

Resources, breeding, eco-tourism, conservation, policies and issues of Indian mahseer: A review

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ABSTRACT

Mahseers are distributed in the lacustrine and riverine ecosystems of many Asian countries in the Himalayan belt of Indian subcontinent, from Afghanistan in west to Myanmar in east. They have a reputation of being one of the hardest fighting game fish which attracts anglers from all over the world and manifests higher potential for eco-tourism and ample livelihood opportunities of local communities. However, due to various factors like pollution, environmental degradation, habitat fragmentation by hydroelectric and irrigation projects and indiscriminate fishing, their population in natural water bodies/habitat had declined sharply. Development of artificial propagation of mahseers helps providing seed for stocking in natural and manmade water bodies, thus promising supplies of the fish for food and sport while assuring the conservation of this magnificent fish. This review article not only aims to summarize the published reports on various aspects related to mahseer taxonomy, resources, breeding, propagation, conservation including recent advances but also enlightens the policies and issues of mahseer fisheries in India.

Keywords: Mahseer; Conservation; Breeding; Captive maturation; Eco-tourism; Ranching

Introduction

Mahseer, an apt name for the long slim creature known to be the toughest fighter amongst freshwater sports fish and is the undisputed king of Indian rivers. It is the largest member of the carp family (Cyprinidae) in the world and reported to a size of 2.75 m (9 ft) in length and 54 kg (118 lb) in weight in their natural eco-systems (Rahman, 1989). Their habitat is characterized with high currents and fast flowing water making this fish an ultimate swimmer. The fish swims upstream and can go through rapids of 20-25 knots (Sarma *et al.*, 2009). Mahseer in the Indian sub-continent encounters in the zone (600-1200 m) of the glacier-fed Himalayan rivers with much more extended distribution to the lower reaches in many river (Sarma *et al.*, 2009). Despite their abundance at one time, the mahseer population has been declining in number and size in natural waters and is considered to be an endangered fish as per IUCN (2014) status. Mahseer is known to be an omnivore fish in its adult stage and have been found to feed on green filamentous algae, insect larvae, small molluscs, and algal coating on rocks (Sarma *et al.*, 2013). Mahseer is an intermittent feeder, besides being mainly herbivorous, is also carnivorous to a lesser extent. However, they prefer carnivorous feed at early stage during larval rearing in hatchery conditions and prefer vegetable matter during adult stages (Sharma *et al.*, 2013). It can be classified as a column and bottom feeder. Mahseer mainly spawn during monsoon i.e. May to August which is the conducive period for the maturation of this fish in natural

waters (Bhatt and Pandit, 2015). It has upstream migratory behavior and prefers clean waters for breeding. During the floods, the mahseer ascends to upper reaches of the river, traversing long distances for breeding and spawning and lay eggs in sheltered rock pools, a batch of eggs at a time, repeating the process 3-4 times in a season (Bhatt and Pandit, 2015). The total fecundity of the fish ranges from 3987 to 7320 eggs in the spawners within the size range of 190 to 250 mm total length (Sarma *et al.*, 2016). The eggs of mahseer are demersal and in case there is loose mud on the bed instead of sand or gravel, they can sink and perish (Qasim, 1956a). Considering the importance of mahseers by virtue of their economic, ecological, recreational, heritage, cultural and food values in the Himalayan sub-continent, present review reports the available information on resources, breeding, eco-tourism and conservation as well as discuss on policies and issues for the holistic and sustainable management of mahseer populations.

Taxonomy of mahseer species

Carp with big scales, fleshy lips continuous at the angles of the mouth with an interrupted fold or groove across the lower jaw, two pairs of big barbells, lateral-line scales ranging from 22 to 28, and length of head equal to or greater or less than the depth of body are taxonomically considered as mahseer (Jayaram, 1999). Mahseer belong to three genus namely *Tor* (Gray), *Neolissochilus* (McClelland) and *Naziritor* (McClelland). However,

genus *Tor* constitutes the bulk of mahseer and there are different opinions of the species of mahseer available under different genus. Menon (1989, 2004) described five valid species of genus *Tor* (*Tor putitora*, *T. tor*, *T. khudree*, *T. progenius* and *T. kulkarni*) distributed in different parts of India. Desai (2003) opined that the genus *Tor* includes 10 valid species namely *Tor tor* (Deep bodied mahseer), *Tor putitora* (Golden mahseer), *Tor mosal* (Copper mahseer), *Tor khudree* (Deccan mahseer), *Tor mussullah* (Mussullah mahseer), *Tor progeneius* (Jungha mahseer) existing in India while *Tor douronensis* (Malaysian mahseer; Kottelat, 2012), *Tor tambroides* (Thai mahseer), *Tor sinensis* (China), *Tor zhobensis* (Pakistan) are found in other countries. *Tor* species is one of the most threatened groups of freshwater fish in the country and there are no reliable estimates of the number of *Tor* species found in Indian waters, mainly due to the taxonomic uncertainties within this genus (Pinder, 2013; Siraj *et al.*, 2007). Out of the present valid species, *Tor khudree*, *T. kulkarni*, *T. malabaricus*, *T. Mussullah* and *T.putitora* are listed as 'Endangered' and *T. tor* and *T. progenius* as 'Near Threatened' as described in the IUCN Red List of Threatened Species (IUCN, 2014).

Neolissochilus (Rainboth, 1985) is one amongst the mahseers. The name is derived either from its large mouth or scales or from its strength to climb the hill streams like a tiger. These fishes are distributed in India and Southeast Asia and are important game as well as highly esteemed food fish, fetch high market price and are potential candidates for aquaculture. *Neolissochilus* includes more than twenty species in the world. The systematic description of the genus is given below:

The genus includes medium to large carps with barbells

of Southern and South-Eastern Asia. The fishes generally migrate upstream to clear, rocky, headwaters, live in deep, slowly moving pools during wet season, and moving downstream at onset of dry season. They attain nearly a meter in length and weigh over 10 kg, but commonly found in the size of 50-60 cm and 2-3 kg (Talwar and Jhingran, 1991). The species of *Neolissochilus* which are available in India are- *Neolissochilus hexagonolepsis*, *N. hexastichus*, *N. stracheyi*, *N. paucisquamatus* and *N. stevensonii* (Talwar and Jhingran, 1990; Vishwanath *et al.*, 2009, 2011).

Relationships of genus *Neolissochilus* with *Tor*

Neolissochilus is closely related to *Tor* and occurs over the same range. However, *Tor* is differentiated from *Neolissochilus* in its development of the lower lobe into a fleshy lobe below the mandibular symphysis having a fleshy lobe (Vishwanath, 2014). Gill rakers on ceratobranchial in *Neolissochilus* 6-9 and in *Tor* 10-16, although *Tor progeneius* may exhibit intermediate, 8-10. The species has no fleshy mandibular lobe and also no cheek tubercles, thus thought to be an intermediate between the two genera. The pharyngeal arches in *Neolissochilus* is relatively shorter and massive than of *Tor*. The articular margin with tooth bearing arm of the pharyngeal bone in *Neolissochilus* is 75° while in *Tor*, 45°. Tooth commences nearer in *Neolissochilus* and farther in *Tor* (Vishwanath, 2014).

Mahseer resources

Mahseer is known to occur from the extreme west in Afghanistan (Darya-i-Kabul; Landai River which rises in northeastern Afghanistan at the base of Kowtal-e Wonay in the Paghman mountain, enters western Pakistan through the

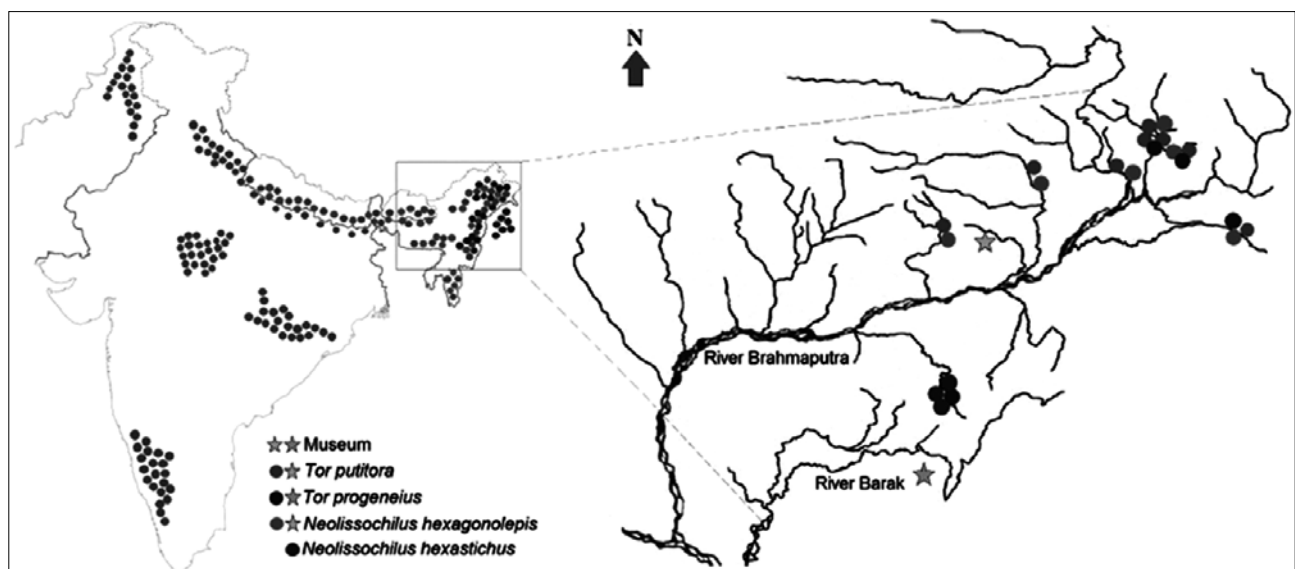


Figure: Distribution of mahseer in India with special emphasis on NE India (Laskar *et al.*, 2013)

Mohmand Hills, the rivers joins the Indus river at Attock) to eastern extremity in the Garo hills, Meghalaya, India suggesting that Mahseer is found in the rivers in and around Himalayas. *Tor putitora* is found in the Indus, Ganga and Brahmaputra river systems draining the Himalayan terrain in Afghanistan, Pakistan, India, Nepal, Bhutan, Sri Lanka and Southeast Asia as far as Malaysia (<http://www.fishbase.org>).

Diversity and distribution of mahseer in North-eastern Himalaya

Northeastern region of India harbors 11 mahseer species (5 *Neolissocheilus* species and 6 *Tor* species (Vishwanath *et al.*, 2014). The river Diyung in Dima Hasao district of Assam has been reported to be inhabited by an important species of mahseer, viz., *Neolissochilus hexastichus*. Thus, the *N. hexastichus* is surviving with a small population in the said region which is perhaps its last stronghold although more survey on the occurrence of this species in other locality is attempted. Further, *Tor barakae* described from river Barak in Manipur (Arunkumar and Basudha, 2003) is considered as endemic in the Barak basin. However, until re-evaluated for its taxonomic validity, it seems to be a synonym of *Tor mosal* which was previously recorded from Barak basin and later considered as a Burmese species. In the recent study by Laskar *et al.* (2013) *Tor progeneius* has been designated as a synonym of *Tor putitora* and *N. hexastichus* has been claimed as a valid species and resurrected from synonymy with *Tor tor*. The occurrence of *Tor tor* from Northeast Indian rivers is also not very convincing and need strategic study.

Mahseer in Meghalaya

The distribution of mahseer in Meghalaya has been analyzed in three different categories- (1) Altitudinal distribution (2) Intra drainage distribution and (3) Distribution according to thermal class. In altitudinal distribution pattern species *Neolissochilus hexagonolepis* and *Tor* species have shown wide distributional pattern (Nath *et al.*, 2016). Occurrence of *Neolissochilus hexagonolepis* was common in all rivers and gradient zones ranging from 1491 m to 150 m asl. Though *Tor tor* and *Tor putitora* are widely distributed but their population in the rivers of Meghalaya is very rare. *N. hexastichus* has been recorded only from the river Janiaw at Mawsynram located in 1000 m msl (Sarma and Bhuyan, 2007).

Mahseer in Kaladan river, Mizoram

Mahseer are known to occur in the rivers of Mizoram and *Neolissochilus hexagonolepis* has been recorded in river Tuiri (Sarma *et al.*, 2016). A detailed study of the Mahseer fishes has been conducted in river Mat in Mizoram, a river joining the Kaladan drainage system of the Indo-Myanmar

region. The Mahseer in river Mat of Kaladan drainage seem to prefer deep pools as one of their favourable habitats in view to provide strong cover to them.

Mahseer of Manas river, Assam

It is reported that upper stretches of Manas river and its tributaries are predominantly inhabited by coldwater fish species specially of mahseer (*Tor putitora*, *Tor tor* & *N. hexagonolepis*). However, in due course of time, climate change, natural calamities and anthropogenic activities have brought a vast change in biodiversity of mahseer in Manas river system. It is observed that heavy flow of water during flood seasons has also made prolonged siltation problem in different parts of the river, causing destruction of breeding ground and loss of fish germplasm associated with various manmade factors (Dubey, 1978).

Mahseer in Jatinga river, Assam

River Jatinga has alluvial segment and pool-riffle and braided type of reach. The micro-habitat is dominated by riffle and run with occasional occurrence of trench pools. The river is less entrenched because of V-shaped valley segment and the substrate type is dominated by gravels and cobbles with the occurrence of some boulders and bedrocks; thus, providing suitable feeding and breeding habitat for Mahseer, like *Tor tor* (Ham-Buch), *Tor mosal* (Ham-Buch), *Tor progeneius* (McClelland), *Neolissochilus hexagonolepis* (Kar, 2007). In addition to river Jatinga, mahseer have been recorded from others rivers in Barak valley such as *Neolissochilus hexagonolepis* in river Dhaleswari, *Tor mosal* in river Sonai (Mahanta and Sarma, 2009).

Mahseer in Jia- Bharali river, Assam

Presence of *Tor* species is significant for this river encouraging lot of tourists for rafting, fish watching and angling (Borgohain and Bania, 2013). *Tor* species found in Jia- Bharali river is *Tor tor*, *Tor putitora* and *Tor progeneius*. The river also harbours *Neolissochilus hexagonolepis*, which fetches a magnificent fishery in the foot hills of Assam and Arunachal Pradesh (Sarma, 2009; Laskar *et al.*, 2013).

Mahseer in Teesta river

The most important indigenous cold water fish species of Teesta river are mahseer/sahar (*Tor* spp.) and katle (*N. hexagonolepis*). Mukherjee *et al.* (2002) recorded 125 fish species from Darjeeling hill area, some of which are found in torrential streams and are remarkably well adopted for clinging to rocks in swift currents. Many feeder streams and rivers joining the Teesta river have spawning grounds of mahseer (Acharjee & Barat, 2013; Bhatt & Pandit, 2015). Spawning beds of the Teesta river located near the Sevok may be selected for Mahseer breeding ground. In the entire stretch of the Teesta river near Sevok Bridge to 1 km upstream

and 3 kms downstream are ideal environmental conditions for mahseer spawning: gravel beds, suitable water current, high dissolved oxygen content, good water quality and low turbidity. The changing river conditions affect abundance of Mahseer. However, five river valley project hampering the mahseer migration *vis-a-vis* breeding in the Teesta river system (Menon & Kohli, 2015).

Diversity and distribution of mahseer in Western ghats

Deccan mahseer in Cauvery river

The Deccan mahseer (*Tor khudree*) is known in vernacular Kannada as *Bilimeenu* (white fish) and since long is associated with heritage and belief. It is considered as *Devara meenu* (Divine fish) in some parts of Karnataka and is fed by local people in the sanctuaries and rivers associated with the temples. The mahseer are distributed in the Siwalik Himalaya and lower reaches of the uplands of the Deccan Plateau (FAO, 2003).

Although mahseer occurs at several reaches in the upper stretch of river Cauvery, three reaches are important from the abundance point of view *viz.* Kushalnagar (Walnoor to Kushalnagar), Ramanathapur and Bheemeswari (Shivasamudram falls to Mekedatu) (ZSI, 1982).

Mahseer in Chalakudy river, Kerala

Mahseer inhabits rapid rivers and streams with rocky substrates and attains a maximum size of one meter in length and 23 kg in weight in Chalakudy river (Chandrasekharah *et al.*, 2000). It is one of the common species of the Chalakudy river of Kerala and forms the major fishery for the tribes residing on the banks of the upper reaches of the river in colonies. The species has recorded a decline in the population and a need has arisen to conserve this important resource (Ajithkumar *et al.*, 1999). It may also be noted that there is ample potential for developing a few mahseer angling stations in the Chalakudy river to encourage the sport fisheries and angling tourism (Ajithkumar *et al.*, 1999).

Mahseer in Savitri river

Mahseer, the 'king' of Indian freshwater fish in Raigad is found in the Savitri river (Katwate and Apte, 2014). It is informed by the local people that this is one of the rare species in the Savitri river, locally known as *khadas*. It is known that a large protected population of mahseer is available at *Walan kond* (Katwate *et al.*, 2014) which is one of the biggest pools in the Savitri watershed, is a notable example of a 'community fish sanctuary' in the northern Sahyadri. The complete absence of mahseer in the tributaries of the Savitri which have dams at numerous sites clearly indicates that the dams have adversely affected the distribution of this species in the river and its tributaries. The mahseer habitats

in the upper catchment areas of the Savitri are still free from industrial and urban pollution (Katwate and Apte, 2014).

Deccan mahseer in Indrayani river

Deccan mahseer (*Tor khudree*) is an indigenous fish which was found in the Indrayani river flowing in India's western state of Maharashtra. The fish was last sighted many years ago until it disappeared due to excessive pollution of the waters and urbanization. But due to the efforts of a conservation organization, today the fishes have again made Indrayani their home (Dahanukar *et al.*, 2012).

The Wayanad mahseer of peninsular India

The Wayanad mahseer, *Neolissochilus wynaadensis* (Day, 1873) is one of two species within the genus that occurs in peninsular India; the other being *N. bovanicus*, found in the Bhavani river. Day (1873) described *Barbus (Barbodes) wynaadensis*, from Vythiri, Wayanad and reported it to be a common species in the larger streams of the region. The species was considered to be endemic to the streams in the Wayanad region of Kerala, until Manimekalan (1998) and subsequently, Yazdani *et al.* (2001) recorded it from Mudumalai, Tamil Nadu. Also Arunachalam *et al.* (2005) recorded it from Abbey Falls near Madikeri, Kodagu, Karnataka. *Neolissochilus wynaadensis* has been considered to be a rare species with several surveys in and around the type locality, failing to collect this species, and very few records available in the recent ichthyological literature which are backed by voucher specimens (Abraham, 2011). Due to its restricted distribution and severe population declines (up to 80%) in the last decade, *N. wynaadensis* has been listed as 'Critically Endangered' in the IUCN Red List of Threatened Species (Abraham, 2011). *Neolissochilus wynaadensis* is endemic to the Western Ghats of India (Dahanukar & Raghavan 2013). In Kodagu, *N. wynaadensis* has also been recorded in Hamyala and Kakkehole. However, no voucher specimens are available. The species is currently known between the altitudinal range of 400–1100 m. The fact that the species has a very restricted distribution, and is confined to only a few tributaries/streams in its range is additionally evident from the studies of Johnson & Arunachalam (2009). *Neolissochilus wynaadensis* prefers fast flowing upland streams and rivers where they occur in both rocky pools (Abraham, 2011) as well as riffles (Kurup *et al.* 2004). Kurup *et al.* (2004) provides information on several microhabitat variables in the locations frequented by *N. wynaadensis*. Abraham (2011) mentioned that the fish also occurs in the Chooralmala and Kanthampara areas in Wayanad (part of the west flowing Chaliyar river system). The species occurs in the Periya Forest Range near Mananthavady, Wayanad (Ali *et al.*, 2014). It is to be noted that, in a comprehensive study of the fishes of Nilgiri Biosphere

Reserve including parts of Wayanad and upper reaches of Chaliyar not a single specimen of *N. wynaadensis* was reported from Chooralmala and Kanthampara suggesting that the species could be restricted to only the east flowing drainages (Easa & Shaji, 1997). Therefore, in the absence of any references to the records, and actual voucher specimens, it is premature to conclude that *N. wynaadensis* occurs in the west flowing drainages as suggested by Abraham (2011). Further studies are, however, required to understand the diversity of this genus especially from the southern regions of the Western Ghats from where many 'nomina nuda' under the genus *Neolissochilus* (Raghavan *et al.*, 2013) as well as previous records (Pillai 1929; Hora & Law 1941) of *N. wynaadensis* are available. There is specifically a need to examine specimens of mahseer identified and catalogued in various museums. The *Neolissochilus* from peninsular India (*N. wynaadensis*) forms a monophyletic grouping with other *Neolissochilus* species from north-eastern India and Southeast Asia. Also, the specimens of *Neolissochilus* found in various locations in Kodagu (Coorg, in Bhagamandala and Mukkodlu), were genetically similar to those that occur in the type locality of the species i.e., Wayanad (Ali *et al.*, 2014). The discontinuous distribution of the genus *Neolissochilus* (Sundaland, Indo Burma, Eastern Himalaya and Western Ghats) could also form the basis for interesting biogeographic hypothesis testing for instance, to check the scenario of 'true disjuncts' (Dahanukar *et al.*, 2013). On the other hand, detailed anatomical and morphological analysis is needed to ascertain if the Western Ghats representatives of the genus are 'false disjuncts' and need a separate generic allocation. Such biogeographic and evolutionary questions should however be validated with larger multi-locus datasets (Ali *et al.*, 2014).

Mahseer resources in Himachal Pradesh

The golden mahseer is an important fauna in the rivers of Himachal Pradesh namely Sutlej, Beas, Chenab. However, in recent years due to their proximity to human intervention, Mahseer stock is threatened with multifaceted dangers posed by construction of series of dams, barrages/ weirs across the rivers on one hand and over-exploitation on the other. While uncontrolled fishing and destructive fishing devices have adversely affected the riverine population, the construction of dams are acting as physical barrier to this migratory species, tending to prevent their access to their usual breeding and feeding grounds. The denial of migration also results in permanent and irrevocable eradication of mahseer stock ranging from depletion to complete extermination (Walia, 2006). The ever-diminishing catches of Mahseer from the river Satluj, Giri, Beas, Chenab and their tributaries clearly bespeaks the effects caused by the construction of Pandoh, Chamera, Pong, Bhakra & Giribata barrages. Regardless of their height, weirs and dams constitute barriers to

breeding migration of mahseer in Himachal Pradesh (Butt, 2013). Further, mahseer population is also affected by morphological modifications resulting from completion of river valley projects. These include change in slope, river-bed profile, submersion of gravel zones or riffle section as well as destruction of riparian vegetation and changes in tropic regimes. Most of the negative factors affect upper parts of the streams where lacustrine conditions are superimposed on the river. Downstream, the hydrological conditions get severely altered through reduction of water discharge. The adverse conditions of the flow can extend over many km downstream of the obstruction, so that, fish passages become difficult particularly of mahseer which have a long migratory root (Sehgal *et al.*, 1971; Mahanta and Sarma, 2009)

Indiscriminate hooking, netting, dynamiting and electrocuting have also greatly affected the mahseer availability in the Himachal rivers and streams. In the pursuit of more and more catches, even the declared mahseer sanctuaries have not been spared by the poachers (EMPNRM, 2002). Further, due to reduced availability of large mahseer in the streams, fishing pressure on juveniles is on the increase with the result that streams earlier assuring a bountiful harvest have started giving a dismal picture. Once teeming with thousands of mahseer, streams like Giri, Ashwani, Binwa Neugal, Beas, etc. the returns are sharply declining, raising the number of disgruntled anglers each year (EMPNRM, 2002).

The sharp decline in mahseer catches has also been noticed in Himachal Pradesh reservoirs. Gobind Sagar reservoir- known earlier as store-house of mahseer has recently become a silver carp reservoir. As per available information, mahseer used to constitute as high as 9% of the total catch during 1984-95 which has plummet to a level of 1% during 1999-2000 (Environment Master Plan, 2013). Pong reservoir however has steady catch of mahseer during the last two decades ranging from 60-90 t. The mahseer catches during 1999-2000 were 90 t accounting 20% of the total catch. Further, the average size of mahseer in Pong reservoir has ranged from 1.5 to 1.7 kg during the last 15 years. Against this the average size of mahseer in Gobind Sagar declined from 1.9 to 0.6 kg. during the last 15 years barring the last two years when it has increased to 1.2 kg because of number of management efforts by the fishery department (Petr, 2002). Its migration into the Kangra valley has been completely stopped due to the construction of Pong Dam across the river Beas (Petr, 2002). However, it has established self-reproducing stocks in the fragmented populations The Maharana Pratap Sagar reservoir (Popularly known as Pong Dam) in Kangra with its 42 km length and 2 km breadth, offers a variety of activities and waters are excellent for mahseer fishing. Golden Mahseer

with whiskers is available in the dam whilst the silver and black mahseer is also found largely in the tributaries (Petr, 2002).

Mahseer resources of Madhya Pradesh

The Madhya Pradesh Government has declared Mahseer (*Tor tor*) a species of fish found in rivers and reservoirs of the state as state fish. The transformation of fluvial environment into a lentic one during the impoundment has had an impact on the fish species particularly of mahseer in Gandhisagar (Dubey and Chatterjee, 1976). Mahseer species facing threat of extinction used to be richly found during sixties in the states rivers, including Narmada, Ken, Betva, Tons, Tapti and Chambal. Tawa reservoir has also witnessed extreme decrease in its abundance (Karam Chandani et al, 1967). The fish fauna of Jabalpur also included *T. tor* (Malviya, 1961). Mahseer was also reported from Chambal river (Dubey and Mehra, 1959) long back and is regularly fished in Gandhi Sagar reservoir in Madhya Pradesh. Monthly landings of *Tor tor* at Hoshangabad and Shahganj centres, coming from the 48-km stretch of the Narmada during earlier days showed that the fish supported an important fishery all the year round except monsoon months. It was poor during July to September, improved considerably from October onwards, to become outstanding until June. At the Hoshangabad centre during this period the species contributed on an average of 28.0% to total landings and 46.5% to carp landings (Desai, 2003).

Diversity and distribution of mahseer in Central Himalaya

The *Tor* mahseer though reported from entire Himalaya is abundant in the Aravali, Vindhya and Satpura ranges, which can be conveniently called as Central India. The lower reaches of Yamuna, Narmada and Tapi river systems between the plains of Indus, Ganga and Deccan Plateau drain this region. Observations on the size composition of *Tor putitora* in the foothill section of the torrential coldwater Ganga between Rishikesh-Hardwar and its upstream springfed relatively placid-springfed tributaries, the Nayar and Saung and glacierfed torrential of Alaknanda, revealed that only the fingerlings and juveniles (<19 cm) constituted the resident stock in the Nayar and Saung. In the Saung and Nayar, 10-25 cm and 1-22 cm TL accounted for 11-75% and 22-75%, respectively, in the non-migratory and migratory phase (Nautiyal *et al.*, 1997).

It is recorded that the foothill section of the torrential coldwater Ganga between Rishikesh – Hardwar serves as the abode of the juvenile, adolescent and adult component of the Himalayan mahseer stock. The fishes above 15 cm were common in the Ganga. Of these, the fishes measuring 28-64 cm size accounted for 11-50% in the non-migratory phase,

while 13-38% in the migratory phase. The percentage of larger fish (>64 cm) was found to be much less, 11-22%. The huge environment of the river is adequate for the fish to attain the large size for which it is well known (Nautiyal *et al.*, 1997).

The migration of *T. putitora* is completed in three phases from mid February to mid September with brooders ascending the breeding grounds, the Nayar and Saung only during peak monsoon (mid July to mid August). The delay in rains may shift the migration to late August. The juveniles move in shoals and so do the adults. Moving in schools is known to save energy (Nautiyal *et al.*, 1997).

Mahseer resources of Jammu and Kashmir

Golden Mahseer population also occurs in the Himalayan range of Jammu & Kashmir. The elegant group of sport fish, Mahseer is considered as the tiger of water in Peril (Joshi, 1987). In Kashmir valley, mahseer was the major fish having a significant socio-economic role. But in recent years it has come under threatened category of fish species and is now rare in catches with dangers posed by construction of series of dams, barrages & weirs across the river in one hand and over exploitation on the other hand. Mahseer (*T. putitora*) of river Tawi, Jammu are facing the biggest threat. The absence of great mahseer (*T. putitora*) in Jhelum is due to presence of the Mangla dam further downstream in Pakistan. This barrage lacks a fish ladder and thus cut the migration route of this anadromous fish which earlier had its spawning grounds in the Kashmir valley (Nyman, 1995). The alarming trend of its decline forced the J&K state fisheries department to establish an exclusive mahseer hatchery at Anji (Distt. Reasi), where successful breeding programme of this species being taken up since 1999.

The important streams which support the sizeable mahseer for angling, are Tawi, Naddar, Duddar, Jhajarkotli, Neeladhab, Ujh, Anji, Behani and Chenab. The mahseer being a migratory fish ascends from plains to the upper reaches of Ravi, Chenab and Jhelum rivers for spawning and descends back every year (Sehgal, 1971). The presence of fry and fingerlings of mahseer in thousands in the spawning streams like Jhajar-kotli, Duddar, Naddar, Anji, Neeladhab, Behani and Ujh is of importance. They perish when the water level in the streams reaches to a drying point (Sunder and Joshi, 1969).

Breeding and captive management of mahseer

Natural breeding of mahseer

The mahseer are the denizen in the cool water streams in the hills and survive within a narrow range of ecological factors. They mostly remain within 10-2 degree slope (steep to gentle). In the steep region, the substratum is comprised

predominantly of boulders, rocks, and cobbles; while, in gentle slope region, the substratum composition becomes cobbles, pebbles, gravels, and sands (Sarma *et al.*, 2016). In the mahseer habitat, the level of dissolved oxygen remains always high due to continuous agitation and bubbling of coldwater. So, the Mahseer fishes are used to live in water having high level of dissolved oxygen, above 6 mg/L (Sarma *et al.*, 2016). Mahseer are also known as seasonal migratory fish, as they migrate upward for reproduction. Golden mahseer is an intermittent breeder and lays eggs at intervals throughout the year, but peak spawning occurs in the monsoon. During June-August, mahseer brooder migrate upwards in the river, sometimes in the tributaries in search of shallow water having pebbles and gravels as substratum and exhibit breeding at the ground conducive for spawning. Thus, there are strict habitat requirements of mahseer which comprise cold water temperature, high level of dissolved oxygen, habitat heterogeneity with occurrence of in-stream pools/ deep storage of water, ground conducive for spawning (Sarma *et al.*, 2016). The fry of mahseer settle in the shallow habitats particularly near the banks of the streams. As soon as the summer retreats, the water in the streams starts immediate recession so that some pits and pockets in the streams get disconnected from the main streams. Unfortunately, thousands of early fry of mahseer which left in such pits and pockets undergo predation and culminate to large scale mortality. The drying up of water in such pockets also causes mortality. This is a serious issue and needs attention for rescuing such fry for rehabilitating them in safe system (Sarma *et al.*, 2016).

Seed production and hatchery technology of golden mahseer

Mahseer is of considerable importance because of its large size. As a food fish, it is highly esteemed and fetches the highest market price in North and Northeast of India. Despite their abundance at one time, the population has been declining in number and size in natural waters. Its population is declining in the natural water bodies because of degradation of the aquatic environment and biological changes in the ecosystem due to urbanization as well as overfishing especially with pressure from illegal catching methods such as electro fishing, poisoning, and dynamiting. As a result, the population has become unsustainable with fish catch from fisher communities being very low in most parts of the country, and the fish is declared endangered (IUCN, 2014). Developments of breeding and culture techniques along with hatchery management practices are the means for conservation, promotion of aquaculture, rehabilitation, sustainability of mahseer population. ICAR-DCFR, Bhimtal has been doing tremendous effort and developed the protocol for seed production and hatchery management of golden mahseer at Bhimtal (Sarma *et al.*,

2009; 2010, 2014, 2016). The water flow is the crucial criteria for the hatchery management of golden mahseer (Sarma *et al.*, 2009, 2010).

Water flow	Rearing capacity
1 litre/minute	Incubation and rearing of 2,000 eggs at 20-25°C.
3-4 litres/minute	Rearing of 2,000 fry (0-3 months) at 20-27°C.
4-6 litres/minute	Rearing of 1,500 fingerlings (4-9 months old).
Flow through hatchery	
Overhead tank	1,000 litres capacity installed at a height of 5 m above ground
Hatchery tanks	Galvanized iron sheets or fibreglass of 200x 60x 30cm size.
Hatching trays	50 x 30 x 10 cm. with synthetic netting cloth 1-2 mm mesh size. 5,000-6,000 eggs can be stocked

There are important possible options for increasing the population of mahseer in natural water bodies through ranching. This involves rearing of brood stock, breeding and propagating their seed on a large scale with due consideration of genetic issues of both brood stock and wild populations, and releasing them to streams, lakes and reservoirs for rehabilitation. The ICAR-DCFR, Bhimtal has standardized the protocol of hatchery technology of golden mahseer and seed has been produced at the mahseer hatchery complex of DCFR regularly for ranching in different parts of India as well for aquaculture purpose (Sarma *et al.*, 2016). Golden Mahseer hatchery and farm has been established at the premises of Eco-Camp ABACA, Nameri by Assam (Bhorelli) Angling & Conservation Association in March 2012 with the technical and financial assistance from ICAR- Directorate of Coldwater Fisheries Research, Bhimtal (Sarma *et al.*, 2016). Brood bank of golden mahseer at Jasingffa Aqua Tourism Resort, Nagaon, Assam in collaboration with DCFR and establishment of mahseer based eco-tourism center is a notable achievement in this area (Sarma *et al.*, 2016).

Breeding and larval development of chocolate mahseer, *Neolissochilus hexagonolepis* in pond environment

Neolissochilus hexagonolepis (McClelland, 1839) commonly known as chocolate mahseer is considered as one of the delicious foods as well as game fish species of the Indian upland region specially of Northeastern Himalayan region. However, the culture of this fish species in large scale is still not common due to lack of adequate supply of seed and knowledge of their feeding and breeding techniques among the farmers. In the natural water bodies, the population

of this fish is also decreasing due to various natural and anthropogenic factors (Sarma, 2009). Therefore, the species has been brought to DCFR from Arunachal Pradesh and successfully reared and bred by Sarma *et al.*, (2014) in pond conditions. The larval development of chocolate mahseer has been carried out and it is proven to be an important fish in hill fisheries and aquaculture (Sarma *et al.*, 2014). The hatchery produced seed has been stocked in Nongmahir lake Meghalaya during 2014. Also, seed has been reared in Jhora fisheries pond at Kalingpong, Darjeeling, West Bengal along with grass carp (Sarma *et al.*, 2015; Guharoy, 2012). Commendable success also has been achieved at TEC, Lonavala, Maharashtra regarding captive breeding, cage culture & river ranching of pond raised golden & Deccan mahseer (Ogale, 2014; Basavaraja, 2011). Cage culture to grow the fish from fingerling to advanced fingerling size for ranching after imprinting was successfully demonstrated at Walwhan, Lonavala by TPC jointly with CIFE in recent times (Ogale, 2014).

Mahseer in eco-tourism

Mahseer in India is regarded as the king fish for angling sport and mostly liked by anglers all over the world who considered superlative sporting quality of mahseer over the salmon (Thomas, 1881; Lacy and Cretin, 1905). The thrills and sport involved in snaring of mahseer is evident since very past, that has been documented in many famous records like “The rods in India”, Thomas (1881), “Anglers Handbook of India” by Lacy and Cretin (1905) and “Circumventing the mahseer and other sporting fish in India and Burma” by McDonald (1948). The amount of fight it exerts during the time of its catching is loved by all the anglers to play with the mahseer (Baruah and Sarma, 2016).

Angling / sport fishing

Angling or sport fishing is one of the most fascinating outdoor physical activities which satisfy diverse taste and pursuits. It is a form of eco tourism promoting sustainable form of resource use contributes to environmental conservation while proving accrued socio-economic benefits to the society through non consumptive use and provides high values to natural biological resources. Tourism is a big business globally accounting for 8 percent of the world’s domestic product and 9 percent of the world’s total employment as per WTO report (Blanke & Chiesa, 2013).

Angling holidays and sport fishing tourism is a booming international business opportunity. It is one of the most sought after adventure tourism activities and there is an ever increasing number of international angling itineraries throughout the world destination in search of big fish and thrilling sports fishing adventure in an unspool fishing

destination. Sport fishing is one of the leading adventure tourism activities in Europe and USA (Mahanta *et al.*, 2011). Near home in NE India, the average fishing trip for golden mahseer in Subansiri river of Arunachal Pradesh cost about Rs. 2600 per kg of which market price is only about Rs. 250/- per kg, calculated on an average of 4 fishing trip from Guwahati in 2010-2011 (Batra, 2009).

The essential elements of angling tourism (eco-tourism) may be natural environment, optimum number of environmental friendly visitors and activities not causing serious environmental and cultural impact on ecosystem with positive involvement of local community i.e. “uniting conservation, communities and sustainable travel” for development of a relatively remote inaccessible destination (Harris *et al.*, 2002). It is essentially a tourism activity which minimizes the conflict between resource of tourism and livelihood of the local inhabitants, their environment and socio-cultural life with major thrust for conservation and preservation of nature and culture. It is for the sport fishing interest itself the angler like to conserve the nature, the tree line, the riverbed, the clean and clear water bodies and springs with abundance of fish fauna, their spawning ground, the catchment area of the river, the nature and its surrounding as a whole (Eagles, 2002).

Constraints in sport fishing

There are several constraints for which this could not get proper focus among the policy makers as well as the local people in India. These can be classified into the lack of mapping of the sport fishery rivers, lack of awareness among the local people, non-availability of check list of fish and the places with the tour operators etc. People participation in conservation and angling is not in proper order. Difficulties of anglers to commute to remote areas, the red tapism of the local administration, lack of NGO and angling clubs inhibit the westerners. Religious and community ownership of lakes and rivers prohibits angling in some of the most wonderful water bodies (Brown, 2009). Of late, coming up of several hydroelectric projects in different parts of India will definitely wipeout the entire sport fish fauna. Although there is tremendous potentiality of angling tourism in many sites, yet it has not developed to the expected level till date. There is an urgent need to identify the sport fishery areas, policy formulation for sport fisheries including development of platform for promotion. Entrepreneurship development for promotion of fish based eco-tourism with supportive and ancillary service development is a far cry. National and international publicity, awareness and marketing strategies for promoting angling tourism are important factors that need immediate attention for its development (Brown, 2009).

Mahseer conservation efforts in India

Mahseer is important in the head water stream ecosystem where occupies wide range of food web and is responsible for balancing the ecological pyramids (Laskar, 2012). However, it is well understood that various anthropogenic threats on the aquatic ecosystems, most devastating is the poisoning and dynamiting in the headwaters and the streams therein, have threatened the mahseer population in the natural water bodies and is now considered as an endangered fish (IUCN, 2014). Although such practices of fish harvest have been declared illegal, yet unless mass awareness is generated and fruitful strategy not employed, such practices will continue to aggravate. There is urgent need to conserve and rehabilitate the fish by creating awareness to local stakeholders covering different age groups, and strategic people participation in order to reduce the threats to mahseer fishes in natural water bodies (Mahanta *et al.*, 1994; Mahanta and Sarma, 2009).

Although in India, the Wildlife (Protection) Amendment Act, 2002 redefined the term 'Animal' including fishes, but, existing protected areas are not taking additional protection measure and scientific management for the freshwater fishes. On the backdrop of severe mortality of early fry in the river pockets due to recession of water, there is paramount demand of population rescuing/rehabilitation and restocking of mahseer in safe and suitable water bodies, especially lake and river, for the establishment of germplasm as treasure trove (Sarma *et al.*, 2016). This would augment the conservation effort and allow long run conservation in the way of consequential recruitment in to connecting streams/ rivers through outlet after natural reproduction. In the process of stocking of mahseer in safe zone, the seeds of the indigenous mahseer are to be rescued from nearest streams. Simultaneously, it is the need of the hour to discuss on the issue of creating designated mahseer sanctuaries in India (Sarma *et al.*, 2014). Mahseer zones are also important breeding sites for recruitment of many other small to large fishes having both food and ornamental value. Virtually, with the aim of mahseer harvest, innumerable biotic components including galaxy of beautiful small fishes are also ruined by the adoption of illegal method of mahseer harvest. Mahseer are meant as key stone species (GRBEMP Interim Report, 2013). Given that, if mahseer are protected and conserved in a fair length of river (covering natural spawning ground), a large number of other small to large endemic fish species would be indirectly protected and conserved and their recruitment in the downstream would be increased.

It may be noted that conservation and establishment of mahseer population in Mehao lake, Arunachal Pradesh was successfully done by ICAR-DCFR in 2009 in collaboration with Rufford Foundation, London (<http://www.assamtimes.org/node/12282>). The status of Cauvery mahseer (*Tor*

khudree) may be categorized as endangered (Adrian & Raghavan, 2013) and several conservation measures are needed to be taken care for increasing its population in the Cauvery water bodies (Adrian & Raghavan, 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. The association also obtained a lease of a 22 km reach of the river Cauvery with the aim to conserve native mahseer populations (Adrian & Rajeev, 2013). The main focus of the WASI effort is to control illegal fishing and replenish wild stocks using captive bred fish (Adrian & Raghavan, 2013). The organization 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, private individuals (Jung & Subhan, 2012), and the State Government-owned Jungle Lodges and Resorts (JLR) (www.junglelodges.com) to set up both seasonal and full-time angling camps on the river Cauvery. 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 (Sehgal, 1999).

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 practicing 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 (Dinesh *et al.*, 2010). 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, 2001).

Barring a few tributaries of Teesta river in Sikkim and West Bengal, where the mahseer population may be in good health, the overall status has invariably become endangered. At many places, river courses have changed and spawning beds were destroyed. Keeping this alarming situation in mind, ICAR-DCFR, Bhimtal has transported 2 lakh hatchery produced fingerlings of golden mahseer to stock in Teesta river during 2008-2010. The conservation efforts thus made have positive impact in reestablishing the population of golden mahseer in some of the stretches of Teesta (Sarma *et al.*, 2014).

Walen Kondh in Mahad Taluka of Raigad district in the Western Ghats of Maharashtra is one of the several critical community fish sanctuaries of India that protect the mahseer fish. These sanctuaries have been successful in conserving not only the fish, but also stretches of rivers through their unique actions which find no support from the establishment and limited recognition from the conservation community. In such a scenario, community conserved fish sanctuaries which are scattered across the country are playing a very important role in conserving various species of mahseer as well as stretches of rivers (Dandekar, 2013; Swar, 2002). In Maharashtra, Tilase is one more such small village in Wada Taluka of Thane district which protects mahseer fish in Vaitarna river (Dandekar 2013). Goa too has community conserved fish sanctuaries protecting the mahseer at 'Pistyachi Kon' nestled between Bhimgad and Mhadei Sanctuaries (Dandekar 2013). In Orissa, along the Mahanadi on the banks of the leaning temple of Huma exist the "Huma Mahseer Sanctuary" (Dandekar 2013). Karnataka has the highest number of community fish sanctuaries in the Western Ghats (Dandekar 2013). Uttarakhand and Himachal Pradesh too have many temple fish sanctuaries, notably the Baijanath Temple complex on the banks of river Gomti in Uttarakhand conserves Golden Mahseer (*Tor putitora*) and supports a small fish sanctuary on its banks (Dandekar 2013). Many isolated fish sanctuaries are also reported from the Ramganaga and Kosi area near Corbett and Kherna. The fishes are also protected at Naldamayanti Tal by the local communities where catching of mahseer is totally banned in the name of religious background (Kumar & Shukla, 2013). In Jogindernagar, a town in Mandi district of Himachal Pradesh lies a lake known as Machchiyal, fed by river Uhl. This lake is supposed to be the abode of 'Machendru Devta', the "Fish God". Fishes are fed and worshipped here regularly and fishing is strictly prohibited in the lake. Machchiyal supports a large population of Himalayan Mahseer (Dandekar 2013). In Tura district of Meghalaya, a chocolate mahseer sanctuary has been established by the local community in some river stretch of mighty Samsung ((MSAM, 2014).

It is urged to all concern to document the existing sanctuaries and grant immediate protection to all the existing fish sanctuaries in the country, protecting them from the onslaught of dams and other pressures. These sanctuaries stand testimony to the fact that community conservation is one of the most sustainable and effective ways of protecting ecosystems. It is also well understood that besides contributing to the tourism coffers, angling tourism supports conservation of mahseer. The setting up of anti-poaching camps along the river has curtailed poaching and helped in protection of the river and the aquatic species. Mass media has been so successful in keeping the news about wildlife in front of people, similarly there could be a potential for raising awareness for our often neglected river ecosystems and the species supported by them like mahseer (ADB & ICIMOD, 2006). After all, our riverine ecosystem is as important as our forests. In addition, other riverine species such as the smooth-coated otter, the oriental small-clawed otter and the mahseer (*Tor* and *Neolissochilus sp.*) fish species could have the potential to generate substantial public interest and people love to watch mahseer and play with this magnificent fish (Sarma *et al.*, 2016). There are multiple benefits of promoting and protecting the mahseer species. They are regarded as an apex species in some river systems of India, helping to maintain the overall integrity of the ecosystem. Some scientists have referred to the mahseer as a keystone species, while others suggest promoting the golden mahseer as a flagship fish species for the conservation of Himalayan rivers (Johnsingh, 2006). Promoting Mahseer fish in the mass media can result in tourists visiting hotspots in the rivers for sighting mahseer. This tourism revenue can help the locals a lot and may hopefully lessen the migration of people from rural areas to urban areas (Bhatt & Pandit, 2015).

Issues and strategies required for mahseer fish-ery development

In central Himalayas the golden mahseer available both in lentic and lotic systems has declined through the years in their size groups and the unit availability in catches by the anglers (Malik, 2011). In Kumaon lakes presently nearly 42% of mahseer are in the length range of 250-400 mm while fishes of above 600 mm in size are usually less than 10%. It is recorded that prior to nineties majority of size groups were in the weight range of 600–1800 g while earlier to that reports indicate weight range of 4-10 kg with a record of Bhimtal at 28 kg. The percentage of golden mahseer from the Himalayan lotic systems range generally to the tune of 10-20% with low size frequency. Rarely a specimen of > 2kg is noticed barring few deep pools or fast flowing rivers (Bhatt *et al.*, 2000). The reasons for such decline are well documented (Bhatt *et al.*, 2000). In this scenario the conservation through aquaculture of these species becomes

the most viable mechanism to propagate these species on one hand and on the other produce the valuable fish protein to provide nutrition security to our people apart from generating economic avenue to our rural population (FAO, 2014).

At present there are some reservations about the suitability of this species as a candidate for economic aquaculture by a farmer. If we are looking at aquaculture practices in Maharashtra, Madhya Pradesh Gujarat, the farmer has choice of species to culture he could club a slow grower and compensate the biomass loss through other fast growing species in his culture combination. But on the other hand, the choice with a farmer in hills is rather limited either he does not have promising combination or if he has, the agro-climatic conditions do not permit him to extend culture period beyond certain months (Meenakumari & Mahanta., 2012; Singh *et al.*, 2014). It is believed from the study that mahseer fish will command a better price in comparison to other carps keeping aside the local preferences but to bring the species to farming status lot of technology development and up-scaling of the existing one is required, some of the aspects of technology gaps are indicated hereunder which require attention at various levels (recommendation of ICAR-DCFR mahseer workshop, 2014):

- Up-scaling of the existing breeding technology especially in Himalayan regions where the low temperatures are acting as constraints at various developmental processes.
- Improvements in nursery management to cut down the losses and adequate the engineering designs for various culture systems.
- Stock improvement especially in hills through better selection of traits or through genetic improvement to develop faster growing strain.
- Critical water requirements both in terms of quality and quantity required to a viable culture system of this fish.
- Production enhancement in a culture system will result in environmental stress to the stocks and cause diseases, this aspect to be addressed with adequate preventive measures.
- Better growth of stocks could also be linked with the balanced diet; the existing diets developed for the species are fundamentally based on the approaches made on other species of carps. There is fundamentally very limited information on the physiology of nutrition in mahseer which should be addressed to answer partly the question of slow rate of growth.

Recent research advances on mahseer

Ontogeny of digestive enzymes in golden mahseer

The objective of the research findings is to get an insight into the development of the larvae digestive functions in terms of different digestive enzymes in order to obtain essential data for the formulation of a compound larval diet. In summary, the activities of digestive enzymes indicate that mahseer larvae are able to digest protein, lipid and carbohydrate at an early stage. In this study, although a sharp increase occurred at the start of exogenous feeding, the specific activity of most digestive enzymes exhibited fluctuations. This variation in enzyme activities during the early stage may be due to the under developed digestive system. The specific activities were gradually increased during the first one week of life and reached higher values during this time, and a decline occurred afterwards. This decrease in specific activities of different enzymes like lipase, protease and amylase on 15 DAH might be due to an increase of body protein (as specific activity is the ratio activity per mg protein) and does not reflect a lowering in digestive capacity. The results of the present study revealed that micro-particulate diets could be formulated for rearing of golden mahseer larvae from 7 DAH onwards, more preferably, from 15 DAH taking into account the digestive capacity of larvae (Akhtar *et al.*, 2013b; Akhtar *et al.*, 2014).

Development and evaluation of a formulated micro diet for larval rearing of golden mahseer

Nutritionally complete, formulated diets are seen as attractive and valuable alternatives to live food. Therefore, numerous attempts have been made to develop formulated diets that effectively replace live food fully or partially. But, formulated diets are used as supplements because when used exclusively, growth and survival are often compromised. Reasons for difficulties in successful rearing the early stages of fish larvae on artificial diets are not specifically known but several factors are thought to play an important role. The main reason is that the digestive systems of larvae are usually not fully developed and may not possess sufficient digestive enzyme activity necessary for effective digestion of artificial diets (Hamlin *et al.*, 2000; Kolkovski, 2001). Researchers speculate that the enzyme manufacturing capacity within the gut is far lower than what is needed and that effective digestion may be accomplished through the assistance of exogenous enzymes that originated from the sources of live food (Kolkovski *et al.*, 1997). That is why growth and survival is higher when fish larvae fed with live food due to supplementation effects of exogenous enzymes from them. Cahu and Zambonino (2001) suggest that it will be necessary to formulate diets that are specifically designed

to complement the digestive physiology of fish larvae. In this study, an attempt was made to develop a suitable micro diet to substitute live food for larval rearing of golden mahseer considering the ontogeny of digestive enzymes and their functions (Akhtar *et al.*, 2013 a.).

From the study, it is evident that the endogenous enzyme activity in golden mahseer larvae was not sufficient for the digestion of microdiets as indicated by the low growth performance of T-mpd0 group. However, supplementation of dietary digestive enzyme mix in the micro diet positively affected the larval growth. Better growth performance of golden mahseer larvae fed enzyme mix supplemented micro diet in the present study supports the findings of several authors in different species (López-Alvarado, 2015; Patil and Singh, 2014; Kolkovski *et al.*, 1993; Lauff and Hofer, 1984). This may be due to the increase in digestive capacity of larvae because of the ready availability of digestive enzymes along with the feed. Additionally, supplementation of exogenous enzymes may lead to the activation of endogenous enzymes or zymogens in the digestive system and might have resulted in increased digestive capacity and nutrient utilization in larvae. Improved growth and feed utilization was reported in the larvae of *Cyprinus carpio* by exogenous supplementation of trypsin in its larval diets (Dabrowski *et al.*, 1979). Further, this study revealed that low level incorporation of dietary digestive enzyme mix in the larval diet of golden mahseer resulted in better growth suggesting development of cost effective larval diet.

The study demonstrated that the growth and survival of golden mahseer larvae is highest when fed with live feed *Artemia* nauplii. However, the microparticulate diet supplemented with exogenous dietary digestive enzyme mix (2.0 g Kg⁻¹ diet) gives nearly comparable growth with similar survival. Hence, the microparticulate diet supplemented with exogenous dietary digestive enzyme mix at 2.0 g Kg⁻¹ diet is an alternative for the feeding of golden mahseer larvae after 15 days of hatching.

Physiological responses of golden mahseer fry to dietary zinc and assessment of its optimum requirement

Minerals are required for the normal life processes of the fish. Many essential micro or trace elements such as zinc, manganese and copper are required for growth and development of fish (Lall, 2002). Like other animals, zinc is a vital micronutrient present in all organs, tissues and body fluids of fish and it act as a stabilizer of membranes and cellular components involved in various metabolic pathways (NRC, 1993). Zinc also function as cofactors of variety enzymes that involved in the biosynthesis and catabolism of carbohydrates, proteins and lipids. Fish can obtain this mineral directly from the water or via their diet; however, dietary intake is the major route of mineral uptake

in fish (Wang and Rainbow, 2008). Growth performance of fish can be correlated with the digestive and absorptive capacity (Zhao *et al.*, 2007). Zinc is the cofactor of RNA polymerases involved in protein synthesis (Hayashi *et al.*, 2001). In fish, the content of nucleic acids such as RNA and DNA can be used as a measure of tissue growth and protein deposition (Bastrop *et al.*, 1992).

Despite of its essentiality, studies have also shown that elevated concentrations of zinc can be toxic to fish (Hayashi *et al.*, 2001). Zinc deficiency in fish leads to growth retardation, which is found to be especially pronounced if other minerals are also lacking (Hughes, 1985). Inadequate zinc supply may also result in impaired digestibility of protein and carbohydrate, increased moisture content and lipid concentrations (Sato *et al.*, 1987). To overcome such deficiency, zinc is usually added in fish feed. A study conducted by Bhagwati *et al.*, (2014) concluded that dietary zinc has significant impact on growth, digestive and zinc related enzyme activities in golden mahseer fry. The optimum dietary zinc requirement of *Tor putitora* fry was found to be in the range of 44.62 to 46.73 mg/kg diet based on growth performance and physiological indices.

Nutritional composition of golden and chocolate mahseer

As a whole freshwater fish is being well recognized for its health promoting characteristics. Freshwater fishes contain high quality protein and various major and minor minerals. It is well known that dietary protein act as replacement of endogenous loss of body protein due to tear, formation of new tissues during growth period and synthesis of blood, hormone, etc. which are protein in nature (Torres 2000, Nurullah *et al.* 2003, Harry 1958, Pedrini *et al.* 1996, Huang *et al.* 2001, Mat Jais 1994, Skonberg *et al.* 2002). Certain amino acids like aspartic acid, glycine and glutamic acid are also known to play a key role in the process of wound healing (Chyun and Griminger 1984, Wahbeh 1997, Zuraini *et al.* 2006). Although the nutrient quantity of various freshwater fish species have been characterized, coldwater fishes vary widely in their body composition, amino acids, Fatty acids and major minerals - Na, K, Ca & trace elements - Fe, Mn, Zn, Se in relation to geographical location, seasonal variation and production system (Sarma *et al.*, 2013, 2014, 2015; Das *et al.*, 2012; Mohanty *et al.*, 2014). Basic knowledge of nutrient quality is very much essential to deal with the production, processing and marketing of high valued Himalayan golden and chocolate mahseer for human consumption.

Captive maturity and spawning of endangered golden mahseer

Overall results of series of experiments at the ICAR-Directorate of Coldwater Fisheries Research, Bhimtal for

decoding the reproductive dysfunction (Akhtar *et al.*, 2017) in captivity suggested that exposure of golden mahseer to 12L:12D could be considered as the physiologically optimum photoperiod for inducing maturity in cultured conditions as evidenced by the elevated levels of 17β -estradiol and 17α , 20β -diOH-P. Temperature was found to be an important and relatively stronger determinant of ovarian maturation in females under captive conditions as compared to photoperiod. Elevated temperature within the physiological limits clearly induced gonadal development and maturation in female golden mahseer as substantially indicated through the analyzed biochemical and phenotypic parameters (Akhtar *et al.*, 2018). However, final oocyte maturation was still unsolved and to address this, we further explored the simulation of spawning substratum (FRP tank installed with gravel bed biofilter system) along with optimum photoperiod and elevated temperature. After four months of rearing the brooders, golden mahseer brooders not only got the captive maturity but also spawned several times in the rearing tank itself. Finally, the study has successfully addressed a longstanding issue of captive maturation and spawning in golden mahseer which otherwise has been a major bottleneck for large scale rehabilitation efforts to conserve this esteemed species in India and Indian sub-continent (Akhtar *et al.*, 2018).

Genetic stock of golden mahseer in India

Genetic diversity is influenced by selection, mutation, migration, population size, and genetic drift and understanding how each of these factors influences the genetic diversity of a population is critical to the conservation of species. In recent years, different morphometric and molecular tools have been successfully used to characterize the natural occurring populations as well as captive resources (Sati *et al.*, 2013; 2014; 2015). Different types of molecular markers like allozymes, microsatellite and rRNA markers (Mahindra *et al.*, 2004; Gopalakrishnan *et al.*, 2008; Singh *et al.*, 2009), mtDNA markers (Sati *et al.*, 2015) as well as their morphometric and meristic characters (Ali *et al.*, 2014; Patiyal *et al.*, 2014) were used to study the variability in the population. Such information is useful for describing the species as well as differentiating the population.

Conclusion

The conservation and sustainable development of mahseer fishery resources require dedicated efforts by integrating capture, culture fisheries and environmental programmes. Environmental laws with strict enforcement mechanisms have to be implemented to achieve the desired objectives to improve the fish habitat and biodiversity conservation. Mahseer is a fish for food, sport and also migratory in behavior therefore, sustainable development of its fishery would need policy and governance intervention

from different stake holders apart from fishery researcher. It is essential that fishery research should have linkage and plan intervention strategy in collaboration with the local communities. May be we will have to embed our policy research for mahseer in our research projects right from the start of programme (Vass, 2014).

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