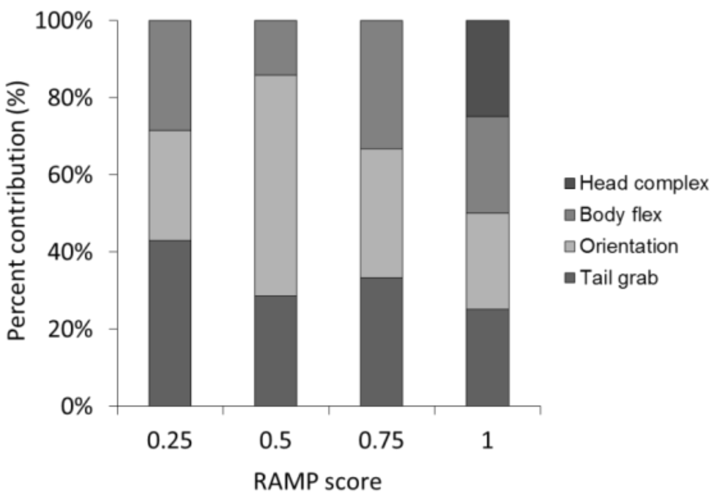


Figure 7.2.4. Proportional contributions of individual indicators to RAMP score (0, 0.25, 0.5, 0.75, 1).

Air exposure, angling time, lure type and injury score were included in analyses of mahseer RAMP score. Longer air exposure times were significantly more likely to result in non-zero RAMP scores (χ^2 = 5.55, d.f. = 1, P = 0.02), as were longer angling times (χ^2 = 4.02, d.f. = 1, P = 0.045). Of the different lure types used (pellet floats, plugs, ragi, soft plastics, spinners and spoons), spinners caught the most mahseer over the study period (25 of 49 fish were angled using spinners). However, lure-specific catch-per-unit-effort was not tracked so it is unclear which lure type was most effective. Possibly due to the dominance of captures by spinners, not a single lure type was associated with a significant increase in RAMP score, suggesting that reflex impairment was not related to lure type in this study (χ^2 = 4.11, d.f. = 6, P = 0.53). Injured fish were also not more likely to demonstrate reflex impairment: among mahseer angled during the rapid assessment as there was no evidence of a significant relationship between injury scores (1, 2, 3) and non-zero RAMP scores (χ^2 = 5.66, d.f. = 3, P = 0.12).

DISCUSSION

Overall, injuries were found to be minor in nature and mortality was negligible in the mahseer rapid assessment. A high rate of minor injury to mahseer was observed (46%), but this was likely due to the conservative standards employed in the assessment of injury. It is worth noting that it is impossible to capture a fish by hook without causing some level of injury; an unavoidable function of hook and tissue interaction (Cooke & Sneddon 2007). Measurements of injury were categorised using conservative standards by including any visible tissue damage, including hook puncture sites, as a minor injury and by considering a tissue tear > 5 mm as a moderate injury. This standard was deemed appropriately risk averse due to the endangered status of mahseer. Given the lack of significant association between injury and angling variables such as gear type, this standard was likely responsible for the high rate of minor (23 of 39 fish assessed for injury) and moderate (five of 39 fish assessed) injury recorded during the rapid assessment. The rate of foul-hooking (9%) may also be a result of the use of treble hooked lures in targeting blue-finned mahseer (commonly considered to be an aggressive striking fish). These lures are commonly employed in the study area, but to date less frequently used elsewhere in south India (D. Plummer, Cauvery River angling guide personal communication). Despite this relatively high rate of minor injury (60%), 91% of these injuries occurred at the hook site in the mouth. Throughout the study, only one fish was considered likely to die, but no cases of mortality were observed during the study period. Additional mortality can occur after release (i.e. delayed mortality) but fish were generally vigorous at time of release with little reflex impairment (see below) suggesting mortality was unlikely. Analysis of blood chemistry in angled blue-finned mahseer revealed that longer angling times correlated with increases in blood lactate and glucose, and decreases in blood pH, while longer air exposure times and smaller fish size were found to correlate with higher blood glucose values. The relationship between angling time and key stress markers has been documented in a number of species, including great barracuda (*Sphyraena barracuda*; O'Toole et al. 2010) and bonefish (*A. vulpes* L.; Suski et al. 2007). As with angling time, the relationship between longer air exposure times and increases in blood glucose has also been noted in other popular sport fish, such as largemouth bass (*Micropterus salmoides* Lacepede; White et al. 2008) and northern pike (*Esox Lucius* Linnaeus; Arlinghaus et al. 2009). The negative relationship between air exposure and fish length in this study, however, is contrary to typical findings that describe larger bodied fish as more likely to exhibit higher stress responses (see Meka & McCormick 2005). Meka and McCormick (2005) postulated that fish maintaining a higher weight/length ratio may exhibit increased stress response as a result of experiencing more anaerobic exercise (than fish maintaining a lower weight/length ratio) during a stressor of equal duration and intensity. No trophy-sized fish (blue-finned mahseer can attain masses that exceed 50 kg in this region) were landed during the rapid assessment, however, and as mahseer weight was not measured it was not possible to determine whether this hypothesis applies to blue-finned mahseer. The potential impacts of species-specific stress responses are also important to consider. For example, the amount of variability in blood lactate, glucose and pH measurements explained by the predictors was low, suggesting that these correlations may be weak in this species. Weak correlations may also be a result of species- specific physiological traits robust to such stressors. Nonetheless, we did observe that quickly angled mahseer (i.e. angled and sampled in <1 min, n = 9) had levels of lactate that averaged 3.9 ± 0.2 mmol L^{-1} which is presumably indicative of near-baseline values for this species (Romero 2004). The minimum values found in this study for lactate were 1.4 ± 0.2 mmol L^{-1} with a maximum of 11.6 ± 0.2 mmol L^{-1}. Given the potamodromous ecology of mahseer, further study to explore the role of lactate metabolism in mahseer recovery from angling is warranted. Exploratory analysis of RAMP scores demonstrated that rates of mahseer reflex impairment were relatively low, with the 40 of 49 fish exhibiting no impairment (n = 33) or impairment of a single indicator behaviour (n = 7). Burst swimming and equilibrium were the most likely to be impaired, followed by loss of torso flexion and irregular operculum beats. While other studies employing RAMP have also found that the burst swimming reflex is most likely to be impaired (for e.g. see Raby et al. 2012; Brownscombe et al. 2013), these studies also found that loss of torso flexion was the second most frequently impaired reflex. During the present rapid assessment, it was noted that body flex in mahseer is less evident than in other species and therefore its presence or absence was less easily visible. Anglers using

RAMP to assess the status of landed fish prior to release, or future studies incorporating measurements of RAMP to study mahseer, should consider prioritising indicators other than body flex. Longer angling and air exposure times were the variables most likely to contribute to non-zero (impaired) RAMP scores. The rate of minor impairment (14%) in this study further suggests that negative reflex response to these angling stressors is not uncommon in mahseer. Both the contributions of angling variables and this evidence of reflex impairment suggest that further research into the occurrence of sub-lethal effects in mahseer may be advisable.

Conclusions from rapid assessment and recommended best practices

The rapid assessment findings suggest mahseer are robust to C&R, but also provide data to support the development of best angling practices designed to reduce unnecessarily long angling times and air exposures. While angling times for larger bodied fish are likely to be longer than for smaller fish, anglers should opt for gear choices appropriate to their target species as inappropriate gear choices can result in extended angling times (Meka & McCormick 2005) and avoid unnecessary delay in landing hooked fish. Handling time may be reduced by using fewer hooks (i.e. single hooks rather than treble hooks) and/or barbless hooks, which may reduce the time needed for hook removal (Cooke et al. 2001). Anglers should also attempt to reduce the amount of time landed fish are subjected to air exposure, particularly in higher water temperatures (Gingerich et al. 2007). In this study, mahseer demonstrated increased blood glucose after air exposures greater than 30 s in mean water temperatures of 27 ± 2 °C, which could be considered a conservative maximum for cumulative exposure time in similar conditions. Future research recommendations include quantifying the physiological stress responses of larger bodied fish (i.e. trophy mahseer) and identifying sub-lethal impacts resulting from angling, particularly those relevant to mahseer natural history (which is understudied in most Tor spp.; Nautiyal 2014). Fish considered to be of trophy size were not targeted or captured in this study. Such mahseer are known to be subject to fight times often exceeding 1 h (D. Plummer, Cauvery River angling guide, personal communication) and may therefore be more susceptible to delayed recovery and stress induced mortality. The physiological challenges posed by migration behaviours may increase the likelihood sub-lethal impacts of recreational angling on mahseer at certain times of year (i.e. migratory periods) or in differing environmental conditions (i.e. different water temperatures). It should be noted that mahseer are not typically targeted by C&R anglers during monsoon season (approximately May-October); however, migration phases may extend beyond monsoon season according to habitat type/life stage (e.g. T. putitora is believed to migrate at different times according to age class; Nautiyal 2014). Moreover, information on population size and demographics/life-history characteristics (e.g. age at maturation, natural mortality rates) is needed to understand the level of C&R-induced mortality than can be considered sustainable – information that is typically absent for endangered species targeted by recreational C&R anglers (Cooke et al. In Press).

ACKNOWLEDGEMENTS

Cooke is supported by the Canada Research Chairs Program and the Natural Sciences and Engineering Research Council of Canada. Danylchuk is supported by the National Institute of Food & Agriculture, U.S. Department of Agriculture, and the Massachusetts Agricultural Experiment Station and Department of Environmental Conservation. Raghavan is supported by the Mohammed Bin Zayed Species Conservation Fund. Pinder is supported by the Mahseer Trust. We appreciate the logistic support provided by CWS, WASI and our many volunteer anglers, and permission for the study (through CWS) from N.R. Ramakrishna, Joint Director of Fisheries, Government of Karnataka. Special thanks go to Neethi Mahesh, Ambily Nair, Shyam Aiyappa, Aiyappa C.P., Dayan Mandappa, Sandeep Chakrabarti, Shine Sathvik, Naren Sreenivasan, Steve Lockett, and Derek D’Souza. Special thanks also to the Fisheries Society of the British Isles and the Marion and Jasper Whiting Foundation for financial support for this project.

REFERENCES

Arlinghaus, R., Cooke, S.J., Lyman, J., Policanksy, D., Schwab, A., Suski, C., 2007. Understanding the complexity of catch-and-release in recreational fishing: an integrative synthesis of global knowledge from historical, ethical, social and biological perspectives. *Reviews in Fisheries Science* 15, 75–167.

Arlinghaus, R., Klefoth, T., Cooke, S.J., Gingerich, A. & Suski, C., 2009. Physiological and behavioural consequences of catch-and- release angling on northern pike (Esox lucius L.). *Fisheries Research* 97, 223–233.

Bartholomew, A. & Bohnsack, J.A., 2005. A review of catch-and-release angling mortality with implications for no-take eserves. *Reviews in Biology and Fisheries* 15, 129–154.

Barton, B., 2002. Stress in Fishes: a diversity of responses with particular reference to changes in circulating corticosteroids. *Integrative & Comparative Biology* 42, 517–525.

Bower, S.D., Nguyen, V.M., Danylchuk, A.J., Beard, T.D. Jr & Cooke, S.J., 2014. 'Inter-sectoral conflict and recreational fisheries of the developing world: Opportunities and challenges for co-operation'. In: P. McConney, R. Medeiros & M. Pena (eds) Enhancing Stewardship in Small-Scale isheries: Practices and Perspectives. Too Big To Ignore (TBTI) and Centre for Resource Management and Environmental Studies, The University of the West Indies, Cave Hill Campus, Barbados. CERMES Technical Report No. 73, 88–97.

Brownscombe, J.W., Thiem, J.D., Hatry, C., Cull, F., Haak, C.R., Danylchuk, A.J., 2013. Recovery bags reduce post release impairments in locomotory activity and behavior of bonefish (Albula spp.) following exposure to angling-related stressors. *Journal of Marine Biology & Ecology* 440, 207–215.

Cooke, S.J. & Sneddon, L.U., 2007. Animal welfare perspectives on catch-and-release recreational angling. *Applied Animal Behaviour Science* 104, 176–198.

Cooke, S.J., & Suski, C.D., 2005. Do we need species-specific guidelines for catch-and-release recreational angling to effectively conserve diverse fishery resources? *Biodiversity & Conservation* 14, 1195–1209.

Cooke, S.J., Philipp, D.P., Dunmall, K.M., & Schreer, J.F., 2001. The influence of terminal tackle on injury, handling time and cardiac disturbance of rock bass. *North American Journal of Fisheries Management* 21, 333–342.

Cooke, S.J., Raby, G.D., Donaldson, M.R., Hinch, S.G., O'Connor, C.M., Arlinghaus, R., 2013. The physiological consequences of catch-and-release angling: perspectives on experimental design, interpretation, extrapolation and relevance to stakeholders. *Fisheries Management & Ecology* 20, 268–287.

Cooke, S.J., Hogan, Z.S., Butcher, P.A., Stokesbury, M.J.W., Raghavan, R., Gallagher, A.J., In Press. Angling for endangered fish: conservation problem or conservation action? *Fish & Fisheries*. doi:10.1111/faf.12076

Davis, M.W., 2010. Fish stress and mortality can be predicted using reflex impairment. *Fish & Fisheries* 11, 1–11.

Everard, M. & Kataria, G., 2011. Recreational angling markets to advance the conservation of a reach of the Western Ramganga River, India. *Aquatic Conservation: Marine and Freshwater Ecosystems* 21, 101–108.

FAO, 2012. Recreational Fisheries. Technical Guidelines for Responsible Fisheries. No. 13. Rome, FAO, 176 pp.

Gingerich, A.J., Cooke, S.J., Hanson, K.C., Donaldson, M.R., Hasler, C.T., Suski, C.D., 2007. Evaluation of the interactive effects of air exposure duration and water temperature on the condition and survival of angled and released fish. *Fisheries Research* 86, 169–178.

Gutowsky, L.F.G., Harrison, P.M., Landsman, S.J., Power, M. & Cooke, S.J., 2011. Injury and mortality associated with recreational troll capture of bull trout (Salvelinus confluentus) in a reservoir in the Kootenay-Rocky Mountain region of British Columbia. *Fisheries Research* 109, 379–383.

IUCN, 2014. IUCN Red List of Threatened Species. Version 2014.3. www.iucnredlist.org. [Accessed: November 2014].

Meka, J.L. & McCormick, S.D., 2005. Physiological response of wild rainbow trout to angling: impact of angling duration, fish size, body condition and temperature. *Fisheries Research* 72, 311–322.

Muoneke, M.I. & Childress, W.M., 1994. Hooking mortality: a review for recreational fisheries. *Reviews in Fisheries Science* 2, 123–156.

Nautiyal, P., 2014. Review of the art and science of Indian mahseer (game fish) from nineteenth to twentieth century: road to extinction or conservation? *Proceedings of the National Academy of Science, India, Section B, Biological Sciences* 84, 215–236.

Nguyen, V.M., Martins, E.G., Robichaud, D., Raby, G.D., Donaldson, M.R., Lotto, A.G., 2014. Disentangling the roles of air exposure, gill net injury, and facilitated recovery on the post capture and release mortality and behaviour of adult migratory sockeye salmon (Oncorhynchus nerka) in freshwater. *Physiological & Biochemical Zoology* 87, 127–1353.

O'Toole, A.C., Danylchuk, A.J., Suski, C.D. & Cooke, S.J., 2010. Consequences of catch-and-release angling on the physiological status, injury, and immediate mortality of great barracuda (Sphyraena barracuda) in The Bahamas. *ICES Journal of Marine Science* 67, 1667–1675.

Pankhurst, N.W. & Van Der Kraak, G., 1997. 'Effects of stress on reproduction and growth of fish' In: G.K. Iwama, J. Sumpter, A.D. Pickering & C.B. Schreck (eds) Fish Stress and Health in Aquaculture. Society for Experimental Biology Seminar Series 62, Cambridge University Press, Cambridge, UK, pp. 73–95.

Pinder, A.C. & Raghavan, R., 2013. Conserving the endangered mahseers (Tor spp.) of India: the positive role of recreational fisheries. *Current Science India* 104, 1472–1475.

Pinder, A.C., Raghavan, R. & Britton, R., In Press. Efficacy of angler catch data as a population and conservation monitoring tool for the flagship Mahseer fishes (Tor spp.) of Southern India. *Aquatic Conservation: Marine and Freshwater Ecosystems* doi:10.1002/aqc.2543

Raby, G.D., Donaldson, M.R., Hinch, S.G., Patterson, D.A., Lotto, A.G., Robichaud, D., 2012. Validation of reflex indicators for measuring vitality and predicting the delayed mortality of wild coho salmon bycatch released from gears. *Journal of Applied Ecology* 49, 90–98.

Raghavan, R., Ali, A., Dahanukar, N. & Rosser, A., 2011. Is the Deccan mahseer, Tor khudree (Sykes, 1839) (Pisces: Cyprinidae) fishery in the Western Ghats hotspot sustainable? A participatory approach to stock assessment. *Fisheries Research* 110, 29–38.

Romero, L.M., 2004. Physiological stress in ecology: lessons from biomedical research. *Trends in Ecology & Evolution* 19, 249–255.

Stoot, L.J., Cairns, N.A., Cull, F., Taylor, J.J., Jeffrey, J.D., Morin, F., 2014. Use of portable blood physiology point-of-care devices for basic and applied research on vertebrates – a review. *Conservation Physiology* 2, cou011.

Suski, C.D., Cooke, S.J., Danylchuk, A.J., O'connor, C.M., Gravel, M.A., Redpath, T., 2007. Physiological disturbance and recovery dynamics of bonefish (Albula vulpes), a tropical marine fish, in response to variable exercise and exposure to air. *Comparative Biochemistry & Physiology, Part A* 148, 664–673.

White, A.J., Schreer, J.F. & Cooke, S.J., 2008. Behavioural and physiological responses of the congeneric largemouth (Micropterus salmoides) and smallmouth (M. dolomieu) to various exercise and air exposure durations. *Fisheries Research* 89, 9–16.

WWF- India, 2013. In: P. Nautiyal, S. Babu & S. Behera (eds) Mahseer Conservation in India: Status, Challenges and the Way Forward. New Delhi, INR: WWF-India, 38 p.

Zuur, A., Ieno, E.N., Walker, N., Saveliev, A.A. & Smith, G.M., 2009. 'Mixed effects models and extensions with R'. In: M. Gail, K. Krickeberg, J.M. Samet, A. Tsiatis & W. Wong

(eds) Statistics for Biology and Health. Springer, NY, USA, 574 p.

CHAPTER 8: RESOLVING THE TAXONOMY AND CONSERVATION STATUS OF THE WORLD'S LARGEST SPECIES OF MAHSEER

8.1 Prelude to Submissions 7 and 8:

Pinder A.C, Manimekalan, A., Knight, J.D.M, Krishnankutty, P., Britton, J.R., Philip, S., Dahanukar, N., & Raghavan, R., 2018. Resolving the taxonomic enigma of the iconic game fish, the hump-backed mahseer from the Western Ghats biodiversity hotspot, India. *PLoS ONE* 13(6): e0199328. https://doi.org/10.1371/journal.pone.0199328

Pinder A.C., Katwate, U., Dahanukar, N., Harrison, A.J., 2018. *Tor remadevii*. The IUCN Red List of Threatened Species 2018-2.

Despite representing the essential foundation of biodiversity and ecological research (Costello et al. 2015), the science of classic taxonomy has fallen out of vogue in recent years, with maintenance of museum fish collections frequently reported to be threatened by both a lack of specialist skills and available funding being redirected towards a rapidly expanding field of molecular based phylogenetic study (Wheeler 2004; Chakrabarty 2010). While the race is currently on to sequence the genomes of all of Earth's eukaryotic biodiversity over the next decade (Earth Biogenome Project 2018), a high volume of publications concerning freshwater ichthyofauna have relied implicitly on the generation of molecular DNA barcodes from fishes collected from the wild without any reference to species type localities and/or cross referencing with original species descriptions and type specimens. This disconnect from classic taxonomic convention and the strict rules within the International Code for Zoological Nomenclature (ICZN) is particularly prevalent in Indian research. Many studies have thus generated erroneous assumptions and added confusion rather than taxonomic clarity; this has been further amplified through the propagation of errors through citation networks (Greenberg 2009). With specific reference to mahseer range countries, and other developing countries harbouring rich biodiversity where research is underfunded and access is problematic, many species have not yet been discovered and risk going extinct without our knowledge (Cooke et al. 2012). Persisting taxonomic uncertainties pertaining to described species also continue to constrain knowledge on species distributions, population status, and the development and implementation of effective conservation strategies (Hogan 2011). Indeed, this was the case with the hump-backed mahseer; erroneously referred to under the Nomina nuda Tor mussullah; through blind citation, numerous publications have incorporated this name within phylogenetic trees. This was despite no reference ‘type’ specimens and, even after Knight et al. (2013, 2014) stabilised the name mussullah to a species of the cyprinid genus *Hypselobarbus* (a genus with very little resemblance to *Tor*).

With the preliminary analysis of the angler catch data reported in Chapter 6 commencing in 2012, and early indications that the population of hump-backed mahseer was imperilled, resolving the taxonomic identity of this fish (and the invasive blue-fin mahseer) were firmly at the top of my research priority list, as I knew that the lack of a formal scientific name would act as a major impediment to garnering conservation interest. This was indeed evidenced in feedback from conservation grant proposals I had submitted, which confirmed that while it lacked a ‘threatened’ status in the IUCN Red List, the hump-backed mahseer would not qualify for conservation funding. Considering that the hump-backed mahseer was by now extremely scarce and recreational angling had been banned in the protected area which supported these fish, securing the evidence to achieve this task presented a major challenge, defined by the following initial hurdles:

1) To find a single hump-backed mahseer to acquire a tissue sample for DNA analysis; and
2) Assuming the DNA did not match previously described *Tor*, procure three small specimens of hump-backed mahseer to deposit as voucher ‘type’ specimens.

Despite being geographically focussed in the upper reaches of the Cauvery where the hump-backed mahseer had been rarely recorded in recent years, the planned fieldwork to undertake the rapid assessment study in March 2014 provided the first opportunity, but subsequent failure to secure a hump-backed specimen (see Chapter 7; Submission 6). Following the acquisition of research permissions from Karnataka Forest Department, and with the support of the Wildlife Association of South India (WASI), I led a further expedition to survey the Protected Area at the former Galibore Fishing Camp in February 2015. Again this effort failed to secure a specimen, or even confirm that the fish was still present. Over the duration of these two expeditions in 2014 and early 2015, the survey team did manage to catch and release a total of 115 blue-fin mahseer (*Tor* spp.) from which fin-clip samples were collected for subsequent mitochondrial DNA analysis. With 114 of these samples providing an exact match with records submitted to Genbank from *Tor* collected in the state of Maharashtra and topotypic museum specimens, we were able to confirm the identity of the blue-finned mahseer as *Tor khudree*, a species now known to be endemic to the River Krishna basin in Maharashtra and North Karnataka, and the species that had been artificially propagated by Tata Power at their Lonavla Hatchery in Maharashtra for the previous 40 years. This left a single sample from a fish of 35 cm in length captured from the upper River Cauvery in 2014 that did not match *Tor khudree*. Although not recognised by the captor as a different species, the DNA results were different but did not match with any previously described species of *Tor*. The DNA sequence did however offer a perfect match with three other records in Genbank, deposited by a A. Manimekalan from the lower River Cauvery and one of its tributaries, the River Bhavani, in the neighbouring state of Tamil Nadu.

An internet search soon revealed that Dr A. Manimekalan was an associate professor within the Department of Environmental Sciences at Barathiar University in Coimbatore, Tamil Nadu. Following discussions about specific sampling sites and the visual characteristics of the *Tor* which matched my Cauvery fish, it was agreed that in return for me delivering an open lecture at Barathiar University, Dr Manimekalan would show me the fish in the wild. On the 15th December 2015, Manimekalan organised my access to the River Moyar, where my search for the hump-backed mahseer was finally completed (Figure 8.1.1).

Figure 8.1.1. The author and the elusive hump-backed mahseer acquainted for the first time in December 2015.

Despite having found a population of fish which superficially matched the giant hump-backed mahseer of the middle Cauvery, it was a further two years before official research permits were issued to allow the collection of specimens, which were subsequently used for genetic and morphometric analysis and comparison with historic photographs. This facilitated an integrated approach to characterise what at the time I believed was a new species to science. Indeed, armed with all the evidence required to name the hump-backed mahseer as Tor kaveri (Kaveri being the pre-anglicized Cauvery), I thought that this process was now completed. However, during the preparation of the initial draft manuscript, a relatively recent description of a fish from the River Pambar (the Cauvery's most southern tributary) came to light. Despite lacking any molecular characterisation against which to compare the hump-backed mahseer, the description of *Tor remadevii* (Kurup & Radhakrishnan 2007) reported some similarities. Thus, until a DNA sample could be sourced from these fish, this work was put on hold.

With these results evidencing an exact match, and morphometrics of *T. remadevii* type specimens deposited at the Zoological Survey of India - Southern Regional Center, Chennai, India (ZSI-SRC) also clustering with the humpback with discriminant analysis, it was apparent that the iconic hump-backed mahseer was conspecific with *Tor remadevii*. Regardless of the name finally attributed to the hump-backed mahseer, the taxonomy of this species was finally fixed in June 2018 (see Submission 7), thus affording the hump-backed mahseer formal recognition and qualifying it for IUCN Red List Assessment.

With reference to Chapter 3, my research journey began in earnest when Dr K. Rema Devi, a senior ichthyologist at the Zoological Survey of India, put me in touch with my co-author Rajeev Raghavan. With the etymology of the hump-backed mahseer adopted from the earlier description of *T. remadvii*, following the publication of Submission 7, I re-established contact with Dr Rema Devi to inform her that the largest mahseer and one of the most iconic freshwater fish in the world was named after her. Her response was of delight, with the comical exception of being associated with a humpback.

Red Listing Tor remadevii

The IUCN is the global authority on the status of the natural world and the measures to safeguard it. Its Red List uses precise criteria based on population size and distributions, to assess species' extinction risks, with assessments made in formal meetings by panels of international experts. With the manuscript clarifying the identity of the hump-backed mahseer as *T. remadevii* finally submitted and under review at PLOS One, I contacted Drs William Darwall and Ian Harrison of the IUCN Global Species programme to enquire about the process of Red Listing this species as a matter of urgency. This was met with considerable enthusiasm and encouragement to convene a workshop of select experts, to not only assess *T. remadevii*, but also to revise the entire genus Tor, consisting of the 16 species presented in Chapter 9 (Submission 9 – Mahseers of the World).

Capitalising on Raghavan's considerable experience through his role as Freshwater Fish Red List Authority Coordinator (Asia/Oceania), in April 2018 we jointly convened a three-day workshop at the Indian Institute of Science and Environmental Research, Pune (IISER). In November 2018, the IUCN Red List was updated with *T. remadevii* being the first *Tor* to be assessed as Critically Endangered. The full assessment is presented as Submission 8, with all 16 species assessments available to download and view online at https://www.iucnredlist.org/.

8.1.1 **References**

Cooke, S.J., Paukert, C., & Hogan, Z., 2012. Endangered river fish: factors hindering conservation and restoration. *Endangered Species Research* 17(2), 179-191.

Chakrabarty, P., 2010. The transitioning state of systematic ichthyology. *Copeia*, 2010(3), 513-515.

Costello, M.J., Vanhoorne, B., & Appeltans, W., 2015. Conservation of biodiversity through taxonomy, data publication, and collaborative infrastructures. *Conservation Biology*, 29(4), 1094-1099.

Earth Biogenome Project, 2018. https://www.earthbiogenome.org/. [Accessed January 2019].

Greenberg, S.A., 2009. How citation distortions create unfounded authority: analysis of a citation network. *Bmj* 339, b2680.

Hogan, Z.S., 2011. Ecology and conservation of large-bodied freshwater catfish: a global perspective. In *American Fisheries Society Symposium* (No. 77).

Knight, J.D.M., Rai, A., & D'Souza, R.K.P., 2013. On the identities of *Barbus mussullah* Sykes and *Cyprinus curmuca* Hamilton with notes on the status of *Gobio canarensis* Jerdon (Teleostei: Cyprinidae). *Zootaxa*. 3750: 201–215. http://dx.doi.org/10.11646/zootaxa.3750.3.1

Knight, J.D.M., Rai, A., & D'Souza, R.K.P., 2014. A further note on the identity of *Barbus mussullah* Sykes (Teleostei: Cyprinidae). *Zootaxa* 3821(2): 280–284. http://dx.doi.org/10.11646/zootaxa.3821.2.8

Kurup, B.M., & Radhakrishnan, K.V., 2007. *Tor remadevii*, a new species of mahseer from Kerala (South India), and distribution and abundance of *Tor* spp. in the river systems of Kerala. In. Mahseer, the biology, culture and conservation (Siraj, S.S., Christianus, A., Kiat, N.C., De Silva, S.S. eds). Proceedings of the International Symposium on the mahseer, 29th to 30th March 2006, Kuala Lumpur, Malaysia (Malaysian Fisheries Society Occasional Publication No 14, Kuala Lumpur): 236 p.

Wheeler, Q. D., 2004. Taxonomic triage and the poverty of phylogeny. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 359(1444), 571-583.

8.2 Submission 7

PLOS ONE, VOL 13(6), e0199328 (2018)

Resolving the taxonomic enigma of the iconic game fish, the hump-backed mahseer from the Western Ghats biodiversity hotspot, India

Adrian C. Pinder[1,2], Arunachalam Manimekalan[3], J.D. Marcus Knight[4], Prasannan Krishnankutty[5], J. Robert Britton[1], Siby Philip[6], Neelesh Dahanukar[7,8], Rajeev Raghavan[2,8,9]

[1] Faculty of Science and Technology, Bournemouth University, Dorset, United Kingdom

[2] Mahseer Trust, Freshwater Biological Association, Wareham, Dorset, United Kingdom

[3] Department of Environmental Sciences, Bharathiar University, Coimbatore, India

[4] India Ministry of Environment Forest and Climate Change, Government of India, New Delhi, India

[5] Department of Zoology, Mahatma Gandhi College, Thiruvananthapuram, India

[6] Department of Zoology, Nirmalagiri College, Kannur, India

[7] Indian Institute of Science Education and Research, Pune, India

[8] Zoo Outreach Organization (ZOO), Coimbatore, India

[9] Department of Fisheries Resource Management, Kerala University of Fisheries and Ocean Studies Kochi, Kerala, India

ABSTRACT

Growing to lengths and weights exceeding 1.5 m and 45 kg, the hump-backed mahseer fish of the Western Ghats biodiversity hotspot, India, is an iconic, mega-faunal species that is globally recognized as a premier freshwater game fish. Despite reports of their high extinction risk, conservation approaches are currently constrained by their lack of valid taxonomic identity. Using an integrative approach, incorporating morphology, molecular analysis and historical photographs, this fish can now be revealed to be conspecific with *Tor remadevii*, a species lacking a common name, that was initially, but poorly, described in 2007 from the River Pambar, a tributary of the River Cauvery in Kerala. Currently known to be endemic and restricted to the River Cauvery basin in the Western Ghats, *T. remadevii* is distinguished from congeners by its prominent hump originating above the pre-opercle and extending to the origin of the dorsal fin, a well-developed mandible resulting in a terminal or slightly superior mouth position, and the dorsal orientation of the eyes. While body colouration varies (silver, bronze, greenish) and is not considered a reliable diagnostic character, orange coloration of the caudal fin (sometimes extending to all fins) is considered a consistent characteristic. Having been first brought to the attention of the scientific community in 1849, and the recreational angling (game fishing) community in 1873, it has taken over 150 years to finally provide this iconic fish with a valid scientific name. This taxonomic clarity should now assist development and delivery of urgent conservation actions commensurate with their extinction risk.

INTRODUCTION

Freshwater megafauna (defined as species with adult body weights of at least 30 kg) occur in large rivers and lakes of every continent except Antarctica (Carrizo et al. 2017). These megafauna comprise one of the world's most vulnerable groups of vertebrates to extinction, with 58 % of species at threat from stressors including overexploitation, habitat alteration and pollution (Carrizo et al. 2017; He et al. 2017). Despite this, for many freshwater mega-fauna, knowledge on their taxonomy, natural history and threats remain incomplete, as despite their body sizes providing high anthropogenic interest, some species have only recently been described (Last et al. 2008), while the identity of others remain to be elucidated (Stewart 2013).

With validated body weights exceeding 45 kg (Pinder et al. 2015a), the hump-backed mahseer of the River Cauvery (Western Ghats, India) represents the largest of all known mahseers of the *Tor* genus (Figure 8.2.1). Globally recognized by recreational fishers as an iconic game fish for over a century (Thomas 1873), it was initially brought to their attention in 1873, under the nom de plume 'Barbus tor' (Thomas 1873), with documentation of a world record specimen of 119 lbs (54 kg) captured in 1921 from the River Kabini, a tributary of the River Cauvery (Wild life 1977). Following Indian independence in 1947, the fish was largely forgotten until a resurgence in recreational angling interest and subsequent development of catch-and-release fisheries in the main River Cauvery in the early 1970s (Pinder & Raghavan 2013; Pinder et al. 2015b). These fisheries subsequently became world famous for the size of mahseer they produced (Pinder & Raghavan 2013; Pinder et al. 2015b) and were also recognized for the socio-economic benefits afforded to poor rural communities via ecotourism based employment opportunities (Pinder & Raghavan 2013).

Figure 8.2.1. Adult Cauvery hump-backed mahseer, *Tor remadevii* captured by Martin Clark, 1978 [Photo Credit: Trans World Fishing Team].

Despite this long-term interest in the species, the hump-backed mahseer continued to be erroneously known under the names *Barbus mussullah* and *Tor mussullah*, both in scientific (Hora 1943a, 1943b; Sen & Jayaram 1982; Jayaram 1997) as well as in popular literature (Jung 2012). This continued until Knight and coworkers (Knight et al. 2013, 2014) stabilized the use of the name 'mussullah' to a species of the cyprinid genus *Hypselobarbus*. However, this taxonomic revision continued to leave the hump-backed mahseer without a valid scientific identity, thus denying the formal recognition required to undertake IUCN Red list assessment and afford protection commensurate with their apparent high extinction risk (Pinder et al. 2015a).

A new species of mahseer, *Tor remadevii* was described in 2007 from the River Pambar, the southern-most tributary of the River Cauvery (Kurup & Radhakrishnan 2007). This was based on the examination of 19 juvenile specimens (lengths 113.64mm to 331.82mm) (Kurup & Radhakrishnan 2007). However, neither a photograph of a live/preserved specimen, nor an illustration, accompanied the description, with no comparison to material from congeners. The description thus relied entirely on morphological measurements and counts available in the literature (Kurup & Radhakrishnan 2007). Despite these issues and the limited sample size, many of the characters were consistent with those observed from images of the hump-backed mahseer caught by recreational fishers in the River Cauvery (e.g. body shape: "dorsal profile has a moderate to prominent hump between the head region and the dorsal fin"), colouration: ("fins reddish with black patches"; "younger specimens with red orange fins") and a "distinctively longer mandible than other Southern Indian *Tor* species, resulting in a terminal/posterior and slightly upturned mouth"). Consequently, given the outstanding requirement to resolve the taxonomic identity and assist the conservation of the hump-backed mahseer, the aim of this study was to 1) apply morphological and molecular analyses to test whether the hump-backed mahseer is distinct from the currently known South Indian *Tor* species, and whether it is conspecific with *T. remadevii*, 2) provide definitive morphological characters which can be reliably used to identify this species from congeners in the field, and 3) provide notes on current knowledge relating to distribution and habitat utilization.

MATERIALS AND METHODS

Ethics Statement

Samples for the present study originated from three sources: (1) tissue samples (as fin-clips) for molecular analyses obtained from cast-net sampling and catch-and-release angling, where the specimens were released back in the wild, (2) voucher specimens collected from inland fish markets (from where dead specimens were purchased), and (3) voucher specimens collected from stream habitats inside protected areas. Permissions for collecting specimens inside protected areas were issued by the Department of Forests and Wildlife, Government of Kerala to Rajeev Raghavan (WL12-

8550/2009) and Government of Tamil Nadu (WL5 (A) /26789/2017) to A. Manimekalan. Immediately upon capture using a cast net or rod-and-line, specimens were euthanized (anesthetic overdose; tricaine methanesulfonate, MS222; following the guidelines developed by the American Society of Ichthyologists and Herpetologists (ASIH) (http:// www.asih.org/pubs/; issued 2013)). Samples of pelvic fin tissue were taken and stored in absolute ethanol. Voucher specimens were preserved whole in either 5% formalin or 70% ethanol. Institutional ethics committee of Mahseer Trust approved the design and implementation of the study (MTE/ 17/01). In-country (India) ethical approvals were not required as no experimentation or manipulations were carried out. All molecular genetic work was completed within India and no specimens or fish tissues were taken out of the country. Voucher specimens were primarily deposited in national and/or regional repositories. Individual participants appearing in Figure 8.2.1, Figure 8.2.6 andFigure 8.2.7 in this manuscript have given written informed consent (as outlined in PLOS consent form) to publish these case details.

Specimen collection and vouchers

Topotypic specimens of mahseer species were collected from various rivers in India: *Tor khudree* from River Krishna and its tributaries in Maharashtra, *Tor malabaricus* from River Chaliyar in Kerala, *T. remadevii* from River Pambar in Kerala, and the hump-backed mahseer from River Moyar in Tamil Nadu. The fishes were preserved in 10% formaldehyde and transferred to 5% formaldehyde or 70% ethanol for long-term storage. Fin clips from topotypic *Tor putitora* from River Teesta in West Bengal, and hump-backed mahseer from the River Cauvery at Dubare, Karnataka and River Moyar in Tamil Nadu were taken. In addition, fin clips from a yet-to-be identified mahseer species from River Vaitarna, Harkul Reservoir, Krishna River in Maharashtra and Forbes Sagar Lake in Karnataka (see *Tor* sp 1 in Figure 8.2.2) were also collected following their sampling by catch-and-release angling. Tissue samples were preserved in absolute ethanol. Voucher specimens are in the museum collections of the Zoological Survey of India, Kolkata (ZSI); Zoological Survey of India - Southern Regional Center, Chennai, India (ZSI-SRC); Zoological Survey of India - Western

Regional Center, Pune, India (ZSI-WGRS); Kerala University of Fisheries and Ocean Studies, Kochi, India (KUFOS); Department of Aquatic Biology and Fisheries, University of Kerala, Thiruvananthapuram, Kerala (DABFUK); and in the private collections of J.D. Marcus Knight (MKC).

Comparative material examined for morphometric analysis

Tor malabaricus: 5 ex, MKC 450, 196.6–231.7mm SL, Ivarnadu, Payaswini River, Karnataka, India (12.522°N & 75.425°E); collected by A Rai, August 2014.

Tor kulkarnii: Holotype, ZSI F2710, 220.0mm SL, Nashik, Darna River, between Sawnuri and Beladgaon, Deolali, Maharashtra, India (19.929°N & 73.856°E); collected by AGL Fraser, 29 April 1936; paratypes, ZSI F2711, 3 ex., 103.2–197.0mm SL, same data as holotype.

Tor khudree: ZSI-WRC P/2451, 1 ex, 121.9mm SL, Neera River, Bhor, Pune, Maharashtra, India (18.152°N & 73.829°E); collected by N Dahanukar and M Paingankar, 20 August 2010; ZSI-WRC P/3067, 6 ex. 106.1–171.2mm SL, Krishna River, Wai, Satara, Maharashtra, India (17.991°N & 73.786°E); collected by N Dahanukar and M Paingankar, 2 February 2011; ZSI-WRC P/3072, 5 ex. 77.4–151.2mm SL, Krishna River, Wai, Satara, Maharashtra, India (17.991°N & 73.786°E); collected by N Dahanukar and M Paingankar, 18 February 2011; ZSI-WRC P/3071, 7 ex. 51.5–66.7mm SL, Koyna River, Patan, Satara, Maharashtra, India (17.367°N & 73.903°E); collected by N Dahanukar and M Paingankar, 1 July 2007.

Morphometric analysis

Point to point measurements were made using digital calipers, to the nearest 0.1 mm, based on standard methods employed for cyprinid fishes (Armbruster 2012) and *Tor* mahseer (ZiMing C & JunXing 2014). Morphometric data used in the study is available online on figshare (https://doi.org/10.6084/m9.figshare.6085982). Statistical analysis of the morphometric data was performed on size-adjusted measurements of subunits of the body expressed as proportions of standard length and subunits of head expressed as proportions of head length. The null hypothesis that the data were multivariate-normal was checked (Doornik & Hansen 2008). Multivariate Analysis of Variance (MANOVA) was performed to test whether the populations of different species (see comparative material examined) formed significantly different clusters (Huberty & Olejnik 2006) using Pillay's trace statistic (Harris 2001). Mahalanobis distances (Harris 2001 between pairs of individuals were calculated and used for computing Fisher's distances (distance between the centroids of the clusters, divided by the sum of their standard deviations) between two clusters to check if the species clusters were significantly different from each other. Statistical analyses were performed in PAST 3.16 (Hammer et al. 2001).

Molecular analysis

DNA extraction, PCR amplification for cytochrome oxidase subunit 1 (cox1) gene and sequencing protocols were as per (Ali et al. 2013). Sequences were checked using BLAST (Altschul, et al. 1990) and the sequences generated as part of this work deposited in GenBank (S1 Table). *Neolissochilus* species were used as outgroup based on earlier study (Nguyen et al. 2008). Gene sequences were aligned using MUSCLE (Edgar, 2004), and raw (p) distances for cox1 between pairs of sequences were calculated in MEGA 7 (Kumar et al. 2016). The best-fit partition model and the substitution model was found using the IQTree software (Nguyen et al. 2015) based on the Bayesian Information Criterion (BIC) (Chernomor et al. 2016; Kalyaanamoorthy et al. 2017). Maximum likelihood analysis based on best partition scheme was performed in IQ-Tree (Kumar et al. 2016) with ultrafast bootstrap support for 1000 iterations (Minh et al. 2013). The phylogenetic tree was edited in FigTree v1.4.2 (Rambaut 2009).

RESULTS

Molecular analysis

The results suggested that the best partition scheme was Tamura & Nei's (Tamura & Nei 1993) model with invariant sites (TN+I, BIC = 3622.967, lnL = -1580.211, df = 71) for combined partition of all three codon positions. Topotypic *T. remadevii* formed a monophyletic clade with the hump-backed mahseer collected from widely distributed populations from within the Cauvery River system (Figure 8.2.2; Table 5.2.1). Genetic distance between *T. remadevii* and other species of *Tor* from peninsular India ranged between 2.3 and 4.6% (Table 8.2.1).

Table 8.2.1. Pairwise percentage raw (p) genetic distances between *Tor* species.

	[1]	[2]	[3]	[4]	[5]	[6]
Tor remadeviii [1]	0.0–0.0					
Tor malabaricus [2]	2.3–2.8	0.3–0.3				
Tor khudree [3]	2.7–3.2	1.6–2.0	0.0–0.0			
Tor putitora [4]	2.7–4.3	2.0–3.5	2.2–3.0	0.0–1.0		
Tor sp2 [5]	3.3–4.6	2.1–3.4	3.1–3.8	1.1–2.2	0.0–0.4	
Tor sp1 [6]	2.8–3.6	1.8–3.0	2.8–3.3	2.4–2.9	2.8–3.4	0.0–0.0

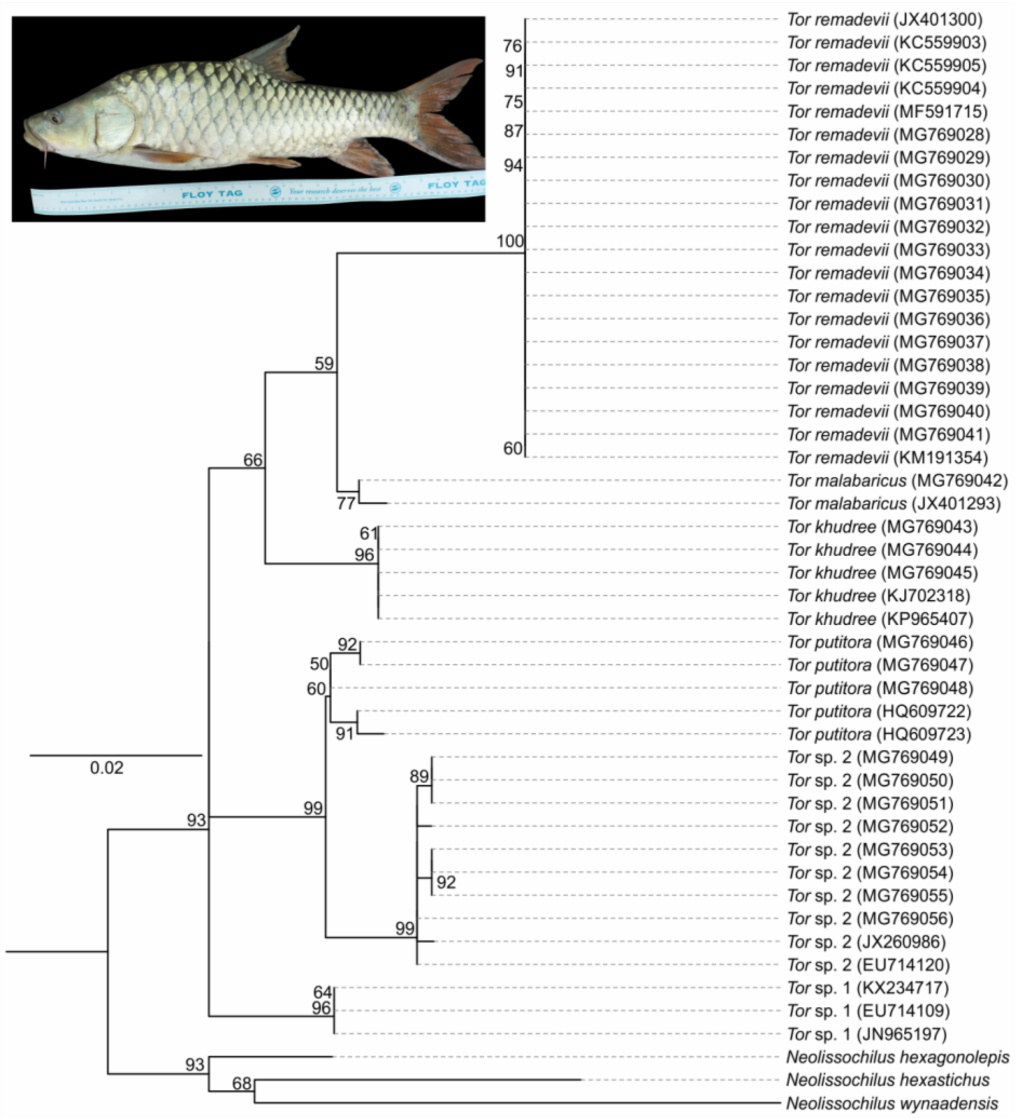


Figure 8.2.2. Maximum likelihood phylogenetic tree based on cox1 sequences of mahseer species occurring in India (*Tor* sp 1 represent individuals not matching any of the described species from India and could potentially comprise new species, *Tor* sp. 2 are sequences available in GenBank with uncertain identities, i.e. under different species names). Species of *Neolissochilius* are used as outgroup. Values along the nodes are percentage bootstraps for 1000 iterations.

Morphometrics

Morphometric data were multivariate normal (Doornik and Hansen omnibus, Ep = 55.11, P = 0.168). The four peninsular Indian species of *Tor* formed distinct clusters (Figure 8.2.3), with *T. remadevii* distinguished based on comparatively larger pre-anal length, head length, pre-ventral length, pre-pectoral length and pre-dorsal length, and comparatively smaller dorsal to caudal length, head length and inter-orbital length (Table 8.2.2). The specimens that make up the *T. remadevii* group/clade includes the type material of the species (ZSI-WGRS V/F 13119a and 13119b) as well as freshly collected specimens from the River Moyar (see section on comparative material below; Table 8.2.3) (ZSI-SRS F 9145, 9148, 9149, 9150).

Table 8.2.2. Factor loading on the first two axes of discriminant analysis.

Character	Axis 1	Axis 2
Head length	-0.19	0.08
Snout length	0.08	-0.12
Inter orbital length	0.32	0.11
Eye diameter	0.18	0.06
Head depth	0.09	-0.22
Head width	0.41	-0.40
Pre-dorsal length	-0.11	-0.02
Dorsal to caudal distance	0.64	0.07
Pre-pectoral length	-0.16	0.01
Pre-ventral length	-0.18	0.00
Pre-anal length	-0.22	0.05
Caudal-peduncle length	-0.03	-0.07
Caudal-peduncle depth	0.03	0.01
Dorsal-fin length	-0.07	-0.01
Dorsal-fin base	0.01	-0.02
Pectoral-fin length	-0.01	0.16
Ventral-fin length	-0.01	0.13
Anal-fin length	-0.02	0.21
Anal-fin base	-0.01	0.06
Body depth (D)	0.05	-0.08
Body depth (A)	0.06	-0.03
Body width (D)	-0.01	0.14
Body width (A)	0.01	0.04

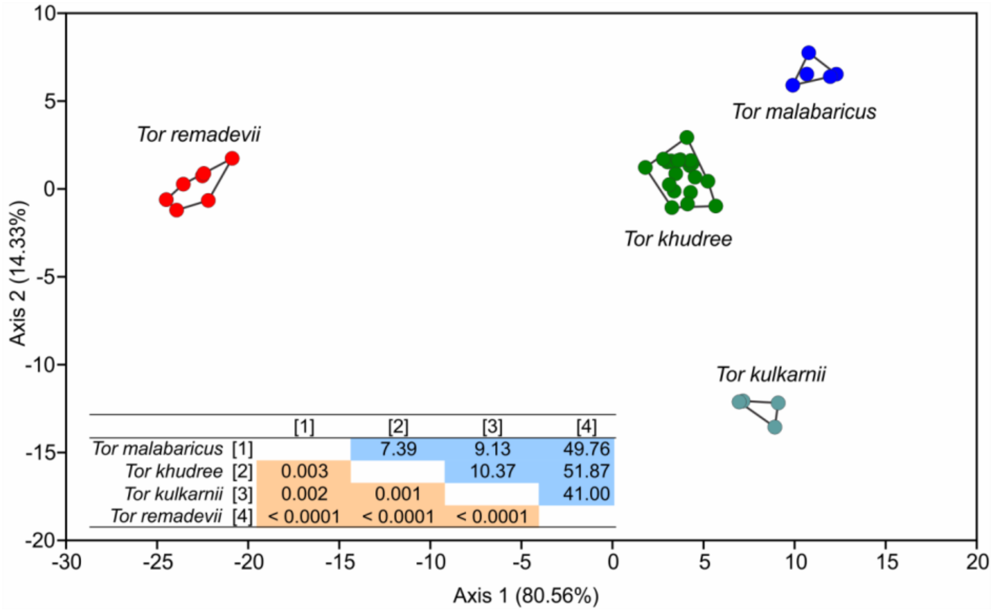


Figure 8.2.3. Discriminant analysis of the four peninsular Indian *Tor* species. Fisher's distances between clusters (blue cells) and associated p values (red cells) are provided in inset. Values in parenthesis are the percentage variation explained by each discriminant axis.

Taxonomy

Tor remadevii Kurup & Radhakrishnan 2007

(Figure 8.2.1and Figure 8.2.4–Figure 8.2.6)

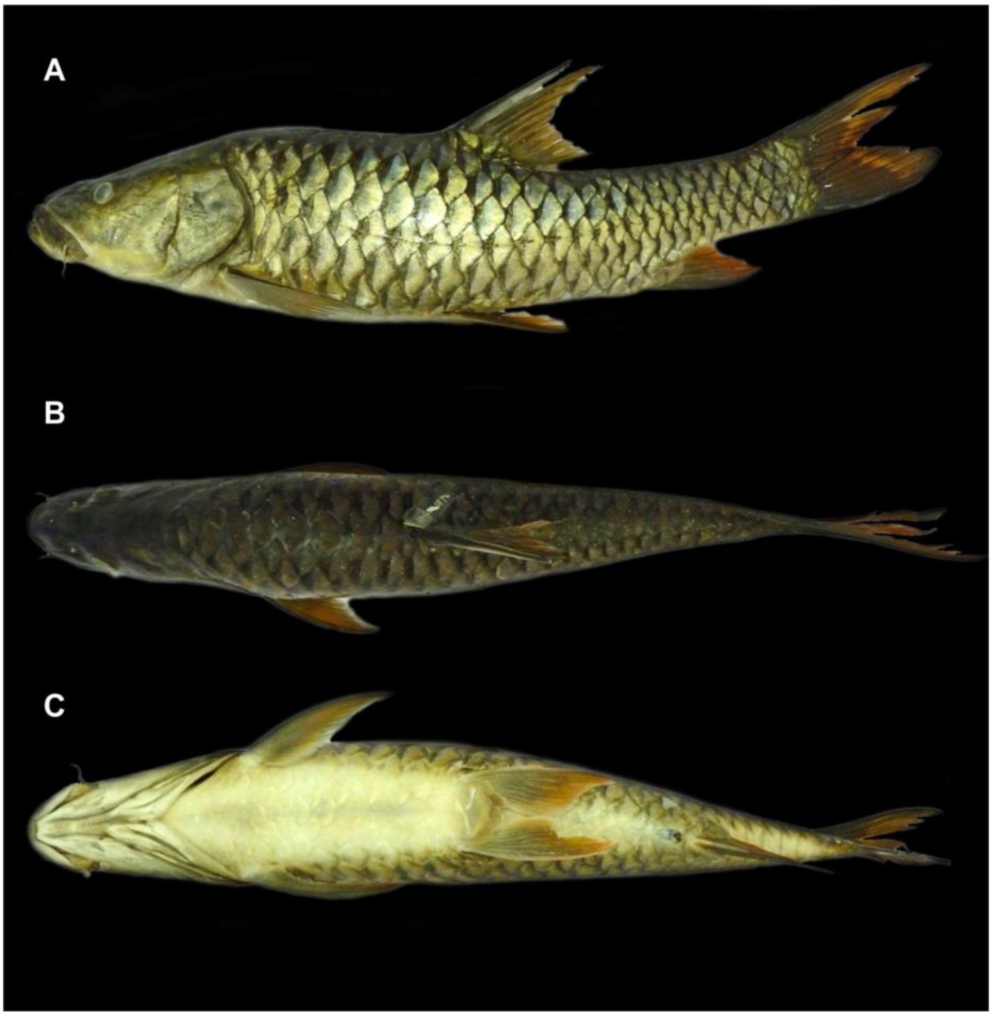


Figure 8.2.4. Lateral (A), dorsal (B) and ventral (C) view of *Tor remadevii* (ZSI F-9150, 487 mm SL) collected from the River Moyar, India.

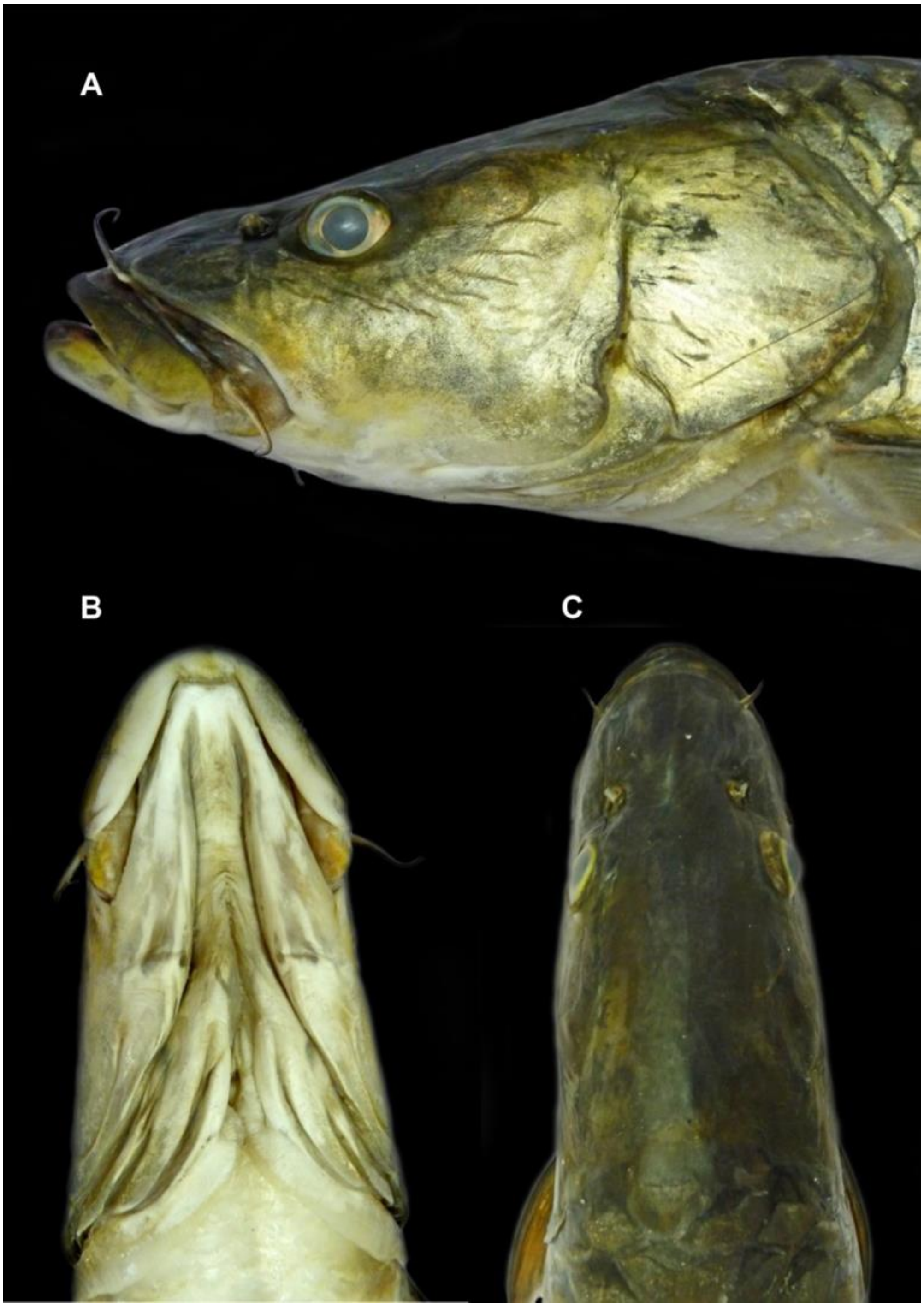


Figure 8.2.5. Lateral (A), ventral (B) and dorsal (C) view of the head region of *Tor remadevii* (ZSI F-9150, 487 mm SL) collected from the River Moyar, India.

Figure 8.2.6. Freshly caught adult *Tor remadevii* from the River Moyar, India, showing the characteristic orange coloured fins

Material Examined

Type material: ZSI-WGRS V/F 13119a (holotype) and 13119b (paratypes), 3 ex, 168.00-217.063mm SL, River Pambar, Champakkad, Kerala, India; collected by KV Radhakrishnan, 18 May 2004.

Additional material: ZSI-SRS F 9145, 9148, 9149, 9150, 4ex, 356–487mm SL, River Moyar, Thengumarahada, Tamil Nadu, India (11.614°N & 76.740°E; 474m ASL); collected by A Manimekalan, 6-7 October 2017; KUFOS-PK-2016.100.1, 1ex, 84mm SL, Pambar River, Chinnar Check Post, Chinnar Wildlife Sanctuary, Kerala, India (10.353°N, 77.216ºE, 454m ASL); collected by P. Krishnankutty, 12 October 2016.

Diagnosis

Tor remadevii can be distinguished from all its congeners by the following combination of characters: large adult body size (≥1500mm Total Length/TL and 45kg), dorsal orientation of eyes not visible from ventral aspect, shorter inter-orbital distance (7.1–9.6% of Standard Length/SL), a distinctive kink in the profile of the pre-opercle and a well-developed mandible extending to either equal distance or anterior of the maxilla, resulting in a terminal or slightly superior mouth position (Figure 8.2.5).

Description

A large sized *Tor* attaining a maximum size of 1500mm TL. For general shape and appearance see Figure 8.2.1– Figure 8.2.2 and Figure 8.2.4–Figure 8.2.6. Morphometric data are provided in Table 5.2.1.

Table 8.2.3. Morphometric data of *Tor remadevii* type and comparative material.

		Paratypes		Comparative material (ZSI-SRS)			
Characters	Holotype	#1	#2	F9148	F9149	F9150	F9145
Standard length (SL, mm)	217.1	194.1	168.0	356.0	369.0	487.0	572.0
Head length (HL, mm)	66.0	63.0	60.5	112.8	117.2	159.0	182.4
%SL							
Head length	30.4	32.5	36.0	31.7	31.8	32.6	31.9
Pre-dorsal length	54.4	52.1	57.1	56.2	51.5	55.0	54.9
Dorsal to caudal distance	30.4	33.0	33.3	33.7	36.3	36.3	32.3
Pre-pectoral length	29.0	31.4	34.0	30.9	29.6	30.3	30.2
Pre-ventral length	53.5	56.8	58.3	58.4	58.3	57.7	56.5
Pre-anal length	82.5	88.8	82.2	84.3	84.6	84.2	81.3
Caudal-peduncle length	19.8	24.2	24.1	17.9	16.7	18.3	15.4
Caudal-peduncle depth	12.0	12.4	13.1	10.8	9.1	10.4	9.9
Dorsal-fin length	27.2	29.4	30.4	23.6	23.3	21.1	21.0

Dorsal-fin base	14.7	15.0	14.3	12.5	12.6	11.3	12.6
Pectoral-fin length	21.2	21.1	20.3	18.5	19.3	19.5	20.1
Ventral-fin length	18.9	18.6	19.1	17.0	17.2	17.2	16.6
Anal-fin length	20.8	20.7	19.7	16.0	18.3	17.6	18.2
Anal-fin base	5.6	7.3	7.2	7.7	7.2	7.2	7.1
Body depth (D)	26.7	28.9	31.6	25.9	26.5	24.5	24.8
Body depth (A)	17.1	19.1	19.1	17.4	16.1	15.9	15.8
Body width (D)	14.0	14.4	13.7	14.6	14.2	15.1	16.2
Body width (A)	9.7	8.8	8.4	8.6	8.3	9.6	11.7
% HL							
Snout length	30.4	32.7	31.5	32.0	29.0	30.6	29.3
Inter-orbital length	28.9	20.7	28.2	24.0	22.6	21.7	23.5
Eye diameter	21.3	19.1	19.9	14.1	14.5	12.2	11.9
Head depth	57.6	50.8	52.9	71.4	76.1	69.9	75.6
Head width	41.0	36.5	33.7	43.0	41.6	46.3	48.2

Consistent with the common name, the dorsal profile of *T. remadevii* exhibits a prominent hump originating above the pre-opercle and extending to the origin of the dorsal fin. Dorsal fin with 4 unbranched and 9 branched rays, the fourth unbranched ray forming a strong smooth spine. Dorsal-fin origin directly above the pelvic-fin origin. Pelvic fin with one un-branched and 7–8 branched rays. Anal fin with two un-branched and five branched rays. Pectoral fin with one un-branched and 14–15 branched rays. Lateral line complete, with 24–29 scales. Transverse scales from dorsal-fin origin to ventral-fin origin ½3/1/2½. Pre-dorsal scales 7–8. In contrast with the description (Kurup & Radhakrishnan 2007), dorsal-fin height less than and not exceeding 91% of dorsal body-depth. Consistent with other species of *Tor*, pharyngeal teeth display a 5,3,2:2,3,5 ratio.

Colouration

Live specimens of *T. remadevii* from the River Moyar display contrasting dorsal and lateral body colouration, from deep bronze to metallic greens.

Bright orange fins (Figure 8.2.6) were consistent in all specimens examined. Photographic records captured by anglers from the main stem of the River Cauvery exhibit body colouration ranging from silver to deep bronze, with orange colouration of fins always evident in caudal fin as a minimum. Colour of the remaining fins range between deep orange and bluish grey. With the exception of fin-colour, observed variations suggest that body colouration may not be a reliable diagnostic character.

Distribution

Tor remadevii is currently known only from the eastward flowing River Cauvery and its tributaries including the Moyar, Kabini, Bhavani and the Pambar, in the Western Ghats Hotspot of peninsular India (Figure 8.2.7).

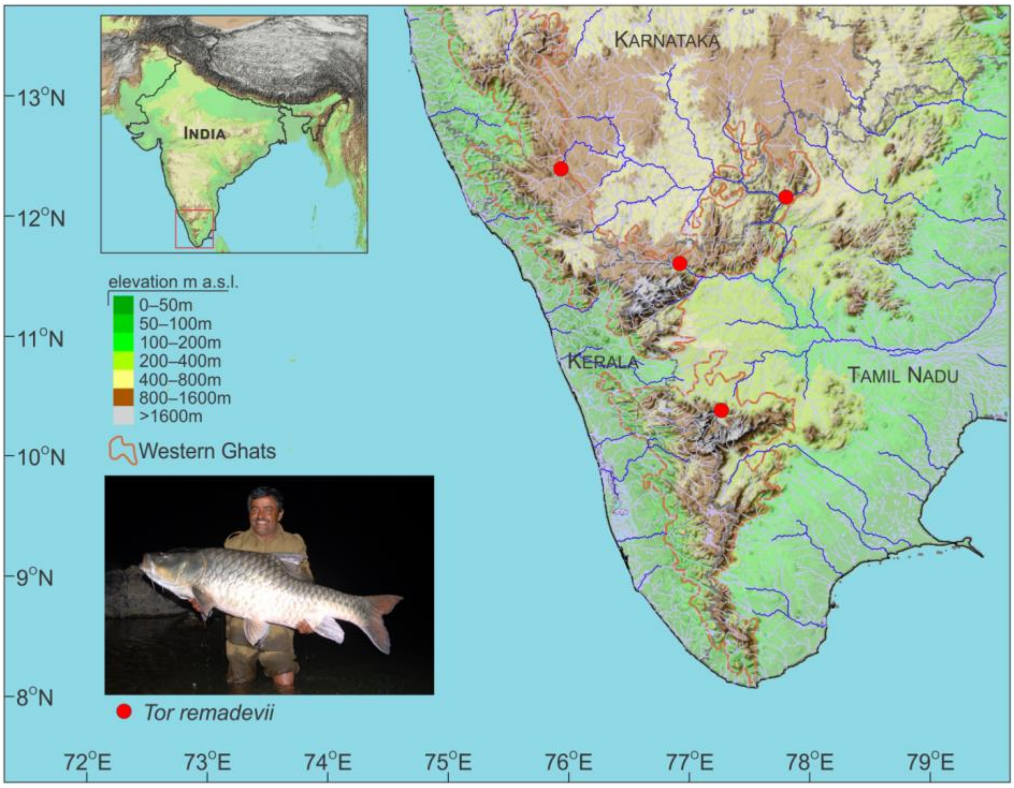


Figure 8.2.7. Collection locations of *Tor remadevii* from the tributaries of the River Cauvery, India

Habitat

While functional habitats are yet to be elucidated, *T. remadevii* inhabits the middle to upper reaches of the River Cauvery and some of its tributaries. Mesohabitat utilization is known to incorporate shallow high velocity rapids to deep, slow flowing pools, with substrates typically composed of bedrock and boulders (Figure 8.2.8).

Figure 8.2.8. Typical habitat of *Tor remadevii* in the River Moyar, India

DISCUSSION

These results confirm that the hump-backed mahseer, an iconic species that can be classed as mega-fauna on account of its large body size, is genetically distinct from other South Indian *Tor* fishes and is conspecific with *T. remadevii*. In addition to their potentially large adult body sizes, they can be distinguished from other *Tor* fishes by definitive morphological characters including their inter-orbital distances, distinctive kink in the pre-opercle, a well-developed mandible and orange colouration of the caudal fin. These results also reveal that *T. remadevii* only occurs in the River

Cauvery basin, and thus appears to be endemic with a limited distribution. Given the on-going threats to their populations in the Cauvery (Pinder et al. 2015a), these results highlight that despite their iconic status, *T. remadevii* is imperiled and urgent conservation assessments and actions are needed forthwith.

The first documented record of the hump-backed mahseer in scientific literature dates back to 1849, when British naturalist Thomas Jerdon (Jerdon 1849) mentioned collecting from Seringapatanam (=Srirangapatanam) in the River Cauvery, a juvenile specimen of a mahseer that grows to enormous sizes, which he identified as *Barbus megalepis*. Later, in a classical work on angling in India (Thomas 1873), Henry Sullivan Thomas characterized this fish as having a deeper body and higher back and called it the Bawwany mahseer, or 'Barbus tor'. Subsequent workers (Hora 1943a, 1943b; Sen & Jayaram 1982; Jayaram 1997) considered Jerdon's and Thomas' fish to be synonymous with *Barbus mussullah* Sykes, and called it the hump-backed mahseer (Menon 1992).

The identity and generic placement of *Barbus mussullah* Sykes, which was long unclear, having been considered a synonym of *Cyprinus curmuca* Hamilton, or a species of *Tor* Gray, was clarified to be a species of *Hypselobarbus* Bleeker and the identity stabilized by the designation of a neotype (Knight et al., 2013, 2014). However, Knight et al. (2013, 2014) also brought attention to the fact that the identity of *Barbus* (*Tor*) *mussullah* sensu Hora (1943a,b) still remained to be elucidated. Hora's use of coloration and local knowledge (including local names) to characterize this species (Hora 1946a) was unreliable, as fishes often have a greater variety of local names than any other group of animals (Spence & Prater 1932), with the same name being used for different species and different names being used for the same species. Although there was uncertainty in the use of vernacular names, Hora (1946a) distinguished the high-backed species, which he called *T. mussullah,* from *T. khudree* sensu Sykes.

In their work, Knight et al. (2013, 2014) also drew attention to a *Tor* specimen in the unregistered, reserve collections in the Zoological Survey of India, Southern Regional Center, Chennai (ZSI-SRS), labeled *Tor neilli* and originating from the River Krishna at Satara, Maharashtra with a characteristic high back and 24 scales in the lateral series. Knight et al. (2013) speculated that this could be the species which Hora (1946a) considered as *T. mussullah*. Quoting Day's description of *T. neilli* from the River Tungabhadra at Kurnool (Day 1878), part of the Krishna River basin (from where Hora (1946a) collected his *T. mussullah*), as a large species of mahseer with tubercles on its snout. His illustration of quite a deep-bodied fish, and opinion that this species sometimes has reddish fins, Knight et al. (2013) suggested that in the event of *T. mussullah* sensu Hora (1946a, 1946b) is found to be a valid, the name *T. neilli* should be considered for it.

Comparison of topotypic specimens and/or type material of valid mahseer species of peninsular India (*T. malabaricus*, *T. khudree* and *T. remadevii*) with specimens of the hump-backed mahseer collected from River Cauvery and its tributaries revealed striking similarities between the hump-backed mahseer and *T. remadevii* in morphometrics, meristics and mitochondrial DNA (cox1). The *Tor* specimens from the Tungabhadra, a tributary of the Krishna matched topotypic *T. khudree* and not the specimens collected in the various tributaries of the Cauvery in their genetic make-up. *Tor neilli* is therefore treated as a junior synonym of *T. khudree*, while *T. remadevii* is considered as a valid species restricted to the Cauvery River system including its northern and southern tributaries. The name 'Tor moyarensis' propagated in popular literature is a 'nomen nudum' (Raghavan et al. 2013).

The first mention of the name *Tor remadevii* was made in 2007, when Kurup & Radhakrishnan's description was published in the proceedings of a global mahseer symposium held in Malaysia (Kurup &, Radhakrishnan 2007). Perhaps, because of the limited circulation of this publication, the description went unnoticed, and the same authors published a second paper in the year 2011 (Kurup & Radhakrishnan 2011) reproducing the bulk of the original text, probably with a view to make a 'formal description' in a peer reviewed journal. However, the description made in 2007, satisfies all the 'criteria of availability' as per the International Code on Zoological Nomenclature (ICZN) (Articles 10, 11, 13 and 16), and therefore the paper published in 2011 (Kurup & Radhakrishnan 2011) is merely a re-description and irrelevant to nomenclature. The original year of publication is 2007, from when the name *T. remadevii* became available.

The Catalog of Fishes (Eschmeyer et al. 2017) mentions that the species epithet should be 'remadeviae' and not 'remadevii' because of the reason that the species was named for K. Rema Devi, (a feminine name). However, the ICZN in its Article 31.2.3 states "If a species-group name (or, in the case of a compound species-group name, its final component word) is not a Latin or latinized word [Articles 11.2, 26], it is to be treated as indeclinable for the purposes of this Article, and need not agree in gender with the generic name with which it is combined (the original spelling is to be retained, with ending unchanged; also see Article 34.2.1)". Therefore, the correct usage should be *Tor remadevii*.

Having been first brought to the attention of the scientific community in the year 1849 (Jerdon 1849), and the recreational angling community in the year 1873 (Thomas 1873), a century and half has since passed before the iconic hump-backed mahseer is afforded a scientific name. With the name now assigned to *T. remadevii* and the previously reported imperiled status of this mega-fauna (Pinder el al. 2015a), there is an immediate urgency to assess its extinction risk based on the IUCN Red List Categories and Criteria, with a view to affording this iconic species appropriate protection and accelerating the conservation agenda to secure the future sustainability of remaining populations from severe and escalating anthropogenic threats (Pinder & Raghavan 2013).

ACKNOWLEDGEMENTS

We are most grateful to a number of individuals and organizations for their contribution of knowledge and assistance in assembling this taxonomic jigsaw. In particular, we thank Arunkumar Anbu Aravazhi for field support; AJT Johnsingh (Nature Conservation Foundation); Steve Lockett (Mahseer Trust/MT) and Derek D'Souza (MT and International Game Fishing Association) for their extensive support in exploring the Cauvery catchment to locate the hump-backed mahseer; Martin and Andy Clark of the Trans World Fishing Team for providing historical photographs; Sandeep Chakrabarti and Naren Sreenivasan of The Wildlife Association of South India (WASI) for historic input/field support; and members of the Coorg Wildlife Society (CWS) for permitting research access to the upper Cauvery; Unmesh Katwate (Bombay Natural History Society), Mandar Paingankar (Government College, Gadchiroli) and Anvar Ali (Kerala University of Fisheries and Ocean Studies/KUFOS) for their help in surveying the Krishna and the Chaliyar catchment; Remya L Sundar (KUFOS) for help in examining the types of *T. remadevii*; The Director, Zoological Survey of India (ZSI), Kolkata, the officer-in-charge at ZSI Regional Centers in Pune (ZSI-WRC), Kozhikode (ZSI-WGRC), and Shrikant Jadhav, Scientist ZSI-WRC for help with registering and examining the specimens at ZSI museums; Rohan Pethiyagoda for his excellent advice on taxonomic and nomenclatural issues, and Ralf Britz and Oliver Crimmen (Natural History Museum, London) for useful discussions and facilitating access to specimens. Two anonymous reviewers provided useful comments that improved the manuscript.

REFERENCES

Ali, A., Dahanukar, N., Kanagavel, A., Philip, S., & Raghavan, R., 2013. Records of the endemic and threatened catfish, *Hemibagrus punctatus* from the southern Western Ghats with notes on its distribution, ecology and conservation status. *J Threat Taxa* 5 (11), 4569–4578.

Altschul, S.F., Gish, W., Miller, W., Myers, E.W., & Lipman, D.J., 1990. Basic local alignment search tool. *J Mol B*iol. 215, 403–410.

Armbruster, J.W., 2012. Standardized measurements, landmarks, and meristic counts for cypriniform fishes. *Zootaxa* 3586, 8–16.

Carrizo, S.F., Jähnig, S.C., Bremerich, V., Freyhof, J., Harrison, I., He, F., 2017. Freshwater megafauna: flagships for freshwater biodiversity under threat. *Biosci* 67(10), 919–927. https://doi:10.1093/biosci/bix099

Chernomor, O., von Haeseler, A., & Minh, B.Q., 2016. Terrace aware data structure for phylogenomic inference from supermatrices. *Syst Biol*. 65, 997-1008.

Day, F., 1878. The Fishes of India; being a natural history of the fishes known to inhabit the seas and freshwaters of India, Burma and Ceylon, part 4. William Dawson & Sons Ltd., London, pp. i–ix + 553–778, pls. 134–195.

Doornik, J.A., & Hansen, H., 2008. An omnibus test for univariate and multivariate normality. *Oxford Bulletin of Economics and Statistics* 70, 927–939.

Edgar, R.C., 2004. MUSCLE: multiple sequence alignment with high accuracy and high throughput. *Nucl Acid Res*. 32, 1792–1797.

Eschmeyer, W.N., Fricke, R., & van der Laan, R. (eds)., 2017. Catalog of Fishes: Genera, Species, References. 2017. http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp. [Accessed July 2017].

Hammer, Ø., Harper, D.A.T., & Ryan, P.D., 2001. Past: Paleontological Statistics Software Package for education and data analysis. *Paleontología Electrónica* 4, 1–9.

Harris, R.J., 2001 A primer for multivariate statistics. Third Edition. Lawrence Erlbaum Associates Publishers, London.

He, F., Zarfl, C., Bremerich, V., Henshaw, A., Darwall, W., 2017. Disappearing giants: a review of threats to freshwater megafauna. *WIREs Water*. e1208.

Hora, S.L., 1943a. The game fishes of India: XVI. The mahseers or the large scaled barbels of India. 9. Further observations on mahseers from the Deccan. *J Bom Nat Hist Soc*. 44(1), 1–8.

Hora, S.L., 1943b. The game fishes of India: XVII. The mahseers or the large scaled barbels of India. 10. On the specific identity of Jerdon's species of mahseer from Southern India. *J Bom Nat Hist Soc*. 44(2), 164–168.

Huberty, C.J., & Olejnik, S., 2006. Applied MANOVA and Discriminant Analysis. 2nd Edition. John Wiley and Sons, NJ: 488 p;

Jayaram, K.C., 1997. Nomenclatural and systematic status of *Barbus mussullah* Sykes, 1839. *J Bom Nat Hist Soc.* 94, 48–55.

Jerdon, T., 1849. On the fresh-water fishes of southern India. (Continued from p. 149.). *Madras Journal of Literature and Science* 15 (2), 302–346.

Jung, S.B., 2012. Subhan & I: My adventures with the angling legend of India. Roli Books. 223 p.

Kalyaanamoorthy, S., Minh, B.Q., Wong, T.K.F., von Haeseler, A., & Jermiin, L.S., 2017. ModelFinder: Fast model selection for accurate phylogenetic estimates. *Nat Method*. 14. 587-589.

Knight, J.D.M., Rai, A., & D'Souza, R.K.P., 2013. On the identities of *Barbus mussullah* Sykes and *Cyprinus curmuca* Hamilton with notes on the status of *Gobio canarensis* Jerdon (Teleostei: Cyprinidae). *Zootaxa* 3750, 201–215.

Knight, J.D.M., Rai, A., & D'Souza, R.K.P., 2014. A further note on the identity of *Barbus mussullah* Sykes (Teleostei: Cyprinidae). *Zootaxa* 3821(2), 280–284.

Kurup, B.M., & Radhakrishnan, K.V., 2007. *Tor remadevii*, a new species of mahseer from Kerala (South India), and distribution and abundance of

Tor spp. in the river systems of Kerala. In. Mahseer, the biology, culture and conservation (Siraj, S.S., Christianus, A., Kiat, N.C., De Silva, S.S. eds). Proceedings of the International Symposium on the mahseer, 29th to 30th March 2006, Kuala Lumpur, Malaysia (Malaysian Fisheries Society Occasional Publication No 14, Kuala Lumpur); 236 p.

Kurup, B.M., & Radhakrishnan, K.V., 2011. *Tor remadevii*, a new species of *Tor* (Gray) from Chinnar Wildlife Sanctuary, Pambar River, Kerala, Southern India. *J Bom Nat Hist Soc*. 107, 227–230.

Kumar, S., Stecher, G., & Tamura, K., 2016. MEGA7: Molecular Evolutionary Genetics Analysis version 7.0 for bigger datasets. *Mol Biol Evol*. 33, 1870–1874.

Last, P.R., Manjaji-Matsumoto, B.M., 2008. *Himantura dalyensis* sp. nov., a new estuarine whipray (Myliobatoidei: Dasyatidae) from northern Australia. In: Descriptions of New Australian Chondrichthyans. Hobart: *CSIRO Marine and Atmospheric Research* 283–291.

Menon, A.G.K., 1992. Taxonomy of mahseer fishes of the genus *Tor* Gray with description of a new species from the Deccan. *J Bom Nat Hist Soc*. 89(2), 210–228.

Minh, B.Q., Nguyen, M.A.T., & von Haeseler, A., 2013. Ultrafast approximation for phylogenetic bootstrap. *Mol Biol Evol*. 30, 1188–1195.

Nguyen, T.T., Na-Nakorn, U., Sukmanomon, S., & ZiMing, C., 2008. A study on phylogeny and biogeography of mahseer species (Pisces: Cyprinidae) using sequences of three mitochondrial DNA gene regions. *Mol Phylogenet Evol* 3, 1223–1231.

Nguyen, L.T., Schmidt, H.A., von Haeseler, A., & Minh, B.Q., 2015. IQ-TREE: A fast and effective stochastic algorithm for estimating maximum likelihood phylogenies. *Mol Biol Evol.* 32, 268–274.

Pinder, A.C., & Raghavan, R., 2013. Conserving the endangered mahseers (*Tor* spp.) of India: the positive role of recreational fisheries. *Curr Sci* 104(11), 1472–1475.

Pinder, A.C., Raghavan, R., & Britton, R.J., 2015a. The legendary humpback mahseer (*Tor* sp.) of India's River Cauvery: an endemic fish swimming towards extinction. *Endang Species Res.* 28, 11–17.

Pinder, A,C,, Raghavan, R., & Britton, R.J., 2015b. Efficacy of data from sport angler catches as a monitoring and conservation tool for the flagship mahseer fishes (*Tor* spp.) of Southern India. *Aquat Conserv: Mar & FW Ecosyst*. 25(6), 829–838. https://doi.org/10.1002/aqc.2543

Raghavan, R., Dahanukar, N., Philip, S., Krishnakumar, K., & Ali, A., 2013. Phantom references, nomina nuda and the dilemma of freshwater fish taxonomy in India. *Curr Sci*. 104(10), 1277–1279.

Rambaut, A., 2009. FigTree. v1. 3.1. 2009. Available from: http://tree.bio.ed.ac.uk/software/figtree [Accessed Nov 2016].

Sen, T.K., Jayaram, K.C., 1982. The mahseer fishes of India – a review. *Rec Zool Surv Ind. Misc Publ.* Occasional Paper No 39, 38 p.

Spence, R., & Prater, S.H., 1932. Game fishes of Bombay, the Deccan and the neighboring districts of the Bombay Presidency. J Bom Nat Hist Soc. 36, 29–66.

Stewart, D.J., 2013. A new species of Arapaima (Osteoglossomorpha: Osteoglossidae) from the Solimoes River, Amazonas State, Brazil. *Copeia* 2013(3), 470–476.

Tamura, K., & Nei, M., 1993. Estimation of the number of nucleotide substitutions in the control region of mitochondrial DNA in humans and chimpanzees. *Mol Biol Evol*. 10(3), 512–526.

Thomas, H.S., 1873. The Rod in India. Stolz, Mangalore, 319 p.

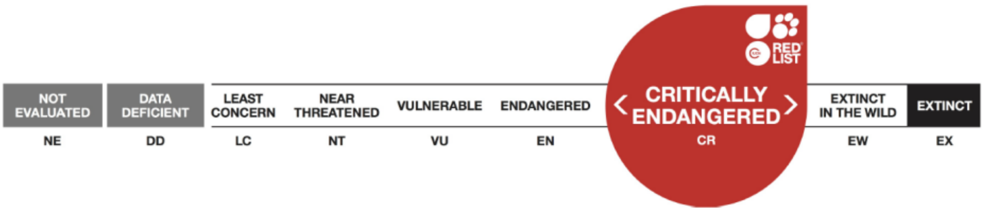
Wildlife, 1977. The monsters of Karnataka. *Wildlife Journal of the Wildlife Association of South India (WASI)* 1977, 1–8.

ZiMing, C., & JunXing, Y., 2004. A new species of the genus *Tor* from Yunnan, China (Teleostei: Cyprinidae). *Environmental Biology of Fishes* 70, 185–191.

8.3 Submission 8

IUCN Red List of Threatened Species: Tor remadevii, Hump-backed Mahseer

Pinder, A.C., Katwate, U., Dahanukar, N. & Harrison, A.



View on www.iucnredlist.org

Taxonomy

Kingdom	Phylum	Class	Order	Family
Animalia	Chordata	Actinopterygii	Cypriniformes	Cyprinidae

Taxon Name: *Tor remadevii* Madhusoodana Kurup & Radhakrishnan, 2011

Common Name(s):

- English: Hump-backed Mahseer

Taxonomic Source(s):

Eschmeyer, W.N. 2014. Catalog of Fishes. Updated 3 January 2014. Available at: http://research.calacademy.org/research/ichthyology/catalog/fishcatmain.asp . (Accessed: 3 Jan 2014).

Taxonomic Notes:

Kurup & Radhakrishnan (2007) described *Tor remadevii* from the Pambar, the southern-most tributary of the River Cauvery in Kerala. A re-description was subsequently published in 2010 (Kurup & Radhakrishnan 2010). While this update usefully included a line drawing of the fish, the authors still failed to include photographs, molecular evidence or congeneric morphological comparisons (using specimens). Despite these descriptive details being limited, recent research has confirmed *T. remadevii* to be conspecific with the Hump-backed Mahseer of the wider Cauvery catchment (Pinder et al. 2018).

The name 'Humpbacked Mahseer' was wrongly applied to *Hypselobarbus mussullah*, another endemic species of the Western Ghats, until Knight et al. (2013, 2014) and Pinder et al. (2018) clarified the identity and nomenclature of the Hump-backed Mahseer. The common name, 'Hump Backed Mahseer' previously available on the IUCN Red List account of *Hypselobarbus mussullah* is therefore incorrect.

Assessment Information

Red List Category & Criteria:	Critically Endangered A2abce ver 3.1
Year Published:	2018
Date Assessed:	April 19, 2018

Justification:

Tor remadevii, endemic to the River Cauvery and its tributaries in the Western Ghats Biodiversity Hotspot of peninsular India has been assessed as Critically Endangered as its populations is estimated to have been reduced by > 90% over three generations due to combined effects of illegal and unsustainable exploitation, effects of introduced taxa and decline in critical habitats. Historic records dating pre-1950s suggest these declines to be even more significant, with the species now absent from the majority of previously known sites.

Geographic Range

Range Description

Endemic and exclusively restricted to the River Cauvery catchment in South India (Pinder et al. 2018), this species is thought to have been once widespread throughout much of the River Cauvery and its major tributaries (Thomas 1873). Following a collapse in recruitment in the main river population during the mid-2000s (see Pinder et al. 2015a, 2015b), the only recent records are restricted to small pockets in the Moyar tributary in Tamil Nadu (Pinder et al. 2018), Pambar tributary in Kerala (Kurup & Radhakrishnan 2007), main Cauvery River in Coorg (from Dubare to Valnur) (Coorg Wildlife Society pers. comm.), and in the Cauvery Wildlife Sanctuary (from Shivasamudram to Mekadattu) (Wildlife Association of South India pers. comm.), and a small reach of the stream and reservoir between Pillur and Athikadavu regions of the Bhavani tributary (A.J.T John Singh pers. comm.) (

Figure 8.3.1). The Extent of Occurrence (EOO) has been estimated at 19744 km2 and the Area of Occupancy (AOO) at 64 km2. Based on the availability of suitable habitat throughout the Cauvery River System, the distribution range is known to have dramatically reduced by around 90%. Due to the intensely controlled and regulated research access to the upper reaches of the Moyar, Bhavani and Kabini tributaries, which lie within the protected area network, it is uncertain whether populations are still extant in these areas.

Country Occurrence

Native: India (Karnataka, Kerala, Tamil Nadu)

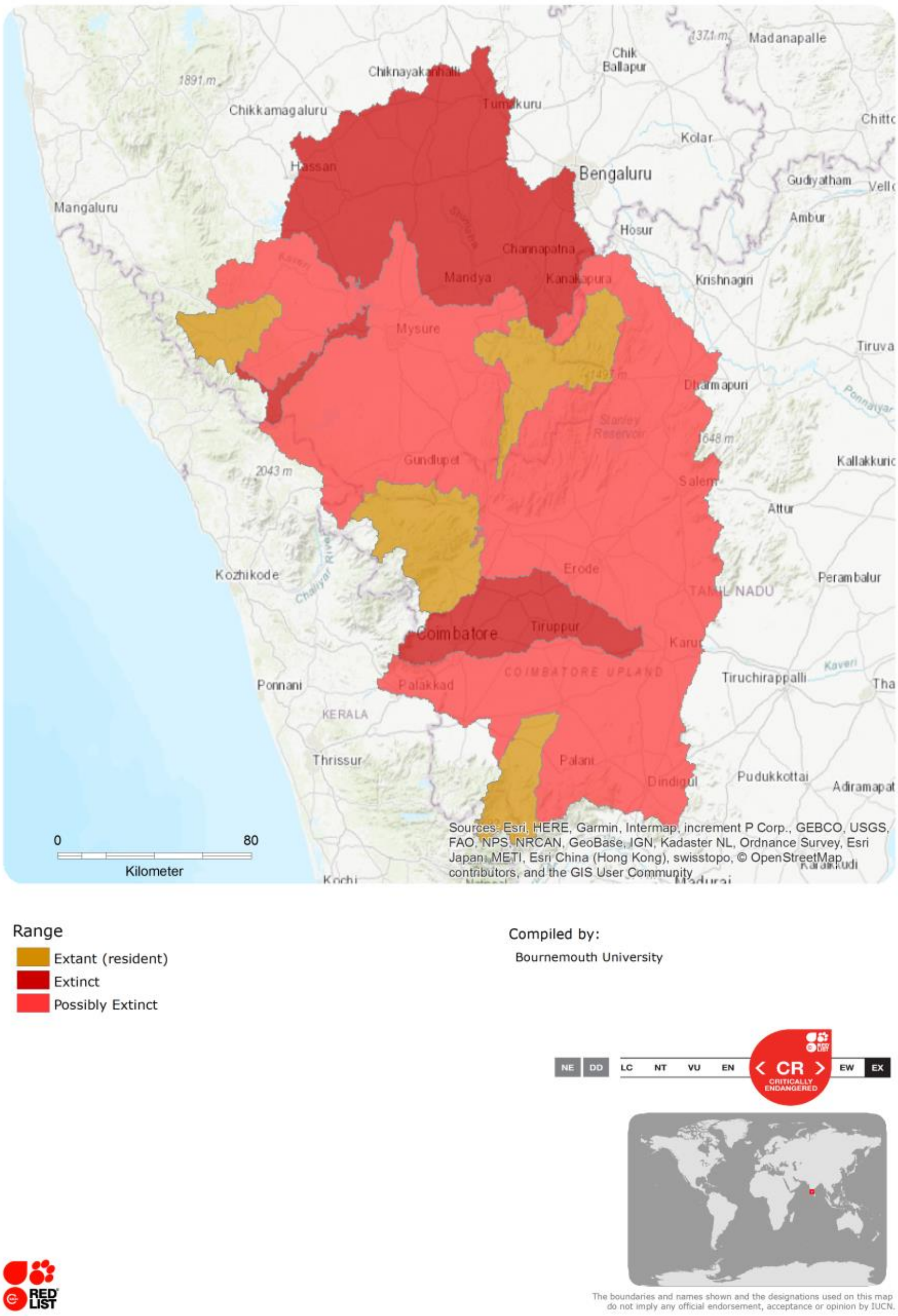


Figure 8.3.1. Distribution of *Tor remadevii*

Population

No scientific studies have been undertaken to assess population status or trends across the entire range of this species. Analysis based on catch-and-release fisheries in the main stem of the River Cauvery suggested declines greater than 90% due to lack of recruitment (Pinder et al. 2015a, 2015b). In the years 2003 and 2004 combined, a total of 174 fish were caught and released from a single fishing camp in the middle reaches of the Cauvery (currently inside the Cauvery Wildlife Sanctuary), which declined to a total of 26 fish between the years 2006 and 2012. In accounting for numbers of hours fished, the catch per unit effort (CPUE) declined from 0.038 fish/hr to 0.002 fish/hr over this period. In 2012, only two individuals were captured from this camp, after which the fishery was closed (Pinder et al. 2015a, 2015b). In the upper reaches of the River Cauvery at Coorg/Kodagu, *T. remadevii* was abundant until 2000, but since 2012 only three individuals have been recorded. In the remainder of the River Cauvery where *T. remadevii* was once abundant, the species is now absent, representing a 100% decline in population. Anecdotal information and local knowledge of fishers in the three major tributaries (Pambar, Bhavani and Moyar) suggest steady declines in catches over the last two decades (Mahseer Trust pers. obs.). In the River Pambar, targeted surveys have recorded 13 individuals in 2007, reducing to the capture of a single individual in 2017. In the River Bhavani where the species was reported to be abundant by Thomas (1873), only a single specimen has been recorded in the past 10 years. In the River Moyar, multiple surveys conducted since 2015 have recorded nine individuals from a 'single pool'. Despite evidence of strong recruitment in the main stem of the River Cauvery until 2004 (Pinder et al. 2015a, 2015b), recruitment is now limited entirely to the Moyar and Pambar tributaries, where immature specimens (n = 9) have been recorded (<40 cm TL) since 2015. Across the entire distribution range, these combined information sources suggest a minimum population decline of 90% in the last ten years. Historic records dating pre-1950s suggest these declines to be more significant, with *T. remadevii* now absent from the majority of previously known sites. Population growth and mortality parameters for *T. remadevii* are not available. However, Raghavan et al. (2011) provided these parameters for six south Indian populations of *T. khudree*. Assuming that two species of the same genus will have similar life-history associated demographic parameters, the average generation time of the species will be approximately 7 years (mean 7.06, sd 1.85). The CPUE data provided by Pinder et al. (2015b) for *T. remadevii* (as Humpback mahseer) suggests that there is a decline in the CPUE since 1998, which can be explained by an exponential function y = 0.0618*Exp(-0.265*x), $R^2 = 0.5638$, $P < 0.001$, where x is the number of years since 1998. The projected CPUE after 3 generations or 21 years since 1998 is 0.00024 fish/hr which is 99% decline from 0.02414 fish/hr in 1998. Thus, for the study area of Pinder et al. (2015a) in the middle reaches of the Cauvery, there is projected decline of 99% in three generations. There is no quantitative data available for the species from other parts of its distribution. However, given that the threats to the species are widespread, other known population of the species are also likely under similar stress. As a conservative estimate, it can be proposed that there could be more than 90% decline in three generations of *T. remadevii* throughout its range.

Current Population Trend: Decreasing

Habitat and Ecology

This species is known to occur in fast flowing rivers and demonstrated adaptations to adjoining lacustrine habitats. In rivers, adult fish have been shown to utilise foraging habitats ranging from deep slow flowing pools with a mixed substrate of sand and rock, through to high energy rapids flowing over bedrock and boulders (Pinder et al. 2018). Temporal and spatial information pertaining to functional habitats are still lacking, yet it seems highly probable that a lack of observed spawning is explained by these activities occurring during the monsoon period (June – October) (Pinder et al. 2018). Insight into the diet of these fish is restricted to the baits used by anglers confirming an omnivorous dietary spectrum, with fish being captured on live/dead fishes, lures and cereal derived pastes (Boote & Wade 1992).

Systems: Freshwater

Use and Trade

It was one of the world's most popular and iconic freshwater sport fish known from the 19th century (Thomas 1873) until the closure of the premier recreational fisheries in the middle River Cauvery in the year 2012 (Pinder et al. 2015a, 2015b). Recreational angling activity is currently restricted to non-protected areas of around 10 km river reach in Coorg/Kodagu (Karnataka) region. Subsistence fisheries occur in many of the currently known localities, and threatens populations through the use of unsustainable capture techniques (dynamiting, small-meshed nets, plant-based poisons) (Mahseer Trust pers. comm.).

Threats

This species is threatened by a range of anthropogenic stressors including habitat degradation and destruction as a result of river engineering projects, sand and boulder mining, domestic, industrial and agro-based pollution, water abstraction and unsustainable methods of harvest such as dynamiting, use of fine-meshed gears and plant-based poisons (Pinder et al. 2018). In addition, *T. remadevii* has been threatened by the introduction of the non-indigenous *T. khudree,* a species which has been demonstrated to have rapidly dispersed throughout the Cauvery catchment and has been implicated as a contributing factor in the collapse of the *T. remadevii* population in recent years (Pinder et al. 2015a, 2015b).

Conservation Actions

No conservation actions are currently in place. However, 70% of the currently known distribution range falls inside protected areas (Wildife

Sanctuaries and National Parks). However, illegal fishing often using unsustainable gears, proliferation of invasive species, and a combination of other anthropogenic threats (e.g. river fragmentation, abstraction, pollution) are known from both inside, as well as areas upstream and downstream of the protected areas, and therefore the protected areas offer no real protection to the species.

Bibliography

Boote, P. & Wade, J. 1992. *Somewhere down the crazy river: journeys in search of the giant fish. The story of the rediscovery of the Indian mahseer and the goliath tigerfish of the Congo*. Sangha Books, Swindon.

IUCN, 2018. The IUCN Red List of Threatened Species. Version 2018-2. Available at: www.iucnredlist.org. [Accessed: Nov 2018].

Knight, J.D.M., Rai, A. & D'Souza, R.K.P., 2013. On the identities of *Barbus mussullah* Sykes and *Cyprinus curmuca* Hamilton with notes on the status of *Gobio canarensis* Jerdon (Teleostei: Cyprinidae). *Zootaxa* 3750, 201-215.

Knight, J.D.M., Rai, A. & D'Souza, R.K.P., 2014. A further note on the identity of *Barbus mussullah* Sykes (Teleostei: Cyprinidae). *Zootaxa* 3821(2), 280-284.

Kurup, B.M. & Radhakrishnan, K.V., 2007. *Tor remadevii*, a new species of mahseer from Kerala (South India), and distribution and abundance of Tor spp. in the river systems of Kerala. In: S.S. Siraj, A. Christianus, N.C. Kiat and S.S. De Silva (eds), Mahseer, the biology, culture and conservation, pp. 236. Kuala Lumpur, Malaysia.

Kurup, B.M. & Radhakrishnan, K.V., 2011. Tor remadevii, a new species of *Tor* (Gray) from Chinnar Wildlife Sanctuary, Pambar River, Kerala, Southern India. *Journal of the Bombay Natural History Society* 107, 227–230.

Pinder, A.C., Manimekalan, A., Knight, J.D.M., Krishnankutty, P., Britton, J.R., Philip, S., Dahanukar, N., & Raghavan, R., 2018. Resolving the taxonomic enigma of the iconic game fish, the hump-backed mahseer from the Western Ghats biodiversity hotspot, India. *PLoS One* 13(6), e0199328.

Pinder, A.C., Raghavan, R., & Britton, R.J., 2015a. The legendary humpback mahseer (*Tor* sp.) of India's River Cauvery: an endemic fish swimming towards extinction. *Endangered Species Research* 28, 11–17.

Pinder, A.C., Raghavan, R. & Britton, R.J., 2015b. Efficacy of data from sport angler catches as a monitoring and conservation tool for the flagship mahseer fishes (*Tor* spp.) of Southern India. *Aquatic Conservation: Marine and Freshwater Ecosystems* 25(6), 829–838.

Thomas, H.S., 1873. *The Rod in India*. Stolz, Mangalore.

CHAPTER 9: FINAL SYNTHESIS - MAHSEER (*TOR* spp.) FISHES OF THE WORLD: STATUS, CHALLENGES AND OPPORTUNITIES FOR CONSERVATION

9.1 Prelude to Submission 9:

Pinder A.C, Britton, J.R., Harrison, A.J., Nautiyal, P., Bower, S.D., Cooke, S,J., Lockett, S., Everard,M., Katwate, U., Ranjeet, K., Walton, S., Danylchuk, A.J. & Raghavan, R., 2019. Mahseer (*Tor* spp.) fishes of the world: status, challenges and opportunities for conservation. *Reviews in Fish Biology and Fisheries* 29, 417-452.

Having undertaken many trips to India and visited eight of her states (many multiple times) at this time of writing, it is now clear that my initial romantasised image of a single stretch of South India's River Cauvery was viewed through 'rose tinted spectacles'. Despite being immediately made aware of the widespread and rampant poaching of fish using highly destructive methods, it was only through subsequent trips that I have personally observed the full range and intensity of anthropogenic stressors acting independently and/or in combination, that compromise (and in some cases destroy) the natural hydroecological functioning of India's rivers. While many of these threats are encompassed and comprehensively discussed within a recent review of emerging threats and persisting conservation challenges for global freshwater biodiversity (see Reid et al. 2018) and summarised in Submisison 9 (Section 9.2), this holistic symptom of the Anthropocene is in some regions threatening not just aquatic biodiversity, but also the future sustainability of the most basic yet essential ecosystem services provided by freshwater systems (e.g. drinking water and crop irrigation) that are fundamental to supporting human life (Millenium Ecosystem Assessment 2005; Darwall et al. 2018). This is particularly concerning as Reid et al. (2018), highlight, "*we are merely at the beginning* *of the ‘great acceleration’ of the Anthropocene*” and are unaware of the nature of environmental challenges likely to emerge in the coming decades.

In response to these escalating stressors, freshwater vertebrate populations have declined by more than 80% at the global scale over the past 50 years. This represents a rate of decline twice as high as recorded in terrestrial or marine systems (WWF 2016) and places freshwater fishes as one of the most threatened taxa on the planet (Cooke et al. 2002; Carrizo et al. 2013; Reid et al. 2013). Yet, due to their general invisibility from both the general public and policy makers, the plight of freshwater fishes and associated freshwater biodiversity has been referred to as the ‘quiet crisis…taking place beneath the surface of the world’s rivers and lakes’ (Richter et al. 1997) and thus afforded inadequate attention and the research needed to inform conservation requirements, particularly within developing countries harbouring rich biodiversity (Dudgeon et al. 2006; Sarkar et al. 2008; Reid et al. 2018).

Large bodied fish species (e.g. mahseers) and particularly those qualifying as megafauna (defined as exceeding a body mass of 30 kg) (Carrizo et al. 2017; He et al. 2017) often represent attractive exploitative targets due to their consumptive value to humans. Many are also apex predators, susceptible to upwardly cascading disruptions within the food chain (Cooke et al. 2012), making the largest, most visible and charismatic species both vulnerable to extinction (Power 1990) and strong indicators of ecosystem change. Akin to the ‘canary in the coal mine’ concept, freshwater fish have the potential to be used as warnings of impending impacts on human well-being from environmental change (Lynch et al. 2016). This leads us to explore the potential for *Tor* spp. as ‘focal species’ (Table 9.1.1) to help raise public awareness and support freshwater conservation (He et al. 2017).

Table 9.1.1. Focal species concepts for freshwater ecosystems (adapted from He et al. (2017))

Type	Description
Flagship	Charismatic species that could act as ambassadors for broad-scale conservation, used to raise conservation funding, and to attract public attention.
Umbrella	Species with large habitat requirements for which conservation action potentially benefits other species

Chapter 4 has already outlined the role of recreational anglers in mahseer conservation, with strong evidence presented for the hump-backed mahseer (*T. remadevii)* of South India's River Cauvery qualifying as both a 'flagship' and 'umbrella' species. This is on the basis of *T. remadevii* having previously attracted anglers from around the world, which supported a thriving ecotourism industry, and in turn afforded effective protection of 27 km of river and associated riparian habitat. In addition to direct economic benefits to local communities and the mahseer representing a regional symbol of pride, the use of funds to police the river by anti-poaching guards effectively protected all aquatic fauna from the impacts of dynamite fishing. The recent naming and Red Listing of *T. remadevii* (see Chapter 8) has since led to significant interest from key conservation organisations (e.g. WWF and the Wildlife Institute of India (WII) and the species being selected as a 'flagship' to raise funds by the soon to launch 'Project Mahseer' supported by the SHOAL initiative https://www.synchronicityearth.org/wp-content/uploads/2018/10/Shoal-2-pager-v4c.pdf. These funds will be used to support the research needed to inform the spatial ecology, critical habitat requirements and feasibility of a species recovery programme, and draw public and government attention to the holistic value and vulnerability of the River Cauvery basin. The promotion of *T. putitora* as a 'flagship' has also been explored in the Himalayan states, with stakeholders (e.g. anglers, forest managers, local communities) embracing the concept based on the charismatic body colouration of the fish, cultural pride, the economic potential of catch and release fisheries, and the potential to discourage undesired illegal activities (such as sand mining and logging) within the floodplain and riparian zone (Gupta et al. 2014). Although not validated to date, due to their considerable migration distances, the presence of self sustaining populations of *T. putitora* (and other *Tor* spp.) in a river system also confirms that other potatodromous species are unlikely to be compromised in their ability to make longitudinal migrations and access the full range of habitats and resources required by all life stages.

It is important here to distinguish the difference between ex-situ and in-situ conservation measures. While ex-situ conservation efforts (e.g. the hatchery production of mahseer) may be necessary in some cases to prevent a critically endangered species from going extinct, the stocking of these fish will not achieve the 'umbrella' effect. Indeed, without addressing the issues limiting natural recruitment (exploitation, habitat quantity, quality and connectivity) and restoring natural ecosystem function through in-situ monitoring and intervention, conservation effort for both the focal species and associated fauna are unlikely to be successful.

While strong evidence already exists for the potential qualification of the two most widely recognised species of *Tor* (*T. remadevii* and *T. putitora*) as both 'flagship' and umbrella' species, throughout my research, many other equally charismatic and threatened *Tor* spp. have come to my attention and stimulated my interest across the full biogeographic range of the genus throughout the remote rivers of South and Southeast Asia. This has revealed that the former taxonomic ambiguity associated with the hump-backed mahseer was not an isolated case. Indeed, the available literature on *Tor* is littered with inconsistencies, conflicting opinion and confusion over a) the number of valid species of *Tor*; b) the identity and distribution of individual species; c) the autecology of individual species; and d) the population status and extinction risk of individual species. These thus represent fundamental knowledge gaps impeding the development of conservation prioritisation and subsequent action plans for implementation (Cooke et al. 2012).

In Chapter 6, it was revealed that my research has identified significant new insight to the endemism and critical population status of *T. remadevii*, and the deleterious impact of the introduction and subsequent invasion of hatchery reared *T. khudree*. This evidence has recently been used to inform policy, with both species now featuring in India's National Wildlife Action Plan 2017-2031 http://www.indiaenvironmentportal.org.in/files/file/nwap_2017_31.pdf. The following actions are listed in Chapter 7, Conservation of inland aquatic ecosystems:

12.2 Initiate special breeding programmes for threatened fish species such as orange-finned (hump-backed) and golden mahseer. Adequate care should be taken to prevent any genetic contamination or deterioration during these breeding and restocking programmes.

12.3 Undertake measures for reviving the population of native species of fish by removal of blue-finned mahseer in the Cauvery and exotic trout in the Himalayan rivers through angling or other suitable means to reduce the population of these undesirable species. This should go hand in hand with the release of captive stocked orange-finned and golden mahseer in Cauvery and the Himalayan rivers respectively.

With *T. khudree* fingerlings originating from Tata's Lonavla hatchery now known to have been dispatched in their millions to every state in India (and to Laos) since the mid 1970's, and the more recent trend of rearing and stocking *T. putitora* both within and beyond its endemic range, I had long recognised a pending urgency for an up to date appraisal of the status of the entire genus *Tor*. In addressing this aim, my key objectives were to a) reduce further risk of endemic extinctions through poorly informed pseudo-conservation actions (e.g. stocking); and b) provide a new error free baseline of knowledge on which to rebuild and develop the knowledge base needed to conserve these fish and explore their individual and collective potential to promote broader conservation gains to both aquatic biodiversity and humans.

Submission 9 represents one of the most significant challenges I have undertaken to date, requiring the back-validation of literature to establish if and how original data had become distorted through inappropriate citation, or where original species descriptions have simply been unreliable and unfit for purpose. In stripping the literature base back to its very foundations, Submission 9 provides a comprehensive overhaul of the genus in revising the current number of valid species of *Tor* to 16. At the time of going to press, FishBase continued to list 50 different species of *Tor* of which 23 were suggested to be valid (Froese & Pauly 2018). Despite considerable remaining knowledge gaps, this simplification of the genus has facilitated the revision of species distribution maps and, through a workshop convened by Raghavan and myself, has enabled revision of the IUCN Red List status of *Tor* fishes. Three species are now assessed as 'Near Threatened', one 'Vulnerable', three 'Endangered' and one 'Critically Endangered'. However, eight species still remain 'Data deficient'.

9.1.1 **References**

Cooke, S.J., Paukert, C., & Hogan, Z., 2012. Endangered river fish: factors hindering conservation and restoration. *Endangered Species Research* 17(2), 179-191.

Carrizo, S.F., Jähnig, S.C., Bremerich, V., Freyhof, J., Harrison, I., He, F., & Darwall, W., 2017. Freshwater megafauna: Flagships for freshwater biodiversity under threat. *Bioscience* 67(10), 919-927.

Darwall, W., Bremerich, V., De Wever, A., Dell, A.I., Freyhof, J., & Gessner, M.O., 2018. The Alliance for Freshwater Life: A global call to unite efforts for freshwater biodiversity science and conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28(4), 1015-1022.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Lévêque, C. & Sullivan, C. A., 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological reviews* 81(2), 163-182.

Froese, R., & Pauly, D., 2018. FishBase 2018, version (06/2018). World Wide Web electronic publication. Home page at: http://www.fishbase.org.

Gupta, N., Sivakumar, K., Mathur, V.B., & Chadwick, M.A., 2014. The 'tiger of Indian rivers': stakeholders' perspectives on the golden mahseer as a flagship fish species. *Area* 46(4), 389-397.

He, F., Zarfl, C., Bremerich, V., Henshaw, A., Darwall, W., Tockner, K., & Jaehnig, S.C., 2017. Disappearing giants: a review of threats to freshwater megafauna. *Wiley Interdisciplinary Reviews: Water* 4(3), e1208.

Lynch, A.J., Cooke, S.J., Deines, A.M., Bower, S.D., Bunnell, D.B., & Cowx, I.G., 2016. The social, economic, and environmental importance of inland fish and fisheries. *Environmental Reviews* 24(2), 115-121.

Millenium Ecosystem Assessment, 2005. Millenium Ecosystem Assessment Synthesis Report. Island Press, Washington D.C., USA.

Power, M.E., 1990. Effects of fish in river food webs. *Science* 250(4982), 811-814.

Reid, A.J., Carlson, A.K., Creed, I. F., Eliason, E.J., Gell, P.A., & Johnson, P.T., 2018. Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*.

Richter, B.D., Braun, D.P., Mendelson, M.A., & Master, L.L., 1997. Threats to imperiled freshwater fauna: amenazas a la fauna dulceacuicola en riesgo. *Conservation Biology* 11(5), 1081-1093.

Sarkar, U.K., Pathak, A.K., & Lakra, W.S., 2008. Conservation of freshwater fish resources of India: new approaches, assessment and challenges. *Biodiversity and conservation* 17(10), 2495-2511.

WWF, 2016. Living Planet Rep 2016. Risk and resilience in a new era. Gland, Switzerland: WWW International.

9.2 Submission 9

REVIEWS IN FISH BIOLOGY AND FISHERIES 29, 417-452.

Mahseer (Tor spp.) fishes of the world: status, challenges and opportunities for conservation

Adrian C. Pinder[**1**,2], J Robert Britton[1], Andrew J Harrison[1,2], Prakash Nautiyal[3], Shannon D Bower[2,4], Steven J Cooke[5], Steve Lockett[2], Mark Everard[2,5], Unmesh Katwate[6], K. Ranjeet[7], Sam Walton[8], Andy J Danylchuk[9], Neelesh Dahanukar[10] and Rajeev Raghavan[2,11]

[1]Faculty of Science and Technology, Bournemouth University, Dorset, UK, [2]Mahseer Trust, Freshwater Biological Association, Wareham, Dorset, UK, [3]Department of Zoology and Biotechnology, Hemwati Nandan Bahuguna Garhwal University, Srinagar, Uttarakhand, India, [4]Natural Resources and Sustainable Development Group, Uppsala University, Campus Gotland, Visby, Sweden, [5]Fish Ecology and Conservation Physiology Laboratory, Department of Biology, Carleton University, Ottawa, ON, Canada [5]University of the West of England, Coldharbour Lane, Frenchay Campus, Bristol, UK, [6]Bombay Natural History Society Hornbill House, Opp. Lion Gate, Shaheed Bhagat Singh Road, Mumbai, Maharashtra, India, [7]Department of Aquatic Environment Management, Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi, India, [8]Rimba, Kuala Lumpur, Malaysia, [9]Department of Environmental Conservation, University of Massachusetts Amherst, Amherst, MA, USA, [10]Indian Institute of Science Education and Research (IISER), Pune, India, [11]Department of Fisheries Resource Management, Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi, India.

ABSTRACT

The mahseer fishes (*Tor* spp.) represent an iconic genus of large-bodied species of the Cyprinidae family. Across the 16 recognised species in the genus, individual fish can attain weights over 50 kg, resulting in some species being considered as premier sport fishes. *Tor* species also generally have high religious and cultural significance throughout South and Southeast Asia. Despite their economic and cultural importance, the status of *Tor* fishes has been increasingly imperilled through their riverine habitats being impacted by anthropogenic activities, such as hydropower dam construction and exploitation. Moreover, conservation efforts have been constrained by knowledge on the genus being heavily skewed towards aquaculture, with considerable knowledge gaps on their taxonomy, autecology, distribution and population status. Whilst taxonomic ambiguity has been a major constraint on conservation efforts, this has been partially overcome by recent, robust taxonomic revisions. This has enabled revision of the IUCN Red List status of *Tor* fishes; three species are now assessed as ‘Near Threatened’, one ‘Vulnerable’, three ‘Endangered’ and one ‘Critically Endangered’. However, eight species remain ‘Data deficient’. Here, information on these 16 *Tor* fishes is synthesised for the first time, outlining the current state of knowledge for each species, including their known distributions and population status. For each species, the outstanding gaps in knowledge are also identified, and their population threats and conservation prospects outlined. Consequently, this review provides the basis for researchers to challenge and enhance the knowledge base necessary to conserve these freshwater icons in an era of unprecedented environmental changes.

INTRODUCTION

Global freshwater resources include a diverse fish fauna comprising close to 16,000 species (i.e. ~47% of all fishes and ~25% of all vertebrates), with around 250 new species described each year (Pelayo-Villamil et al. 2015; Arthington et al. 2016; Eschemeyer and Fong 2016). This diversity is, however, concentrated into limited areas (<1% of the Earth's surface) that are extensively exploited and modified for societal requirements (Dudgeon et al. 2006; Vorosmarty et al. 2010; Closs et al. 2016). For example, 60 % of wetlands have been lost globally (Davidson 2014), the majority of large rivers are now impounded (Poff and Schmidt 2016), and rivers are generally used to discharge high quantities of sewage and industrial waste (Keller et al. 2014). These stressors have resulted in freshwater fishes being among the most threatened taxa. Of approximately 7,588 species of freshwater fish assessed for the IUCN Red List, more than 20% are threatened, with 69 species already 'extinct' or 'extinct in the wild' (Darwall and Freyhof 2016).

A high proportion of fish diversity 'hot-spots' occur within countries with rapidly developing economies where protection of vulnerable habitats is of relatively low priority (Dudgeon et al. 2006; Sarkar et al. 2008; Reid et al. 2018). These hotspots include freshwaters within South and Southeast Asia that cover the native range of the mahseer, an iconic group of fishes of the family Cyprinidae (Thomas 1873; Dhu 1923; Pinder and Raghavan 2013; Nautiyal 2014). Characterised by their very large scales, these large-bodied carps (maximum recorded weight 54 kg) are currently partitioned taxonomically into the genera, *Naziritor, Parator, Neolissochilus* and *Tor* (Kottelat 2013; Froese and Pauly 2017, Eschemeyer et al. 2017). Despite some morphological similarities across these fishes, it is only those species of the genus *Tor* that are considered the 'true mahseers' (Desai 2003; Nguyen et al. 2008) and which form the focus of this review. This genus currently comprises 16 valid species (Table 1), all of which are considered to exhibit highly potadromous behaviours, with upstream spawning migrations, often over ‘considerable’ distances, reported as being necessary to facilitate successful reproduction (Nautiyal et al. 2001, 2008; Shrestha 1997).

The high nutritional value of *Tor* mahseer (Day 1876) and their ability to provide food security in regions with high poverty levels means that reports of their high exploitation date back to the 19^{th} Century (Thomas 1873). More recently, in many Asian countries, combinations of major river engineering projects, declining water quality and other anthropogenic impacts (e.g. invasive species) are resulting in *Tor* mahseers facing unprecedented population pressures (Dudgeon 2011; Grumbine and Pandit 2013). Despite their high economic and cultural importance (Nautiyal 2014), population level data across the *Tor* genus remain severely limited, with fundamental aspects of their biology and autecology unknown for most species (Raghavan et al. 2011; Pinder and Raghavan 2013; Bhatt and Pandit 2016). Whilst research efforts on the genus have accelerated in recent years (Figure 9.2.1), this has been heavily skewed towards aquaculture (Kumar et al. 2013; Norfatimah et al. 2014; Raman et al. 2016).

While some of these studies provide strong contributions to the *Tor* taxonomic knowledge base (Hora 1939; Roberts 1999; Walton et al. 2017), many fail to reference original species descriptions, type localities and lack the integration of morphological data that would assist field biologists (Nguyen et al. 2008; Mani et al. 2009). Furthermore, with frequent evidence of the ‘blind’ propagation of repetition and errors in citation networks (see Greenberg 2009), many studies (for e.g. Laskar et al. 2013; Khare et al. 2014) have only resulted in further taxonomic confusion across the genus.

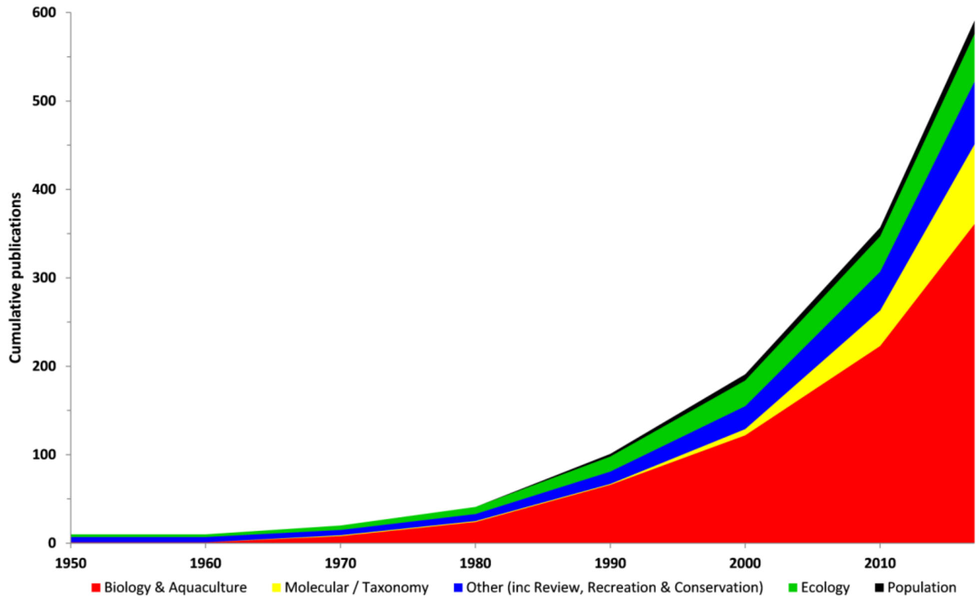


Figure 9.2.1. Cumulative publications by subject area from 1950 to 2017. Based on a Google Scholar search ["tor mahseer", all words, anywhere in article]. First 1,000 search results manually filtered to remove duplicates and retain relevant publications only (n=591). Each publication was categorised into one of five subject areas (Biology and Aquaculture, Molecular/Taxonomy, Population, Ecology or Other [including Review, Recreation and Conservation]), based on the main theme of the publication.

With interest to conserve this group of iconic fishes growing rapidly across multiple stakeholder groups (e.g. scientists, conservationists, recreational anglers, land and water resource managers) (WWF 2013; Bower et al. 2017), there is an immediate urgency to provide practitioners, regulators and policy-makers with standard points of reference to benchmark the current state of knowledge and conservation status of the genus *Tor*. Consequently, by synthesising the literature of *Tor* fishes, the objectives of this paper are to: (1) highlight the importance of the fishes of the genus *Tor* in Asia with respect to religion and society; (2) clarify the validity and taxonomic identity of species included within the *Tor* genus; (3) provide the geographic distribution of each *Tor* species based on current understanding and uncertainties, and outline their population threats and species' extinction risks; and (4) identify the prioritised research and conservation needs, and actions for policy makers. With specific reference to Objective 3, we present a revised conservation status of 16 valid species of which each has been recently assessed (four for the first time) or re-assessed against IUCN Red List categories and criteria (IUCN 2012, 2017). This has resulted in eight species being assessed as Data Deficient, three as Near Threatened, one as Vulnerable, three as Endangered and one as Critically Endangered (Table 9.2.1).

ROLE IN HISTORY RELIGION AND CULTURE

Whether due to their large body size and/or attractive appearance, mahseer fishes have long been afforded saintly status as ‘God’s fishes’ across their biogeographic range, being revered amongst isolated tribal societies (Gupta et al. 2016a). Paintings depicting large-scaled fish on Nal pottery, from the Baluchistan region of Pakistan, indicate an interest in these fishes as early as 3,000 BC (Hora 1956). Other archaeological studies of the same geographic area and era have recorded bones of freshwater fishes, but not those of mahseers. This suggests that although fish represented a staple part of the diet of the Indus Valley Civilisation (Belcher 1998), mahseer were not consumed due to their high cultural value.

References describing sacred and masculine figures of ‘mahseer-like’ fish can also be found in Hindu religious scriptures, symbols, motifs, sculptures, and in ancient literature (Jadhav 2009; Nautiyal 2014). The accounts on Vishnu’s first incarnation as the fish “Matsya”, symbolized in the form of zoomorphic and anthropomorphic sculptures, are commonly found in ancient temples throughout India. At many religious temples nestled along river banks throughout India, adjacent pools have been afforded protection from exploitation for centuries and, outside of the monsoon season, these support dense accumulations of mahseer (Dandekar 2011a, 2011b; Gupta et al. 2016a). These community-protected areas, often described as ‘temple sanctuaries’ or ‘temple pools’, are safeguarded through the social beliefs and sentiments of devotees, and the participatory approach of villagers and temple authorities (Sen and Jayaram 1982; Gadgil 1991; Bhagwat and Rutte

2006; Dandekar 2011a; Katwate et al. 2014). Although the exact number of community-protected fish areas within India is unknown, the state of Karnataka has at least 17 sanctuaries, with Uttarakhand also reported to have a large number of protected sites (Dandekar 2011b). These numbers are likely to be substantial underestimates, as personal observations of the authors have witnessed numerous pools alongside small tributary streams that are adjacent to temples. Although such community-protected areas provide an example of effective *in situ* conservation action, the migratory behavior of these fishes suggests that these need to work alongside catchment-scale habitat management and harvest regulation in order to promote self-sustaining populations.

Paradoxically, there are also examples of where temple sanctuaries have exposed mahseer populations to elevated risk from degraded environmental conditions. For example, large congregations of Deccan mahseer (*Tor khudree*) near the temples of Alandi and Dehu on the Indrayani River and Pandharpur on Bhima River, Maharashtra, have been killed via major pollution events, with the fish unable to escape the pollutants due to their captive habitat (Sen and Jayaram 1982). Other authors have also highlighted the risks posed to temple pools by the upstream construction of hydroelectric dams that subject the stocks to abrupt changes in flow regime (Dandekar 2011b) and block access to spawning habitat (Everard 2013). The intentional destruction of an entire stock of mahseer from a temple pool in River Kapila, Karnataka has also been reported when fishermen who had previously been prosecuted for illegally harvesting the fish, returned and deliberately poisoned the remaining fish in an act of sabotage (Jayaram 1997).

The strength of *Tor* mahseer has also been recognised in ancient Indian culture, with a record highlighting the recreational value of 'such big sized fishes' from the early 12th century (Hora 1951; Jadhav 2009; Nautiyal 2014). In 1127-1138 AD, the King of Western Chalukya, King Someshvara III, authored a compendium in Sanskrit "Mansollasa – Mānasollāsa" (meaning the "refresher of the mind"). This referred to 35 different species of marine and freshwater sport fishes, each with unique name (Sadhale and Nene 2005; Jayaram 2005). Within these works, the riverine game fish called ‘Mahashila’ is described as a ‘riverine scaly large fish’. Mahashila in Sanskrit means a large stone-like (powerful) fish, and is thought to refer to the mahseers (Hora 1953; Sadhale and Nene 2005). There are, however, contradictory views among researchers regarding the exact species of mahseer to which this refers (Hora 1953; Sadhale and Nene 2005). Indeed, during the rule of Someshvara III, the Empire of Western Chalukya was confined to the current geographical areas of Andhra Pradesh, Karnataka, and Maharashtra states, meaning that the fish could have been any one or a combination of *Tor* species found in Southern India. In his compendium, King Someshvara III also provided discussion on angling techniques, selection and use of fishing rod, rope, different kind of fish baits and their preference to the wide array of fish types. This also provided robust evidence that the art of recreational angling was practiced in ancient India since the early 12th century (Hora 1953; Sadhale and Nene 2005; Nautiyal 2014).

POPULATION THREATS

The regions in the developing world in which mahseers occur are subject to spiralling resource demands from a rapidly growing and industrialising population. In examining trends in large-scale hydrological changes across Asia, Dudgeon (2000) highlighted four principal threats to freshwater fishes: flow alteration and regulation (e.g. dam construction and abstraction), pollution, drainage basin alteration (e.g. deforestation), and over-harvesting. Each of these categories is highly relevant to threats to the population status of *Tor* species (Raghavan et al. 2011; Bhatt and Pandit 2016; Everard et al. 2018).

With specific focus on India, the World Bank (2018) recorded a 1.2% annual economic growth rate and a near doubling of energy use between 2000 and 2015. These rising demands place significant pressures on water resources, including the harnessing of river water for domestic, industrial, irrigation and electricity generation purposes. India has a long history of hydropower development with, for example, the hydroelectric power plants constructed at Darjeeling (West Bengal) and Shivanasamudram (Karnataka) at the turn of the 20th Century being among the first in Asia (Ullah 2015). Rivers are also regularly harnessed for water supply purposes, routing river flows by canals and pipes from areas of perceived excess to those of higher demand (World Commission on Dams 2000). To support these spiralling water and energy demands, India has developed a high dependence on large dams, with 4877 completed and 313 more under construction (CWC 2017). Development of large-scale hydropower schemes has also increased across other mahseer range countries, with dams typically impounding rivers in the higher topography landscapes that constitute prime habitat for *Tor* spp. (Shrestha 1997; Nautiyal 2014; Bhatt and Pandit 2016).

The multiple environmental and social impacts of dams are complex but include the compromised movement of diadromous and potamodromous fishes, which can often deny access to optimal - sometimes critical - spawning habitats (Ferguson et al. 2011). Modified flow rates, habitat structure and limited sediment transport also result in progressive erosion, depletion of lithophilic spawning substrates and invasion of novel macrophytes in affected downstream lotic reaches (Poff et al. 2007; Johnson et al. 2008; Poff and Zimmerman 2010; Poff and Schmidt 2016). Ecosystems are further perturbed by simplification of habitat hydrology, often with excess macrophyte growth in the littoral zone, and the colonisation of invasive species in the water and also in the riparian zone (De Jalon et al. 1994). Indeed, the simpler habitat structure and changed hydrology of impounded rivers increases their vulnerability to alien invasive species (Johnson et al. 2008; Quinn and Adams 1996).

With particular relevance to environmental policy designed to protect Indian biodiversity and habitats, freshwater fish are excluded from definitions of ‘wild animals’ and from inclusion in any of the schedules of the India’s Wildlife Protection Act 1972 (Pinder and Raghavan 2013). The net result is that there is minimal responsibility on developers to incorporate fish passage or mitigation into dam construction (Theophilus 2014). Indeed, the consequences of river impoundments on native aquatic biodiversity appear to have been overlooked in favour of the perceived positive benefits of the ‘clean’ contribution of hydropower to energy deficits and the potential for large lentic waterbodies to enhance fisheries potential (particularly of non-native species) to contribute to nutritional food security (Sharma 1987). This is important, as the continuing construction of dams is resulting in increased impoundment and loss of longitudinal connectivity that is assumed to impact the natural movements of *Tor* spp., such as spawning migrations (Shrestha 1997; Nautiyal 2014; Bhatt and Pandit 2016).

In the tropical regions inhabited by mahseer, the creation of large expanses of lacustrine habitat also results in high levels of evaporation, which can result in substantial water losses. This reduces the dilution potential of pollutants, further threatening the maintenance of ecologically acceptable flows to support the various life history stages of *Tor* spp., as well as compromising the quantity of water available for human use (e.g. consumption and irrigation) (Everard et al. 2018).

Invasive aquatic species are a pervasive problem across South and Southeast Asia (Johnson et al. 2008; Peh 2010; Dudgeon 2011). These include fish that may directly compete with mahseer, or other flora and fauna which impact indirectly by disrupting ecological function (Gupta and Everard 2017). Related to this issue, the stocking of captive-reared mahseers, particularly non-indigenous species, has been shown to not only threaten the integrity of ecosystem function, but also threaten the extinction of endemic mahseer species (Pinder et al. 2015b). Further pressure arises from direct exploitation of mahseer stocks beyond natural regeneration rates. This age-old issue, first reported by Thomas (1873) and Dhu (1923), is compounded by contemporary unsustainable fishing methods, such as indiscriminate gill-netting, dynamiting and poisoning (Raghavan et al. 2011), and particularly when mahseer stocks are at their most vulnerable when concentrated in summer pools and/or ascending small tributaries during the spawning migration (Everard and Kataria 2011).

A range of other anthropogenic stressors then further exacerbates these population pressures that primarily relate to human population growth and its upward resource demands, including from industrialisation and intensive farming. Although population growth and resource demands are typically focused on India, throughout Asia as a whole, poverty of resources and poor education is also resulting in people over-exploiting natural resources such as fisheries to fulfil immediate needs, rather than stewarding them for the longer term (Smith et al. 2005). Climate change is a significant additional pressure, with direct impacts on the drying out of springs in the middle Himalayas that constitute important spawning areas (ICIMOD 2009). There is also a trend towards increased river flow variability and river runoff in pre-monsoon months, potentially leading to a higher incidence of unexpected droughts and floods with widespread consequences for climate-dependent sectors such as agriculture, water resources and health (Shrestha et al. 2015).

TAXONOMIC CHALLENGES

Despite the first mahseer species being described in 1822 (Hamilton 1822) and methodical investigations on the taxonomy, nomenclature and systematics starting in the early 20th century (e.g. Hora 1939), some taxonomic ambiguity remains across the *Tor* genus (Pinder and Raghavan 2013). Original descriptions of many mahseer species are vague and finding standard diagnostic characters to distinguish species has been difficult (Walton et al. 2017). In addition, the mahseer literature of the 20th century, particularly descriptions and illustrations available in species accounts, are inconsistent and highly variable, increasing the likelihood of misidentifications. Published evidence on range limits has also been highly confusing and contradictory, and authentication of such information has now become impossible due to the absence of accompanying voucher specimens (*cf.* Walton et al. 2017). The quantity of taxonomic literature is also not an indication of its quality and tends to increase confusion further (Figure 9.2.1). Many recent studies on mahseer taxonomy have not referred to original descriptions and have uncritically relied on compilations and published papers (for a discussion see Raghavan et al. 2017).

Tor are tetraploid (Arai 2011) and possess 100 diploid chromosomes (Mani et al. 2009). Such polyploid taxa therefore pose significant challenges for interpretation of phylogenetic data. Many of the phylogenetic studies carried out on the *Tor* mahseer have focused on the mitochondrial CO1 gene, whilst others have used nuclear markers but without understanding the issue of paralogy associated with polyploid taxa (Yang et al. 2015). Nuclear genes are expected to have two copies in tetraploid taxa and these different gene copies can be quite divergent and belong to distinct clades in a phylogenetic tree (*cf*. Evans et al. 2005; Saitoh et al. 2010; Yang et al. 2015). Therefore, the results of several phylogenetic studies undertaken on *Tor* mahseer to date are considered to be misleading and should be treated with caution.

Issues with historic and current literature on mahseer taxonomy are further exacerbated with the unique morphological variations that mahseer fishes exhibit. As a group, mahseer exhibit considerable phenotypic plasticity, including intra-specific morphological variation, trophic polymorphism, and sexual dimorphism, making precise, morphologically based identifications extremely difficult (Walton et al. 2017). For example, whilst many previous workers have used diagnostic characteristics such as the shape, size and length of the median lobe (the key diagnostic character of the genus), as well as body colour, to distinguish *Tor* species, these characteristics are known to be highly variable within species (Roberts 1999; Menon 1992). This variability has been attributed to environmental influences, habitat changes (Hora 1939; Esa et al. 2006) and trophic polymorphism (Walton et al. 2017). Despite this, there have been very few studies that have explored how this plasticity contributes to the observed diversity of morphologies in mahseers. Whilst Roberts and Khaironizam (2008) attempted to examine these relationships, their observations were based on a polymorphic population of a *Neolissochilus* species and not of a *Tor* species (Walton et al. 2017).

Commensurate with the publication of this paper, the IUCN Red List of Threatened Species™ has published revised assessments of all mahseers currently considered as valid species within the *Tor* genus. Table 9.2.1 lists the currently valid species, their endemism, common names, synonyms and current/previous Red List status. Despite considerable recent advances in knowledge, the taxonomy and conservation status across the *Tor* genus remain dynamic. For example, eight species have been assessed as 'Data Deficient' due to a paucity of currently available data to assess their extinction threat. A summary of the taxonomy and revised Red List assessment status is provided for each species under individual species summaries.

Table 9.2.1. List of currently valid mahseer (*Tor* spp.), distribution and conservation status as per the IUCN Red List of Threatened Species™ (*Version 2018.2)

Valid species name	Common name(s)	Synonyms	Distribution	IUCN Previous status	IUCN Current status*
Tor ater (Roberts 1999)			Laos	VU	NT
Tor barakae (Arunkumar and Basudha 2003)	Barak Mahseer		India	NE	NT
Tor dongnaiensis (Hoang, Pham, Durand, Tran and Phan 2015)	Dongnai Mahseer		Vietnam		NT
Tor khudree (Sykes 1839)	Deccan mahseer	*Barbus longispinis, Tor neilli*	India	EN	EN
Tor kulkarnii (Menon 1992)	Dwarf mahseer		India	EN	DD
Tor laterivittatus (Zhou and Cui 1996)			China, Laos	DD	DD
Tor malabaricus (Jerdon 1849)	Malabar mahseer		India	EN	EN
Tor mosal (Hamilton 1822)	Mosal mahseer, Copper mahseer	*Barbus megalepis*	India, Myanmar	NE	DD
Tor polylepis (Zhou and Cui 1996)			China	DD	DD

Valid species name	Common name(s)	Synonyms	Distribution	IUCN Previous status	IUCN Current status*
Tor putitora (Hamilton 1822)	Putitor mahseer, Himalayan mahseer, Golden mahseer	*Barbus microcephalus, Tor macrolepis, Tor mosal mahanadicus, Tor progeneius*	Afghanistan, Bangladesh, Bhutan, India, Myanmar, Nepal, Pakistan	EN	EN
Tor remadevii (Kurup and Radhakrishnan 2007)	Hump-backed mahseer		India		CR
Tor sinensis (Wu 1977)	Red mahseer		China, Vietnam, Laos	DD	DD
Tor tambra (Valenciennes 1842)		*Puntius streeteri, Tor douronensis, Tor mekongensis*	Indonesia, Malaysia	DD	DD
Tor tambroides (Bleeker 1854)			Indonesia, Malaysia	DD	DD
Tor tor (Hamilton 1822)	Tor mahseer, Red-fin mahseer, Deep-bodied mahseer	*Tor barakae, Tor hamiltonii*	Bangladesh, Bhutan, India, Myanmar, Nepal, Pakistan	NT	DD
Tor yingjiangensis (Chen and Yang 2004)			China		DD

IUCN Red List status key: NE = Not Evaluated; LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN= Endangered; CR = Critically Endangered; DD = Data Deficient *In Press.

INDIVIDUAL SPECIES SUMMARIES

With reference to the key aims stated in the introduction, the purpose of the following species summaries is to (1) clarify the validity and taxonomic identity of species included within this genus (Table 9.2.1); (2) provide the geographic distribution of each *Tor* species based on current understanding and uncertainties; and (3) briefly summarise the evidence informing current IUCN Red List assessment status, inclusive of population threats and extinction risk. Individual species summaries, with varying levels of available detail, are presented in alphabetical order by scientific name, as listed in Table 9.2.1.

Tor ater

Described from Nam Theun at Ban Talang, Central Laos (Roberts 1999) (Figure 9.2.2), *T. ater* is characterised by its relatively small scales and dark fins, with adults and sub-adults also exhibiting a dark mid-lateral band of pigment. The entire distribution range of this species falls within the Nakai National Biodiversity Conservation Area in Laos, having only been recorded from two streams in the upper Nam Theun catchment, with definitive records only from the Nam Xot and the Nam Theun, located upstream of the Nam Theun 2 Dam (Kottelat 2016; Kottelat et al. 2012). Although lacking any scientific information on population status, *T. ater* is considered, based on local knowledge, as a rare species but does feature in the catch of local subsistence fishers. Overfishing and the relatively recent fragmentation of habitat by the construction of the Nam Theun Dam in 2010 are key threats to the species, which has been assessed as Near Threatened (Kottelat et al. 2018a).

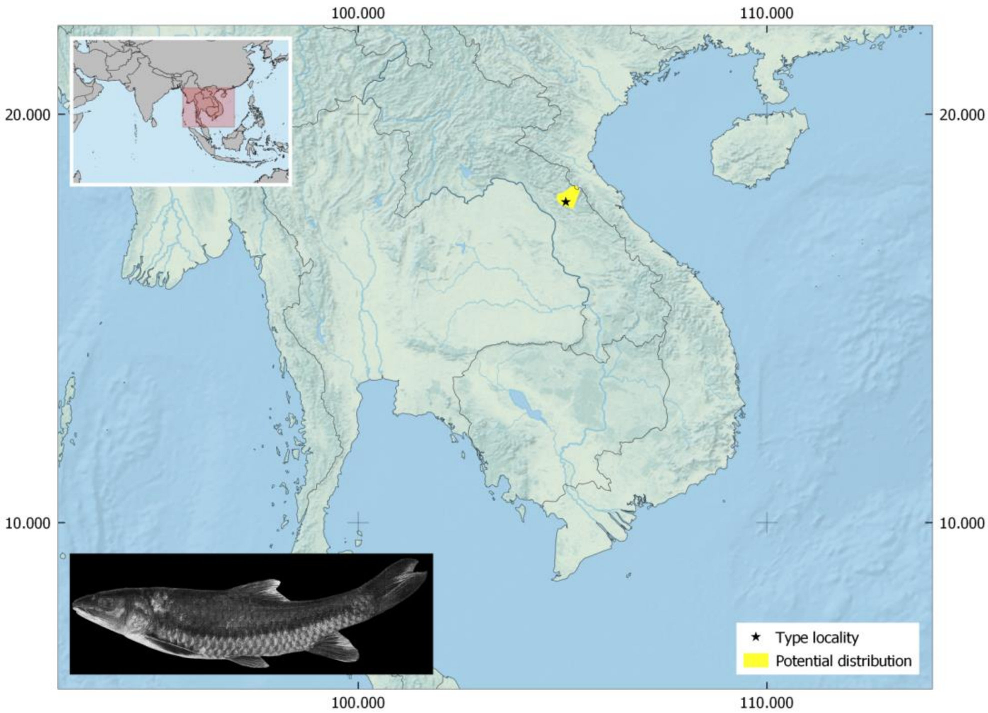


Figure 9.2.2. Distribution of *Tor ater*. Inset image: *T. ater* holotype (308 mm) from the Nam Theun at Ban Talang, Laos. With kind permission of T. Roberts.

Tor barakae

Tor barakae, described from the Barak River, Manipur, India (Arunkumar and Basudha 2003), was considered a questionable synonym of *T. tor* (Kottelat, 2013) until recent research by Laskar et al. (2018) clarified the validity of the species, and distinguished it from co-occurring *T. putitora* by a relatively short head-length to body-depth ratio. Although not compared against *T. tor* from the type locality, the same relative features also reliably separated *T. barakae* from *T. tor* collected from the Central Indian Narmada system. Available photographs from the type locality display a deep-bodied *Tor* with a relatively small terminally positioned mouth and fins of red and blue colouration. This species is endemic to the Barak River, having been recorded from the streams near Vanchengphai, and Makru in Manipur, and from Madhpur on the Manipur-Assam border (Arunkumar and Basudha 2003; Laskar et al. 2018) (Figure 9.2.3). *Tor barakae is poorly-known with no information on the* population, biology and micro-level distribution.

Available information on the restricted distribution of the species and threats to the habitat has led to it being assessed as Near Threatened on the IUCN Red List (Vishwanath et al. 2018).

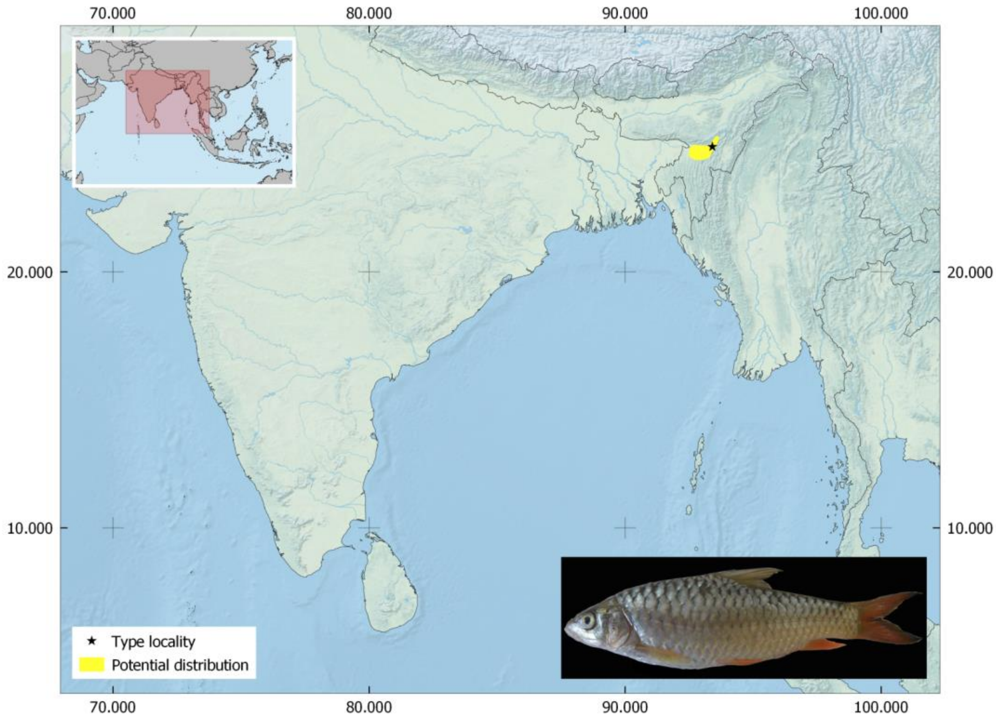


Figure 9.2.3. Distribution of *Tor barakae*. Inset image: *T. barakae* (405 mm) from the Barak River, Manipur, India. With kind permission B. Amin-Laskar.

***Tor dongnaiensis* (and *T. mekongensis*)**

Two species, *Tor dongnaiensis* and *T. mekongensis* were recently described from the Upper Krong No and middle Dong Nai basins in Southern Vietnam (Hoang et al. 2015). While *T. dongnaiensis* has been assessed as Near Threatened on the IUCN Red List (Version 2018-2) due to its apparent restricted distribution (Pinder and Harrison 2018) (Figure 9.2.4), *T. mekongensis* is currently considered to be a questionable synonym of the wide-ranging *T. tambra* (see Walton et al. 2017). Further taxonomic studies are required on both these species of Vietnamese mahseers by including and comparing them to a larger sample/dataset of *Tor* species from other parts of South East Asia.

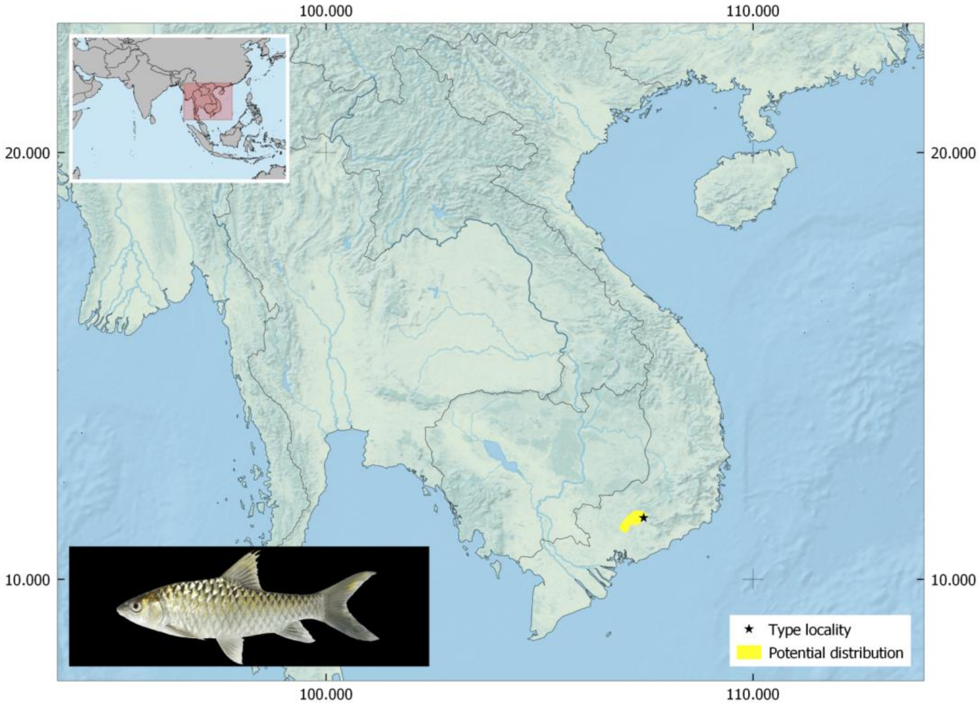


Figure 9.2.4. Distribution of *Tor dongnaiensis.* Inset image: *T. dongnaiensis* (240 mm) from the Đồng Nai River, Vietnam. With kind permission of Huy Đuc Hoang.

Tor khudree

British naturalist W.H Sykes described *Tor khudree* from the 'Mota Mola River, approximately eight miles to the east of Poona' (= Mula-Mutha River in the current day Pune, Maharashtra, India) (Sykes 1839) (Figure 9.2.5). The species epithet was most likely derived from the local name of the species ‘Khudis or Khadshi’ in Marathi Language (Sykes 1839). The original description was laconic, with an extended description later offered by Sykes (1841) still lacking an illustration or details of any type material. For the next one hundred years (from 1849 to 1940), several workers presented contrasting opinions regarding the identity and taxonomic status of this species. Hora (1942, 1943) was the first to resolve the identity of *T. khudree,* re-describing the species based on specimens (and illustrations) collected from the type locality. Although the first genetic characterization of this species was provided by Nguyen et al. (2008), the local extirpation of *T. khudree* from the type locality (Wagh and Ghate 2003; Kharat et al.

2003) dictated that genetic material had to be sourced from fish originating from artificially propagated stocks known to have been introduced, and successfully established populations in reservoirs in Maharashtra and Kerala (see Ogale 2002).

All available evidence suggests that the historic distribution range of *T. khudree* was limited to the northern and Central Western Ghats (current day Maharashtra, Telengana and Karnataka states) in the eastward flowing Krishna River system including its tributaries, the Indrayani, Mula Mutha, Koyna, Krishna, Tungabhadra and Panchaganga (Sykes 1841; Hora 1942, 1943). However, the species is currently known to be distributed throughout peninsular India, particularly in the westward flowing river systems originating from the southern Western Ghats (Menon 1992; Jayaram 1995; Jayaram 2005). Since the early 1970s, artificial propagation and national stocking augmentation policy has resulted in a dramatic expansion of the natural biogeographic range of *T. khudree*, with large numbers of fingerlings having been distributed to every state in India, with a further record, predating 2002, of 1500 *T. khudree* fingerlings being shipped and introduced to Laos (Ogale 2002). Some of these introduced populations in India are now known to be thriving and demonstrating invasive characteristics by limiting populations of endemic fishes, including other species of *Tor* (Pinder 2015; Pinder et al. 2015b). *Tor khudree* has been assessed as Endangered due to continuing decline in the overall population (Raghavan 2018 in press). However, it is to be noted that beyond the Krishna drainage, *T. khudree* is now considered non-indigenous and in some cases (e.g. River Cauvery) invasive and detrimental to endemic aquatic biodiversity (Pinder 2015; Pinder et al. 2015b).

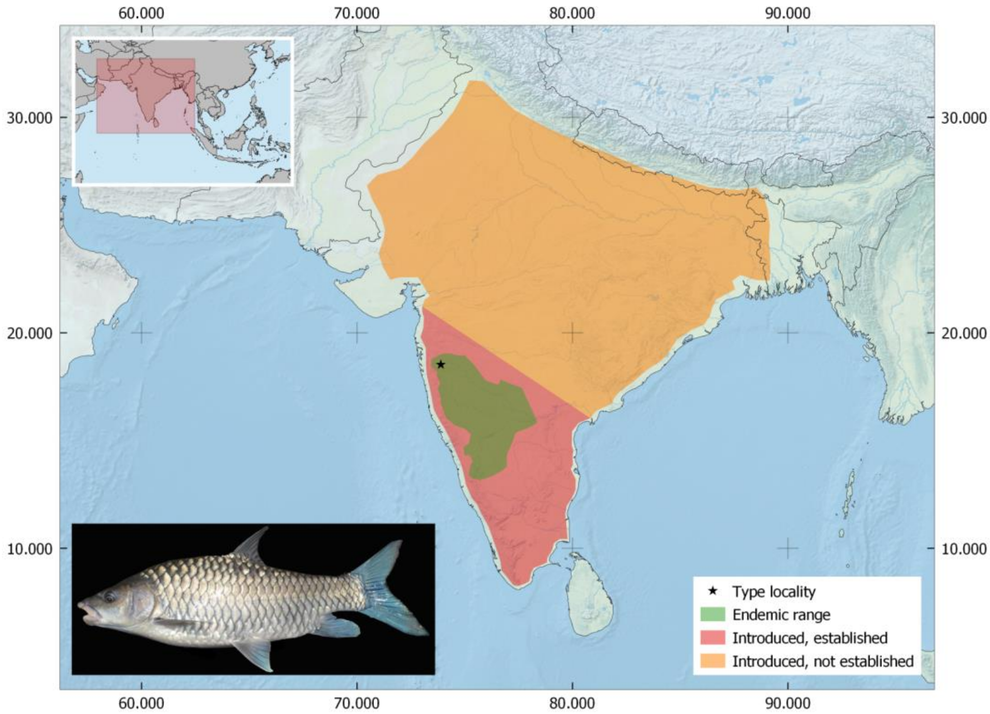


Figure 9.2.5. Distribution of *Tor khudree*. Inset image: *T. khudree* (520 mm) from the River Cauvery and believed to be the progeny of hatchery stocks introduced from Lonavla, Maharashtra, India. Note: delineation of 'introduced, established' and 'introduced, not established' is approximate only.

Tor kulkarni

Tor kulkarnii (Figure 9.2.6) was described as a dwarf cognate of *T. khudree* from the Dharna River at Deolali, a tributary of the River Godavari in Maharashtra, India (Menon, 1992), but subsequently considered as a synonym of *T. khudree* (Jayaram 1999, 2005, 2010). Interestingly, there are no confirmed records of the species backed by voucher specimens or photographs after its description. The species is known from only a single location in the upper reaches of the Godavari River system (Darna River at Deolali, Nashik District, Maharashtra) (Figure 9.2.6) and not from the Krishna River system, as is mistakenly indicated in a distribution map provided by Menon (2004). Despite noting that the species is remarkably similar to *T. khudree* (Dahanukar 2011), subtle yet statistically significant variations in body morphology (e.g. ratio of head length versus standard length) have seen *T. kulkarni* accepted as a valid species. The taxonomic status of this species is, therefore, likely to be secure until molecular evidence from the type locality is available (if the fish is still present) to confirm or dismiss taxonomic validity. In the absence of any other information apart from its type locality and type material, the species is assessed as Data Deficient (Dahanukar et al. 2018a).

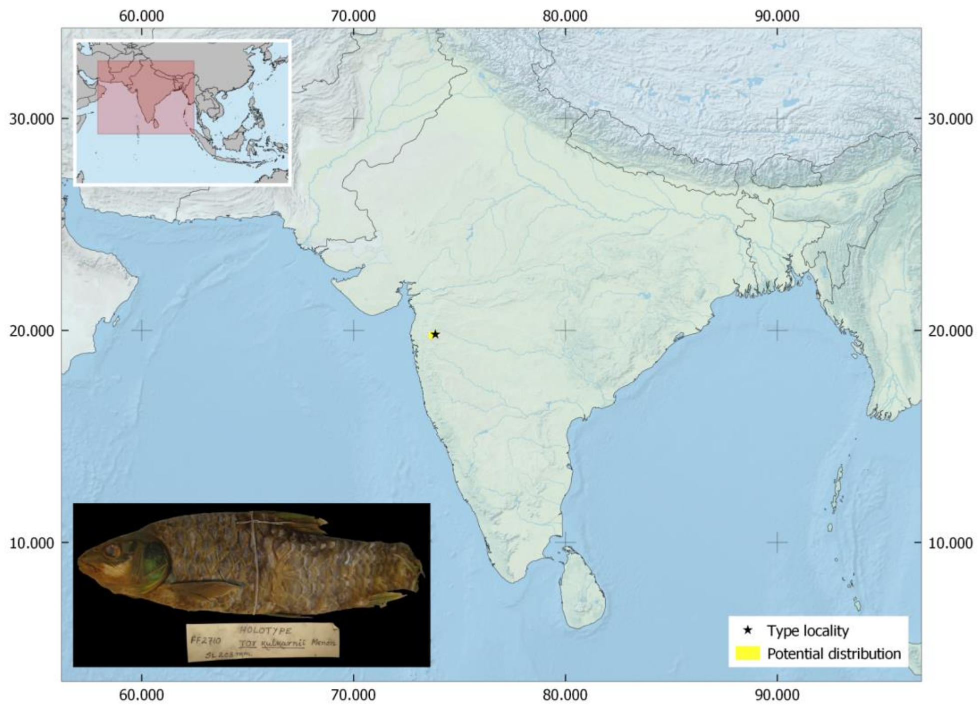


Figure 9.2.6. Distribution of *Tor kulkarnii*. Inset image: *T. kulkarnii* holotype (208 mm) from the museum collection of Zoological Survey of India (ZSI), Kolkata.

Tor laterivittatus

Tor laterivittatus was described from the Nanla tributary of the Lancang Jiang in Yunnan Province (Zhou and Cui 1996) and is known to occur in the Mekong basin in China (Yunnan), Lao PDR (Xe Kong drainage) and Thailand (Kottelat 2001) (Figure 9.2.7). Like many mahseer known from China, *T. laterivittatus* is poorly-studied species and much of the information has been generated outside China (in Laos) and through local knowledge of fishers. This species is known to be threatened by overfishing, especially where dynamite and illegal nets are used. Logging, deforestation, agriculture and hydropower dams represent additional threats. The current conservation status of the species is Data Deficient (Kottelat 2018).

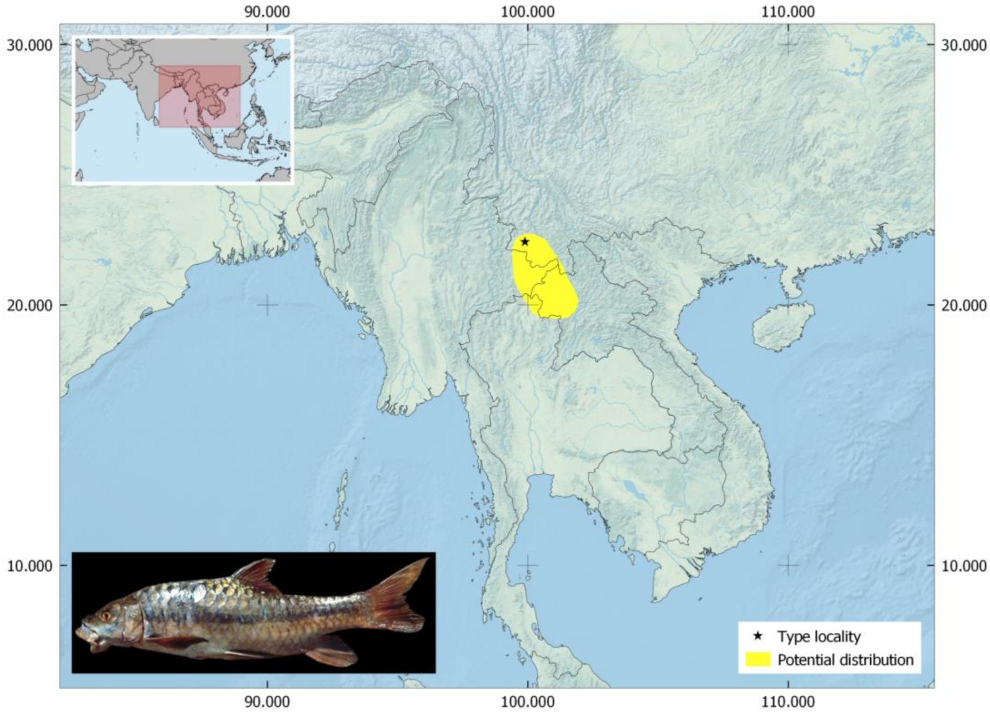


Figure 9.2.7. Distribution of *Tor laterivitattus.* Inset image: adult *T. laterivitattus* collected from a fish market at Louang Prabang, River Mekong basin, Laos. With kind permission Muséum National d'Histoire Naturelle , Paris, France.

Tor malabaricus

The Malabar mahseer, *Tor malabaricus,* was described from the mountain streams of Malabar (an erstwhile province of Southern India; currently in the northern part of Kerala State), India (Jerdon 1849). The species had a confusing taxonomy, as some authors considered it a synonym of the Deccan mahseer, *T. khudree* (Menon 1992; 1999), while others believed it to be a valid sub-species, *T. khudree malabaricus* (Indra, 1993). Known to be endemic to the Western Ghats region (part of the Western Ghats-Sri Lanka Biodiversity Hotspot), the species has been recorded from the upper and middle reaches of westward flowing rivers in the states of Karnataka, Kerala and Tamil Nadu (Figure 9.2.8). In at least two rivers in Kerala, *T. malabaricus* are known to coexist with introduced populations of *T. khudree*

(Raghavan and Ali 2011). It forms the target of subsistence fisheries by local communities in all major river systems in which they occur. Although levels of offtake are not very high, the life history traits of the species (*K* selective) coupled with increasing anthropogenic stressors in their habitats, including habitat loss due to hydropower dams and reservoirs, pollution from multiple sources and sand mining, the species has been assessed as Endangered (Raghavan and Ali 2011).

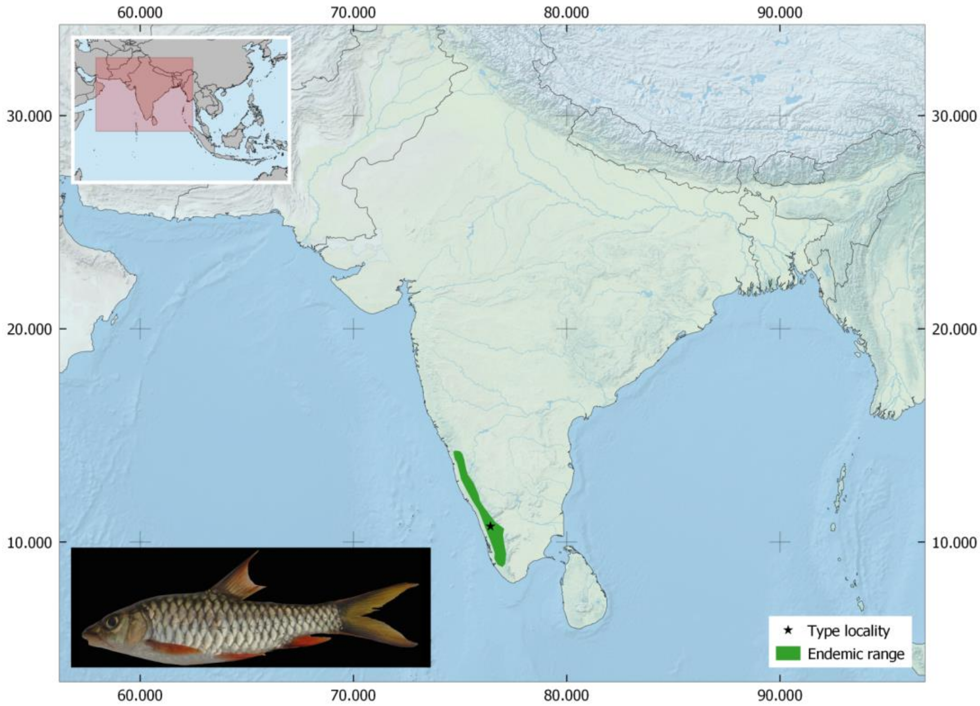


Figure 9.2.8. Distribution of *Tor malabaricus*. Inset image: *T. malabaricus* (260 mm) from the Chaliyar River in Northern Kerala, India.

Tor mosal

Much confusion has surrounded the identity and distribution of the mosal or copper mahseer, *T. mosal* (Figure 9.2.9). Although the species was described by Hamilton (1822), several authors have wrongly attributed the species authority to ‘Sykes’ (e.g. Khare et al. 2014; Lakra et al. 2010; Mohindra et al. 2007). Described as *T. mosal* from the Kosi, a river flowing through Tibet and Nepal before entering the Indian State of Bihar, many authors wrongly considered the type locality of *T. mosal* to be ‘Kosi’ – another river by the same name which is a tributary of the Ramganga in the northern Indian state of Uttarakhand (for a discussion see Raghavan et al. 2017). Adding to this uncertainty has been the suggestion (see Menon 1992, 1999) that *T. mosal* is a synonym of the wide ranging golden mahseer, *T. putitora*; although both species can easily be distinguished by their fin ray counts (13 *vs*. 11 dorsal fin rays, 17 *vs*. 15 pectoral fin rays; 8 *vs*. 7 anal fin rays) (see Hamilton 1822) and additional morphological characters mentioned in Hora (1940). In the absence of reliable records backed by voucher specimens, it has become difficult to ascertain the exact distribution range of *T. mosal*, but it is more or less certain that this species occurs in the rivers of Bihar (and likely further upstream in Nepal) and Assam in India, as well as in northern (Kachin State/Myitkyina) and southern (Tanintharyi/Dawei) regions of Myanmar (Hamilton 1822; Macdonald 1929; Hora 1940). Although a recent paper (Khare et al. 2014) used genetic data to confirm the species level identity of *T. mosal* using specimens from the tributaries of the Ganges in Uttarakhand and Haryana states, no comparisons were made with topotypic fish from the Kosi River in Bihar, thereby raising doubt over the exact identity of the species and the extension of the distribution range of *T. mosal* to the middle reaches of the Central and Western Himalayan rivers (Ramganga, Yamuna and Bhagirathi). The lack of reliable distribution records backed by voucher specimens and the non-availability of specimens in the recent past from its type locality has meant that there is very little scientific evidence to carry out a conservation assessment for the species; hence it has been assessed as Data Deficient (Dahanukar et al. 2018b).

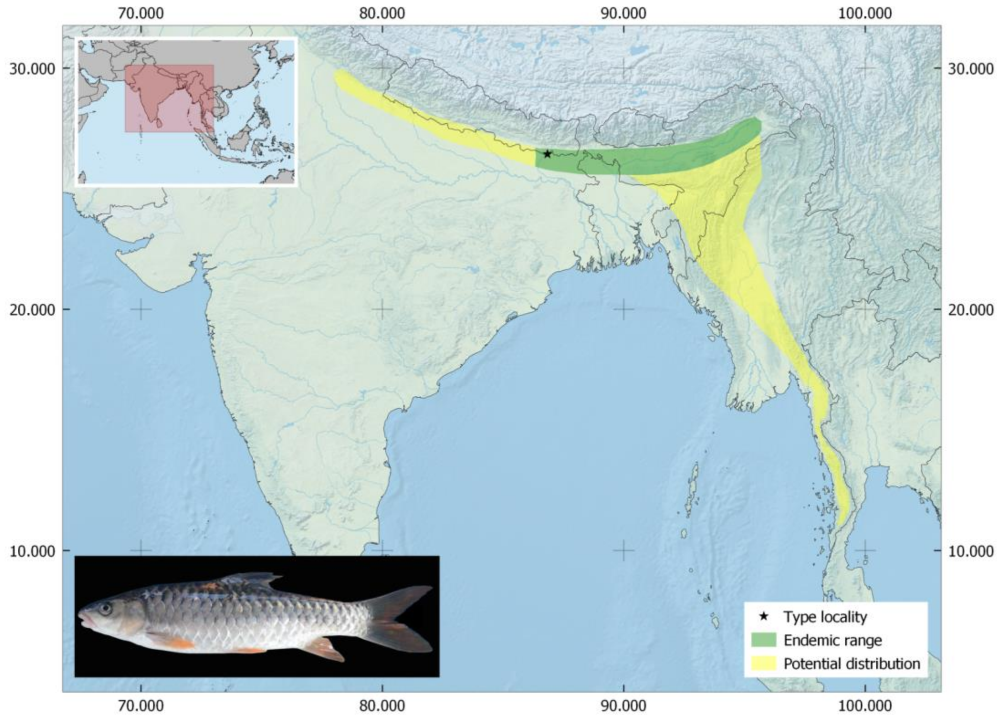


Figure 9.2.9. Distribution of *Tor mosal*. Inset image: *T. mosal* from the Brahmaputra Basin. With kind permission B. Amin-Laskar. Note: until collected from the type locality, data are lacking to validate the genetic authenticity and physical appearance of *T. mosal* collected from other river systems.

Tor polylepis

Tor polylepis was described from the Nanla tributary of the Lancang Jiang in Yunnan, China (Zhou and Cui 1996) (Figure 9.2.10). It is one of the most poorly known of all mahseers as no information exists on the distribution, ecology, population or threats to the species, leading to a 'Data Deficient' assessment (Huckstorf et al. 2018).

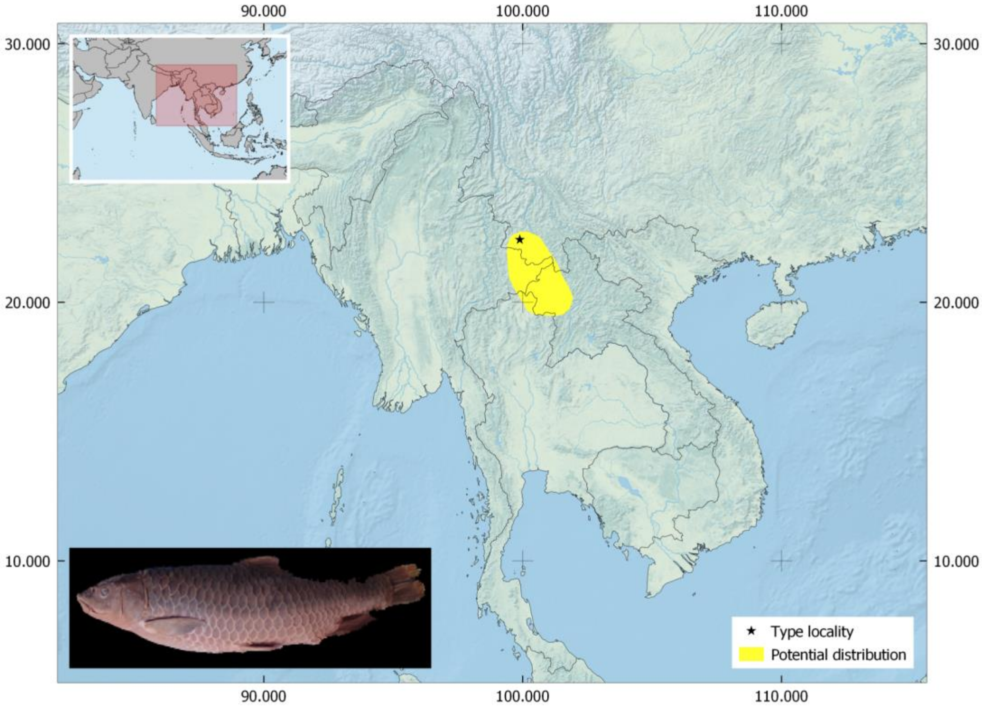


Figure 9.2.10. Distribution of *Tor polylepis.* Inset image: adult *T. polylepis* (Holotype KIZ863563) collected from the Lancang Jiang in Yunnan, China and deposited in the Kunming Institute of Zoology, China.

Tor putitora

Tor putitora was described from Eastern Bengal (now Bangladesh) by Hamilton (1822). This species is naturally distributed throughout the rivers of the South Himalayan drainage (namely the Indus, Ganges and Brahmaputra) from Pakistan (also unverified reports from Afghanistan) in the West, through India, Nepal, Bhutan to Myanmar, with its range also extending throughout the Eastern Brahmaputra catchments encompassing the North-eastern states of India and Bangladesh (Rahman 1989) (Figure 9.2.11). Due to its large size, gaming traits and culinary value, *T. putitora* represents the most comprehensively studied of all *Tor* spp. (Bhatt and Pandit 2016) and has attracted considerable interest from anglers and amateur natural historians from as early as the 1800s (Hamilton 1822). It is the only species of *Tor* to have been studied for its spatial ecology using radio telemetry, with recent research in Bhutan revealing large scale migrations (>50km in a 48h period), the utilisation of warmer (non-snow fed) tributaries for spawning, and homing behaviour of individual fish to distinct tributaries on an annual basis (Fisheries Conservation Foundation and World Wildlife Fund-Bhutan pers. comm. 2018).

Despite having been historically reported to attain lengths of 275 cm (Hamilton 1822) and weights of 54 kg (Nautiyal et al. 2008), the largest fish reported in the last decade by anglers practicing catch and release have not exceeded 150cm (30kg) from North India (M. Dhillon, pers. comm.) and 32kg from Nepal (I. Martin (pers. comm.). *Tor putitora* is under severe threat from overfishing, loss and deterioration of key habitats resulting in loss of breeding grounds, and from other anthropogenic effects that have directly resulted in declines in catches in several locations. In addition, the spate of dams constructed and planned in the Himalayan region, is likely to have a cascading effect on the breeding migrations of the species. Population declines inferred from observed cases across the entire distribution range is around 50% in the past and continuing into the future (if current trends persist). The species is therefore assessed as Endangered and needs urgent conservation efforts to save it from becoming extirpated in several localities (Jha et al. 2018).

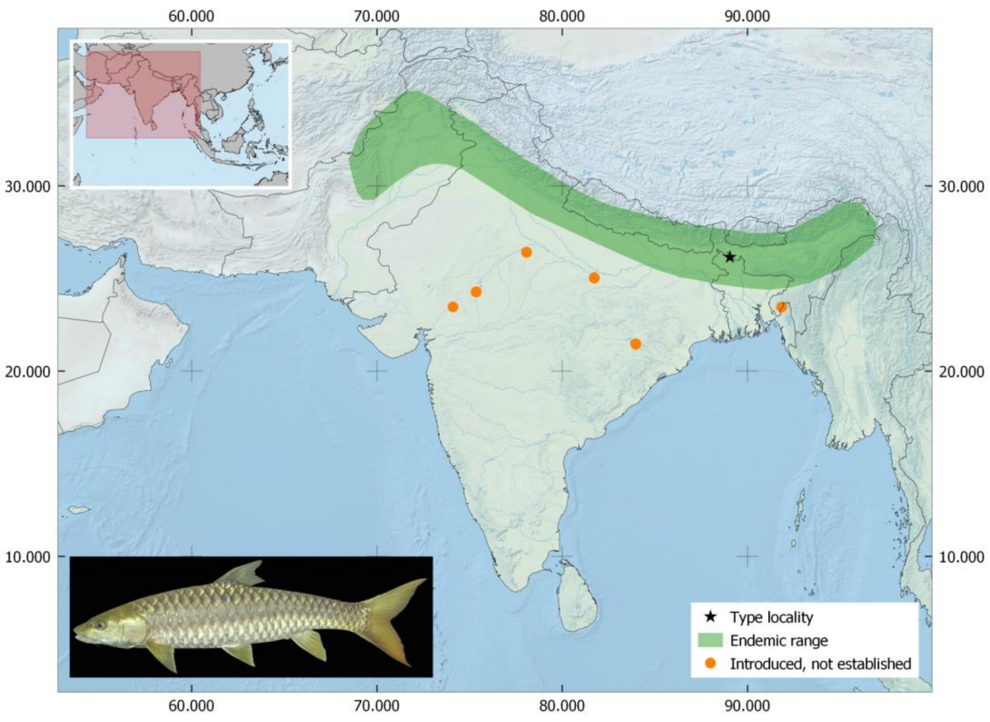


Figure 9.2.11. Distribution of *Tor putitora*. Inset image: *T. putitora* photographed by Tristan Tan/Shutterstock.com.

Tor remadevii

Kurup and Radhakrishnan (2007) described *Tor remadevii* based on 19 juvenile specimens ranging between 114 mm and 332 mm from the Pambar, the southern-most tributary of the River Cauvery in Kerala. Probably, based on the paucity of detail included in the original description, a re-description was published in 2010 (Kurup and Radhakrishnan 2010). While this update usefully included a line drawing of the fish, the authors still failed to include photographs, molecular evidence or congeneric morphological comparisons. Despite these descriptive details being limited, recent research has confirmed *T. remadevii* to be conspecific with the iconic hump-backed mahseer of the wider Cauvery catchment (Pinder et al. 2018a), thus affording the hump-backed mahseer the first valid scientific name since it was first brought to the attention of the scientific community in the early 19th century (Jerdon 1849).

Endemic and exclusively restricted to the River Cauvery catchment in South India (Pinder et al. 2018a), this species is thought to have been once widespread throughout much of the River Cauvery and its major tributaries (Thomas 1873) (Figure 9.2.12). Following a collapse in recruitment in the main river population during the mid-2000s (see Pinder et al. 2015b), the only spawning populations currently known to persist are restricted to a 40 km reach of the River Moyar, Tamil Nadu (Pinder et al. 2018a) and the Pambar River in Kerala (Kurup and Radhakrishnan 2007). Based on its alarming reduction in population size and persistent threats, *T. remadevii* is now recognised as the most imperilled of all *Tor* spp. and the only species to be assessed as Critically Endangered (Pinder et al. 2018b).

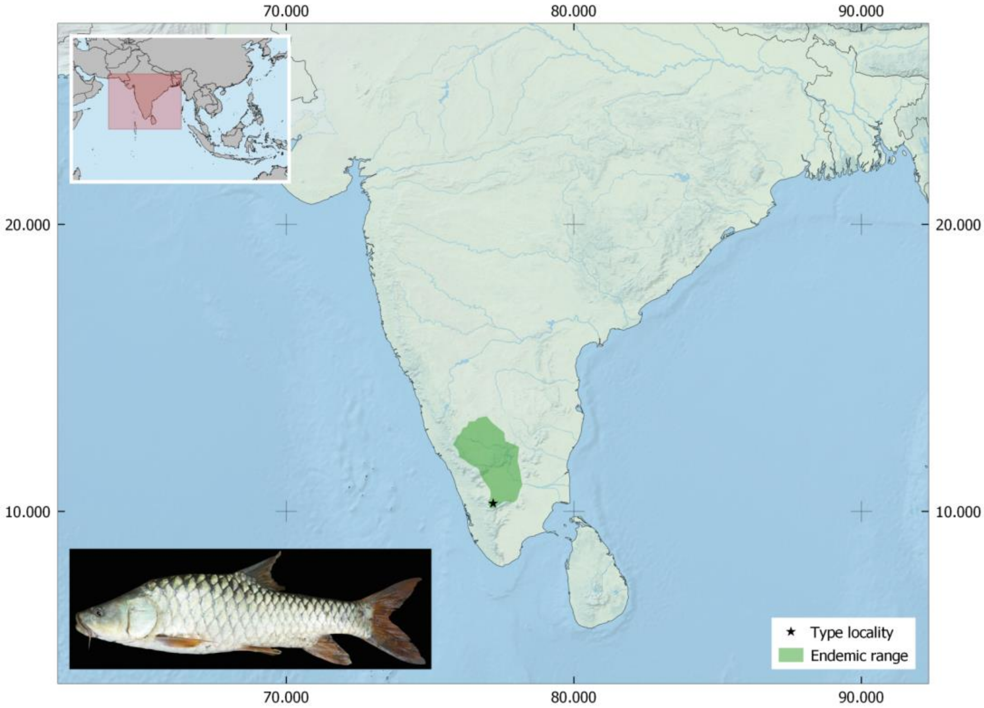


Figure 9.2.12. Distribution of *Tor remadevii*. Inset image: *T. remadevii* (487 mm) from the River Moyar, Tamil Nadu, India.

Tor sinensis

Tor sinensis was described from the upper reaches of the Mekong (Lancang Jiang) in Yunnan Province, China (Wu 1977), with its current distribution confined to the upper Mekong River system, from where it has been recorded from Luosuo Jiang, Jinghong and Menghan in Lancang Jiang (Upper Mekong), Yunnan Province, China (Wu 1977; Zhou and Cui 1996); the Nam Theun, Nam Hinboun, Xe Bang Fai, Se Kong and upper Nam Ngum in Lao PDR (Roberts 1999), upper Ea Krong No and Sre Pok River in Vietnam (Hoang et al. 2015) and Nong Khai in Thailand (on the border with Lao PDR) (Kottelat 2000). Despite the apparent wide distribution (Figure 9.2.13), the actual area of occupancy (AOO) of T. sinensis is not more than 2000 km^2 and the populations exist in nine fragmented basins part of the non-interconnected tributaries of the Mekong System. Due to this restricted distribution and high levels of anthropogenic threats existing and forecasted for the Mekong, most important of which is the mega-hydropower dams, Tor sinensis is assessed as Vulnerable (Vidthayanon and Pinder 2018).

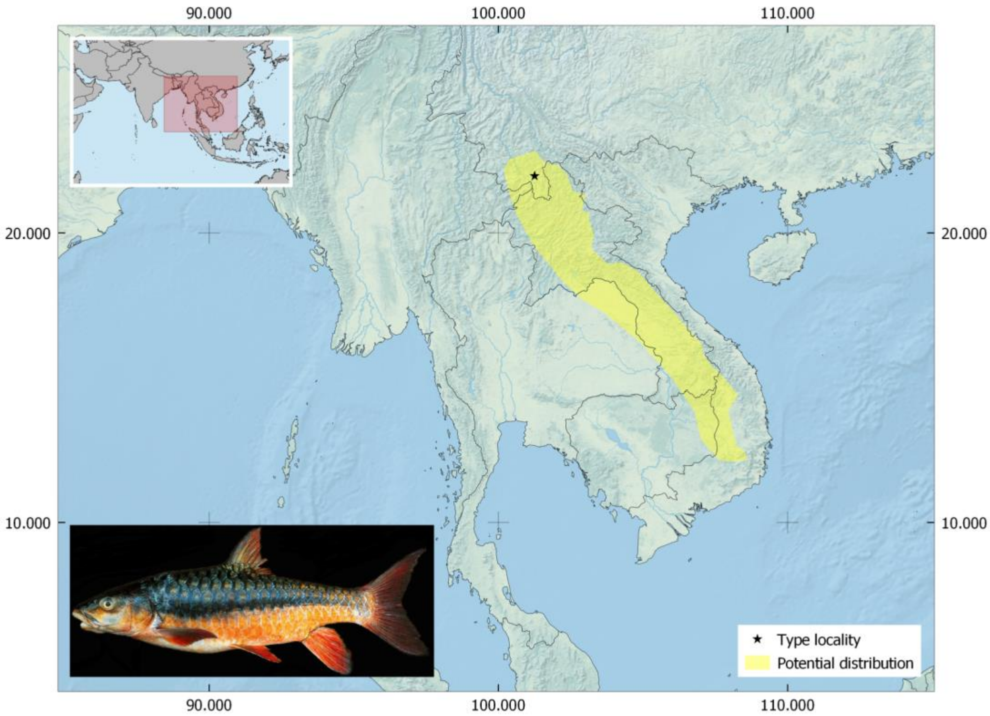


Figure 9.2.13. Distribution of *Tor sinensis.* Inset image: *T. sinensis* (465 mm) from the River Mekong, Laos. With kind permission T. Roberts.

Tor tambra* and *Tor tambroides

Five species names, viz., *douronensis*, *soro*, *soroides*, *tambra* and *tambroides* have been commonly referred to in the literature dealing with mahseers of South-east Asia (e.g. Mohsin and Ambak 1983; Ambak et al. 2012; Ng 2004; Bishop 1973; Kottelat 2013), of which '*soroides*' and '*soro*' have recently been assigned to the genus *Neolissochilus* (see Khaironizam et al. 2015). The original descriptions of *T. tambra*, *T. tambroides* and *T. douronensis* were based on specimens collected from Indonesia (Cuvier and Valenciennes 1842; Bleeker 1854). The type locality of *T. tambroides* is Sumatra: Padang, Paja kombo, Solok, Lake Maninjau /Java; and that of *T. tambra* and *T. douronensis* is Java: Bogor (see Kottelat 2013) (see Figure 9.2.14). The proliferation of nominal names of *Tor* from Indonesia is attributed (by Roberts 1993) to the work of Valenciennes (in Cuvier and Valenciennes 1842), who described *T. tambra* and *T. douronensis*, and Bleeker (1854, 1863), who recognized all of Valenciennes' *Tor* species and added one more, *T. tambroides.* These names were subsequently recognized (without any detailed studies) and uncritically used in the literature pertaining to freshwater fishes of mainland SE Asia, thus propagating un-reliable information over long periods of time. Further, the original descriptions of the three *Tor* species from Indonesia are vague and ambiguous, increasing the likelihood of misidentification (Walton et al. 2017).

Much confusion still surrounds the taxonomy of these three species. Several authors have suggested synonymy between two or all of these fish. Roberts (1993, 1999) maintains *T. tambra* (Figure 9.2.14), a species widely reported throughout S.E. Asia, is the senior synonym of several species; *T. soro* and *T. douronensis* (now both considered invalid) *and T. tambroides,* but provides little quantitative evidence to support this. Kottelat (2013) considers *T. tambroides* valid and agrees with the synonymy of *T. douronensis* and *T. tambra*, based on the similarity of original descriptions of both species, but considered *T. tambroides* only to be valid in its type locality (Sumatra and Java), pending comparison of other suggested populations with Javan topotypic material. Topotypic *T. tambra* has been found to be genetically similar to populations of mahseer occurring throughout mainland S.E. Asia, including populations in Malaysia recorded as *T. tambroides* (Walton et al. 2017), adding weight to the suggestions of Roberts et al. (1993; 1999), who considered *T. tambroides* to be a junior synonym of *T. tambra*. Despite this recent evidence of the misidentification of *T. tambroides* across S.E. Asia (Walton et al. 2017), it cannot currently be concluded that *T. tambra* and *T. tambroides* are synonymous, as material from Sumatra, identified as *T. tambroides*, appears to be genetically distinct to all material of *T. tambra* from the peninsula and Java (Walton et al. 2017). Based on the uncertainties discussed above, both *T. tambra* and *T. tambroides* are currently assessed as Data Deficient (Kottelat et al. 2018b, 2018c).

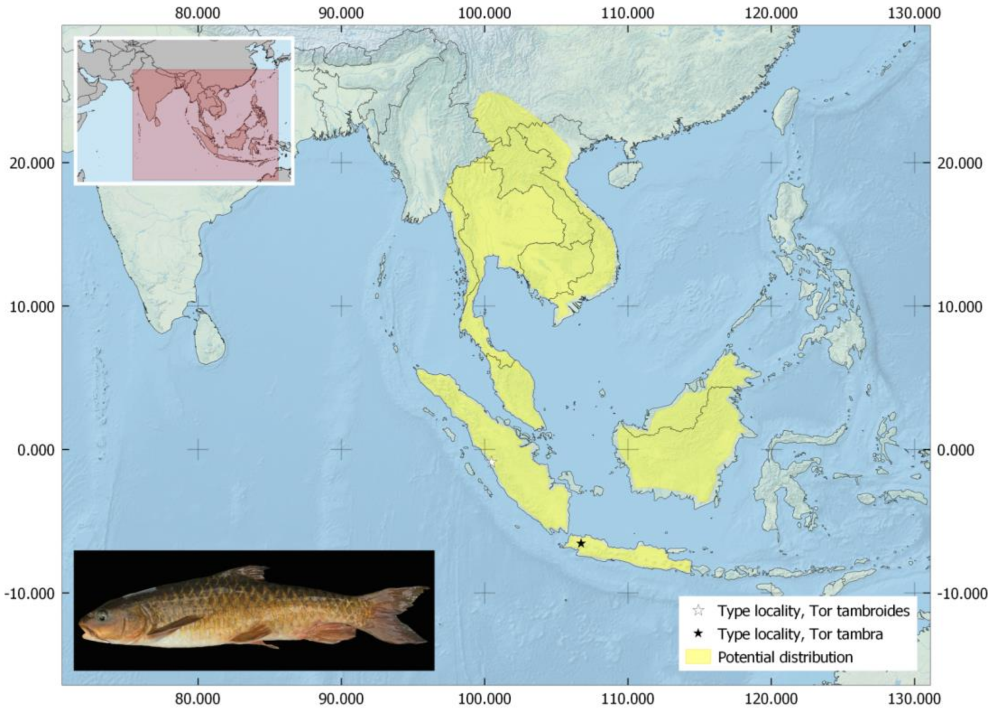


Figure 9.2.14. Distribution of *Tor tambra and Tor tambroides.* Inset image: *T. tambra* (560 mm) from the Serayu River basin South-central Java, Indonesia.

Tor tor

Frequently referred to as the 'red-fin' or 'deep bodied' mahseer, *Tor tor* is the type species of the genus. Described by Hamilton (1822) from the Mahananda, a tributary of the Ganges flowing through Northeast Bengal, India, *Tor tor* is considered to be the most widely distributed of mahseer (Lal et al. 2013), with a range extending throughout the South Himalayan drainage from Pakistan in the west to Myanmar in the East, and southwards to the peninsular Indian rivers (Figure 9.2.15). While the westward flowing Narmada River in Madhya Pradesh (Central India) was believed to be the southernmost limit of native distribution (Desai 2003), the recent discovery of *T. tor* in the Godavari and Krishna River basins (Lal et al. 2013) throws into question whether the species is native to tropical peninsular India, or if range expansion has resulted from the introduction and establishment of populations derived from artificially propagated stock. In spite of a large number of studies on the distribution of *T. tor* in Northern, Central and

Southern India, it remains to be proved conclusively whether *T. tor* of the Mahananda River (type locality) is conspecific with the populations in Central and peninsular Indian rivers from where they have been subsequently recorded. Nonetheless, if the biogeographic range of *T. tor* presented by Lal et al. (2013) is considered accurate, then the apparent wide distribution range of *T. tor* indicates a highly adaptive nature and reveals that the species is naturally eurythermal, inhabiting both cold and warm waters at various altitudes. Previously assessed as 'Near Threatened' in the IUCN Red List due to rapidly declining populations (Rayamajhi et al. 2010), *T. tor* has been recently reassessed as Data Deficient (Rayamajhi et al. 2018), based on an urgent need to validate the conspecificity of the Mahananda type locality population with records of *T. tor* from other parts of India.

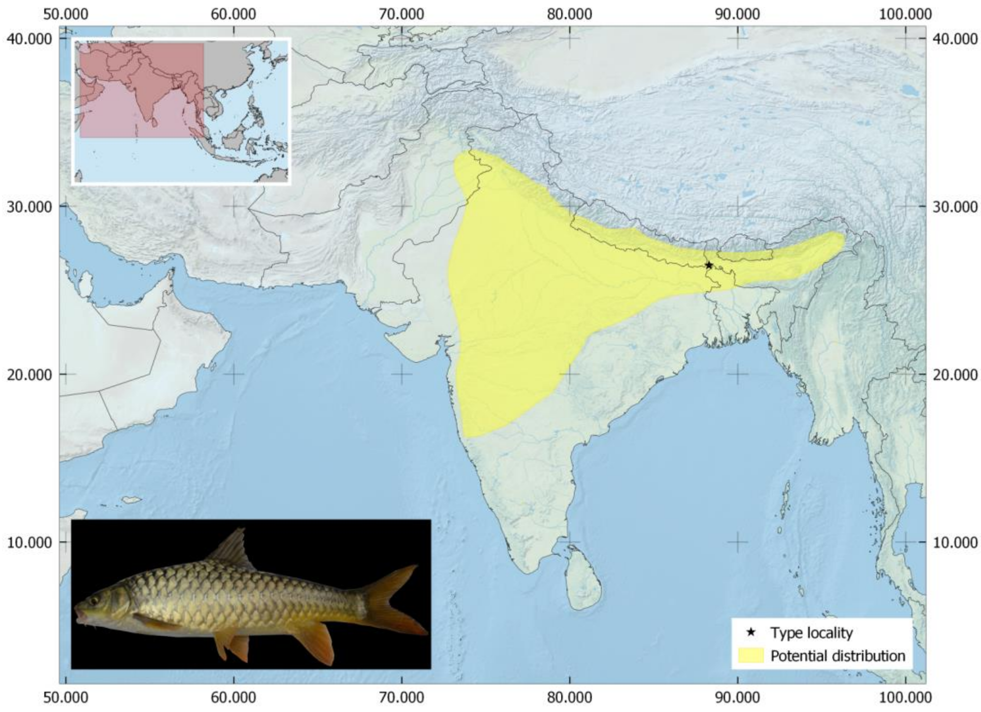


Figure 9.2.15. Distribution of *Tor tor*. Inset image: *T. tor* (410 mm) from the Choral River in the Narmada River basin, Madhya Pradesh, India. Note: until collected from the type locality, data are lacking to validate the genetic authenticity and physical appearance of *T. tor* collected from other river systems.

Tor yingjiangensis

Tor yingjiangensis, described from the Yingjiang River in the upper reaches of the Irrawady, was long misidentified as *T. putitora*, an allopatric species found in the Himalayan river systems in India and Pakistan (Chen and Yang 2004). The Chinese species is currently known only from the upper Irrawady in the Yunnan province of China, although it could possibly also occur in streams of northern Myanmar as well (Chen and Yang 2004) (Figure 9.2.16). No information exists on any aspect of this species including its biology, ecology and threats and is therefore assessed as Data Deficient (Pinder 2018).

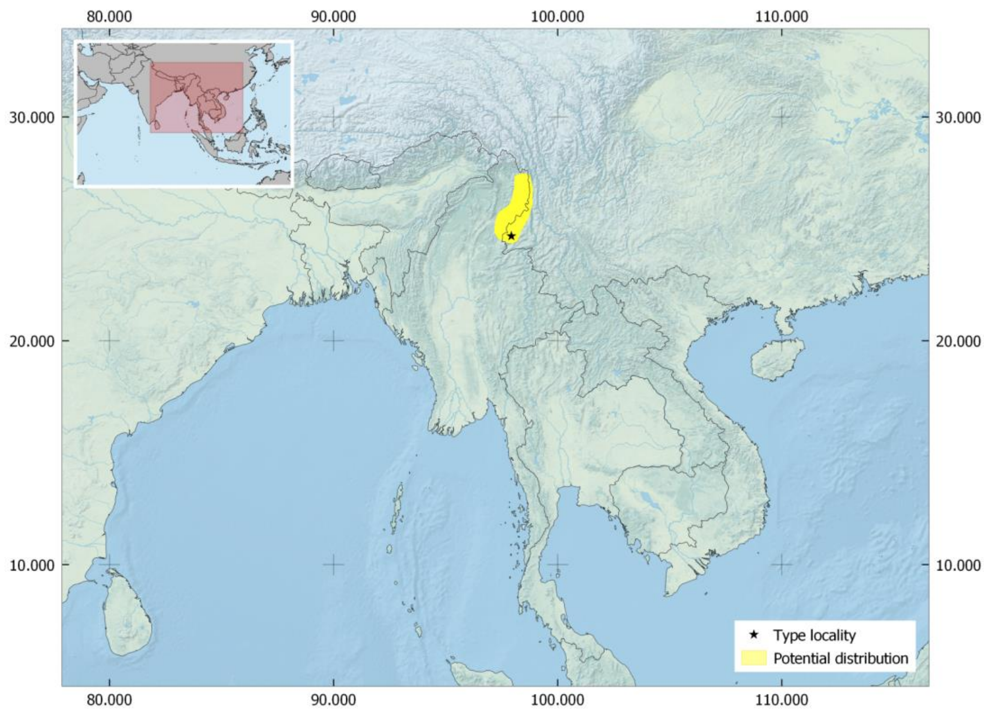


Figure 9.2.16. Distribution of *Tor yingjiangensis.*

Uncertain species

At least one species of *Tor* is present in Sri Lanka, which continues to be referred to as *Tor khudree longispinis*, considered a sub-species of *T. khudree* (Talwar and Jhingran 1991). Historic angling records, referring to the species as vermin, due to it inhibiting the establishment of introduced brown trout, *Salmo trutta* (Ceylon Fishing Club 1925), support the endemic status of *Tor* to Sri Lanka. Exhibiting contrasting pigmentation from the *T.*

khudree of South India, this species is commonly known as the yellow mahseer and often displays a dark lateral band of pigment (Figure 9.2.17) which is consistently absent in Indian *T. khudree*. Recent molecular studies have shown Sri Lankan *Tor* to be genetically distinct from Indian samples, with an average level of divergence of 0.046 (Ngyuen et al. 2008). Accordingly, further taxonomic studies, integrating morphology and molecular techniques are urgently required to elucidate the taxonomic identity and conservation status of this species. Consistent with other *Tor*, this species is likely to be of high conservation concern as evidenced by reports in the mid-1900s of the species becoming scarce, with individual fish rarely reaching the once common weights of over 10 kg (Department of Fisheries, Ceylon 1958).

Figure 9.2.17. The yellow mahseer of Sri Lanka currently recorded in literature as *Tor khudree longispinnis.*

Despite considerable recent progress in resolving taxonomy across the genus *Tor*, fundamental knowledge gaps continue to persist across Asia. Once filled, these may result in further major taxonomic revisions. Such revisions may be due to the addition of new previously undescribed species from poorly researched regions, or through molecular and morphometric evidence from type localities, concluding erroneous former con-specificity assumptions.

MAHSEER CONSERVATION

The recent Red listing of the 16 species in the *Tor* genus (Table 1) should provide fresh impetus to their conservation efforts and guide prioritised research to address remaining data deficiencies. Although it has been outlined that a series of substantial anthropogenic threats remain and continue to imperil populations, there are also various opportunities to conserve *Tor* spp. throughout its native range. These opportunities are outlined in the following sub-sections.

RECREATIONAL FISHING

Recreational fishing, where fish are captured using a variety of gears for purposes other than consumption (fish do not constitute the fisher's main source of protein) or sale (fish are not sold or traded at market), is a highly popular activity occurring worldwide (FAO 2012), particularly in inland waters (Cooke et al. 2016a). In highly industrialized countries, recreational fisheries are the largest fishing sector in inland waters (in terms of both revenue generated and catches reported; Arlinghaus et al. 2015). Estimates suggest that in highly industrialised and transitioning countries, over 10 % of people engage in recreational fishing activities (Arlinghaus et al. 2015), and recreational fishing is believed to be growing rapidly in less industrialised countries around the world (Bower et al. 2014). Several important benefits of recreational fishing activity have been identified (*cf.* Arlinghaus and Cooke 2009). For example, conservative estimates of global recreational fisheries expenditures indicate that recreational fisheries generate $190 billion USD in direct expenditures annually (World Bank 2012). In addition, numerous psycho-social benefits have been ascribed to recreational fishing activities, including heightened relaxation and improved relationships with nature (Fedler and Ditton 1994; Fedler 2000). In fishing communities of the developing world, recreational fisheries can play a different role. Small-scale fishing activity provides the main source of income and protein for millions of people around the world, and these same communities are less resilient to ecological and economic shocks (FAO 2010). Recreational fisheries can act as a livelihood buffer in these communities, providing an important source of income through additional or alternate forms of livelihood (Barnett et al. 2016).

To evaluate recreational fisheries as a conservation tool, the negative impacts and potential trade-offs of the activity need consideration. Recreational fishers (anglers) utilise approaches ranging from entirely catch-and-release (C&R; returning captured fish to the water, presumably unharmed; Arlinghaus et al. 2007) to entirely catch-and-harvest (Cooke et al. 2018). In harvest-based recreational fisheries, the amount of harvest must be accounted for in management models to ensure sustainable management (Lester et al. 2014). In C&R fisheries, or fisheries that permit or require (e.g. due to harvest regulations) a combination of behaviours, managers must account for additional sources of mortality (immediate mortality, Muoneke and Childress 1994; post-release mortality, Bartholomew and Bohnsack 2005), with angling-induced mortality rates varying widely between species (Cooke and Suski 2005). Recreational fishing is, however, rarely considered a factor in the endangerment of fishes, although it has been a factor in the localized extinctions of some populations (Post et al. 2002; Post 2013; Johnston et al. 2014) and has resulted in phenotypic and behavioural changes in others (Jørgensen et al. 2007; Arlinghaus et al. 2010; Alós et al. 2012). Furthermore, numerous data deficiencies are high (e.g. only 39% of known fish species have been assessed by IUCN to date; IUCN 2018), constraining the evaluation of conservation actions.

The role of recreational fishing in fish conservation includes promoting conservation through participation in research and citizen science (Granek et al. 2008). This highlights the relationship between recreational fishing and animal welfare (Arlinghaus et al. 2012) using recreational angling to protect threatened and endangered species (Cooke et al. 2016b), with species-specific examples including *Hucho taimen* (Jensen et al. 2009), *Lutjanus goldiei* (Sheaves et al. 2016) and *Tor putitora* (Everard and Kataria, 2011). Thus, recreational fisheries can play positive roles in conservation (Tufts et al. 2015). However, there are currently few case studies that describe recreational fisheries as a positive factor in fish conservation in the longer-term. This is partly due to the often ignored and highly complex social and cultural attributes of recreational fishing, including understanding angler motivations and behaviours, relationships among governance entities, and community perspectives (for e.g. Hunt et al. 2013; Naiman 2013; Stensland and Aas 2014). Increasingly, researchers are recognising the importance of social-ecological relationships in recreational fisheries and the need to account for interactions among these systems in their evaluation (Barnett et al. 2016; Arlinghaus et al. 2016, 2017). This viewpoint is particularly relevant when examining recreational fisheries targeting mahseers, where differing cultural, traditional, and social norms can produce different conservation outcomes, depending on the existing and potential degree of support for recreational fishing as an activity, and for conservation more broadly.

Recognised as a sporting challenge to anglers as early as the 12th century (*cf.* 'Role in history, religion and culture), mahseers were credited for their fighting qualities in 1833 in the Oriental Sporting Magazine (Cordington 1946), before being further popularised across India during British occupancy (Thomas 1873; Dhu 1923; MacDonald 1948). Following Indian independence in 1947, interest in mahseer fishing diminished, leaving the few who knew of the fish to believe they had become extinct. However, in 1978, a small team of British explorers were successful in catching mahseer to 42 kg (TWFT 1984), which reignited a global interest in mahseer angling and conservation, and launched a new era of Indian angling ecotourism (Everard and Kataria 2011; Pinder and Raghavan 2013).

Case studies of how recreational fisheries have supported mahseer conservation in India can help guide future fisheries management policy across Asia. In Uttarakhand, the potential of 'payments of ecosystem services' (PES) markets based on recirculation of revenues from recreational anglers to local people has been recognised as a potentially powerful conservation mechanism. Based on the longer-term revenues from C&R fisheries exceeding the immediate-term market value of harvested fish, this has led to the incentivised community policing of illegal and destructive fishing (Everard and Kataria 2011). Pinder and Raghavan (2013) described the role of recreational fisheries on the Cauvery River in Karnataka as positive overall, with local NGOs sustainably managing fisheries and offering alternative employment as guides and guards to fishers that previously used illegal tactics to catch fish. Angler catch data has been applied to track changes in mahseer size and weight (Pinder et al. 2015a). Bower et al. (2017) used a participatory approach to include stakeholders in priority-setting activities, finding that a social-ecological systems approach was warranted in studying mahseer recreational fisheries in both Karnataka and Uttarakhand. When examining angler perspectives, Gupta et al. (2015) found that most anglers are aware of the conservation status of mahseer and indicated high willingness to contribute time and money to supporting conservation. A subsequent study found that blue-finned mahseer (*T. khudree*) in the Cauvery River are physiologically resilient to the process of C&R but suggested that best practices should include minimizing angling time and air exposure to reduce post-release mortality (Bower et al. 2016a).

While there is an emerging trend amongst major wildlife organisations, conservationists and scientists towards encouraging angling tourism to support the conservation of mahseer and other sport fishes throughout their ranges, recent scrutiny and re-interpretation of the Indian Wildlife (Protection) Act 1972 (WPA) led to a national prohibition of angling within protected areas, thus terminating the incentivised stock protection practiced over a preceding period of four decades on the River Cauvery (Pinder and Raghavan 2013; Pinder et al. 2015a; 2015b). As a consequence, opportunities for angling on the River Cauvery are currently limited. Despite growing participation levels in recreational angling throughout mahseer range countries, interest in mahseer fishing is now largely focused on the catch and release of *T. putitora* from the Himalayan drainage, with some interest in the wild rivers supporting *T. tambra* in Thailand also evident. While there remains much scope for the development of mahseer angling tourism, organised recreational angling opportunities are currently limited.

AQUACULTURE

Mahseer conservation has tended to rely heavily on the production of hatchery-reared mahseers for release into the wild as a mitigation measure of, for example, loss of river connectivity due to hydropower development. Captive breeding mahseer for conservation and stock enhancement was first carried out in India by the Tata Electric Company (TEC) at Lonavla in Maharashtra in the 1970s, and gradually expanded to Nepal, Bangladesh and Malaysia. Millions of seeds of various mahseer species (*T. khudree, T. putitora* and an ambiguous species 'Tor mussullah') have been bred at Lonavla and distributed to various State Fisheries Departments and other stakeholders throughout India (and elsewhere), primarily for stock enhancement in natural waters (Ogale 2002).

Currently, techniques for breeding and artificial propagation are available for many of the popular mahseer species including *T. khudree, T. putitora, T. tor* and *T. tambroides* (Gurung et al. 2002; Ogale 2002; Ingram et al. 2005, 2007). Early hatchery production of mahseer juveniles were derived by hand stripping wild-caught mature spawners during the breeding season, with or without artificial hypophysation (Ogale 1997), but has now expanded to the use of pond-reared broodstock (Gurung et al. 2002; Ingram et al. 2005; Joshi et al. 2002). Advances in the standardisation of effective induced breeding and seed production technology has enabled development of grow-out techniques that cut across the boundaries of traditional pond-based farming systems to highly sophisticated cage farming (Kohli et al. 2002; Shahi et al. 2014; Sarma et al. 2016).

Evidenced by photographs available from TEC hatchery in Lonavla, Maharshtra (A. Pinder pers. obs.), *Tor remadevii*, the hump-backed mahseer (under the guise of 'T. mussullah') is known to have been translocated to Lonavla from the River Cauvery for aquaculture trials in the 1970s and successfully hybridised with *T. putitora* (Ogale 2002). No further records are available to determine the level of breeding success of 'T. mussullah' at Lonavla and efforts appear to have been redirected in favour of the culture of *T. khudree*, (Kulkarni 1971; Kulkarni and Ogale 1978), *T. tor* (Ogale and Kulkarni 1987; Ogale 2002) and *T. putitora* (Tripathi 1978; Pathani and Das 1979).

The Indian Council for Agricultural Research – Directorate of Coldwater Fisheries Research (ICAR-DCFR) is involved in breeding of *T. putitora*; the fingerlings of which are used for rehabilitating both rivers and lakes in North Eastern India (Sarma et al. 2016). Currently, five mahseer hatcheries operate in India, producing fry and fingerlings primarily for the purpose of ranching and stock enhancement to aid conservation. There is very little information on whether the breeding and culture trials for mahseer in Nepal and Bangladesh (see Shreshta 2002; Gurung et al. 2002; Rahman et al. 2005) have resulted in commercialisation for either food or conservation aquaculture, or even stock enhancement and ranching. Similarly, although the captive breeding techniques for the sundaic species, *T. tambra* and *T. tambrodies* have been standardised (Ingram et al. 2005, 2007), there is a paucity of information to demonstrate its effectiveness for conservation, despite some commercial-scale farming operations being in existence. Since the inception of *Tor* aquaculture, there are numerous examples of seeds of individual species being distributed beyond their natural geographic range (see Ogale 2002). While such activities directly negate conservation action and will have resulted in unknown impacts on local biodiversity, recent raised awareness (e.g. Pinder et al. 2015b) has resulted in some Indian aquaculture facilities recognising the importance of endemic biodiversity and has subsequently driven a shift towards preserving indigenous *Tor* spp. by limiting culture to only using locally sourced broodstock. Overall, despite considerable effort over the last 50 years to utilise aquaculture as a tool to assist the conservation of wild mahseer, there remains a comprehensive lack of population monitoring, both pre- and post-stocking, to quantify the efficacy of these efforts.

FRESHWATER PROTECTED AREAS

The true extent of the world's fresh waters covered by the protected area (PA) network remains largely unknown (Saunders et al. 2002). Although, 15.4% of the world's 'terrestrial and inland waters' (combined) are under the PA network (Juffe-Bignoli et al. 2014), the 'inland/freshwater ecosystems' within terrestrial PAs receive only incidental protection (Saunders et al. 2002). Estimates of the area within mahseer distribution range that fall inside the terrestrial PA network is also not known for many species, but for some range-restricted species such as *T. remadevii*, terrestrial PAs play a significant conservation role as they encompass ~70% of the current species distribution range. Since the majority of national PA networks are biased to higher elevations, steeper slopes and greater distances to urban settlements (Joppa and Pfaff 2009), they coincide with the ecological requirements and distribution of mahseer (i.e. middle to upper reaches of major rivers), and thus have high potential for playing a major role in their current and future conservation.

Even in cases where mahseer populations occur inside PAs, their effectiveness is not typically encouraging. Illegal fishing often using unsustainable gears, alien invasive species, and a combination of other anthropogenic threats (e.g. river fragmentation, abstraction, pollution) is known from both inside, as well as areas upstream and downstream regions of many Indian PAs (Gupta et al. 2014; Raghavan et al. 2011). In reservoirs and streams inside terrestrial PAs, where mahseer can be legally exploited (largely through the provision of the Indian Forest Rights Act), fishing mortality and exploitation rates have been observed to be above the optimal limits, indicating the need for urgent management interventions (Raghavan et al. 2011). The only example of a PA being designated exclusively for the protection of mahseer is the Poonch River National Mahseer Park that flows through Azad Jammu Kashmir (AJK). Initiated as a joint venture between the AJK government and the Mira Power Company Ltd, 62 km of the river has since been afforded protection from illegal exploitation, with the support of newly enacted legislation (AJK Wildlife and Fisheries Act 2010), deterring poachers and allowing the population of *T. putitora* to persist.

Alongside the legal protection, a system of rural support ensures 80 % of the revenue generated inside the PA goes to local villagers (A. Rahman pers. comm.).

Informal forms of protected areas also exist throughout India, where mahseer are revered as god's fishes (Gupta et al. 2015a). Religious sentiments have helped protect the endangered golden mahseer (*T. putitora*) in several tributaries of the River Ganges, while peninsular Indian species of *Tor* (*T. malabaricus* and *T. khudree*) continue to be protected in several stretches of rivers associated with temples (Dandekar 2011b), where exploitation is prohibited and local communities, pilgrims and temple authorities help monitor and safeguard the fish population (Gupta et al. 2015a). Yet another protection strategy for mahseer has been through community-managed areas, the classical example of which is the 'Tagal' system of Borneo which was initiated by the communities in response to dwindling fish resources in the early 20th century (Wong et al. 2009). Under the Tagal management system each pre-assigned stretch of a river is divided into three zones: red, yellow and green, each differing in access and regulations on fishing. Currently 240 Tagal systems are in operation in Sabah helping protect the Malaysian mahseers.

RESTORATION OF RIVER CONNECTIVITY

As already highlighted (*cf*. Population Threats), instream engineering projects represent a major and escalating anthropogenic threat constraining mahseer populations across their entire biogeographic range. While mega-hydroelectric dams are known to exclude the upstream migration of all fishes, the bio-permeability and impact of smaller structures (e.g. check-dams designed for storage and irrigation) also have the potential to fragment the accessibility of key functional habitats by disrupting or obstructing the access of adult cyprinid fishes to their spawning grounds (Ovidio and Philippart 2002). Although large-scale habitat restoration for mahseer is currently constrained due to a paucity of knowledge on their ecological requirements across different life-stages (*cf*. Future Research Opportunities), incorporating fish passes into the design of future projects and the retrofitting of easements on existing barriers has the potential to deliver relatively rapid benefits via enabling the movement of mature adults to access upstream spawning areas. The construction of fish passes on migration barriers has been a common practice in the last 50 years (Wilkes et al. 2018) and although engineering solution designs have been traditionally heavily skewed towards salmonid fishes (Birnie-Gauvin et al. 2018), there are a growing number of studies which have demonstrated appropriate designs which incorporate species specific biological knowledge of behaviour and swimming performance (Williams et al. 2012), can be at least partially successful for enabling the upstream passage of potamodromous cyprinids (Santos et al. 2012; Romão et al. 2017). Notwithstanding the need for appropriate design, the conservation benefits of reconnecting migratory pathways for mahseers would also critically depend on the ability of juveniles to safely navigate these structures during their downstream migration (Kemp and O'hanley 2010).

INTEGRATION WITH WIDER ENVIRONMENTAL PROTECTION POLICY

Recognition of both the taxonomic validity and conservation status of mahseer fishes also offers the potential to integrate them into wider conservation mechanisms beyond the IUCN Red List. These large omnivorous fishes can act as top predators, potentially acting as key agents in trophic cascades, but also as ‘flagship’ conservation species (Everard and Kataria 2011 use the term ‘iconic’ in preference to ‘flagship’ for species that are potentially exploitable); thus mobilising wider public support for protection and restoration of the networks of interconnected habitats upon which they depend to complete their life cycles (Caro, 2010), along with associated uplift in other species and linked ecosystem services beneficial to human communities (Everard et al. 2011). Populations of mahseer fishes, then, can have a direct role as key indicators of the “wise use” of wetlands

(Ramsar Convention Secretariat 2010), wherein exploitation is balanced with protection of the ecological character of the river systems they inhabit.

Mahseer and their sustainable use can also benefit from protections such as management of their host ecosystems under the principles of the Convention on Biological Diversity (https://www.cbd.int [accessed 12/03/2019]); with particular emphasis placed on following the Ecosystem Approach and ensuring exploitation is governed by the Nagoya Protocol (on Access and Benefit Sharing). Controls on the spreading of invasive hybrid species arguably also fall under the aegis of the Cartagena Protocol on Biosafety to the Convention on Biological Diversity. Additional conservation tools, such as the Conservation Management System (https://www.software4conservation.com [accessed 12/03/2019]), can also be applied within an adaptive management framework to secure the long-term viability of mahseer (and other linked species) populations and the habitats upon which they depend.

FUTURE RESEARCH OPPORTUNITIES

In synthesising the current state of knowledge pertaining to *Tor* spp., this review has highlighted a series of high uncertainties regarding species taxonomy, distributions, population status and ecology that provide substantial research opportunities outlined in this subsection.

SPECIES TAXONOMY

There have been some recent advances in taxonomic knowledge in the *Tor* genus that have removed some of the ambiguities that have been problematic for conservation (Pinder et al. 2018a). Original descriptions of some *Tor* fishes do, however, contain inconsistencies and ambiguities, with an absence of accompanying voucher specimens, increasing the likelihood of potential misidentifications (Walton et al. 2017). Consequently, there remains an outstanding research requirement for a comprehensive mahseer range-wide taxonomic study across all major drainage basins, incorporating molecular taxonomic studies using multiple mitochondrial and nuclear genes, and accounting for all visible diagnostic characteristics to discriminate between species.

SPECIES DISTRIBUTION AND POPULATION STATUS

Coupled with their taxonomic ambiguities, there remains a paucity of information on the distribution ranges of some *Tor* fishes. This is at least in part due to resourcing issues around field expeditions, given the range of many mahseer fishes are in developing countries where funding for biodiversity assessments tend to be limited. It might also relate to issues around many mahseer species being present in rivers that are relatively remote and/or difficult to sample. This flags the importance of frequent reviewing and revising *Tor* IUCN Red List assessments in accordance with emerging evidence.

A method that potentially helps overcome this issue is the widespread application of environmental DNA (eDNA), a method based on detecting species DNA from water samples (Jerde et al. 2011; Davison et al. 2016; Turner et al. 2015). The method is increasingly being applied to the monitoring of freshwater species, including those of conservation importance (e.g. Takahara et al. 2012; Thomsen et al. 2012). eDNA can be used to screen to characterise whole communities of organisms using ‘metabarcoding’ (Lawson Handley 2015; Hanfling et al. 2016). For determining mahseer distributions, however, a more cost-effective method could be used of specific primers in real-time PCR that enable detection of the presence/ absence of a specific *Tor* species. Although representing a major development in mapping species’ distributions, a number of issues remain on its use, given multiple factors influencing DNA dynamics in the environment (Barnes et al. 2014). For example, the non-detection of species-specific DNA fragments in a sample of river water does not automatically imply the absence of the target species (Lacoursiere-Roussel et al. 2016).

ECOLOGICAL KNOWLEDGE GAPS

Over the last 20 years, the attention researchers have applied to ecological aspects of study across the genus has been negligible (*cf*. Figure 1) and entirely limited in focus to just two species, *T. putitora* (Shrestha 1997; Nautiyal et al. 2001; Nautiyal 2014; Bhatt and Pandit 2016) and *T. tor* (Shrestha 1997; Desai 2003). While there is considerable scope to enhance knowledge of these two species, attention to other *Tor* species should be prioritised in accordance with their conservation status. For example, nothing is yet known about the basic biology and ecology of *T. remadevii*, despite it achieving the largest body sizes of all *Tor* (Pinder et al. 2018a) and being the only mahseer species assessed as 'Critically Endangered' (Pinder et al. 2018b).

The application of aquatic telemetry technologies as a bio-surveillance tool is still in its infancy across mahseer range countries (Baras et al. 2002). Research to date has been exclusively limited to the Manas watershed in Bhutan, but has revealed fascinating insight to the movements of *T. putitora*, with upstream movements of 30 km and elevation gains of 200 m recorded within single 24 hour periods (J. Claussen pers. comm.). While some records suggest that the elevation range of *T. putitora* extends to a maximum of 1,800 m in India (Cordington 1946) and 2,100 m in Nepal (Shreshta 1997) in-country development of skills will be critical to accelerate the knowledge gain required to validate these observations, quantify natural home ranges and the functional habitat utilisation of all *Tor* spp. across a representative range of watersheds. These data will be of fundamental importance to schemes aiming to restore river connectivity for populations impacted by impoundment (*cf*. Restoration of river connectivity).

Dynamic shifts in physiological and morphological development and corresponding organism/microhabitat associations during early development remain a poorly researched component of life history in fishes (Browman and Skiftesvik 2014). Despite representing the most critical life history period and, thus, key to regulating recruitment success (Fuiman and Higgs 1997), such detail is often overlooked due to perceived challenges associated with capture and identification of larval and juvenile cyprinids (Pinder 2001). While some mahseer habitat has already been lost, most remaining populations are subject to variable but escalating degrees of habitat deterioration. With migratory access frequently compromised or blocked by instream engineering projects and the associated shift from lotic to vast expanses of lentic habitat, understanding the adaptive plasticity of species throughout their entire ontogenetic ecology will be critical in order to assess population resilience to the joint threats of anthropogenic re-engineering of rivers and climate change. Without such knowledge, evidence-based input to Environmental Impact Assessment (EIA), understanding and predicting the mechanistic risks of climate change, and future species conservation planning will remain severely compromised.

CONCLUSIONS

To date, the taxonomy across the genus *Tor* has been confused and a key factor identified in constraining extinction risk assessment and the development of effective species conservation planning. At the time of writing, FishBase continued to list 50 different species of *Tor* of which 23 were suggested to be valid (Froese and Pauly 2018). Incorporating recent species descriptions, examining the validity of synonymies and extensive literature review, the revision of the number of currently valid species to 16, represents a comprehensive overhaul of the genus and a long overdue baseline on which to build further knowledge. With new species descriptions anticipated from less studied regions and the emergence of evidence to challenge former assumptions of species con-specificity also expected, this dynamic state of knowledge means regular conservation reassessments will be essential to prioritise research focus and facilitate effective conservation planning. While this paper presents a synthesis of population threats and opportunities to conserve these freshwater icons, their future security rests in the hands of local and regional biodiversity managers and policy-makers, and critically relies on a shift from piecemeal reactive to proactive multidisciplinary conservation planning.

ACKNOWLEDGEMENTS

We wish to thank A.J.T. Johnsingh, D. D'Souza, A. Nair, M. Dhillon, S. Chakrabarty, N. Sreenivisan, S. Philip, S. Saxena, P. Srivastava and A. Manimekalan for their contribution of knowledge, field support and access to rivers and *Tor* specimens. We are grateful to R. Britz and O. Crimmen at the Natural History Museum, London, and S.J. Srinivasa at Mysore Natural History Museum, Mysore, India for facilitating access to specimens. We thank V. Talwar, V. Vishwasrao and Y. Kulkarni of Tata Power for facilitating enlightening stakeholder workshops and T. Disdale and M. Clark and A. Clark of the Trans World Fishing Team for the provision of historic photographs. T. Roberts, B.A. Laskar and H.D. Hoang kindly contributed specimen images and R. Philpott assisted with image processing.

REFERENCES

Alós, J., Palmer, M., & Arlinghaus, R., 2012. Consistent selection towards low activity phenotypes when catchability depends on encounters among human predators and fish. *PloS One* 7, e48030.

Ambak, M.A., Isa, M.M., Zakaria, M.Z., & Ghaffar, M.A., (Eds). 2012. Fishes of Malaysia. 2nd Edn. Penerbit UMT, Terengganu, MY

Arai, R., 2011. Fish Karyotypes: A Check List. Springer, Tokyo.

Arlinghaus, R., Cooke, S.J., Lyman, J., Policanksy, D., Schwab, A., Suski, C., Sutton, S.G., & Thorstad, E.B., 2007. Understanding the complexity of catch-and-release in recreational fishing: An integrative synthesis of global knowledge from historical, ethical, social and biological perspectives. *Rev Fish Sci* 15, 75–167.

Arlinghaus, R., & Cooke, S.J., 2009. Recreational Fishing: Socio-economic importance, Conservation issues and Management challenges. In B. Dickson, J. Hutton & B. Adams (Eds.), Recreational Hunting, Conservation and Rural Livelihoods: Science and Practice (pp. 39-58). Oxford: Blackwell.

Arlinghaus, R., Matsumura, S., & Dieckmann, U., 2010. The conservation and fishery benefits of protecting large pike (*Esox lucius* L.) by harvest regulations in recreational fishing. *Biol Conserv* 143, 1444–1459.

Arlinghaus, R., Schwab, A., Riepe. C., & Teel, T., 2012. A primer on anti-angling philosophy and its relevance for recreational fisheries in urbanized societies. *Fisheries* 37, 153–164.

Arlinghaus, R., Tillner, R., & Bork, M., 2015. Explaining participation rates in recreational fishing across industrialised countries. *Fisheries Manag Ecol* 22, 45–55.

Arlinghaus, R., Cooke, S.J., Sutton, S.G., Danylchuk, A.J., Potts, W., Freire, K., Alos, J., da Silva, E.T., & Anrooy, R., 2016. Recommendations for the future of recreational fisheries to prepare the social-ecological system to cope with change. *Fisheries Manag Ecol* 23, 177–186.

Arlinghaus, R., Alós, J., Beardmore, B., Daedlow, K., Dorow, M., Fujitani, M., Huhn, D., Haider, W., Hunt, L.M., Johnson, B.M., Johnston, F., Klefoth, T., Matsumura. S., Monk, C., Pagel, T., Post, J.R., Rapp, T., Riepe, C., Ward, H., & Wolter, C., 2017. Understanding and managing freshwater recreational fisheries as complex adaptive social-ecological systems. *Rev Fish Sci and Aquac* 25, 1–41.

Arthington, A.H., Dulvy, N.K., Gladstone, W., & Winfield, I.J., 2016. Fish conservation in freshwater and marine realms: status, threats and management. *Aquat Conserv* 26, 838–857.

Arunkumar, L., & Basudha, C., 2003. *Tor barakae*, a new species of mahseer fish (Cyprinidae: Cyprininae) from Manipur, India. *Aquaculture* 4, 271–276.

Baras, E., Bénech, V., & Marmulla, G., 2002. Outcomes of a pilot fish telemetry workshop for developing countries. *Hydrobiology* 483, 9-11.

Barnes, M.A., Turner, C.R., Jerde, C.L., Renshaw, M.A., Chadderton, W.L., & Lodge, D.M., 2014. Environmental conditions influence eDNA persistence in aquatic systems. *Environ Sci Technol* 48, 1819–1827.

Barnett, A., Abrantes, K.G., Baker, R., Diedrich, A.S., Farr, M., Kuilboer, A., Mahony, T., McLeod, I., Moscardo, G., Prideaux, M., Stoeckl, N., van Luyn, A., & Stoeckl, N., 2016. Sportfisheries, conservation and sustainable livelihoods: a multidisciplinary guide to developing best practice. *Fish Fish* 17, 696–713.

Bartholomew, A., & Bohnsack, J.A., 2005. A review of catch-and-release angling mortality with implications for no-take reserves. *Rev Fish Biol Fisher* 15, 129–154.

Belcher, W.R., 1998. Fish exploitation of the Baluchistan and Indus Valley Traditions: an ethnoarchaeological approach to the study of fish remains – William R Belcher (University of Wisconsin – Madison) 1998.

Bhagwat, S.A., & Rutte, C., 2006. Sacred groves: potential for biodiversity management. *Front Ecol Environ* 4, 519−524.

Bhatt, J.P., & Pandit, M.K., 2016. Endangered Golden mahseer *Tor putitora* Hamilton: a review of natural history. *Rev Fish Biol Fisher* 26, 25–38.

Birnie-Gauvin, K., Franklin, P., Wilkes, M., & Aarestrup, K., 2018. Moving beyond fitting fish into equations: Progressing the fish passage debate in the Anthropocene. *Aquat Conserv*. In Press.

Bishop, J.E., 1973. Limnology of a small Malayan River-Sungai Gombak. Dr. Junk Publisher, The Hague, 485p.

Bleeker, P., 1854. Overzigt der ichthyologische fauna van Sumatra, met beschrijving van eenige nieuwe soorten. *Natuurkundig tijdschrift voor Nederlandsch Indië* 7, 49–108.

Bleeker, P., 1863. Atlas ichthyologique des Indes Orientales Neerlandaises. Tome Ill. Cyprins. Frederic Muller, Amsterdam. 150p.

Bower, S.D., Nguyen, V.M., Danylchuk, A.J., Beard Jr., T.D., & Cooke, S.J., 2014. Inter-sectoral conflict and recreational fisheries of the developing world: Opportunities and challenges for co-operation. In P McConney, R Medeiros, & M. Pena (Eds.), *Enhancing Stewardship in Small-Scale Fisheries: Practices and Perspectives* (pp. 88-97). Barbados: CERMES Technical Report No. 73.

Bower, S.D., Danylchuk, A.J., Raghavan, R., Clark-Danylchuk, S.E., Pinder, A.C., & Cooke, S.J., 2016a. Rapid assessment of the physiological impacts caused by catch-and-release angling on blue-finned mahseer (*Tor* sp.) of the Cauvery River, India. *Fisheries Manag Ecol* 23, 208–217.

Bower, S.D., Danylchuk, A.J., Raghavan, R., Danylchuk, S.C., Pinder, A.C., Alter, A,M., & Cooke, S.J., 2017. Involving recreational fisheries stakeholders in development of research and conservation priorities for mahseer (*Tor* spp.) of India through collaborative workshops. *Fish Res* 186, 665–671.

Browman, H.I., & Skiftesvik, A.B., 2014. The early life history of fish—there is still a lot of work to do!. *ICES J Mar Sci* 71, 907–908.

Caro, T., 2010. Conservation by Proxy: Indicator, Umbrella, Keystone, Flagship, and Other Surrogate Species: Island Press.

CBD (Undated) The Convention on Biological Diversity. (https://www.cbd.int/convention/, Accessed 8th March 2019.)

Ceylon Fishing Club, 1925. Report for the year November, 1924 – October, 1925, 47 p.

Chen, Z.M., & Yang, J.X., 2004. A new species of the genus *Tor* from Yunnan, China (Teleostei: Cyprinidae). *Environ Biol Fish* 70, 185–191.

Closs, G.P., Krkosek, M., & Olden, J.D., 2016. Synthesis – what is the future of freshwater fishes? In G.P. Closs, M. Krkosek, J.D. Olden (Eds.), Conservation of Freshwater Fishes (99. 563-572) Cambridge: University Press.

Cooke, S.J., & Suski, C.D., 2005. Do we need species-specific guidelines for catch-and-release recreational angling to effectively conserve diverse fishery resources? *Biodivers Conserv* 14, 1195–1209.

Cooke, S.J., Arlinghaus, R., Johnson, B.M., & Cowx, I.G., 2016a. Recreational fisheries in inland waters. In: J.F. Craig (ed) Freshwater Fisheries Ecology. Oxford: Wiley Blackwell, pp. 449–465.

Cooke, S.J., Hogan, Z.S., Butcher, P.A., Stokesbury, M.J., Raghavan, R., Gallagher, A.J., Hammerschlag, N., & Danylchuk, A.J., 2016b. Angling for endangered fish: conservation problem or conservation action? *Fish Fish* 17, 249–265.

Cooke, S.J., Twardek, W.M., Lennox, R.J., Zolderdo, A.J., Bower, S.D., Gutowsky, L.F., Danylchuk, A.J., Arlinghaus, & R., Beard, D., 2018. The nexus of fun and nutrition: Recreational fishing is also about food. *Fish Fish* 19, 201–224.

Cordington, K. De. B., 1946. Notes on Indian Mahseer. *Journal of the Bombay Natural History Society* 46, 336–334.

Cuvier, G., & Valenciennes, A., 1842. Histoire naturelle des Poissons. Vol. 16. Paris. 472p.

Cuvier, G., & Valenciennes, A., 1829. Histoire naturelle des poissons. Tome troisième. Suite du Livre troisième. Des percoïdes à dorsale unique à sept rayons branchiaux et à dents en velours ou en cardes. *Histoire Naturelle des Poissons* 3, 500.

CWC, 2017. National register of large dams. Central Water Commission, Pune. [online.] (http://www.cwc.nic.in/mn/downloads/New%20NRLD.pdf, accessed 25th January 2017.)

Dahanukar, N., 2011. *Tor kulkarnii*. The IUCN Red List of Threatened Species 2011: e.T172355A6875134. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T172355A6875134.en. Accessed 13 March 2019.

Dahanukar, N., Raghavan, R., Ali, A., Abraham, R., Shaji, C.P., 2011. The status and distribution of freshwater fishes of the Western Ghats. In S. Molur, K.G. Smith, B.A. Daniel, & W.R.T. Darwall (compilers) The status and distribution of freshwater biodiversity in the Western Ghats, India (pp 21–48). Coimbatore: IUCN, Cambridge, and Zoo Outreach Organisation.

Dahanukar, N., Katwate, U., Pinder, A., & Harrison, A., 2018a. *Tor kulkarnii*. The IUCN Red List of Threatened Species 2018: e.T172355A60609857. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T172355A60609857.en. Accessed 13 March 2019.

Dahanukar, N., Pinder, A., & Harrison, A., 2018b. *Tor mosal*. The IUCN Red List of Threatened Species 2018: e.T188106A1855151. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T188106A1855151.en. Accessed 13 March 2019.

Dandekar, P., 2011a. India's community fish sanctuaries protect wild fish and rivers. *World Rivers Review* 26, 1−7.

Dandekar, P., 2011b. Temple fish sanctuaries: Last bastions of native fish and pristine river stretches - A report. http://www.indiawaterportal.org/articles/temple-fish-sanctuaries-last-bastions-native-fish-and-pristine-river-stretches-report. Accessed 21 September 2018.

Darwall, W.R., & Freyhof, J., 2016. Lost fishes, who is counting? The extent of the threat to freshwater fish biodiversity. In G.P. Closs, M. Krkosek & J.D. Olden (Eds.) *Conservation of Freshwater Fishes* (pp. 1-36). Cambridge: University Press.

Davison, P.I., Créach, V., Liang, W.J., Andreou, D., Britton, J.R., & Copp, G.H., 2016. Laboratory and field validation of a simple method for detecting four species of non-native freshwater fish using eDNA. *J Fish Biol* 89, 1782–1793.

Davidson, N.C., 2014. How much wetland has the world lost? Long-term and recent trends in global wetland area. *Mar Freshwater Res* 65, 934–941.

Day, F., 1876. On some of the Fishes of the Deccan. *Journal of the Linnean Society of London, Zoology* 12, 565–578.

Department of Fisheries, Ceylon, 1958. A guide to the fisheries of Ceylon – Bulletin No. 8. Publication of the Fish Res Station, Ceylon, 72 p.

De Jalon, D.G., Sanchez, P., & Camargo, J.A., 1994. Downstream effects of a new hydropower impoundment on macrophyte, macroinvertebrate and fish communities. *Regul River* 9, 253-261.

Desai, V.R., 2003. Synopsis of biological data on the Tor mahseer, *Tor tor* (Hamilton, 1822). FAO Fisheries Synopsis, 158: 36 p.

Dhu, S., 1923. The angler in India or the mighty mahseer. Dehra Dun: Natraj.

Dudgeon, D., 2000. Large-Scale Hydrological Changes in Tropical Asia: Prospects for Riverine Biodiversity: The construction of large dams will have an impact on the biodiversity of tropical Asian rivers and their associated wetlands. *BioScience* 50, 793–806.

Dudgeon, D., 2011. Asian river fishes in the Anthropocene: threats and conservation challenges in an era of rapid environmental change. *J Fish Biol* 79, 1487–1524.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.I., Knowler, D.J., Lévêque, C., Naiman, J., Prieur-Richard, A., Soto, D., Stiassny, J., & Sullivan, C.A., 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biol Rev* 81, 163–182.

Esa, Y., Siraj, S.S., Daud, S.K., Rahim, K.A.A., Abdullah, M.T., Japning, J.R.R., & Tan, S.G., 2006. Mitochondrial DNA Diversity of Tor douronensis Valenciennes (Cyprinidae) in Malaysian Borneo. Pertanika *Journal of Tropical Agricultural Science* 29, 47–55.

Eschmeyer, W.N., & Fong, J.D., 2016. Catalog of Fishes. http://www.calacademy.org/scientists/projects/catalog-of-fishes. Accessed 21 September 2018.

Eschmeyer, W.N., Fricke, R., van der Laan, R., 2017. Catalog of Fishes, electronic version (3 January 2017). San Francisco, CA (California Academy of Sciences).

Evans, B.J., Kelley, D.B., Melnick, D.J., & Cannatella, D.C., 2005. Evolution of RAG-1 in polyploid clawed frogs. *Mol Biol Evol* 22, 1193–1207.

Everard, M., 2013. The Hydropolitics of Dams: Engineering or Ecosystems? Zed Books, London.

Everard, M., & Kataria, G., 2011. Recreational angling markets to advance the conservation of a reach of the Western Ramganga River. *Aquat Conserv* 21,101–108.

Everard, M., Fletcher, M., Powell, A., Dobson, M., 2011. The feasibility of developing multi-taxa indicators for freshwater wetland systems. *Freshwater Rev* 4, 1-19.

Everard, M., Sharma, O.P., Vishwakarma, V.K., Khandal, D., Sahu, Y.K., Bhatnagar, R., Kumar, V., Nawab, A., Kumar, A., Kumar, V., Kashyap, A., Pandey, D.N., & Pinder, A.C., 2018. Assessing the feasibility of integrating ecosystem-based with engineered water resource governance and management for water security in semi-arid landscapes: A case study in the Banas catchment, Rajasthan, India. *Sci Total Environ* 612, 1249–1265.

FAO, 2012. Recreational Fisheries. Technical Guidelines for Responsible Fisheries. No. 13. Rome, FAO. 176p.

Fedler AJ (2000) Participation in boating and fishing: a literature review. Report of Human Dimensions Consulting to the Recreational Boating and Fishing Foundation. Alexandria, Virginia, USA.

Fedler, A.J., & Ditton, R.B., 1994. Understanding Angler Motivations in Fisheries Management. *Fisheries* 19, 6-13.

Finlayson, C.M., Davidson, N., Fennessy, S., Coates, D., Gardner, R.C. with contributing authors Darwall, W., Dema, M., Everard, M., McRae, L., Perennou, C., Stroud, D., 2018. Section 2: Status and trends. In: Gardner RC, Finlayson CM (eds), Global Wetland Outlook: State of the World's Wetlands and their Services to People. Gland, Switzerland: Ramsar Convention Secretariat.

Forest Department (2018) Mahseer Conservation Reserve, Badi Lake, Udaipur. Forest Department, Udaipur.

Froese, R., & Pauly, D., 2018. FishBase. World Wide Web electronic publication. www.fishbase.org, version (02/2019).

Fuiman, L.A., & Higgs, D.M., 1997. Ontogeny, growth and the recruitment process. In RC Chambers, EA Trippel (Eds.), Early Life History and Recruitment in Fish Populations. Dordrecht: Springer.

Ferguson, J.W., Healey, M., Dugan, P., & Barlow, C., 2011. Potential effects of dams on migratory fish in the Mekong River: lessons from salmon in the Fraser and Columbia Rivers. *Environ Manage* 47, 141-159.

Gadgil, M., 1991. Conserving India's biodiversity: the societal context. *Evol Trend Plant* 5, 3−8.

Granek, E.F., Madin, E.M.P., Brown, M.A., Figueira,W., Cameron, D.S., Hogan, Z., Kristianson, G., De Villiers, P., Williams, J.E., Post, J., Zahn, S., & Arlinghaus, R., 2008. Engaging recreational fishers in management and conservation: Global case studies. *Conserv Biol* 22, 1125–1134.

Greenberg, S.A., 2009. How citation distortions create unfounded authority: analysis of a citation network. *Bmj* 339, b2680.

Grumbine, R.E., Pandit, M.K., 2013. Threats from India's Himalaya dams. *Science* 339, 36–37.

Gupta, N., & Everard, M., 2017. Non-native fishes in the Indian Himalaya: an emerging concern for freshwater scientists. *International Journal of River Basin Management* 15, 1-5.

Gupta, N., Raghavan, R., Sivakumar, K., Mathur, V.B., 2014. Freshwater fish safe zones: a prospective conservation strategy for river ecosystems in India. *Curr Sci India* 107, 949–950.

Gupta, N., Raghavan, R., Sivakumar, K., Mathur, V., & Pinder, A.C., 2015. Assessing recreational fisheries in an emerging economy: Knowledge, perceptions and attitudes of catch-and-release anglers in India. *Fish Res* 165, 79–84.

Gupta, N., Kanagavel, A., Dandekar, P., Dahanukar, N., Sivakumar, K., Mathur, V.B., & Raghavan, R., 2016a. 'God's fishes: religion, culture and freshwater fish conservation in India' *Oryx* 50, 244–249.

Gurung, T.B., Rai, A.K., & Joshi, P.L., 2002. Breedin*g* of pond reared golden mahseer *(Tor putitora) in Pokhara,* Nepal. In: Cold water fisheries in the trans-Himalayan countries. FAO Fisheries Technical Paper 43, 147–160.

Hamilton, F., 1822. An account of the fishes found in the river Ganges and its branches. Edinburgh (1981), Bishan Singh Mahendra Pal Singh, Dehradun, India.

Hänfling, B., Lawson Handley, L., Read, D.S., Hahn, C., Li, J., Nichols, P., Blackman, R.C., Oliver, A., & Winfield, I.J., 2016. Environmental DNA metabarcoding of lake fish communities reflects long-term data from established survey methods. *Mol Ecol* 25, 3101–3119.

Hoang, H.D., Pham, H.M., Durand, J.D., Trần, N.T., & Phan, P.Đ., 2015. Mahseers genera *Tor* and *Neolissochilus* (Teleostei: Cyprinidae) from southern Vietnam. *Zootaxa* 4006, 551–568.

Hora, S.L., 1939. The game fishes of India iii: The mahseer or the large scaled barbels of India. 1. The putitor mahseer *Barbus* (*Tor*) *putitora* Hamilton. *Journal of the Bombay Natural History Society* 41, 272–285.

Hora, S.L., 1940. The game fishes of India IX. The mahseer or the large scaled barbels of India 2. The tor mahseer, *Barbus (Tor) tor* (Hamilton). *Journal of the Bombay Natural History Society* 41, 518–25.

Hora, S.L., 1942. The game fishes of India xv. The Mahseers or large-scaled Barbels of India 8. On the specific identity of Syke's species of Barbus from the Deccan. *Journal of the Bombay Natural History Society* 42, 163–169.

Hora, S.L., 1943. The game fishes of India XVII. The mahseers or the large-scaled barbels of India 10. On the specific identity of Jerdon's species of mahseer from Southern India. *Journal of the Bombay Natural History Society* 44, 164–168.

Hora, S.L., 1951. A Sanskrit work on angling of the early twelfth century. *Nature* 167, 778.

Hora, S.L., 1953. Knowledge of ancient Hindus concerning Fish Fish of India 4. Fish in Sutras and Smriti literature. *Journal of the Royal Asiatic Society of Bengal: Letters* 110, 63–77.

Hora, S.L., 1956. Fish paintings of the third millennium B.C. from Nal (Baluchistan) and their zoogeographical significance. *Memoirs of the Indian Museum, Kolkata* 14, 78–84.

Huckstorf, V., Pinder, A., & Harrison, A., 2018. *Tor polylepis*. The IUCN Red List of Threatened Species 2018: e.T188025A126323203. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T188025A126323203.en. Accessed 13 March 2019.

Hunt, L.M., Sutton, S.G., & Arlinghaus, R., 2013. Illustrating the critical role of human dimensions research for understanding and managing recreational fisheries within a social-ecological system framework. *Fisheries Manag Ecol* 20,111–124.

ICIMOD, 2009. The Changing Himalayas: Impact of climate change on water resources and livelihoods in the Greater Himalayas. ICIMOD, Lalitpur, Nepal.

Indra, T.J., 1993. Report on the ichthyofauna of Kanyakumari District, Tamil Nadu. *Records of the Zoological Survey of India* 92, 177–192.

Ingram, B., Sungan, S., Gooley, G., Sim, S.Y., Tinggi, D., De Silva, S.S., 2005. Induced spawning, larval development and rearing of two indigenous Malaysian mahseer, *Tor tambroides* and *T. douronensis*. *Aquac Res* 36, 983–995.

Ingram, B., Sungan, S., Tinggi, D., Sim, S.Y., & De Silva, S.S., 2007. Breeding performance of Malaysian mahseer, *Tor tambroides* and *T. douronensis* broodfish in captivity. *Aquac Res* 38, 809–818.

IUCN, 2012. IUCN Red List Categories and Criteria: Version 3.1. Second edition. Gland, Switzerland and Cambridge, UK: IUCN. iv + 32pp.

IUCN, 2018. The IUCN Red List of Threatened Species. Version 2018.2. http://www.iucnredlist.org.

IUCN Standards and Petitions Subcommittee, 2017. Guidelines for using the IUCN Red List Categories and Criteria. Version 13.

Jadhav, U., 2009. Aquaculture technology and environment. PHI Learning Pvt. Ltd., 21–22.

Jayaram, K.C., 1995. The Krishna River System: A Bioresources Study. *Records of Zoological Society of India* Occasional Paper No. 160.

Jayaram, K.C., 1997. Massacre of mahseer fish. *Curr Sci India* 72, 901.

Jayaram, K.C., 1999. The freshwater fishes of the Indian region. Delhi: Narendra Publishing House.

Jayaram, K.C., 2005. The Deccan mahseer fishes: their ecostatus and threat percepts. *Records of the Zoological Survey of India*, Occasional Paper 238, 1–102.

Jayaram, K.C., 2010. The Freshwater Fishes of the Indian Region. Narendra Publishing House, Delhi.

Jensen, O.P., Gilroy, D.J., Hogan, Z., Allen, B.C., Hrabik, T.R., Weidel, B.C., & Chandra, S., 2009. Evaluating recreational fisheries for an endangered species: a case study of taimen, *Hucho taimen*, in Mongolia. *Can J Fish Aquat Sci* 66, 1707–1718.

Jerde, C.L., Mahon, A.R., Chadderton, W.L., & Lodge, D.M., 2011. "Sight-unseen" detection of rare aquatic species using environmental DNA. *Conserv Lett* 4, 150–157.

Jerdon, T.C., 1849. On the fresh-water fishes of southern India. *Madras Journal of Literature and Science* 15, 302–346.

Jha, B.R., Rayamajhi, A., Dahanukar, N., Harrison, A., & Pinder, A., 2018. *Tor putitora*. The IUCN Red List of Threatened Species 2018: e.T126319882A126322226. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T126319882A126322226.en. Accessed 13 March 2019.

Johnson, P.T.J., Olden, J.D., & Vander Zanden, M.J., 2008. Dam invaders: impoundments facilitate biological invasions into freshwaters. *Front Ecol Environ* 6, 357–363.

Johnston, F.D., Beardmore, B., & Arlinghaus, R., 2014. Optimal management of recreational fisheries in the presence of hooking mortality and noncompliance—predictions from a bioeconomic model incorporating a mechanistic model of angler behaviour. *Can J Fish Aquat Sci* 72, 37–53.

Joppa, L.N., & Pfaff, A., 2009. High and far: biases in the location of protected areas. *PloS One* 4(12), e8273.

Jorgensen, C., Enberg, K., Dunlop, E.S., Arlinghaus, R., Boukal, D.S., Brander, K., Ernande, B., GŒrdmark, A., Johnston, F., Matsumura, S., Pardoe, H., Raab, K., Silva, A., Vainikka, A., Dieckmann, U., Heino, M., & Rijnsdorp, A.D., 2007. Ecology-Managing evolving fish stocks. *Science* 318, 1247–1248.

Joshi, P.L., Gurung, T.B., Basnyat, S.R., ad Nepal, A.P., 2002. Domestication of wild golden mahseer (*Tor putitora*) and hatchery operation. In: Cold water fisheries in the trans-Himalayan countries. *FAO Fisheries Technical Paper* 431, 173–178.

Juffe-Bignoli, D., Burgess, N.D., Bingham, H., Belle, E.M.S., de Lima, M.G., Deguignet, M., Bertzky, B., Milam, A.N., Martinez-Lopez, J., Lewis, E., Eassom, A., Wicander, S., Geldmann, J., van Soesbergen, A., Arnell, A.P., O'Connor, B., Park, S., Shi, Y.N., Danks, F.S., MacSharry, B., & Kingston, N., 2014. Protected planet report 2014. UNEP-WCMC: Cambridge, UK.

Katwate, C., Pawar, R., Shinde, V., Apte, D., & Katwate, U., 2014. How long will social beliefs protect the pride of River Savitri? MIN: The *Newsletter of the IUCN SSC/WI Freshwater Fish Specialist Group (South Asia)* 2, 21−24.

Keller, V.D., Williams, R.J., Lofthouse, C., & Johnson, A.C., 2014. Worldwide estimation of river concentrations of any chemical originating from sewage-treatment plants using dilution factors. *Environ Toxicol Chem* 33, 447–452.

Kemp, P.S., & O'hanley, J.R., 2010. Procedures for evaluating and prioritising the removal of fish passage barriers: a synthesis. *Fisheries Manag Ecol* 17, 297-322.

Khaironizam, M.Z., Zakaria-Ismail, M., & Armbruster, J.W., 2015. Cyprinid fishes of the genus *Neolissochilus* in Peninsular Malaysia. *Zootaxa* 3962, 139–157.

Kharat, S.S., Dahanukar, N., Raut, R., & Mahabaleshwarkar, M., 2003. Long term changes in freshwater fish species composition in north Western Ghats, Pune District. *Curr Sci India* 84, 816–820.

Khare, P., Mohindra, V., Barman, A.S., Singh, R.K., & Lal, K.K., 2014. Molecular evidence to reconcile taxonomic instability in mahseer species (Pisces: Cyprinidae) of India. *Org Divers Evol* 14, 307–326.

Kohli, M.P.S., Ayyappan, S., Ogale, S.N., Langer, R.K., Prakash, C., Dube, K., Reddy, A.K., Patel, M.B., & Saharan, N., 2002. Observations on the performance of *Tor khudree* in floating cages in open waters. *Applied Fisheries and Aquaculture* 2, 51–57.

Kottelat, M., 1998. Fishes of the Nam Theun and Xe Bangfai basins, Laos, with diagnoses of twenty-two new species (Teleostei: Cyprinidae, Balitoridae, Cobitidae, Coiidae and Odontobutidae). *Ichthyol Explor Fres* 9, 1–128.

Kottelat, M., Whitten, A.J., Kartikasari, S.N., & Wirjoatmodjo, S., 1993. Freshwater fishes of Western Indonesia and Sulawesi. Periplus Editions, Hong Kong.

Kottelat, M., 2000. Notes on taxonomy, nomenclature and distribution of some fishes of Laos. *Journal of South Asian Natural History* 5, 83–90.

Kottelat, M., 2001. Fishes of Laos. Wildlife Heritage Trust. Colombo: 198 p.

Kottelat, M., Baird, I.G., Kullander, S.O., Ng, H.H., Parenti, L.R., Rainboth, W.J., & Vidthayanon, C., 2012. The status and distribution of freshwater fishes of Indo Burma. In: Allen, D.J., Smith, K.G, Darwall, W.R.T (Eds.), The status and distribution of freshwater biodiversity in Indo-Burma, 38-65, International Union for Conservation of Nature [IUCN]. Cambridge and Gland.

Kottelat, M., 2013. The fishes of the inland waters of Southeast Asia: a catalogue and core bibliography of the fishes known to occur in freshwaters, mangroves and estuaries. *Raffles Bulletin of Zoology* 27, 1–663.

Kottelat, M., 2016. The fishes of the Nam Theun and Xe Bangfai drainages, Laos. *Hydroécologie Appliquée* 19, 271–320.

Kottelat, M., 2018. *Tor laterivittatus*. The IUCN Red List of Threatened Species 2018: e.T187921A126323049. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T187921A126323049.en. Accessed 13 March 2019.

Kottelat, M., Pinder, A., & Harrison, A., 2018a. *Tor ater*. The IUCN Red List of Threatened Species 2018: e.T188038A126323308. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T188038A126323308.en. Accessed 13 March 2019.

Kottelat, M., Pinder, A., & Harrison, A., 2018b. *Tor tambra*. The IUCN Red List of Threatened Species 2018: e.T188012A89801879. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T188012A89801879.en. Accessed 27 March 2019.

Kottelat, M., Pinder, A., & Harrison, A., 2018c. *Tor tambroides*. The IUCN Red List of Threatened Species 2018: e.T187939A91076554. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T187939A91076554.en. Accessed 13 March 2019.

Kulkarni, C.V., 1971. Spawning habits, eggs and early development of Deccan mahseer, *Tor khudree* (Sykes). *Journal of the Bombay Natural History Society* 67, 510–521.

Kulkarni, C.V., & Ogale, S.N., 1978. The present status of mahseer (fish) and artificial propagation of *Tor khudree* (Sykes). *Journal of the Bombay Natural History Society* 75, 651–660.

Kumar, R., Singh, M., Kushwaha, B., Nagpure, N.S., Mani, I., & Lakra, W.S., 2013. Molecular characterization of major and minor rDNA repeats and genetic variability assessment in different species of mahseer found in North India. *Gene* 527, 248–258.

Kurup, B.M., & Radhakrishnan, K.V., 2007. *Tor remadevii*, a new species of mahseer from Kerala (South India), and distribution and abundance of *Tor* spp. the river systems of Kerala. In S.S. Siraj, A. Christianus, N.C. Kiat, S.S. De Silva (Eds.), Mahseer, the biology, culture and conservation. Proceedings of the International Symposium on the Mahseer, 29th to 30th March 2006, Kuala Lumpur, Malaysia. Kuala Lumpur: Malaysian Fisheries Society.

Kurup, B.M., & Radhakrishnan, K.V., 2010. *Tor remadevii*, a new species of *Tor* (gray) from Chinnar Wildlife Sanctuary, Pambar River, Kerala, Southern India. *Journal of the Bombay Natural History Society* 107, 227–230.

Lacoursière-Roussel, A., Côté G, Leclerc, V., & Bernatchez, L., 2016. Quantifying relative fish abundance with eDNA: a promising tool for fisheries management. *J Appl Ecol* 53, 1148–1157.

Lakra, W.S., Sarkar, U.K., Gopalakrishnan, A., & Pandian, A.K., 2010. Threatened freshwater fishes of India. National Bureau of Fish Genetics Resources (NBFGR) Publication, Lucknow, India.

Lal, K.K., Singh, R.K., Pandey, A., Gupta, B.K., Mohindra, V., Punia, P., Dhawan, S., Verma, J., Tyagi, L.K., Khare, P., & Jena, J.K. 2013. Distributional records of Tor mahseer *Tor tor* (Hamilton, 1822) from Southern India. *J Appl Ichthyol* 29, 1086–1090.

Laskar, B.A., Bhattacharjee, M.J., Dhar, B., Mahadani, P., Kundu, S., & Ghosh, S.K., 2013. The species dilemma of northeast Indian mahseer

(Actinopterygii: Cyprinidae): DNA barcoding in clarifying the riddle. *PloS One* 8, e53704.

Laskar, B.A., Kumar, V., Kundu, S., Tyagi, K., & Chandra, K., 2018. Taxonomic quest: validating two mahseer fishes (Actinopterygii: Cyprinidae) through molecular and morphological data from biodiversity hotspots in India. *Hydrobiologia* 815, 113–124.

Lawson-Handley, L., 2015. How will the 'molecular revolution' contribute to biological recording? *Biological Journal of the Linnean Society* 115, 750–766.

Lester, N.P., Shuter, B.J., Venturelli, P., & Nadeau, D., 2014. Life-history plasticity and sustainable exploitation: a theory of growth compensation applied to walleye management. *Ecol Appl* 24, 38–54.

MacDonald, A.S.J., 1948. Circumventing the Mahseer. Dehra Dun: Natraj.

Mani, I., Kumar, R., Singh, M., Kushwaha, B., Nagpure, N.S., Srivastava, P.K., & Lakra, W.S., 2009. Karyotypic diversity and evolution of seven mahseer species (Cyprinidae) from India. *J Fish Biol* 75, 1079–1091.

Menon, A.G.K., 1992. Taxonomy of the Mahseer fishes of genus *Tor* Gray with description of new species from Deccan. *Journal of the Bombay Natural History Society* 89, 210–228.

Menon, A.G.K., 1999. Checklist of Freshwater fishes of India. *Records of the Zoological Survey of India* 175, 56–57.

Menon, A.G.K., 2004. Threatened Fishes of India and their Conservation. Zoological Survey of India. Kolkata, 170pp.

Mohindra, V., Khare, P., Lal, K.K., Punia, P., Singh, R.K., Barman, A.S., & Lakra, W.S., 2007. Molecular discrimination of five Mahseer species from Indian peninsula using RAPD analysis. *Acta Zoologica Sinica* 53, 725–732.

Mohsin, A.M., & Ambak, M.A., 1983. Freshwater Fishes of Peninsular Malaysia. Penerbit Universiti Pertanian Malaysia

Muoneke, M.I., & Childress, W.M., 1994. Hooking mortality: a review for recreational fisheries. *Rev Fish Sci* 2, 123–156.

Naiman, R., 2013. Socio-ecological complexity and the restoration of river ecosystems. *Inland Waters* 3, 391–410.

Nautiyal, P., 2014. Review of the art and science of Indian Mahseer (Game fish) from nineteenth to twentieth century: road to extinction or conservation? *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences* 84, 215–236.

Nautiyal, P., Bahuguna, S.N., & Thapliyal, R.P., 2001. The role of ecological factors in governing the direction, time and purpose of migration in Himalayan Mahseer *Tor putitora* (Ham.). *Applied Fisheries and Aquaculture* 1, 133–138.

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 Sc* 8, 125–132.

Ng, C.K., 2004. Kings of the River - Mahseer in Malaysia and the region. Inter Sea Fishery (M), Kuala Lumpur, Malaysia.

Nguyen, T.T., Na-Nakorn, U., Sukmanomon, S., & ZiMing, C., 2008. A study on phylogeny and biogeography of mahseer species (Pisces: Cyprinidae) using sequences of three mitochondrial DNA gene regions. *Mol Phylogenet Evol* 48,1223–1231.

Norfatimah, M.Y., The, L.K., Salleh, M.Z., Isa, M.M., & SitiAzizah, M.N., 2014. Complete mitochondrial genome of Malaysian Mahseer (*Tor tambroides*). *Gene* 548, 263–269.

Ogale, S.N., 1997. Induced spawning and hatching of golden mahseer *Tor putitora* (Hamilton) at Lonavla, Pune District (Maharashtra) in Western Ghats. *Fishing Chimes*, June 1997, 27–29.

Ogale, S.N., 2002. Mahseer breeding and conservation and possibilities of commercial culture. The Indian experience. In: Cold water fisheries in the trans-Himalayan countries. *FAO Fisheries Technical Paper* 431, 193–212.

Ogale, S.N., & Kulkarni, C.V., 1987. Breeding of Pond-raised Hybrids of Mahseer Fish, *Tor Khudree* (Sykes) and *T. tor* (Ham.). *Journal of the Bombay Natural History Society* 84, 332–335.

Ovidio, M., & Philippart, J.C., 2002. The impact of small physical obstacles on upstream movements of six species of fish. *Hydrobiologia* 483, 55–69.

Pathani, S.S., & Das, S.M., 1979. On induced spawning of mahseer *Tor putitora* (Hamilton) by mammalian and fish pituitary hormone injection. *Science and Culture* 45, 209-210.

Peh, K.S.H., 2010. Invasive species in Southeast Asia: the knowledge so far. *Biodivers Conserv* 19, 1083–1099.

Pelayo-Villamil, P., Guisande, C., Vari, R.P., Manjarrés-Hernández, A., García-Roselló, E., González-Dacosta, J., Heine, J., González Vilas, L., Patti, B., Quinci, E.M., Jiménez, L.F., Granado-Lorencio, C., Tedesco, P.A., & Lobo, J.M., 2015. Global diversity patterns of freshwater fishes – potential victims of their own success. *Divers Distrib* 21, 345–356.

Pinder, A.C., 2001. Keys to larval and juvenile stages of coarse fishes from fresh waters in the British Isles. Scientific Publication No. 60. Ambleside: Freshwater Biological Association.

Pinder, A.C., 2015. Icon of the Cauvery. *Sanctuary Asia* October 2015, 50–53.

Pinder, A.C., 2018. *Tor yingjiangensis*. The IUCN Red List of Threatened Species 2018:e.T188067A1850734. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T188067A1850734.en. Accessed 13 March 2019.

Pinder, A.C., & Raghavan, R., 2013. Conserving the endangered Mahseers (*Tor* spp.) of India: the positive role of recreational fisheries. *Curr Sci India* 104, 1472–1475.

Pinder, A.C., Raghavan, R., & Britton, J.R., 2015a Efficacy of angler catch data as a population and conservation monitoring tool for the flagship Mahseer fishes (*Tor* spp.) of Southern India. *Aquat Conserv* 25, 829–838.

Pinder, A.C., Raghavan, R., & Britton, J.R., 2015b. The legendary hump-backed mahseer *Tor* sp. of India's River Cauvery: an endemic fish swimming towards extinction? *Endanger Species Res* 28, 11–17.

Pinder, A.C., & Harrison, A., 2018. *Tor dongnaiensis*. The IUCN Red List of Threatened Species 2018: e.T126318880A126323439. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T126318880A126323439.en. Accessed 13 March 2019.

Pinder, A.C., Manimekalan, A., Knight, J.D.M., Krishnankutty, P., Britton, J.R., Philip, S., Dahanukar, N., & Raghavan, R., 2018a. resolving the taxonomic enigma of the iconic gamefish, the hump-backed mahseer from the Western Ghats hotspot, India. *Plos One* 13(6), e0199328.

Pinder, A.C., Katwate, U., Dahanukar, N., & Harrison, A., 2018b. *Tor remadevii*. The IUCN Red List of Threatened Species 2018: e.T56096394A56717605. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T56096394A56717605.en. Accessed 13 March 2019.

Poff, N.L., Olden, J.D., Merritt, D.M., & Pepin, D.M., 2007. Homogenization of regional river dynamics by dams and global biodiversity implications. *Proceedings of the National Academy of Sciences* 104, 5732–5737.

Poff, N.L., & Zimmerman, J.K., 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. *Freshwater Biol* 55, 194-205.

Poff, N.L., Schmidt, J.C., 2016. How dams can go with the flow. *Science* 353, 1099–1100.

Post, J.R., Sullivan, M., Cox, S., Lester, N.P., Walters, C.J., Parkinson, E.A., Paul, A.J., Jackson, L., & Shuter, B.J., 2002. Canada's recreational fisheries: The invisible collapse. *Fisheries* 27, 6-17.

Post, J.R., 2013. Resilient recreational fisheries or prone to collapse? A decade of research on the science and management of recreational fisheries. *Fisheries Manag Ecol* 20, 99–110.

Quinn, T.P., & Adams, D.J., 1996. Environmental changes affecting the migratory timing of American shad and sockeye salmon. *Ecology* 77, 1151–1162.

Raghavan, R., 2013. *Tor khudree*. The IUCN Red List of Threatened Species 2013: e.T169609A6653249. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T169609A6653249.en. Accessed 13 March 2019.

Raghavan, R., & Ali, A., 2013. *Tor malabaricus*. The IUCN Red List of Threatened Species 2013: e.T172457A6895822. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T172457A6895822.en. Accessed 13 March 2019.

Raghavan, R., Ali, A., Dahanukar, N., & Rosser, A., 2011. Is the Deccan Mahseer, *Tor khudree* (Sykes, 1839) (Pisces: Cyprinidae) fishery in the Western Ghats Hotspot sustainable? A participatory approach to stock assessment. *Fish Res* 110, 29–38.

Raghavan, R., Dahanukar, N., & Britz, R., 2017. The type locality of *Tor mosal* (Hamilton, 1822) (Teleostei: Cyprinidae). *Zootaxa* 4317, 593–596.

Rahman, A.A., 1989. Freshwater Fishes of Bangladesh. Zoological Society of Bangladesh.

Rahman, M.A., Mazid, M.A., Rahman, M.R., Khan, M.N., Hossain, M.A., & Hussain, M.G., 2005. Effect of stocking density on survival and growth of critically endangered mahseer, *Tor putitora* (Hamilton), in nursery ponds. *Aquaculture* 249, 275–284.

Rajasthan High Court, 2017. High Court of Judicature for Raiasthan at Jodhpur, D.B. Civil Writ Petition No. 7077 / 2OL4. Rajasthan High Court, 4th April 2017.

Raman, S., Pavan-Kumar, A., Koringa, P.G., Patel, N., Shah, T., Singh, R.K., Krishna, G., Joshi, C.G., Gireesh-Babu, P., Chaudhari, A., & Lakra, W.S., 2016. Ion torrent next-generation sequencing reveals the complete mitochondrial genome of endangered mahseer *Tor khudree* (Sykes, 1839). *Mitochondrial DNA Part A* 27, 2949–2950.

Ramsar Convention Secretariat, 2010. Wise use of wetlands: Concepts and approaches for the wise use of wetlands. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 1. Ramsar Convention Secretariat, Gland, Switzerland.

Rayamajhi, A., Jha, B.R., & Sharma, C.M., 2010. *Tor tor*. The IUCN Red List of Threatened Species 2010: e.T166534A6231157. http://dx.doi.org/10.2305/IUCN.UK.2010-4.RLTS.T166534A6231157.en. Accessed 30 May 2017.

Rayamajhi, A., Jha, B.R., Sharma, C.M., Pinder, A.C., Harrison, A., Katwate, U., & Dahanukar, N., 2018. *Tor tor*. The IUCN Red List of Threatened Species 2018: e.T166534A126321898. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T166534A126321898.en. Accessed 13 March 2018.

Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T.J., Kidd, K.A., MacCormack, T.J., Olden, J.D., Ormerod, S.J., Smol, J.P., Taylor, W.W., Tockner, K., Vermaire, J.C., Dudgeon, D., & Cooke, S.J., 2018. Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biol Rev.* In Press.

Roberts, T.R., 1993. The freshwater fishes of Java, as observed by Kuhl and van Hasselt in 1820–23. *Zoologische Verhandelingen* 285, 1–94.

Roberts, T.R., 1999. Fishes of the cyprinid genus *Tor* in the Nam Theun watershed (Mekong basin) of Laos, with description of a new species. *Raffles Bulletin of Zoology* 47, 225–236.

Roberts, T.R., & Khaironizam, M.Z., 2008. Trophic polymorphism in the Malaysian fish *Neolissochilus soroides* and other old world barbs (Teleostei, Cyprinidae). *Natural History Bulletin of the Siam Society* 56, 25–53.

Romão, F., Quaresma, A.L., Branco, P., Santos, J.M., Amaral, S., Ferreira, M.T., Katopodis, C., & Pinheiro, A.N., 2017. Passage performance of two cyprinids with different ecological traits in a fishway with distinct vertical slot configurations. *Ecol Eng* 105, 180-188.

Sadhale, N., & Nene, Y.L., 2005. On Fish in Manasollasa (c. 1131 AD). *Asian Agri-History* 9, 177–199.

Saitoh, K., Chen, W.J., & Mayden, R.L., 2010. Extensive hybridization and tetrapolyploidy in spined loach fish. *Mol Phylogenet Evol* 56, 1001–1010.

Santos, J.M., Silva, A., Katopodis, C., Pinheiro, P., Pinheiro, A., Bochechas, J., & Ferreira, M.T., 2012. Ecohydraulics of pool-type fishways: getting past the barriers. *Ecol Eng* 48, 38-50.

Sarma, D., Das, R., Akhtar, M.S., Ciji, A., Sharma, N.K., & Singh, A.K., 2016. Morpho-histological and ultra-architectural changes during early development of endangered golden mahseer *Tor putitora*. *J Fish Biol* 89, 2038–2054.

Sarkar, U.K., Pathak, A.K., & Lakra, W.S., 2008. Conservation of freshwater fish resources of India: new approaches, assessment and challenges. *Biodivers Conserv* 17, 2495–2511.

Saunders, D.L., Meeuwig, J.J., & Vincent, A.C., 2002. Freshwater Protected Areas: Strategies for Conservation. *Conserv Biol* 16, 30–41.

Sen, T.K., & Jayaram, K.C., 1982. Mahseer fishes of India: a review. *Records of the Zoological Survey of India, Occasional Paper* 39, 1–34.

Shahi, N., Mallik, S.K., & Sarma, D., 2014. Golden mahseer, *Tor putitora* – a possible candidate species for hill aquaculture. *Aquaculture Asia* 14, 22–28.

Sharma, R.C., 1987. Aims and Strategies of Fisheries Management for the Tehri dam reservoir in the Garhwal Himalaya, India. In S.S. DeSiva (Ed.), *Proceedings.* Reservoir Fishery Management and Development in Asia (pp. 145-153). Kathmandu: IDRC.

Sheaves, M., Baker, R., McLeod, I., Abrantes, K., Wani, J., & Barnett, A., 2016. The conservation status of Niugini black bass: a world-renowned sport fish with an uncertain future. *Fisheries Manag Ecol* 23, 243–252.

Shrestha, T.K., 1997. The mahseer in the rivers of Nepal disrupted by dams and ranching strategies. The mahseer in the rivers of Nepal disrupted by dams and ranching strategies. Bimala Shrestha, Kathnandu, 259 p

Shrestha, T.K., 2002. Ranching mahseer *(Tor tor* and *Tor putitora)* in the running waters of Nepal. In: Cold water fisheries in the trans-Himalayan countries. FAO Fisheries Technical Paper 431:297–300.

Shrestha, A.B., Agarwal, N.K., Alfthan, B., Bajracharya, S.R., Marechal, J., & van Oort, B., (eds), 2015. The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins. ICIMOD, GRID-Arendal and CICERO, pp.1–96.

Smith, L.E., Khoa, S.N., & Lorenzen, K., 2005. Livelihood functions of inland fisheries: policy implications in developing countries. *Water Policy* 7, 359-383.

Stensland, S., & Aas, Ø., 2014. The role of social norms and informal sanctions in catch-and-release angling. *Fisheries Manag Ecol* 21, 288–298.

Sykes, W.H., 1839. On the fishes of the Deccan. *Proceedings of the Zoological Society of London* 6, 157–165.

Sykes, W.H., 1841. On the fishes of the Dukhun. *Transactions of the Zoological Society of London* 2, 349-378.

Takahara, T., Minamoto, T., Yamanaka, H., Do, H., & Kawabata, Z.I., 2012. Estimation of fish biomass using environmental DNA. *PloS One* 7(4), e35868.

Talwar, P.K., & Jhingran, A.G., 1991. Inland Fishes of India and Adjacent Countries. A.A. Balkema, Rotterdam, 541 p.

Theophilus, E., 2014 Headwater Extinctions – Hydropower projects in the Himalayan reaches of the Ganga and the Beas: a closer look at fish and river ecosystems. South Asia Network on Dams, Rivers and People (SANDRP), Delhi. https://sandrp.files.wordpress.com/2018/03/headwater_extinctions221114.pdf. Accessed 13 March 2019.

Thomas, H.S., 1873. The Rod in India. Mangalore: Stolz.

Thomsen, P.F., Kielgast, J.O.S., Iversen, L.L., Wiuf, C., Rasmussen, M., Gilbert, M.T.P., Orlando, L., & Willerslev, E., 2012. Monitoring endangered freshwater biodiversity using environmental DNA. *Mol Ecol* 21, 2565–2573.

Tripathi, Y.R., 1978. Artificial breeding of *Tor putitora*. *Journal of International Fisheries Society of India* 9, 161.

Tufts, B.L., Holden, J., & DeMille, M., 2015. Benefits arising from sustainable use of North America's fishery resources: economic and conservation impacts of recreational angling. *Int J Environ Stud* 72, 850–868.

Turner, C.R., Uy, K.L., & Everhart, R.C., 2015. Fish environmental DNA is more concentrated in aquatic sediments than surface water. *Biol Conserv* 183:93–102.

TWFT, 1984. *Trans*-world fishing team*: Quest for a Legendary Fish*. International Book Distributors: Dehra Dun.

Ullah, A., 2015. Public Private Partnership in Hydro-Power Development of India: Prospects and Challenges. *Journal of Business Management and Social Sciences Research* 4, 190–201.

Vidthayanon, C., & Pinder, A.C., 2018. *Tor sinensis*. The IUCN Red List of Threatened Species 2018: e.T187891A126322879. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T187891A126322879.en. Accessed 13 March 2019.

Vishwanath, W., Dahanukar, N., Pinder, A.C., & Harrison, A., 2018 *Tor barakae*. The IUCN Red List of Threatened Species 2018: e.T168258A126322721. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T168258A126322721.en. Accessed 13 March 2019.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S.E., Sullivan, C.A., Liermann, C.R., & Davies, P.M., 2010. Global threats to human water security and river biodiversity. *Nature* 467, 555–561.

Wagh, G.K., & Ghate, H.V., 2003. Freshwater fish fauna of the rivers Mula and Mutha, Pune, Maharashtra. *Zoo's Print* 18, 977–981.

Walton, S.E., Gan, H.M., Raghavan, R., Pinder, A.C., & Ahmad, A., 2017. Disentangling the taxonomy of the mahseers (*Tor* spp.) of Malaysia: an integrated approach using morphology, genetics and historical records. *Rev Fish Sci and Aquaculture* 25, 171–183.

Wildlife, 1977. The monsters of Karnataka. *Wildlife Journal of the Wildlife Association of South India (WASI)* 1977, 1–8.

Wilkes, M.A., Mckenzie, M., & Webb, J.A., 2018. Fish passage design for sustainable hydropower in the temperate Southern Hemisphere: an evidence review. *Rev Fish Biol Fisher* 28,117-135.

Williams, J.G., Armstrong, G., Katopodis, C., Larinier, M., & Travade, F., 2012. Thinking like a fish: a key ingredient for development of effective fish passage facilities at river obstructions. *River Res Appl* 28, 407-417.

Wong, J.Z., Etoh, S., & Sujang, A.B., 2009. Towards sustainable community-based fishery resources management: the Tagal system of Sabah, Malaysia. *Secretariat, Southeast Asian Fisheries Development Center* 7, 18–27.

World Bank, 2012. Hidden Harvest: The global contribution of capture fisheries. Report # 66469-GLB. World Bank, Washington, D.C., USA. 69 p.

World Bank, 2018. Population growth (annual %). http://data.worldbank.org/indicator/SP.POP.GROW, Accessed 21September 2018.

World Commission on Dams, 2000. Dams and Development: A New Framework for Better Decision-making. Earthscan, London.

Wu, X.W. (Ed.), 1977. Cyprinid fishes of China, Vol. 2. Science and Technology Publishing House, Shanghai. 209–598. (In Chinese).

WWF-India, 2013. Mahseer Conservation in India: Status, Challenges and the Way Forward. In: Nautiyal, P., Babu, S., Behera, S. (Eds.). WWF-India, New Delhi, India, 38 p.

Yang, L., Sado, T., Hirt, M.V., Pasco-Vie, E., Arunachalam, M., Li, J., Wang, X., Freyhof, J., Saitoh, K., Simons, A.M., & Miya, M., 2015. Phylogeny and polyploidy: resolving the classification of cyprinine fishes (Teleostei: Cypriniformes). *Mol Phylogenet Evol* 85, 97–116.

Zhou, W., & Cui, G.H., 1996. A review of *Tor* species from the Lancangjiang River (Upper Mekong River), China (Teleostei: Cyprinidae). *Ichthyol Explor Fres* 7, 131–142.

CHAPTER 10: CONCLUDING SUMMARY

10.1 Scientific obscurity: the unknown mahseers of the River Cauvery

The iconic hump-backed mahseer, endemic to the River Cauvery of South India, was brought to the attention of the scientific community in 1849 (Jerdon, 1849) and the sport angling community in 1873 (Thomas, 1873). Despite its popularity and global recognition as a premier sport fish for a century and a half, scientific information available on this fish was so scarce that it remained to be scientifically described (Pinder & Raghavan, 2013). It took another five years and systematic integrative taxonomic studies (morphology, genetics, historic photographs, and museum specimens) to reach a conclusion regarding the identity and nomenclature of the hump-backed mahseer (Pinder et al., 2018a;). Subsequently, in November 2018, the hump-backed mahseer *Tor remadevii*, was assessed as being 'Critically Endangered' on the Red List of the International Union for Conservation of Nature (Pinder et al., 2018b; IUCN, 2019), triggering an international multi-agency conservation effort to save the species from extinction. In this final chapter, I summarise the process by which these and further outcomes to conserve mahseer across the genus *Tor* have been achieved and the broader implications for the future sustainable management of major Asian river systems.

The starting point of this large bodied (> 50 kg) and iconic species of freshwater mega-fauna going from scientific obscurity to a global conservation priority was triggered by the author's first trip to India as an angling tourist and his subsequent development of an interest in understanding the population status and taxonomy of the mahseer present. The multiple challenges associated with the effective assessment of fish populations (such as mahseer populations) in large tropical monsoonal river systems (such as the River Cauvery) include high flows, deep water and high habitat heterogeneity that, in combination, preclude the use of conventional scientific sampling gears (i.e. fishery independent monitoring tools such as netting and electric fishing) (Casselman et al., 1990). As the hump-backed mahseer attains sizes in excess of 50 kg and can inhabit areas of extreme flows, this further inhibits attempts to assess their population status. This is further compounded by the remoteness of the rivers they inhabit and the wildlife associated with these jungle environs (Jung, 2012). Consequently, there is still no known example of a robust 'fishery-independent' population assessment of any *Tor* species across their entire genus and associated biogeographic ranges (Pinder et al. 2019). This is consistent with Cooke et al., (2012), who highlighted that sampling difficulties represent a major obstacle in generating knowledge on the spatial and temporal patterns in the population abundances and conservation management of many threatened riverine fishes.

In the former mahseer sport fishery of the middle reaches of South India's River Cauvery (Figure 10.1.1), this paucity of information on the temporal patterns in the mahseer population was overcome through analyses of sport angler log-books that had been maintained by the 'Galibore catch-and-release (C&R) fishery' between 1998 and 2012 (see Pinder & Raghavan, 2013 and Pinder et al., 2015a for context).

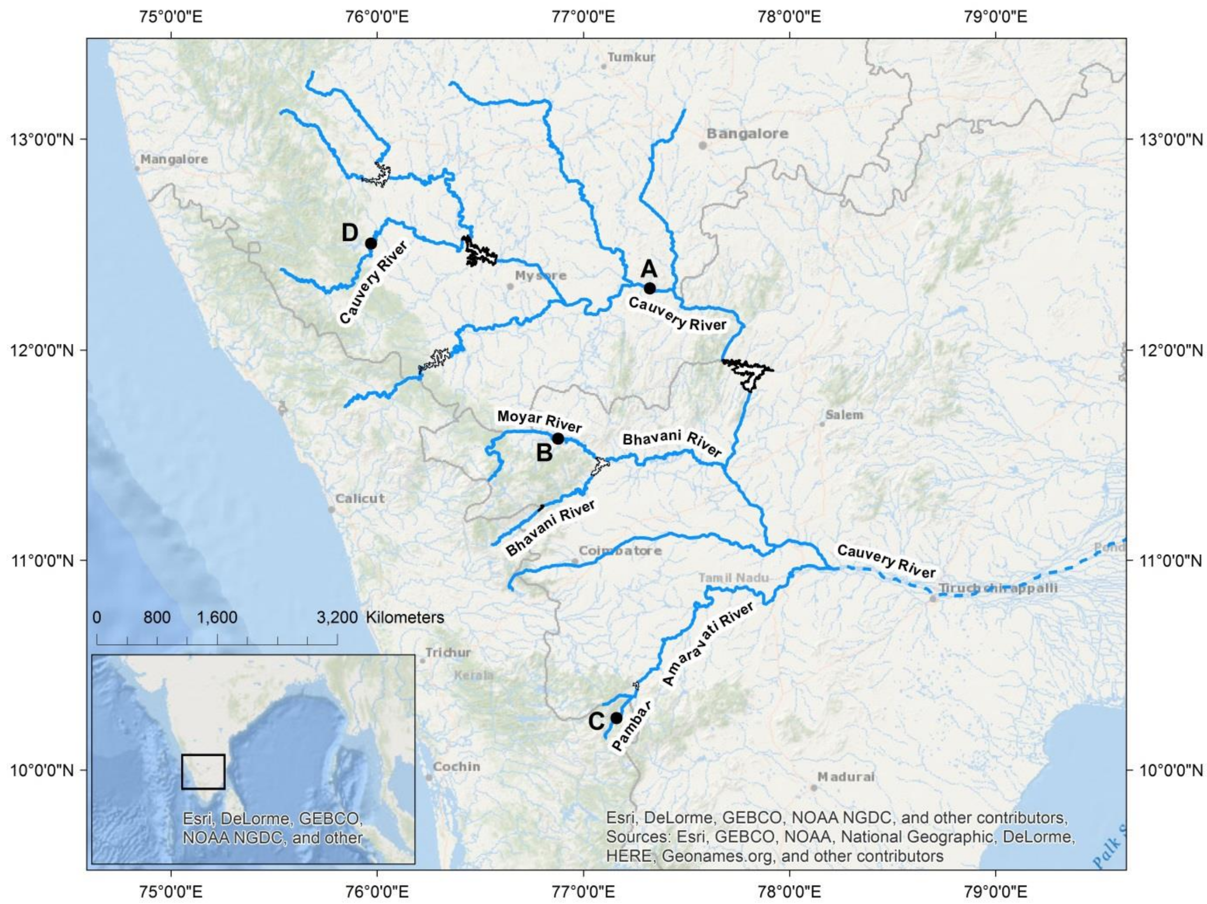


Figure 10.1.1. Map of River Cauvery basin and key sites of interest. Locations are coded: A: Galibore Fishing Camp, B: collection site of *T. remadevii* on Moyar River, C: type locality of *T. remadevii* on Pambar River, D: upper River Cauvery, Kodagu District (Coorg). The dashed line represents tidal reach of River Cauvery.

In the study period, 23,620 hours fishing effort were recorded in this fishery, during which 6161 mahseer had been captured and released in sizes between 0.45 and 46.8 kg. Although catch per unit effort (CPUE) in number of mahseer had increased significantly over time, this was concomitant with a decrease in CPUE by weight, suggesting a pattern of strong recruitment in the mahseer population overall and a shift in population size structure (Pinder et al., 2015a). These results suggested a positive conservation influence of the fishery via the generation of alternative livelihoods and employment of local villagers driving community led protection of illegal exploitation of their assets (i.e. mahseer stocks) on which the sustainability of the C&R fishery and the local economy then relied. Further, this afforded the mahseer with exemplar ‘umbrella’ species status, due to their economic value supporting the broader conservation of non-target fauna (e.g. fish, amphibians, reptiles) and associated higher trophic levels (terrestrial and avian) vulnerable to the effects of illegal and non-species-selective dynamite fishing (Pinder & Raghavan, 2013). At this point, however, the taxonomy of the mahseers being captured in the river remained uncertain (Pinder et al., 2015a).

10.2 Invasive mahseer

Although Pinder et al. (2015a) was important in demonstrating a strong and positive response in the Cauvery mahseers to the C&R policy and the reduced illegal fishing, and the high utility of using angler catch and release data to monitor populations of large-bodied fishes, the paper also acted as a springboard to investigate in more detail which mahseer species were being captured by anglers. This was because it was apparent that the angler catch records were comprised of two distinct mahseer phenotypes, a golden (‘hump-backed’) mahseer (that had been marked with ‘G’ on the records) and a silver (‘blue-finned’) mahseer (marked with ‘S’ on the records) (Figure 10.2.1).

Figure 10.2.1. The non-indigenous blue-finned (AKA silver) mahseer, since confirmed as *Tor khudree* (top) and endemic hump-backed (AKA golden) mahseer, since confirmed as *Tor remadevii* (bottom), both contributed to angler catches during the study period 1998 – 2012.

At this point, the taxonomic identity of these phenotypes remained unclear and the fish had to be referred to as just *Tor* spp. Subsequent analyses of the catches revealed that the catches of these two mahseer phenotypes could be decoupled temporally and identified that there had been a comprehensive shift in the mahseer community structure over the duration of the study period (1998 to 2012) (Pinder et al., 2015b). Numerical catch rates of the blue-finned phenotype had increased substantially over time, while the hump-backed phenotype revealed the opposite pattern, with a marked decrease in CPUE (Figure 10.2.2; Pinder et al. 2015b). Whilst the catches of the blue-finned phenotype revealed relatively small fish present in catches in all years, this was not evident in the hump-backed phenotype (Pinder et al., 2015b). Indeed, between 2007 and 2012, only 25 hump-backed mahseer were captured in the fishery and all but 5 were over 40lb (18.1 kg), with mean weight of captured individuals increasing from 21.1 ± 2.8 lbs (9.6 ± 1.3 kg) between 1998 and 2006 to 59.0 ± 2.7 lbs (26.8 ± 1.2 kg) between

2007 and 2012. This reduction in the number of smaller hump-backed fish in the catches suggested a collapse in their recruitment (Pinder et al., 2015b).

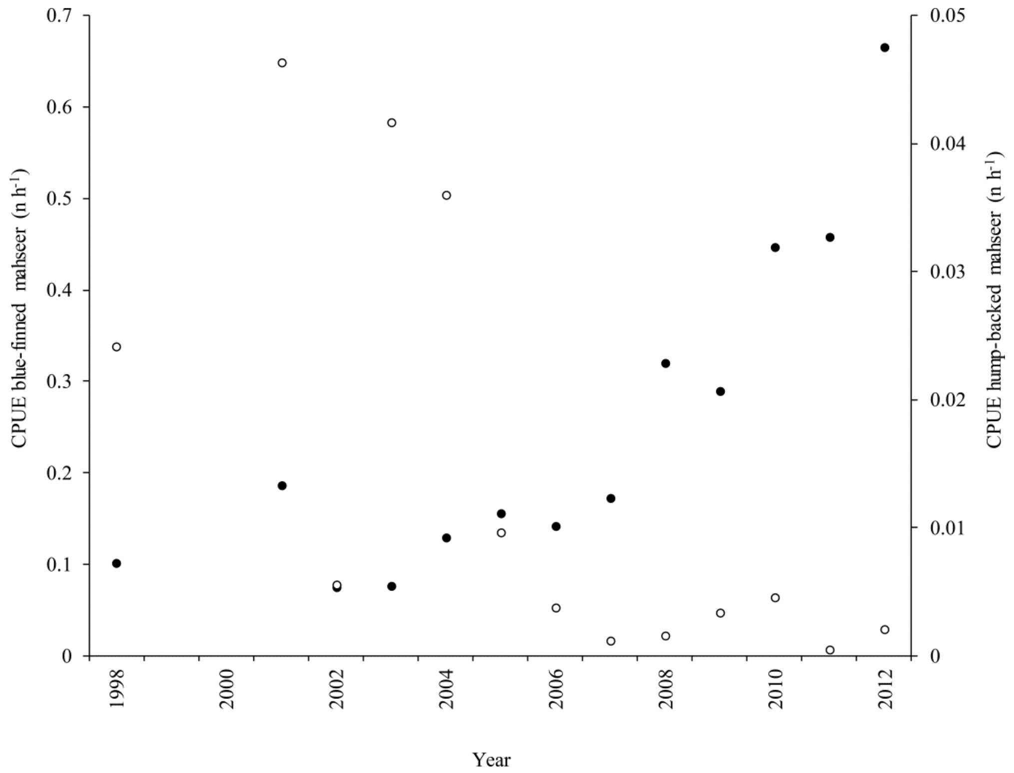


Figure 10.2.2. Catch per unit effort (n/h^{-1}) of blue-finned mahseer (filled circles) and hump-backed mahseer (clear circles) recorded at Galibore Fishing Camp between 1998 and 2012 (from Pinder et al., 2015b).

It was at this juncture that it became apparent that further investigation was needed into the blue-finned mahseer phenotype that had dominated catches in the latter years of the recreational fishery. This was because when historical images of Cauvery mahseer were viewed in angling books, they were all - without fail - the hump-backed phenotype (e.g. TWFT, 1984; Boote & Wade, 1992; Wilson, 1999), with earliest photographic records of the same species dating back to 1919 (Wild Life, 1977). Following some initial investigations by the authors of Pinder et al. (2015a,b), there was conclusive evidence that the study reach had been stocked with hatchery-reared mahseer since 1976, when the Tata Electric Company (TEC) had initially gifted large numbers (10,000) of blue-finned mahseer fingerlings to the Wildlife Association of South India (WASI). These fingerlings had been produced at Tata's Lonavla hatchery in Maharashtra and been stocked into the controlled angling sections of the River Cauvery (Wild Life, 1976). Sehgal (1999) and Desai (2003) later reported the release of 150,000 advanced fry/fingerlings to the River Cauvery by the Department of Fisheries of the State of Karnataka. In investigating this further, Pinder et al. (2019) concluded that brood fish of this species had been procured from the River Krishna River Basin and were the mahseer species *Tor khudree (*Kulkarni & Ogale, 1978). Furthermore, by 2002, hatchery-reared *T. khudree* fingerlings had been stocked to waters in the majority of Indian states and even shipped outside India to Laos (Ogale, 2002). The increase in the catch rates of the blue-finned mahseer (i.e. *T. khudree*) in the angler catches of the River Cauvery reported by Pinder et al. (2015a,b) thus represented the increased presence in the river of a non-indigenous and invasive fish of relatively high trophic level.

Further analyses of photographic records of mahseer captured in the River Cauvery then suggested that their initial appearance in angler catches was not until 1993, when a notably blue-finned fish of approximately 5 kg was captured during the mahseer world angling championships (A. Clark pers. comm.), with all photographic evidence of mahseer captured up to that point in the river (since at least 1919) were of hump-backed mahseer (Wild Life, 1977). Although circumstantial, this suggested it was the hump-backed mahseer that was the endemic mahseer of the River Cauvery and yet despite apparently being imperilled by the presence of the invasive *T. khudree*, this endemic species had yet to be even taxonomically described.

10.3 The importance of taxonomic classification

Whilst Pinder et al. (2015a,b) had now highlighted that the hump-backed mahseer, endemic to the River Cauvery, was now highly imperilled, its lack of a valid scientific name impeded more formal assessment of its conservation status. This was only overcome following the taxonomic determination of the hump-backed mahseer as *Tor remadevii* by Pinder et al. (2018a). This species had already been described from the Pambar River, the southernmost tributary of the River Cauvery catchment in the Southern Indian state of Kerala (Kurup & Radhakrishnan, 2007). However, its original description was based on the examination of individuals between 114 and 332 mm in length and lacked both molecular characterisation and comparative morphometric information (*cf*. Kurup & Radhakrishnan, 2007). As a result, the original description had previously been overlooked due to both its lack of rigour and it being completed on a small and morphologically confusing endemic *Tor* species that was believed to be restricted to the Pambar tributary.

Now that the endemic *T. remadevii* of the River Cauvery finally had a valid scientific name (Pinder et al., 2018a), when combined with the temporal patterns in their angler catch rates reported by Pinder et al. (2015a,b), then their conservation status could now be formally assessed. Given the first appearance of the hump-backed mahseer in the scientific literature in 1849 (Jerdon, 1849), and in angling catches in 1873 (Thomas, 1873), then this represented a major step-forward in affording this iconic species of mega-fauna some level of protection and conservation management.

10.4 The importance to conservation of the IUCN Red List

The IUCN Red List of Threatened Species™ ('Red List' hereafter) is the world's most widely accepted, objective and authoritative database detailing the global extinction risk and conservation status of plant and animal species (Vie et al., 2009). Currently 105,700 species have been assessed for their conservation status on the Red List, of which 28000 (27%) are threatened with extinction (IUCN Red List, 2019). Supported by an extensive network of >10,000 voluntary experts who provide information, assessment and peer-review, the Red List is based on scientifically rigorous criteria and categories (IUCN, 2012). Red List categories and criteria are supported by data on distribution, population, threats and conservation actions of the focal species (Rodrigues et al., 2006). In addition, the Red List provides a source of critical information that is essential to guide conservation investment, efforts and actions (Rodrigues et al., 2006), including recovery plans for species identified as at least threatened (Cumberlidge & Daniels, 2007), and systematic conservation planning, including the identification and design of protected areas (Hoffmann et al., 2008).

10.5 Red List assessment of *Tor remadevii*

In April 2018, the hump-backed mahseer *T. remadevii* was assessed as 'Critically Endangered' (Pinder et al., 2018b. The Red List assessment of the species has been based on the 'A' criteria which take into account the population status and trends. Populations of *T. remadevii* are estimated to have been reduced by over 90 % over three generations due to the combined effects of illegal and unsustainable fishing, the effects of introduced taxa (*T. khudree*) and declines in their critical habitats. Historic records dating from before the 1950s also indicate that even more significant declines have occurred, with the species now absent from the majority of its historical range. Population information underlying this assessment is based entirely on the analysis of catch-and-release fisheries data in the main stem of the River Cauvery (Pinder *et al*., 2015 a,b), supported by anecdotal information and local knowledge of fishers in the three major tributaries (Pambar, Bhavani and Moyar – see Figure 10.1.1) that suggest steady declines in catches over the last two decades (Mahseer Trust pers. obs.). Surveys in the various tributaries of the Cauvery where the fish was known to be abundant in the late 1800s and early 1900s have yielded only very few individuals, such as 13 fish in 2007, reducing to the capture of a single individual in 2017 in the Pambar River; a single specimen in the past 10 years in the Bhavani River, and nine individuals from a 'single pool' since 2015 in the Moyar River. Following the closure of the mid-Cauvery angling camps, since 2012 records of hump-backed mahseer from the main-stem of the

River Cauvery have been limited to a small number (< 5) of large fish (> 20 kg) from the upper reaches of the river in the Coorg region (Figure 10.1.1). It is probable that the recruitment of this species in the River Cauvery is now limited entirely to the Moyar and Pambar tributaries, where a small number of immature specimens (n = 9) have been recorded (< 40 cm TL) since 2015 (Pinder et al., 2018a).

10.6 Contextualising the imperilment of hump-backed mahseer at the genus level

While strong evidence already exists for the potential qualification of *T. remadevii* as both a 'flagship' and umbrella' species, other equally charismatic and threatened *Tor* spp. have not previously been afforded adequate scientific attention. In assessing the current status of the taxonomy and conservation status across the full biogeographic range of the genus (see Chapter 9), the former taxonomic ambiguity associated with the hump-backed mahseer has been found not to be an isolated case. Indeed, the available literature on *Tor* has been littered with inconsistencies, conflicting opinion and confusion over a) the number of valid species of *Tor*; b) the identity and distribution of individual species; c) the autecology of individual species; and d) the population status and extinction risk of individual species. These thus represent fundamental and persisting knowledge gaps impeding the development of conservation prioritisation and subsequent action plans for implementation (Cooke et al. 2012). In tackling these issues, Pinder et al. (2019) provided a comprehensive overhaul of the genus in revising the current number of valid species of *Tor* to 16. At the time of going to press, FishBase continued to list 50 different species of *Tor* of which 23 were suggested to be valid (Froese & Pauly 2018). Despite considerable remaining knowledge gaps, this simplification of the genus has facilitated the revision of species distribution maps and enabled revision of the IUCN Red List status of *Tor* fishes. Three species are now assessed as 'Near Threatened', one 'Vulnerable', three 'Endangered' and one 'Critically Endangered'. However, eight species still remain ‘Data deficient’. While much work is still required to address persisting data deficiencies across all 16 species, this exercise has confirmed the hump-backed mahseer of South India’s River Cauvery as being of immediate priority conservation concern.

10.7 Conservation impact

10.7.1 **Government and industry level impacts**

Following the publication of Pinder et al. (2015a,b) and a further popular article summarising this research in the Sanctuary Asia magazine (Pinder, 2015), Tata Power convened a workshop engaging a range of stakeholders (including Mahseer Trust, WWF India and Bombay Natural History Society) at their Lonavla hatchery, Maharashtra, from where the Cauvery’s *T. khudree* population had originated. At the same meeting, Tata Power also committed to support a research and outreach programme to conserve the endemic hump-backed mahseer, and also pledged to cease their long-term supply of the non-native *T. khudree* to national rivers beyond its natural biogeographic distribution range, including the River Cauvery (Dutt, 2019).

In addition to the Endangered Himalayan golden mahseer (*T. putitora*), both the hump-backed and blue-fin mahseers of the River Cauvery now feature in India’s National Wildlife Action Plan 2017-2031. (Ministry of Environment, Forests and Climate Change, 2017; Pinder et al., 2019). Within this Plan, actions included in ‘Chapter 7, Conservation of inland aquatic ecosystems’, include the initiation of special breeding programmes for threatened fish species, such as orange-finned (i.e. hump-backed) and golden mahseer, where ‘adequate care should be taken to prevent any genetic contamination or deterioration during these breeding and restocking programmes’ (Ministry of Environment, Forests and Climate Change, 2017). Actions also include the undertaking of measures ‘...for reviving the population of native species of fish by removal of blue-finned mahseer in the Cauvery…..through angling or other suitable means to reduce the population of these undesirable species. This should go hand in hand with the release of captive stocked orange-finned and golden mahseer in [the] Cauvery…' (Ministry of Environment, Forests and Climate Change, 2017). Acting on these recommendations, other Indian states and authorities are now starting to apply ex-situ conservation strategies for mahseer (e.g. Madhya Pradesh Forest Department). Having recognised the risk to endemic biodiversity from stocking non-indigenous mahseer, these strategies have focussed their attention to the exclusive culture of *Tor* species native to individual river systems (S. Saxena, pers. comm.). Furthermore, the 'Development and Implementation of Responsible Fish Stocking Policies' now features as one of the seven key recommendations within the declaration, proclaimed at the First International Mahseer Conference held in Paro, Bhutan December 2-8, 2018 (WWF Bhutan, Ministry of Agriculture and Forests, and Fisheries Conservation Foundation, 2019).

10.7.2 **Stakeholder level conservation impacts**

Within this current body of work, many examples of recreational fisheries supporting conservation success stories driving major national and local economies around the world are presented (see chapters 4 and 6). However, to qualify the potential conservation benefits of any recreational fishery, the monitoring of participation rates (Arlinghaus et al. 2015) and angler behaviours (Hunt et al. 2011) are recognised as being vital to understand how anglers interact with fish and their environment and, ultimately, their collective impact on the sustainability of the exploited biological resource (Brownscombe et al. 2019). The stakeholder engagement research presented within this thesis has contributed significantly to understanding the current status, threats and opportunities for the future development of recreational mahseer fisheries throughout South and Southeast Asia (Pinder & Raghavan, 2013; Gupta et al., 2015; Bower et al., 2017). In acknowledging the potential sensitivities and sustainability of catch-and-release (C&R) angling for endangered fishes, the research presented in Chapter 7 has provided vital evidence to engage anglers and fishery/wildlife regulators in informed discussion. Specifically, the study into the physiological response of mahseer to C&R (Bower et al., 2016), has provided the angling community with the ability to develop scientifically informed best practice guidance to educate anglers in the conservation benefits of catch and release angling and the importance of safe angling practices that ensure the health and enhance the long-term survival prospects of Indian mahseer. These safe angling and fish handling protocols have been disseminated by India's national angling body, the All India Game Angling Association (AIGFA), throughout the mahseer regions and increasingly adopted by angling organisations and individuals.

Further supported by the above research, the value of recreational mahseer fishery derived data presented in Chapter 4 (see Pinder & Raghavan, 2013; Pinder et al., 2015a,b) has now been recognised and incorporated in the recommendations of Indian national strategy paper for conservation policies for hilsa and mahseer (NAAS, 2018). This paper specifically recommends 'a need to develop science-led angling protocols to monitor population response to ecosystem restoration interventions', with a view to providing evidence informed policy development.

10.8 Concluding remarks

This body of research has demonstrated the high value of organised angling as a monitoring tool for data-poor fish populations and the potential for assessing the patterns in temporal population performance of other threatened, large bodied fishes in monsoonal rivers. It has also provided the basis for subsequent works that, in entirety, have enabled the taxonomic identification and international conservation designation of all 16 valid species of *Tor,* including *T. remadevii*. This mega-faunal species is now recognised as Critically Endangered, despite its previous taxonomic ambiguity. Indeed, it is considered highly likely that in the absence of this collective body of works, the species would have remained on a trajectory towards rapid extinction. Instead, the first major steps to safeguarding its future have been taken. In 2019, 'Project Mahseer' was launched by the

NGO ‘Shoal’, a ‘new partnership aimed at engaging a wide range of organisations to accelerate and escalate action to save the most threatened fish and other freshwater species’ (Shoal, 2019a). Project Mahseer has been launched by Shoal, with the initial priority being to conserve the hump-backed mahseer of the River Cauvery (Shoal, 2019b). Work is now underway to address major knowledge gaps on spatial ecology, behaviour and population genetics of the world’s last remaining hump-backed mahseer populations, to inform the future development and implementation of an effective species breeding and restocking programme, to secure the long term survival of this freshwater icon.

Rather than marking the end of my research journey, this thesis arguably represents the opposite, given it highlights many knowledge gaps in this genus across South Asia. In providing a new baseline of up-to-date reliable knowledge across the genus *Tor*, it identifies the priority knowledge gaps and aims to motivate co-researchers to engage in a new era of strategic research needed to conserve these freshwater icons, the ecological integrity of the rivers in which they swim and the people dependent on these critical freshwater resources. The research journey has just begun and I feel immensely privileged to have been involved to date.

10.9 References

Arlinghaus, R., Tillner, R., & Bork, M., 2015. Explaining participation rates in recreational fishing across industrialised countries. *Fisheries Management and Ecology* 22, 45–55.

Boote, P., & Wade, J., 1992. *Somewhere down the crazy river: journeys in search of the giant fish. The story of the rediscovery of the Indian mahseer and the goliath tigerfish of the Congo*. Sangha Books, Swindon.

Bower, S.D., Danylchuk, A.J., Raghavan, R., Clark-Danylchuk, S.E., Pinder, A.C., & Cooke, S.J., 2016. Rapid assessment of the physiological impacts caused by catch-and-release angling on blue-finned mahseer (*Tor* sp.) of the Cauvery River, India. *Fisheries Management and Ecology* 23, 208–217.

Bower, S.D., Danylchuk, A.J., Raghavan, R., Danylchuk, S.C., Pinder, A.C., Alter, A,M., & Cooke, S.J., 2017. Involving recreational fisheries stakeholders in development of research and conservation priorities for mahseer (*Tor* spp.) of India through collaborative workshops. *Fisheries Research* 186, 665–671.

Brownscombe, J.W., Hyder, K., Potts, W., Wilson, K.L., Pope, K.L., Danylchuk, A.J., Cooke, S.J., Clarke, A., Arlinghaus, R. & Post, J.R., 2019. The future of recreational fisheries: Advances in science, monitoring, management, and practice. *Fisheries Research* 211, 247-255.

Casselman, J.M., Penczak, T., Carl, L., Mann, R.H.K., Holcik, J., & Woitowich, W.A., 1990. An evaluation of fish sampling methodologies for large river systems. *Polish Archives of Hydrobiology* 37, 521-551.

Cooke, S.J., Paukert, C., & Hogan, Z., 2012. Endangered river fish: factors hindering conservation and restoration. *Endangered Species Research* 17, 171-191.

Cumberlidge, N., & Daniels, S.R. (2007). A conservation assessment of the freshwater crabs of southern Africa (Brachyura: Potamonautidae). *African Journal of Ecology* 46, 74–79.

Desai, V.R., 2003. Synopsis of biological data on the tor mahseer *Tor tor* (Hamilton, 1822). FAO Fisheries Synopsis. No. 158. FAO, Rome. 36p.

Dutt, B., 2019. *Rewilding: India's experiments in saving nature*. Oxford University Press. 244 p.

Froese, R., & Pauly, D., 2018. FishBase 2018, version (06/2018). World Wide Web electronic publication. Home page at: http://www.fishbase.org.

Gupta, N., Raghavan, R., Sivakumar, K., Mathur, V., & Pinder, A.C., 2015. Assessing recreational fisheries in an emerging economy: Knowledge, perceptions and attitudes of catch-and-release anglers in India. *Fisheries Research* 165, 79–84.

Hoffmann, M., Brooks, T. M., Da Fonseca, G. A. B., Gascon, C., Hawkins, A. F. A., James, R. E., … Cardoso da Silva, J. M., 2008. Conservation planning and the IUCN Red List. *Endangered Species Research* 6, 113-125.

Hunt, L.M., Sutton, S.G., & Arlinghaus, R., 2013. Illustrating the critical role of human dimensions research for understanding and managing recreational fisheries within a social-ecological system framework. *Fisheries Management and Ecology* 20,111–124.

IUCN, 2012. IUCN Red List Categories and Criteria, version 3.1, second edition. IUCN Species Survival Commission. Gland and Cambridge. 32p.

IUCN, 2019. The IUCN Red List of Threatened Species. Version 2019-2. http://www.iucnredlist.org, accessed 22nd October 2019.

Jerdon, T.C., 1849. On the fresh-water fishes of southern India. *Madras Journal of Literature and Science* 15, 302–346.

Jung, S.B., 2012. *Subhan and I: My Adventures with the Angling Legend of India*, Roli Books, New Delhi.

Kulkarni, C.V., & Ogale, S.N., 1978. The present status of mahseer (fish) and artificial propagation of *Tor khudree* (Sykes). *Journal of the Bombay Natural History Society* 75, 651–660.

Kurup, B.M., & Radhakrishnan, K.V., 2007. *Tor remadevii*, a new species of mahseer from Kerala (South India), and distribution and abundance of *Tor* spp. in the river systems of Kerala, pp53-60, In. Mahseer, the biology, culture and conservation (Siraj, S.S., Christianus, A., Kiat, N.C., De Silva, S.S. eds). Proceedings of the International Symposium on the mahseer, 29th to 30th March 2006, Kuala Lumpur, Malaysia (Malaysian Fisheries Society Occasional Publication No 14, Kuala Lumpur), 236p.

Ministry of Environment, Forests and Climate Change, 2017. India's National Wildlife Action Plan.

(http://www.indiaenvironmentportal.org.in/files/file/nwap_2017_31.pdf, accessed 21st October 2019).

NAAS, 2018. Conservation policies for hilsa and mahseer. Strategy Paper #8. *National Academy of Agricultural Sciences, New Delhi*, 28 pp.

Ogale, S.N., 2002. *Mahseer breeding and conservation and possibilities of commercial culture. The Indian experience*. In: Cold water fisheries in the trans-Himalayan countries. *FAO Fisheries Technical Paper* 431,193–212.

Pinder, A.C., 2015. Icon of the Cauvery. *Sanctuary Asia, October 2015*, 50–53.

Pinder, A.C., & Raghavan, R., 2013. Conserving the endangered Mahseers (*Tor* spp.) of India: the positive role of recreational fisheries. *Current Science* 104, 1472–1475.

Pinder, A.C., Raghavan, R., & Britton, J.R., 2015a. Efficacy of angler catch data as a population and conservation monitoring tool for the flagship Mahseer fishes (*Tor* spp.) of Southern India. *Aquatic Conservation: Marine and Freshwater Ecosystems* 25, 829–838.

Pinder, A.C., Raghavan, R., & Britton, J.R., 2015b. The legendary hump-backed mahseer *Tor* sp. of India's River Cauvery: an endemic fish swimming towards extinction? *Endangered Species Research* 28, 11–17.

Pinder, A.C., Manimekalan, A., Knight, J.D.M., Krishnankutty, P., Britton, J.R., Philip, S., … Raghavan, R., 2018a. Resolving the taxonomic enigma of the iconic gamefish, the hump-backed mahseer from the Western Ghats hotspot, India. *Plos One* 13, e0199328.

Pinder, A.C., Katwate, U., Dahanukar, N., & Harrison, A., 2018b. *Tor remadevii*. The IUCN Red List of Threatened Species 2018: e.T56096394A56717605. (http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T56096394A56717605.en, accessed 22nd October 2019).

Pinder A.C, Britton, J.R., Harrison, A.J., Nautiyal, P., Bower, S.D., Cooke, S,J., … Raghavan, R., 2019. Mahseer (*Tor* spp.) fishes of the world: status, challenges and opportunities for conservation. *Reviews in Fish Biology and Fisheries* 29, 417-452.

Rodrigues, A.S., Pilgrim, J.D., Lamoreux, J.F., Hoffmann, M., & Brooks, T.M., 2006. The value of the IUCN Red List for conservation. *Trends in Ecology & Evolution* 21, 71-76.

Sehgal, K.L., 1999. Coldwater fish and fisheries in the Indian Himalayas: rivers and streams. *Fish and fisheries at higher altitudes: Asia. Food and Agriculture Organization of the United Nations Technical Paper* 385, 41-63.

Shoal, 2019a. Mission and Vision. (https://shoalconservation.org/the-partnership/#mission-and-vision, accessed 21st October 2019).

Shoal, 2019b. Project Concept: Tiger of the Water - Saving the Critically Endangered hump-backed mahseer. (https://shoalconservation.org/wp-content/uploads/2019/03/Tiger-of-the-Water-Conserving-the-hump-backed-mahseer.pdf, accessed 21st October 2019).

Thomas, H.S., 1873. *The Rod in India*. Mangalore: Stolz.

TWFT, 1984. *Trans*-world fishing team*: Quest for a Legendary Fish*. International Book Distributors: Dehra Dun.

Vié, J.C., Hilton-Taylor, C., Pollock, C., Ragle, J., Smart, J., Stuart, S.N., & Tong, R., 2009. The IUCN Red List: a key conservation tool. *Wildlife in a changing world–An analysis of the 2008 IUCN Red List of Threatened Species*, 180pp.

Wild Life, 1976. *Wildlife Journal of the Wildlife Association of South India (WASI), 1976*.

Wild Life, 1977. The monsters of Karnataka. *Wildlife Journal of the Wildlife Association of South India (WASI), 1977*, 1–8.

Wilson, J., 1999. *Fifty years an angler*. Boxtree Publishing, London.

WWF Bhutan, Ministry of Agriculture and Forests, and Fisheries Conservation Foundation, 2019. The first international mahseer conference proceedings.(http://mahseerconference.org/wp-content/uploads/2019/07/Internl-Mahseer-Conference-Proceedings.pdf, accessed 21st October 2019).

APPENDIX I - Co-authorship statements

This thesis consists of a cohesive commentary linking a total of eight published papers across seven peer review journals and an IUCN Red List assessment. Although I have led the authorship of six of these outputs, I have included a further three papers I have contributed to, which form important links within my own strategy for contextualising, engaging and communicating my research across the diverse stakeholder groups needed to effect future conservation efforts.

The multi-disciplinary approach required to bring many of these studies to publication has required the input of a number of specialists and the statements provided below define my own contribution to each paper in relation to that of my co-authors:

Submision 1

Pinder, A.C and Raghavan, R. (2013) **Conserving the endangered mahseers (*Tor* spp.) of India: the positive role of recreational fisheries**. *Current Science* 104, 1472-1474.

> I conceptualised the paper, conducted the research and wrote the manuscript. Raghavan was instrumental in fact checking and assisting with editing.

Submission 2

Gupta, N., Raghavan, R., Sivakumar, K., Mathur, V. and **Pinder, A.C**. (2015). **Assessing recreational fisheries in an emerging economy: Knowledge, perceptions and attitudes of catch-and-release anglers in India**. *Fisheries Research*, 165, 79-84.

> Contributing a supervisory and mentoring role, I worked with the lead author to develop the survey design, stakeholder engagement strategy and the data analysis approach. Along with Raghavan, I also contributed to manuscript preparation and editing.

Submission 3

Bower, S.D., Danylchuk, A.J., Raghavan, R., Clark-Danylchuk, S., **Pinder, A.C.**, Alter, A. and Cooke, S.J. (2017) **Involving recreational fisheries stakeholders in development of research and conservation priorities for mahseer (*Tor* spp.) of India through collaborative workshops** *Fisheries Research* 186, 665-671.

> My key contribution to this paper was facilitating the international interaction between co-authors and leading the organisation and hosting the workshop held in Karnataka. I co-designed the agenda with co-authors and contributed to the final stages of manuscript preparation and editing.

Submisison 4

Pinder, A. C., Raghavan, R., & Britton, J. R. (2015). **Efficacy of angler catch data as a population and conservation monitoring tool for the flagship Mahseer fishes (Tor spp.) of Southern India**. *Aquatic Conservation: Marine and Freshwater Ecosystems* 25, 829-838.

> I was responsible for conceptualisation, survey design, data collection, initial data analysis, writing the manuscript and editing. Britton contributed more advanced statistical analyses to improve the paper and Raghavan contributed to the final stages of manuscript preparation.

Submission 5

Pinder, A. C., Raghavan, R., & Britton, J. R. (2015). **The legendary hump-backed mahseer Tor sp. of India's River Cauvery: an endemic fish swimming towards extinction?** *Endangered Species Research* 28, 11-17.

> I was responsible for conceptualisation, survey design, data collection, initial data analysis, writing the manuscript and editing. Britton contributed more advanced statistical analyses to improve

the paper and Raghavan contributed to the final stages of manuscript preparation.

Submisison 6

Bower, S.D., Danylchuk, A.J., Raghavan, R., Clark-Danylchuk. S., **Pinder, A.C**. and Cooke, S.J. (2016) **Rapid assessment of the physiological impacts caused by catch-and-release angling on blue-finned mahseer (*Tor* sp.) of the Cauvery River, India.** *Fisheries Management and Ecology* 23, 208-217.

While Bower designed the study, collected and analyzed the data, and wrote the manuscript, I, was responsible for identifying appropriate study sites. I also contributed to data collection and the final stages of manuscript preparation and editing. The research skills I learned during this study have since been applied to UK fish species and a further two papers for which I have led the authorship, including Submission 7.

Submission 7

Pinder A.C, Manimekalan, A., Knight, J.D.M, Krishnankutty, P., Britton, J.R., Philip, S., Dahanukar, N., and Raghavan, R. (2018) **Resolving the taxonomic enigma of the iconic game fish, the hump-backed mahseer from the Western Ghats biodiversity hotspot, India**. *PLoS ONE* 13(6): e0199328. https://doi.org/10.1371/journal.pone.0199328

I was responsible for conceptualisation, survey design, data collection, interpretation of results, manuscript writing and editing. Dahanukar led on laboratory based molecular and morphometric analysis; Knight, Krishnnkutty and Philip contributed morphometric data from comparative materials; Raghavan and Britton contributed to the final stages of manuscript preparation and editing.

Submission 8

Pinder A.C., Katwate, U., Dahanukar, N. & Harrison, A.J. (2018) Tor remadevii. The IUCN Red List of Threatened Species 2018: Scheduled publication November 2018.

Assisted by Bournemouth University impct acceleration funding, I was responsible for organising and convening the workshop which resulted in the revision of Red List assessments for all 16 species of *Tor*. In his role as IUCN Freshwater Fish Red List Authority Coordinator (Asia/Oceania) Raghavan provided helpful guidance/training and Harrison assisted with the production of the distribution map.

Submission 9

Pinder A.C, Britton, J.R., Harrison, A.J., Nautiyal, P., Bower, S.D., Cooke, S,J., Lockett, S., Everard,M., Katwate, U., Ranjeet, K., Walton, S., Danylchuk, A.J. & Raghavan, R. (2019) Mahseer (*Tor* spp.) fishes of the world: status, challenges and opportunities for conservation. *Reviews in Fish Biology and Fisheries* 29, 417-452.

I was responsible for conceptualisation, identification of contributing authors to assist with the production of some of the introductory sections. I wrote the bulk of the manuscript and edited section contributed by others. Harrison provided GIS expertise to assist with map production and Britton and Raghavan contributed to the final stages of manuscript preparation.

APPENDIX II - Full list of scientific publications (exclusive of commercial reports)

Books

Pinder, A. C. (2001). Keys to larval and juvenile stages of coarse fishes from fresh waters in the British Isles. Scientific Publication #61 Freshwater Biological Association, Ambleside, UK. 136 pp.

Chapters

Hodder, K. H., Masters, J. E., Beaumont, W. R., Gozlan, R. E., **Pinder, A. C**., Knight, C. M., & Kenward, R. E. (2007). Techniques for evaluating the spatial behaviour of river fish. In *Developments in Fish Telemetry* (pp. 257-269). Springer, Dordrecht**.**

Masters, J. E. G., Welton, J. S., Beaumont, W. R. C., Hodder, K. H., **Pinder, A. C**., Gozlan, R. E., & Ladle, M. (2002). Habitat utilisation by pike Esox lucius L. during winter floods in a southern English chalk river. In *Aquatic Telemetry* (pp. 185-191). Springer, Dordrecht.

Journal articles

Pinder A.C, Britton, J.R., Harrison, A.J., Nautiyal, P., Bower, S.D., Cooke, S,J., Lockett, S., Everard,M., Katwate, U., Ranjeet, K., Walton, S., Danylchuk, A.J. & Raghavan, R. (2019) Mahseer (*Tor* spp.) fishes of the world: status, challenges and opportunities for conservation. *Reviews in Fish Biology and Fisheries* 29, 417-452.

Pinder, A.C., Harrison, A.J., & Britton, J.R. (2019) Temperature effects on the physiological status and reflex impairment in European grayling Thymallus thymallus from catch-and release angling. *Fisheries Research*, *211*, 169-175.

Everard, M., **Pinder, A. C**., Raghavan, R., & Kataria, G. (2019) Are well-intended Buddhist practices an under-appreciated threat to global aquatic biodiversity?. *Aquatic Conservation: Marine and Freshwater Ecosystems*.

Basavaraja, N., Lun, K.P.B., Katare, M.B., & **Pinder, A.C**. (2019) Hormone induced spawning and embryogenesis of Cauvery carp, Barbodes carnaticus (Jerdon 1849): implications on commercial culture and conservation. *Indian Journal of Experimental Biology*, *57*(February), 86-94.

Pinder, A. C., Manimekalan, A., Knight, J. M., Krishnankutty, P., Britton, J. R., Philip, S., Dahanukar, N., & Raghavan, R. (2018). Resolving the taxonomic enigma of the iconic game fish, the hump-backed mahseer from the Western Ghats biodiversity hotspot, India. *PloS one*, *13*(6), e0199328.

Everard, M., Sharma, O. P., Vishwakarma, V. K., Khandal, D., Sahu, Y. K., Bhatnagar, R., Kumar, V. & **Pinder, A.C**. (2018). Assessing the feasibility of integrating ecosystem-based with engineered water resource governance and management for water security in semi-arid landscapes: A case study in the Banas catchment, Rajasthan, India. *Science of the Total Environment*, *612*, 1249-1265.

Walton, S. E., Gan, H. M., Raghavan, R., **Pinder, A. C**., & Ahmad, A. (2017). Disentangling the Taxonomy of the Mahseers (Tor spp.) of Malaysia: An Integrated Approach Using Morphology, Genetics and Historical Records. *Reviews in Fisheries Science & Aquaculture*, *25*(3), 171-183.

Pinder, A. C., Velterop, R., Cooke, S. J., Britton, J. R., & Handling editor: Michel Kaiser. (2016). Consequences of catch-and-release angling for black bream Spondyliosoma cantharus, during the parental care period: implications for management. *ICES Journal of Marine Science*, *74*(1), 254-262.

Bower, S. D., Danylchuk, A. J., Raghavan, R., Danylchuk, S. C., **Pinder, A. C**., Alter, A. M., & Cooke, S. J. (2017). Involving recreational fisheries stakeholders in development of research and conservation priorities for mahseer (Tor spp.) of India through collaborative workshops. *Fisheries Research*, *186*, 665-671.

Bower, S. D., Danylchuk, A. J., Raghavan, R., Clark-Danylchuk, S. E., **Pinder, A. C**., & Cooke, S. J. (2016). Rapid assessment of the physiological impacts caused by catch-and-release angling on blue-finned mahseer (Tor sp.) of the Cauvery River, India. *Fisheries Management and Ecology*, *23*(3-4), 208-217.

Pinder, A. C., Hopkins, E., Scott, L. J., & Britton, J. R. (2016). Rapid visual assessment of spawning activity and associated habitat utilisation of sea lamprey (Petromyzon marinus Linnaeus, 1758) in a chalk stream: implications for conservation monitoring. *Journal of Applied Ichthyology*, *32*(2), 364-368.

Pinder, A. C., Raghavan, R., & Britton, J. R. (2015). The legendary hump-backed mahseer Tor sp. of India's River Cauvery: an endemic fish swimming towards extinction?. *Endangered Species Research*, *28*(1), 11-17.

Gupta, N., Raghavan, R., Sivakumar, K., Mathur, V., & **Pinder, A. C**. (2015). Assessing recreational fisheries in an emerging economy: Knowledge, perceptions and attitudes of catch-and-release anglers in India. *Fisheries Research*, *165*, 79-84.

Pinder, A. C., Raghavan, R., & Britton, J. R. (2015). Efficacy of angler catch data as a population and conservation monitoring tool for the flagship Mahseer fishes (Tor spp.) of Southern India. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *25*(6), 829-838.

Harrison, A. J., Walker, A. M., **Pinder, A. C**., Briand, C., & Aprahamian, M. W. (2014). A review of glass eel migratory behaviour, sampling techniques and abundance estimates in estuaries: implications for assessing recruitment, local production and exploitation. *Reviews in Fish Biology and Fisheries*, *24*(4), 967-983.

Pinder, A. C., & Raghavan, R. (2013). Conserving the endangered mahseers (Tor spp.) of India: the positive role of recreational fisheries. *Current Science*, *104*(11), 1472-1475.

Ibbotson, A. T., Riley, W. D., Beaumont, W. R., Cook, A. C., Ives, M. J., **Pinder, A. C**., & Scott, L. J. (2013). The source of autumn and spring downstream migrating juvenile A tlantic salmon in a small lowland river. *Ecology of Freshwater Fish*, *22*(1), 73-81.

Ibbotson, A. T., Beaumont, W. R., & **Pinder, A. C**. (2011). A size-dependent migration strategy in Atlantic salmon smolts: Small smolts favour nocturnal migration. *Environmental Biology of Fishes*, *92*(2), 151-157.

Riley, W. D., Ibbotson, A. T., Lower, N., Cook, A. C., Moore, A., Mizuno, S., **Pinder.A.C**. & Privitera, L. (2008). Physiological seawater adaptation in juvenile Atlantic salmon (Salmo salar) autumn migrants. *Freshwater Biology*, *53*(4), 745-755.

Britton, J. R., Davies, G. D., Brazier, M., & **Pinder, A. C**. (2007). A case study on the population ecology of a topmouth gudgeon (Pseudorasbora parva) population in the UK and the implications for native fish communities. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *17*(7), 749-759.

Pinder, A. C., Riley, W. D., Ibbotson, A. T., & Beaumont, W. R. C. (2007). Evidence for an autumn downstream migration and the subsequent estuarine residence of 0+ year juvenile Atlantic salmon Salmo salar L., in England. *Journal of fish Biology*, *71*(1), 260-264.

Hodder, K. H., Masters, J. E., Beaumont, W. R., Gozlan, R. E., **Pinder, A. C.**, Knight, C. M., & Kenward, R. E. (2007). Techniques for evaluating the spatial behaviour of river fish. In *Developments in Fish Telemetry* (pp. 257-269). Springer, Dordrecht.

Ibbotson, A. T., Beaumont, W. R. C., **Pinder, A.C**., Welton, S., & Ladle, M. (2006). Diel migration patterns of Atlantic salmon smolts with particular reference to the absence of crepuscular migration. *Ecology of Freshwater Fish*, *15*(4), 544-551.

Knight, C. M., Gozlan, E. G., Beaumont, W. R., **Pinder, A. C**., Scott, L., & Lucas, M. C. (2005, December). Utilization and significance of off-river habitats to lowland river fishes. *Journal of Fish Biology* 67, 268-268).

Pinder, A. C., Gozlan, R. E., Beyer, K., & Bass, J. A. B. (2005). Ontogenetic induced shifts in the ecology of sunbleak Leucaspius delineatus during early development. *Journal of Fish Biology, 67*, 205-217.

Pinder, A. C., Gozlan, R. E., & Britton, J. R. (2005). Dispersal of the invasive topmouth gudgeon, Pseudorasbora parva in the UK: a vector for an emergent infectious disease. *Fisheries Management and Ecology*, *12*(6), 411-414.

Gozlan, R. E., **Pinder, A. C**., & Shelley, J. (2002). Occurrence of the Asiatic cyprinid Pseudorasbora parva in England. *Journal of Fish Biology*, *61*(1), 298-300.

Pinder, A. C. (2005). Larval taxonomy and early identification of topmouth gudgeon Pseudorasbora parva: a screening tool to reduce risks of unintentional species translocation. *Fisheries Management and Ecology*, *12*(2), 99-104.

Ibbotson, A. T., Beaumont, W. R. C., Collinson, D., Wilkinson, A., & **Pinder, A. C**. (2004). A cross-river antenna array for the detection of miniature passive integrated transponder tags in deep, fast flowing rivers. *Journal of Fish Biology*, *65*(5), 1441-1443.

Pinder, A. C., & Gozlan, R. E. (2004). Early ontogeny of sunbleak. *Journal of Fish Biology*, *64*(3), 762-775.

Gozlan, R. E., Flower, C. J., & **Pinder, A. C**. (2003). Reproductive success in male sunbleak, a recent invasive fish species in the UK. *Journal of Fish Biology*, *63*, 131-143.

Gozlan, R. E., **Pinder, A. C**., Durand, S., & Bass, J. (2003). Could the small size of sunbleak, Leucaspius delineatus (Pisces, Cyprinidae) be an ecological advantage in invading British waterbodies?. *Folia Zoologica* *52*(1), 99-99.

Masters, J. E. G., Welton, J. S., Beaumont, W. R. C., Hodder, K. H., **Pinder, A. C**., Gozlan, R. E., & Ladle, M. (2002). Habitat utilisation by pike Esox lucius L. during winter floods in a southern English chalk river. *Hydrobiologia* 483(1):185-191.

Kowe, R., Skidmore, R. E., Whitton, B. A., & **Pinder, A. C**. (1998). Modelling phytoplankton dynamics in the River Swale, an upland river in NE England. *Science of the Total Environment*, *210*, 535-546.

Mann, R. H. K., Bass, J. A. B., Leach, D., & **Pinder, A.C**. (1997). Temporal and spatial variations in the diet of 0 group roach (Rutilus rutilus) larvae and juveniles in the River Great Ouse in relation to prey availability. *Regulated Rivers: Research & Management*, *13*(3), 287-294.

Pinder, L. C. V., Marker, A. F. H., **Pinder, A. C**., Ingram, J. K. G., Leach, D. V., & Collett, G. D. (1997). Concentrations of suspended chlorophyll a in the Humber rivers. *Science of the Total Environment*, *194*, 373-378.

Tipping, E., Marker, A. F. H., Butterwick, C., Collett, G. D., Cranwell, P. A., Ingram, J. K. G., **Pinder,A.C**. & Simon, B. M. (1997). Organic carbon in the Humber rivers. *Science of the Total Environment*, *194*, 345-355.

House, W. A., Leach, D., Warwick, M. S., Whitton, B. A., Pattinson, S. N., Ryland, G., **Pinder, A.C**., Ingram,J., Lishman, J.P., Smith, S.M., Rigg, E. & Denison, F.H. (1997). Nutrient transport in the Humber rivers. *Science of the Total Environment*, *194*, 303-320.

IUCN Red List Assessments

Dahanukar, N., Katwate, U., **Pinder, A.C**, & Harrison, A. (2018) *Tor kulkarnii*. The IUCN Red List of Threatened Species 2018: e.T172355A60609857. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T172355A60609857.en.

Dahanukar, N., **Pinder, A.C**, & Harrison, A. (2018) *Tor mosal*. The IUCN Red List of Threatened Species 2018: e.T188106A1855151. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T188106A1855151.en.

Huckstorf, V., **Pinder, A.C**, & Harrison, A. (2018) *Tor polylepis*. The IUCN Red List of Threatened Species 2018: e.T188025A126323203. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T188025A126323203.en. Jha, B.R., Rayamajhi, A., Dahanukar, N., Harrison, A., & **Pinder, A.C.** (2018) *Tor putitora*. The IUCN Red List of Threatened Species 2018: e.T126319882A126322226. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T126319882A126322226.en. Kottelat, M., **Pinder, A.C**, &

Harrison, A. (2018) *Tor ater*. The IUCN Red List of Threatened Species 2018: e.T188038A126323308. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T188038A126323308.en.

Kottelat, M., **Pinder, A.C**. & Harrison, A. (2018) *Tor tambra*. The IUCN Red List of Threatened Species 2018: e.T188012A89801879. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T188012A89801879.en..

Kottelat, M., **Pinder, A.C**. & Harrison, A. (2018) *Tor tambroides*. The IUCN Red List of Threatened Species 2018: e.T187939A91076554. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T187939A91076554.en. Accessed 13 March 2019.

Pinder, A.C. (2018) *Tor yingjiangensis*. The IUCN Red List of Threatened Species 2018:e.T188067A1850734. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T188067A1850734.en.
Pinder, A.C., & Harrison, A. (2018) *Tor dongnaiensis*. The IUCN Red List of Threatened Species 2018: e.T126318880A126323439. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T126318880A126323439.en. **Pinder, A.C**., Katwate, U., Dahanukar, N., & Harrison, A. (2018) *Tor remadevii*. The IUCN Red List of Threatened Species 2018: e.T56096394A56717605. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T56096394A56717605.en. Rayamajhi, A., Jha, B.R., Sharma, C.M., **Pinder, A.C**., Harrison, A., Katwate, U., & Dahanukar, N. (2018) *Tor tor*. The IUCN Red List of Threatened Species 2018: e.T166534A126321898. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T166534A126321898.en. Vidthayanon, C., & **Pinder, A.C**. (2018) *Tor sinensis*. The IUCN Red List of Threatened Species 2018: e.T187891A126322879. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T187891A126322879.en. Vishwanath, W., Dahanukar, N., **Pinder, A.C**., & Harrison, A. (2018) *Tor barakae*. The IUCN Red List of Threatened Species 2018: e.T168258A126322721. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T168258A126322721.en.

Popular articles

Pinder, A. C., & Gozlan, R. E. (2003). Sunbleak and topmouth gudgeon: two new additions to Britain's freshwater fishes. *British Wildlife*, *15*(2), 77-83.

Pinder, A.C. (2015) Icon of the Cauvery. *Sanctuary Asia*, *XXXV*(10), 50-53.