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Assessing the societal benefits of mahseer (*Tor* spp.) fishes and habitats to strengthen the basis for their conservation

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Abstract

1. Mahseer (*Tor* spp. Cyprinidae) are iconic, large-bodied, migratory freshwater fishes of Asian rivers. Long valued as a food source and serving other societal roles, these fishes are severely threatened by a broad range of interacting and escalating human impacts, including dam construction, water pollution, over exploitation and habitat destruction. Mahseer fishes are therefore beneficial to people both directly and as indicators of ecosystem functionality and the associated ecosystem service benefits provided by the rivers they inhabit.

2. A literature review demonstrated that wild mahseer populations have a direct role in 11 of 36 assessed ecosystem services, and are indicative of a further 18 ecosystem services provided by the habitats which support them.

3. Recognition of this range of ecosystem service benefits is helpful for describing to non-specialist public and policy-making communities the diversity of values provided by mahseer fishes and their supporting habitats, and hence the importance of their conservation.

4. Assessment of the broad range of ecosystem services to which mahseer contribute is an approach that could usefully be applied to promote the benefits of conserving other 'umbrella' taxa and the habitats that support them.

Keywords
Asian rivers; ecosystem services; Sustainable Development Goals; flagship species.

1. Introduction

Freshwater ecosystems are disproportionately vulnerable, with an 84% decline in freshwater vertebrate populations reported since 1970 (WWF, 2020). This dramatic decline in freshwater biodiversity has been described as a "*quiet crisis…taking place beneath the surface of the world's rivers and lakes*" (Richter et al., 1997) that is often invisible to the general public and to policy-makers (Dudgeon et al., 2006; Reid et al., 2019). In many communities throughout the world, fish and fisheries play a significant role in economic and social structures. Lynch et al. (2020a; 2020b) demonstrated that inland fisheries can contribute substantially to increased food security, poverty alleviation, human well-being and ecosystem functioning. Sustainable management of inland fisheries relies on maintaining aquatic ecosystems in a healthy state, yet anthropogenic pressures continue to accumulate, escalating the pressure on freshwater biodiversity (McIntyre, Reidy Liermann & Revenga, 2016; Reid et al., 2019). Freshwater fishes are amongst the most threatened taxa globally (Cooke, Paukert & Hogan, 2012; Carrizo, Smith & Darwall, 2013; Reid, Contreras MacBeath & Csatádi, 2013), with migratory and megafauna fishes in alarming decline (Carrizo et al., 2017; He et al., 2017; WWF, 2021). Although millions of people globally rely on freshwater ecosystems for nutrition, income, recreational and cultural services (Cooke et al., 2016; Youn et al., 2014), current trends in exploitation of freshwater resources and fishes demonstrate a failure to adequately value and protect these systems and the vital ecosystem services they provide.

1.1 Applying an ecosystem services approach

The need to integrate 'nature' with human activities and development needs within integrated socio-ecological systems is a fundamental component of modern-day conservation philosophy (Sala & Torchio, 2019). Consequently, systemic interdependence between people and ecosystems, and the need to recognize and respect the limits of natural systems to ensure human wellbeing, represent central aspects of the Millennium Ecosystem Assessment (2005). This interdependence is also recognised as vital for addressing climate stability (IPCC, 2018) and is also

explicitly recognised under the Inter-governmental Panel on Biodiversity and Ecosystem Services (Brondizio et al., 2019; IPBES, 2020). New approaches are required to safeguard species, habitats, ecosystems and their functions, specifically recognizing the breadth of societal values dependent upon them (Costanza et al., 1997; Finlayson et al., 2011; Costanza et al., 2017).

The ecosystem services framework, defined as "…*the benefits people obtain from ecosystems*" (Millennium Ecosystem Assessment, (MEA), 2005), identify the multiplicity and inherently interlinked nature of benefits of natural systems to humanity. It serves as a conceptual underpinning model articulating how ecosystems contribute to human wellbeing, in both monetary and non-monetary terms and in language familiar and relevant to multiple beneficiaries (for example in terms of food security, disease or flood management, or recreational opportunities). Importantly, it provides a means of integrating stakeholder views and value systems into decision-making; in so doing it can raise societal awareness, and strengthens the case for conservation beyond a simplistic reliance on intrinsic values (Schmidt, Sachse & Walz, 2016).

Demonstrating that functioning ecosystems are vital for human wellbeing promotes recognition that conservation of nature is fundamental to supporting societal needs. This is reflected by the central role of ecosystem services in underpinning the delivery of the United Nations' Sustainable Development Goals (SDGs) (UN, 2015). Meeting these SDGs can be linked to maintaining or enhancing flows of ecosystem services (Everard & Longhurst, 2018), and ecosystem services making direct or important contributions to subsidiary targets under the SDGs (Wood et al., 2018). Despite this, the ecological basis underpinning the SDGs are still substantially neglected (Reid, Contreras MacBeath & Csatádi, 2013).

1.2 Applying the ecosystem services approach to Mahseer fishes

Iconic fish species (*sensu* Everard & Kataria, 2011) are frequently referred to as 'focal species' (e.g. 'flagship', 'umbrella' and 'indicator' species) reflecting the health of the aquatic habitats that support them and their associated biodiversity (e.g. Belmar et al., 2018; Zarkami et al., 2019). However, such assertions have often lacked supporting evidence demonstrating clear direct or indirect benefits to society. The need to recognise and promote the societal benefits associated with mahseer fishes (*Tor* spp., Cyprinidae) in Asia as a means to improve their conservation was recognised at the 2nd International Mahseer Conference (IMC2) held in Chiang Mai, Thailand, in February 2020. This paper considers how the diversity of beneficial ecosystem services associated with mahseer fishes can support the conservation both of these fishes and of the ecosystems supporting them.

Mahseer are large-bodied, migratory freshwater fishes [which can exceed 35kg in weight (Carrizo et al., 2017). These potadromous cyprinid river fishes are distributed

throughout many of the rivers of South and Southeast Asia, including the biodiversity 'hot-spots' of the Himalayas and India's Western Ghats. Across this broad Asian range, mahseer are threatened by multiple human impacts, including dam construction (longitudinal river fragmentation), water pollution, over-exploitation and habitat destruction. Accordingly, of the 16 currently valid species of *Tor*, seven are assessed as threatened ('Vulnerable' to 'Critically Endangered'), eight are 'Data Deficient' and one species is assessed as 'Least Concern' on the IUCN Red List of Threatened Species (see Supplementary Material and Pinder et al. (2019) for a comprehensive review of the genus *Tor*)).) Despite their high economic and cultural importance (Nautiyal, 2014; Pinder et al., 2019), countries in which mahseer occur have rapidly developing economies in which protection of vulnerable habitats is a relatively low priority (Dudgeon, 2002; Reid et al., 2019). Effective conservation measures are largely lacking, beyond scattered, small-scale initiatives led by recreational catch-and-release angling initiatives. While efforts to bolster populations through the stocking of hatchery cultured mahseer have been underway since the mid-1970s, no evidence exists to support a positive effect on populations in the wild. Furthermore, some well-intentioned stocking programmes have been demonstrated to have had perverse outcomes by spreading mahseer species beyond their native distribution ranges, where they have competed and threatened the extinction of endemic mahseer species (Pinder, Raghavan & Britton, 2020). Mahseer also remain poorly protected by nature conservation legislation; for example, they are not scheduled under the Indian Wildlife Act 1972 despite being iconic species of Indian river systems. On the basis of their vulnerability and iconic role, mahseer may qualify as designated features of any Protected Areas in which they occur. However, there appear to be no mahseer-driven efforts to restore habitat or control pollution. The omission of mahseer from nature conservation and environmental management measures highlights the need for this paper.

This context suggests that mahseer fishes are particularly suitable for applying an ecosystem services approach as part of a conservation strategy. Therefore, a comprehensive literature review was undertaken to examine contributions to ecosystem services provided both directly by wild populations of mahseer fishes as well as by the functioning of the habitats of which they are indicators. The results from this analysis can strengthen the case for the conservation of mahseer fishes and of their habitats by demonstrating the benefits gained by a range of stakeholder groups, including those responsible for river management.

2. Methods

2.1. Ecosystem service assessment

Assessment of ecosystem service flows can illustrate the range of societal benefits provided by species and the ecosystems that support them, as well as the

implications for these benefits when these resources are exploited or managed (Bagstad et al., 2013; Everard, 2017).

The ecosystem service classification scheme from the RAWES (Rapid Assessment of Wetland Ecosystem Services) approach, adopted by the Ramsar Commission under Ramsar Resolution XII.17 (Ramsar Convention, 2018), was used for this assessment. This is adapted from the MEA (2005) classification of ecosystem services, comprising provisioning, regulating, cultural and supporting service categories. Supporting services and regulating services are deliberately retained in this assessment as their roles in ecosystem integrity and resilience are important for decision-making at policy and practical levels (Everard, 2017). This is despite them being redefined as functions in some subsequent ecosystem service classifications to avoid 'double-counting' benefits (e.g. TEEB, 2010; Braat & de Groot, 2012).

2.2 Literature review

A literature review, using Google Scholar and Web of Science, and the search terms 'mahseer' and '*Tor*', was undertaken to determine the contribution to ecosystem services made directly by mahseer fishes and, by inference, the functions of catchment habitats on which mahseer depend. Due to several complicating factors, (notably the problem that many societal benefits are generally defined without being referred to as ecosystem services), it was not practical to conduct a fully systematic review. Therefore reports, news and other informal sources were included in addition to peer-reviewed literature, thereby ensuring that important benefits were not overlooked.

2.3 Assignment of scores in this assessment

Evidence concerning the direct contributions of mahseer fishes, or the indirect implications of their presence as indicators, was applied to each of the 36 ecosystem services within the RAWES classification. As literature directly linking mahseer fishes to ecosystem service flows is very sparse, the scoring system in Table 1 was applied.

Table 1: Scores assigned to ecosystem services contributions from mahseer fishes and the habitats supporting mahseer populations

Score assigned	Rationale for assignment of score
+++	Strong evidence related directly to mahseer
++	Indirect evidence of likely contributions of mahseer fishes, derived from references addressing other fishes
+	Inferred from the roles of mahseer in ecosystems either as (1) indicators of intact and functional ecosystems; or (2) resulting from

	their roles in ecosystems (predation or other roles in food webs, bioturbation, etc.)
0	No supporting evidence. Nonetheless, this does not imply that not role is served (e.g. where mahseer indicate intact catchment that might have potential roles in services such as fire regulation or noise/visual buffering.)

3. Results

3.1 Mahseer and ecosystem services

Ecosystem service contributions of mahseer fishes and their supporting habitats are outlined for each of the MEA (2005) categories in the Supplementary Material. Tables respectively for Provisioning, Regulating, Cultural and Supporting services in the Supplementary Material provide assigned scores and supporting evidence for the direct or inferred contributions of populations of mahseer fishes, or of the habitats supporting wild, self-sustaining populations and for which mahseer serve as indicators. Recognition of the broad range of ecosystem service values can be helpful for describing to general public and policy-makers the range of benefits provided by mahseer fishes and their supporting habitats. Table 2 summarises these contributions.

Table 2: Contributions of mahseer fishes to ecosystem services (see details in the Supplementary Material)

Ecosystem services	**Contributions of mahseer fishes to the assessed ecosystem service**
Provisioning services 6 out of 9 services for which evidence is available, 2 as +++, 1 as + and 3 as +	
Fresh water available for abstraction and use	++
Food production (e.g. crops, fruit, fish, etc.)	+++
Fibre and fuel production (e.g. timber, wool, etc.)	+
Genetic resources (used for crop/stock breeding and biotechnology)	+++
Biochemicals, natural medicines, pharmaceuticals	+
Ornamental resources (e.g. shells, flowers, etc.)	+
Harvesting of clay, mineral, aggregates, etc.	0
Waste disposal	0
Energy harvesting from natural air and water flows (if relevant)	0

Regulating services 10 out of 14 services for which evidence is available, 2 as +++, 1 as + and 7 as +	
Air quality regulation	+
Local climate regulation - microclimate, temperature, precipitation	+
Global climate regulation - greenhouse gas sequestration, etc.	+
Water regulation (timing and scale of run-off, flooding, etc.)	+
Natural hazard regulation (i.e. storm protection)	+
Pest regulation	0
Disease regulation – human	+++
Disease regulation – stock	+++
Erosion regulation	+
Water purification and waste treatment	+
Pollination and seed dispersal	++
Salinity regulation - implications for soil salinity build-up	0
Fire regulation - tendency of ecosystems in the catchment to burn	0
Noise and visual buffering - impacts on the buffering effects of ecosystems	0
Cultural services 7 out of 7 services for which evidence is available, all as +++	
Cultural heritage	+++
Recreation and tourism	+++
Aesthetic value	+++
Spiritual and religious value	+++
Inspiration of art, folklore, architecture, etc.	+++
Social relations (e.g. fishing, grazing or cropping communities)	+++
Educational and research	+++
Supporting services 6 out of 6 services for which evidence is available, 0 as +++, 1 as ++ and 5 as +	
Soil formation	+
Primary production	+
Nutrient cycling	++

Water recycling	+
Photosynthesis (production of atmospheric oxygen)	+
Provision of habitat	+

3.2 Structured review of mahseer publications

Of 641 references located by literature search, 46 publications were used in the supporting analysis set out in the Supplementary Material. The ecosystem service contributions of mahseer fishes, together with the functional habitats of which wild, self-sustaining mahseer populations are indicative, are clearly diverse and substantive. In total, positive contributions (+++, ++ or +) were identified for 29 out of the 36 assessed ecosystem services.

Of these 29 ecosystem services, there was strong evidence (+++) of direct contributions by mahseer fishes to all seven cultural services, but only for two provisioning services (food and genetic resources), two regulating services (both relating to the role in mahseer in controlling disease vectors) and no supporting services. Mahseer played roles inferred from other fishes (++) in just three ecosystem services, relating to roles in ecosystem cycling contributing to fresh water, pollination and seed dispersal, and nutrient cycling. These roles in ecosystem functions also led to inference of roles (+) in 15 of the 36 assessed services, including seven of the 14 assessed regulating services and five of the six assessed supporting services.

A recent structured literature review by Pinder et al. (2019) of papers published between 1950 and 2017 addressing the genus *Tor* concluded that the literature was substantially biased towards the utilitarian value of mahseer in aquaculture and as food, with some papers also addressing angling and spiritual values. Cumulative publication numbers from a total of 591 papers produced before the end of 2017 expressed by selected contextual category were: Biology & Aquaculture (361: 61%); Molecular / Taxonomy (90: 15%); Other (including Review, Recreation & Conservation) (71: 12%); Ecology (54: 9%); and Wild Population Status (15: 25%). The review found a substantial lack of literature addressing the importance of wild populations of mahseer, the roles they play within ecosystems, and their non-utilitarian contributions to human wellbeing, broadly consistent with the evidence gaps identified in this study.

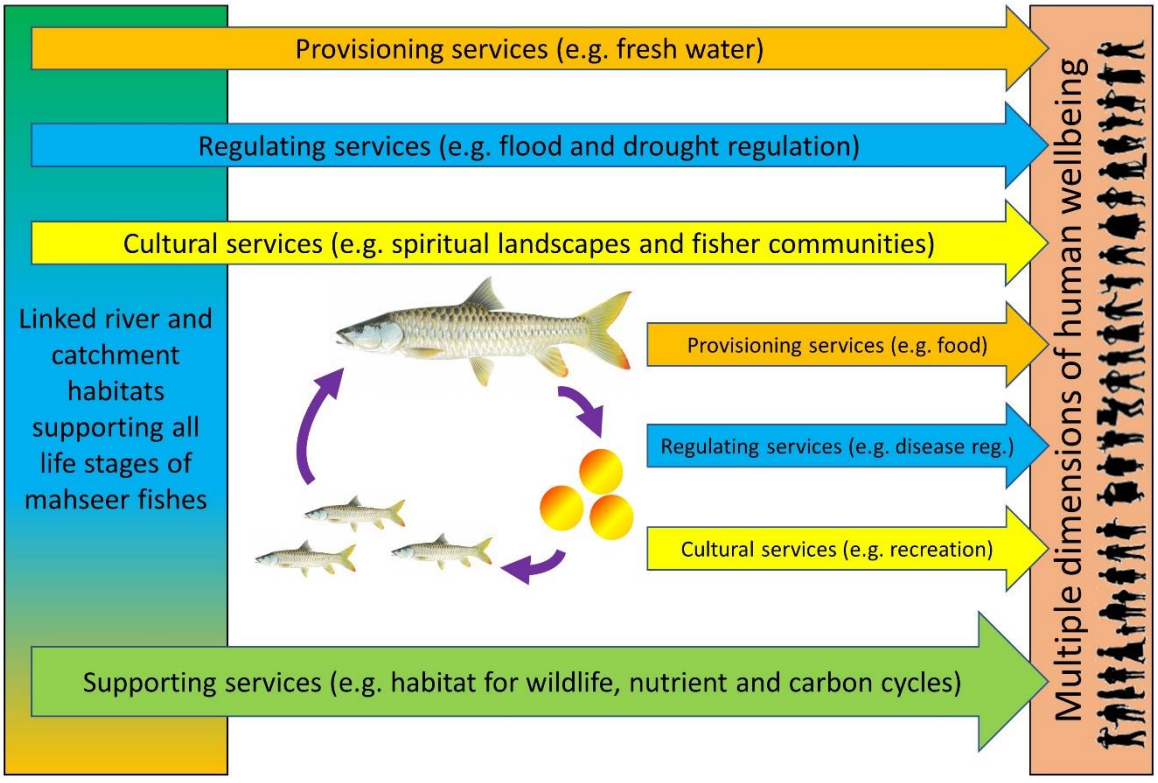
4. Discussion

The significant number of cultural services for which there is evidence of direct contributions reflects the societal importance of mahseer fishes. By contrast,

utilitarian uses reflected by direct evidence for just two of the nine assessed provisioning services (food and genetic resources) is somewhat surprising, particularly given the widespread exploitation of aquatic and other natural resources as food in Asian countries. However, evidence from pottery and other archaeological records (such as bones in middens) as well as the worship of mahseer fishes across much of their biogeographic range (see Supplementary Material) suggests that mahseer were widely worshipped, imposing taboos on their consumption. Mahseer are nonetheless eaten by some communities, and the provisioning service of 'genetic resources' is also directly linked to their value as food particularly in aquaculture and in the stocking of rivers.

Despite a sparse literature giving little direct evidence of the value of the contributions of mahseer fishes to many of the other positively assessed ecosystem services (18 out of 29 positively assessed services were ++ or +), these fishes nonetheless play important roles as indicators of the wider benefits provided by the habitats supporting their populations. The loss of mahseer from a system would therefore be indicative of the loss or degradation of these wider but nonetheless important ecosystem services being compromised or lost (notably those relating to fresh water provision, carbon and nutrient cycling, pollination and seed dispersal, and maintenance of hydrological regimes). Despite a lack of direct evidence of contributions to all ecosystem services, all services are inherently interdependent. This highlights the importance of accounting for all of these values, including those relating to the often-overlooked supporting services, within decision-making. It also recognises that indicator organisms such as mahseer fishes have roles beyond simply reflecting the vitality of the ecosystems. They can also indicate the resilience of the ecosystems that support them and the capacity of these systems to provide a wide range of societally important ecosystem service benefits. This in turn is important in terms of the contributions that ecosystem services make to meeting the SDGs, and *inter alia* supporting continuing multiple dimensions of human well-being. Figure 1 represents these flows of benefits provided by mahseer fishes and the ecosystem that support them.

Figure 1: Schematic illustrating flows of multiple and diverse ecosystem services from mahseer fishes and the habitats that support them, in providing direct and indirect benefits for human wellbeing



Mahseer fishes and the habitats that support them provide multiple and diverse ecosystem services, directly and indirectly, of benefit to human wellbeing

Garcia-Moreno et al. (2014) recognise that maintaining freshwater biodiversity is essential to ensure the future functionality of freshwater ecosystems, securing the socio-economic benefits they provide for people. At present, substantial research gaps exist relating specifically to mahseer fishes and their supportive habitats to flows of ecosystem services, and onwards to the meeting diverse human needs. These knowledge gaps endorse the view of Reid et al. (2017) that the ecological roots underpinning the SDGs are still substantially neglected. Nonetheless, it is wise to adopt a precautionary principle to protect these and other prominent species, not merely for inherent conservation purposes but as a proxy strategy for securing a wide range of direct and indirect societal benefits for local communities provided both by these fishes and the habitats that support them.

Although this assessment is incomplete, primarily due to major gaps in the literature, it does demonstrate the utility of the ecosystem services framework for recognising multiple, interlinked societally important values of iconic species and the supportive ecosystems of which they are indicative. It does so by spanning inherently interlinked, often fragmented, policy interests. It also presents a framework for the integration of different values systems and societal perspectives, enabling more relevant dialogue and decision-making in respect of resource exploitation, reducing impacts and applying effective conservation measures. It can also provide a

platform for assessing often overlooked unintended consequences of development decisions. For example, the systemic ramifications of dam-building decisions for mahseer populations, both directly and as indicators of the functioning of their supporting habitats are often ignored in dam-building decisions, but could be revealed by an ecosystem services analysis potentially promoting parallel appraisal of alternative development options or enhanced mitigation measures (Everard, 2013).

The systemic overview provided by ecosystem services assessment can help identify multi-beneficial uses of natural resources, such as the development of recreational angling markets around mahseer beneficial to local livelihoods and the regional economy based on conservation-minded catch-and-release angling. Thus, recreational catch-and-release angling without killing fish to secure economic returns, whilst recognising the spiritual and cultural importance of these fishes, has been demonstrated in the Western Ramganga River in the Indian Himalayas (Everard & Kataria, 2011) and in South India (Pinder & Raghavan, 2013).

This type of dialogue and enquiry can also promote awareness of the often formerly disregarded though diverse socio-economic and cultural values provided by species and the continued functioning of the habitats that support them for multiple. It can thereby alert policy-makers, as well as local resource managers and beneficiary communities, to the importance of functioning aquatic ecosystems and the key role of mahseer as indicators. This in turn should lead to better policy and practical management decisions and actions about their implications for vulnerable and indicator taxa, helping to secure environmental protection and conservation measures that contribute to sustainable development. This assessment of ecosystem service provision by mahseer fishes and their supporting habitats can serve as a model for broadening perception of the values of other focal taxa and the ecosystems that support them.

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6. Data Availability Statement

All data used in this study are summarised within the paper.

7. Conflict of Interest statement

The authors have no conflict of interest affecting objectivity in this paper including any of: patent or stock ownership, membership of a company board of directors, membership of an advisory board or committee for a company, or consultancy for or receipt of speaker's fees from a company.

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