STUDY ON ECOLOGY AND MIGRATORY PATTERNS OF GOLDEN MAHSEER (*Tor putitora*) IN RIVER GANGA USING RADIO TELEMETRY TECHNIQUES

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भारतीय वन्यजीव संस्थान
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Executive Summary

Golden Mahseer, ***Tor putitora*** is popularly known as 'Himalayan mahseer' and it is one of the largest freshwater fishes of India It occurs along the mid-hills stretch of Himalayan region including Shivaliks and part of Terai landscape. Over the years, the golden mahseer populations and their habitats have depleted due to various anthropogenic activities, hence, it is listed as an Endangered species in the IUCN Red List. Due to rapid hydro-power developments in the river valleys, habitats of golden mahseer have been fragmented, which in turn affects the ecology and spawning biology of golden mahseer. In order to, understand ecology, habitat use and movement pattern of golden mahseer, this project was proposed in 2017. The study was carried out in the two river systems of Western Himalaya: Kosi river in Ramnagar and Kolhu river in Kotdawar. To study the movement and migratory patterns of golden mahseer, 11 individuals were tagged with radio telemetry tags in the month of June (before onset of monsoon) to understand the migratory behaviour of tagged individuals. Manual tracking and monitoring were performed for all the tagged individuals to get location points and to generate movement data during the period from June-October, 2019. Correspondingly, information related to the fish habitat-type, depth, velocity, temperature and weather was collected. Simultaneously, habitat inventory was performed in three zones in both the rivers; upper, middle and down streams. At each zone 200-meter stream reach was selected for assessment of habitat availability, habitat use by different life history stages of golden mahseer (fingerlings, juveniles and adults). This study was performed for three seasons: Post-winter (March-April), Pre-monsoon (May-early June) and Post-Monsoon (October-November) during 2018-2019. Adults of the golden mahseer were mostly found in deep waters (> 2 m) with cool temperature (18-23^{o} C) and low water velocity (0-0.4m/s). Adults prefer pool habitats with sand and gravel/cobbles as the dominant substratum. Similarly, availability of juveniles and fingerlings were recorded along the river basins and mapped to see the available nursery grounds of the golden mahseer. Habitat preference and microhabitat use were analysed for the available nursery grounds. The results for both the rivers exhibited backwater pools, secondary channels and run habitats as highly used habitats of fingerlings. And, run habitats were mostly as used habitats by juveniles in these rivers. Fingerlings were mostly seen at depth ranges (0.1-0.6m) with velocity (0-1.2m/s) where dominant substratum was gravel and sand. Similarly, depth range between (0.3- >1.8m), moderate velocity (0.3- >1.2m/s) and habitats with cobbles, bed rock and gravel as substrate were used by the juveniles. Based on the habitat availability and use by golden mahseer, Habitat Suitability Curves (HSC's) for the youngs were formulated. The study revealed that variation in the habitat use by the fish, significantly varied during the monsoons. In the present study, we also recorded other fish species co-existing with golden mahseer in Kosi and Kolhu. Various threats which harm the golden mahseer population and their habitats in Kosi and Kolhu river were recorded and possible conservation measures are discussed.

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1. Introduction

1.1 Background

The golden mahseer, ***Tor putitora*** (Hamilton, 1822) is one of the charismatic large-sized freshwater fishes of India and it is distributed along the streams/ rivers flowing through the mid-hills to foot-hills of Himalayan region. It is known to reach impressive length of 2.75 meters and weight of 54 kg (Hora, 1939; Talwar and Jhingran, 1991) and migrates to upstream for spawning (Johal *et al.,* 1994; Joshi, 1994). This mighty fish occurs in pools, lakes and large reservoirs. It prefers fresh flowing river habitats with high dissolved oxygen content. The fresh monsoon flow is the environmental clue, which triggers mahseer to migrate upstream for spawning. Golden mahseer spawns from the month of July to September after breeding and flows through long rivers and reservoirs in the lower altitudes to replenish for the next breeding season (Johal *et al.,* 1994; Joshi, 1994). Owing to the rapid construction of hydropower dams and barrages, indiscriminate fishing and other anthropogenic activities, the golden mahseer species is facing serious threat of extinction. The construction of a series of dams and barrages in the upper segments of the river Ganga is considerably reducing the water flow and have shown detrimental effects on the physical attributes, such as alteration in feeding behaviour, distribution patterns, and spawning grounds (Sarkar *et al*., 2012 and Rajvanshi *et al*., 2012). Due to modification and altered flow in the Himalayan rivers, this species is under threat of being extinct at least locally in many regions, and there is a higher chance of losing this charismatic species, if the treats continue.

1.2. Geographical distribution of Golden Mahseer

1.2.1. India

Golden Mahseer is one of the most interesting freshwater fish species of the Indian sub-continent, even though it is endemic to Himalayan rivers (Everard and Kataria, 2011; Gupta *et al.,* 2014). In India, this species occurs in Assam, Bihar, Himachal Pradesh, Jammu & Kashmir, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Uttarakhand, Uttar Pradesh West Bengal and Arunachal Pradesh (Nautiyal *et al.,* 2008; Johal *et al.,* 1994). It has also been recorded in Afghanistan, Bangladesh, Bhutan, Nepal and Pakistan. Over all, its longitudinal distribution extends from Hindu Kush–Kabul–Kohistan in the North West Himalaya to Sadiya (Brahmaputra) in the North-East Himalaya (Figure 1), covering Indus, Ganges and Brahmaputra river systems (Talwar and Jhingran, 1991; Mirza, 2004; Pervaiz *et al*., 2011).

1.2.2. Uttarakhand

In the state of Uttarakhand; this species has its distribution from River Yamuna in the west to Mahakali river in the east. The Ganga River system is one of the largest sources of golden mahseer

population in India. Almost all tributaries between these rivers inhabit one of the rich sources of golden mahseer and it has distribution range between 300 to 1500m msl altitude. Thus, the Uttarakhand state holds the high population of golden mahseer in the wild. Population of golden mahseer also thrive well in tributaries of river Ramganga such as Kosi, Khoh, Kolhu streams in Kumaun region and Nayyar, Alakhnanda and Bhagirathi river systems in Garhwal region. However, being a state with large number of river systems, numerous small and big hydro-projects have come up in series for the development purpose in the last few years. The construction of dams and barrages in the upper regions of the river Ganga is considerably reducing the water flow in the downstream area and have shown detrimental effects on mahseer habitats (Rajvanshi *et al.*, 2012).

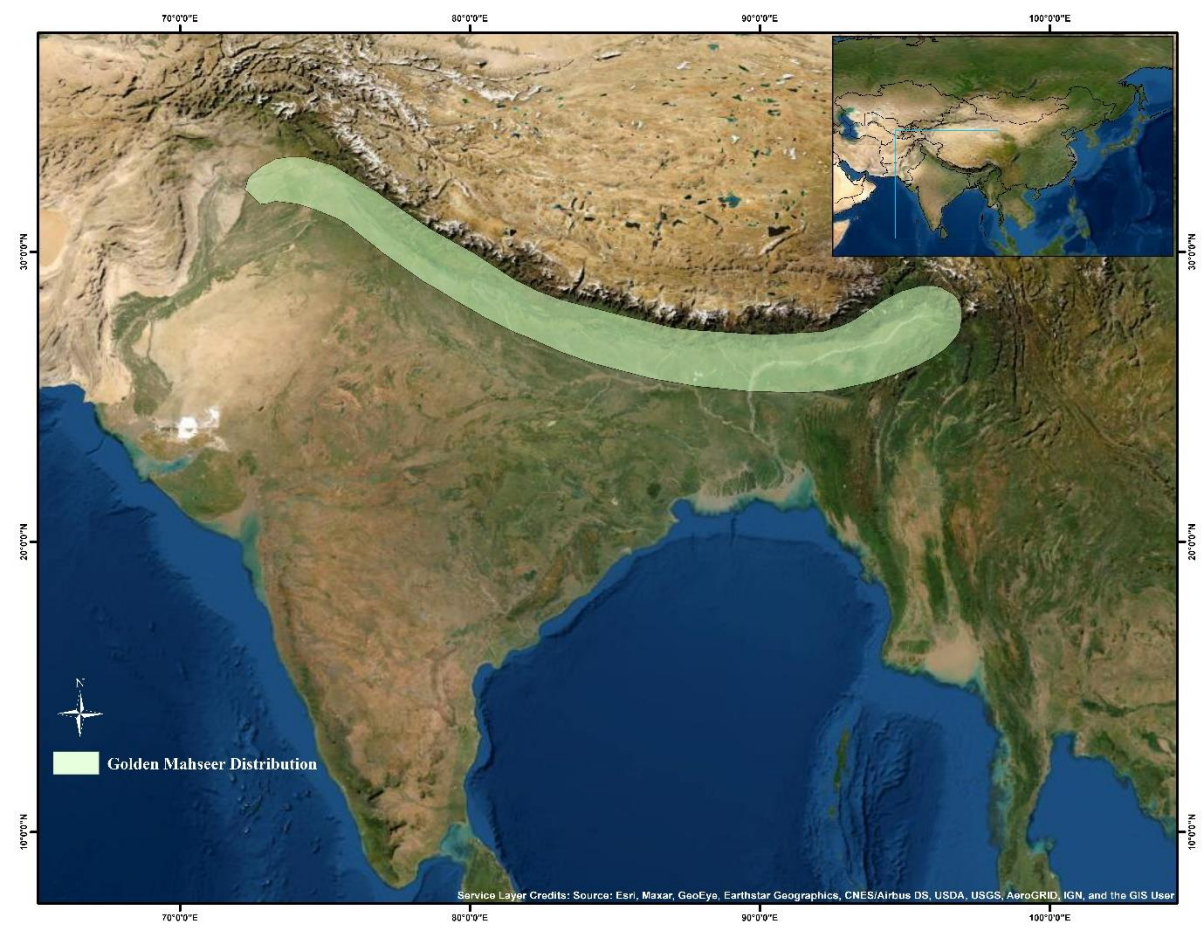


Figure 1. Distribution record of golden mahseer (*Tor putitora*) in Indian sub-continent.

1.3. Habitat of Golden mahseer

Tor putitora, inhabits natural running waters with low temperature. It prefers semi lacustrine waters especially in the Himalayan region. Long back, this species was introduced into selected Himalayan lakes in Kumaun; Bhimtal, Nainital and Sattal in 1858 (Walker, 1888). Golden mahseer is essentially a rheophilic species inhabiting the hill-streams of Himalaya with rocky river beds (Nautiyal, 2014). The foothill stretches of the Himalayan rivers are reported to be the feeding grounds of the Golden mahseer. The reported habitats have observed to have large volumes of water and the river bed is

mostly covered with sand, silt and small boulders (Figure 2) (Bhatt *et al.*, 2015). The physico-chemical properties of the feeding grounds are characterised by water temperature in the range of 14–22^{o}C. Dissolved oxygen in these habitats varies from 5.2 to 12.9 mg/L (Bhatt *et al.*, 2004, 2015). Golden mahseer is potamodromous in nature (migrating within freshwater system) and it migrates upper reaches from the larger rivers to small streams. These smaller hill streams act as the spawning grounds of golden mahseer. In general, the spawning grounds of the fish are characterised by riverbeds with large boulders, cobbles and gravel. The spawning grounds are characterised by water temperature varying from 11 to 30.5^{o}C and dissolved oxygen concentration in the range of 6.4–11 mg/l (Bhatt *et al.*, 2004; Joshi, 1994). The important spawning habitats of golden mahseer are

Figure 2**.** Habitat types and substrate categories in fresh velocitizing rivers (i) riffle; (ii) pool; (iii) run; (iv) sand; (v) pebbles/gravel and (vi) cobbles

1.4. Life cycle of Golden mahseer

The life cycle of golden mahseer vary dramatically in size from embryo to adult that associates with the variation in the body size. Related to the functionality of different life-history stages, fishes use different kind of habitats throughout their life. The primary requirement for any cold-water fish to lay and bury the eggs in gravel substratum or into the water column or broadcast over the surface of substrates or remain attached to the plant material. Incubation period in *Tor* mahseers generally lasts for 4-7 days (Kulkarni, 1980) the eggs mature and hatch and rely on energy entirely from egg yolk. As soon as embryo phase is complete and fish switches to the external sources feed, that stage they are termed as Fry (Desai, 1973). After complete development of fully formed organ system and fins, the fish is called as fingerling stage, according to (Pathani, 1983) mahseer reaches this stage after 12

days of rearing of fry. After the fingerling stage, fish go through number of seasonally favourable periods until they attain sexual maturity and called as juveniles/sub-adults (Desai, 1973). All through the life, mahseer uses different habitat condition at different stage of life.

1.5. Migration in golden mahseer

According to Nautiyal (1989), golden mahseer exhibits a phased manner migration in the Himalayan waters. The first phase of migration is commenced during the months of March–April, when the snow melt water reaches at the foot hills of Himalaya. In this, fish ascend to small tributaries from larger rivers in the Himalayan foothills such as Chenab (Jammu & Kashmir) and Ganga, Brahmaputra etc. The spawning grounds of the fish are generally at the low elevation in the middle elevation hills, at the same time they don't possess adequate water to sustain adults till the rainfalls in monsoon. The fish, hence, prefers to continue migration in the main upstream channels and enters higher order tributaries having the perennial water source with cool temperature, this first phase of migration in golden mahseer is defined as the learning behaviour of mahseer (Nautiyal, 1994). Second phase of migration takes place when the rainfall occurs with the onset of monsoon when water becomes turbid. Turbidity acts as a trigger for the mahseers migration. In the rain-fed streams only the adults ascend up in the smaller tributaries in the Himalayan rivers. After obtaining optimal conditions for breeding in the breeding grounds, the fish starts to spawn in these tributaries. This migration of the brooders along with juveniles from small upstream to descend to large streams in the foothills is defined as the third phase of migration (Nautiyal, 1994). Monsoon is the most appropriate time for migration because of high volume of water in the river provide river channel connectivity and turbidity access in the upstream area.

1.6. Conservation status of Golden mahseer

Golden mahseer is considered as "umbrella species" of Himalayan waters, it lives, near or top of the aquatic food chain. We would see that the well-being of mahseers in a river habitat not only helps us to understand their health but also represents the health quality of the aquatic system as a whole. Furthermore, when we take a close look at the river basin under consideration, whether it is Ganges or Brahmaputra which supports millions of people's livelihood. Conserving the mahseers inevitably lead to the better managements being met out to rivers and water bodies. This in turn conserves other flora and fauna dependent on the river system. Despite their abundance at one time, the population of golden mahseers is declining very rapidly in numbers. Due to the lack of exact numerical assessments of the availability and catches there is no proper comparison of its present status in rivers. So, forth data is available and because of its considerable depletion the population trend and status of golden mahseer is considered as throughout 'declining' trends. Hence, this species is listed in endangered category in the IUCN Red list (2018). Since this species migrates upstream during the pre-monsoon (glacier fed rivers) and monsoon seasons from the foothill of the Himalaya for spawning, the

migration routes are blocked by many river valley modifications. As a result, golden mahseer population has declined drastically in the recent past. Its declining rates due to several reasons raised among the conservationists. One of the major reasons for population decline is habitat loss due to river valley modifications. In addition to that illegal/overfishing practices, pollution, man-made development pressure along the river banks, sand and boulder mining also responsible for continuous declining of golden mahseer population in Himalaya.

Literature Review

The Mighty Mahseer, acclaimed to be as sport fish globally, was originally identified by Hamilton in 1822. Its first mention in a sporting context was in the Oriental Sporting Magazine of 1833 (Walker, 1888). This huge fish is believed to be very powerful, superior and having fighting nature. In 1903, the term 'Mighty Mahseer' was incorporated in a book on angling in India written by an Englishman who used the nom-deplume of Skene Dhu. But long before this book was published, the Mahseer had already captured the hearts of generations of British sportsmen. India has several species of large freshwater fish but the sporting qualities of the Mahseer has rapidly elevated it to the prime interest of large numbers of anglers. As early as 1873, Henry Sullivan Thomas, the Izaak Walton of Indian angling literature, had stated in his celebrated book The Rod in India his belief that pound for pound, the Mahseer was a fish superior in fighting prowess even to the "Lordly Salmon" of his native land. Although, golden mahseer is one of the important fish which has commercial as well as local importance, people in hilly areas sustain their livelihoods however; its population is exploited indiscriminately which lead to its habitat structure destruction. Due to precarious in nature, it becomes an important species with respect to habitat utilization, home range and migration patterns, hence it is very essential for its conservation. Way back in 1900's, in relation to golden mahseer studies have been conducted in the field of limnology, capture of fisheries, feeding habit, commercial exploitation, conservation, and aquaculture practices of this fish species (Desai, 1970; Sehgal, 1971; Jhingran and Sehgal, 1978; Badola and Singh, 1980; Rainboth, 1991; Johal *et al.*,1994; Bhatt *et al.*, 1998; Gopal and Zutshi, 1998; Sugunan, 2000; Chari and Abbasi *et al.*, 2005; Kar *et al.*, 2006*;* Sarkar *et al*., 2008; Singh *et al*., 2009; Lakra *et al.*, 2010; Sani *et al*., 2010 and Sarkar *et al*., 2010). Rich knowledge related to the age, growth and life-history stages of golden mahseer are available concerning its population abundance and conservation (Bhatt *et al*., 2000; Chatta *et al.*, 2000; Dhanze *et al.*, 2005; Sahoo *et al.*, 2007; Nautiyal *et al*., 2008; Naeem *et al.*, 2011; Langer *et al.*, 2013; Sodhi *et al.*, 2013; Ali *et al.*, 2014 and Gupta *et al.*, 2014). Preliminary information related to the different history stages came from the British anglers during their angling pursuits (Thomas, 1897; Dhu, 1923). After the Britishers time, unfortunately not much scientific information has found related to fingerlings and juveniles as indiscriminate fishing hampered the recruitment process of the species. Some of the earliest studies have also been reported related to the general and reproductive biology of the golden mahseer (Lal, 1961; Lal, 1962). In comparison to other freshwater fish species, studies connected to the taxonomy of the Mahseer have been documented by various Ichthyologists (Hamilton, 1822; Hora, 1952; Talwar and Jhingran, 1991 and Jayaram, 2010). Phenotype, genetic and molecular biology studies have been done to study the species' evolution, functioning and developmental processes of this fish species (Prasanna *et al.*, 2000; Kushwaha *et al.*, 2001; Chen *et al.*, 2002; Gurung

et al., 2002; Mohindra *et al.*, 2004; Lakra *et al.*, 2006; Nguyen *et al.*, 2008; Singh *et al.*, 2009; Mani *et al.*, 2009; Sivaraman *et al.*, 2009; Akhtar *et al.*, 2013; Laskar *et al.*, 2013; Sati *et al.*, 2014; Khare *et al.*, 2014 and Bharat *et al.*, 2016). Study of the population of golden mahseer in India showed five populations of *Tor putitora* in India (Singh *et al.*, 2009). Also, earlier studies in the field of genetics have showed significant differences between these populations (Singh *et al.*, 2009). Apart from this, studies been done in relation to the diet analysis and it has been reported that mahseer take aquatic feed of all types; seeds of many types of trees, bamboo seeds, bate thrown by humans (Nautiyal, 2014). Detailed studies and examination on the dietary components of the mahseer species have shown that it varies among the different life-history stages and stock of each species in a river (Islam *et al.*, 2004; Mohan *et al.*, 2009 and Sawhney *et al.*, 2010; Nautiyal, 2014). Owing to an important freshwater species, haematological and histological studies have also been conducted on this fish species (Kapila *et al.*, 2006; Bhatt *et al.*, 2004; Gupta *et al.*, 2013; Nautiyal 2014; Shahi *et al.*, 2015). Since, this fish species thrives in cold water and suitable physical and chemical properties are important for its survival, some related studies based on temperature and other physical factors have been executed in earlier reports (Nautiyal, 1986; Akhtar *et al.*, 2013; Akhtar *et al.*, 2014).

Several reports are available concerning the commercial exploitation due to the altered natural habitats of the golden mahseer (Joshi, 1988; Khan and Sinha, 2000; Bhatt *et al.*, 2004; Atkore *et al.*, 2011; Kataria 2011; WWF, 2013). Although, mahseer is one of important fish which could sustain livelihoods of local communities at certain extent but it was exploited indiscriminately and their habitats have been disturbed resulted decline in population. Many studies have been reported the population structure of golden mahseer and its migration in relation to upstream movement (Bhatt *et al.*, 2000; Bhatt *et al.*, 2004; Zafar *et al*, 2013; Nautiyal and Lal, 1988; Talwar and Jhingran, 1991; Johnsingh *et al.*, 2006). Habitat alteration and modifications in the upstream routes because of the construction of dams, barrages and illegal fishing (Pathani, 1994; Lakra *et al.*, 2010; Nautiyal, 2011, 2014; Pandit *et al.*, 2014) has reported in large number of river systems. Habitat alteration by dams, barrages, and illegal sand and boulder mining, poaching and indiscriminate fishing are largely responsible for the number decline of *Tor putitora* (Sharma *et al.*, 2015). Over the past two decades, rapid human population growths in the Himalaya and construction of hydropower projects have enforced changes in the Himalayan landscape (Pandit *et al.*, 2014). Construction of multiple dams are reported to result in habitat fragmentation of migratory species, habitat degradation, which bring about significant changes in the quantity, quality and regime of water flow in the downstream sections of these rivers (Everard and Kataria, 2011). These human–induced changes result in habitat loss, changes in the fish reproductive environments and cut off migration routes has resulted in substantial decline of biodiversity (World Commission on Dams, 2000). However, this fish species is also having great demand in the market as it forms an important food fish, therefore the breeding and hatchery techniques have been developed for rearing of fingerlings and juveniles for aquaculture practices (Joshi, 1994; Panday *et al.*, 1998; Ogale, 2001; Ingram *et al.*, 2005; Islam *et al.*, 2002; Joshi *et al.*,

2002; Laskar *et al.,* 2009). In addition, recent studies have shown that the fish species richness is primarily driven by the amount of water discharge in the rivers therefore, water withdrawals will greatly undermine the fish species diversity and distribution in these rivers. The primary impacts anticipated due to dams on the Himalayan rivers are decreased water velocity, diurnal flow variation, rise in channel water temperature, interruption in the longitudinal connectivity and low turbidity of downstream waters (Bunn and Arthington, 2002). Equally important are the life history and ecological traits of *Tor putitora*, which will be useful in evaluating the species' vulnerability to decline. Some life history characters such as migratory habit, low fecundity and delayed sexual maturity combined with numerous external threats like damming of rivers are responsible for declining numbers of golden mahseer. Rising interests on the valuability of mahseer due to its sport and fighting qualities and its threatened status (Dehadrai *et al.,* 1994) has encouraged many biologists to provide more information on this species so that the attention fishery scientists of the world can be caught towards this species and they contribute scientifically towards the much-needed data base for devising conservation measures for this species (Kumar, 2001) and promoting its recreational value.

Studies have been carried out for the conservation and protection of this species, albeit appropriate effective management tools which can help in the conservation of the species in its natural conditions are need of the hour. For better understanding of the habitat structure, movement patterns and locating suitable breeding and spawning grounds in concern to its conservation effective technology which can help the organism in its natural conditions is very important. This understanding can be obtained with the help of telemetry techniques. The freshwater telemetry study began in 1950's (Stasko and Pincock, 1977; Mitson, 1978). However, after this study a fairly extensive literature had developed though. Different studies have been done in relation to the movement, distribution patterns and habitat use of different organisms. Extensive work has been performed on salmon in temperate regions (Nogro *et al*., 1985; Nigro and ward, 1985; Faler *et al*., 1988; Ward *et al*., 1988; Lariniar *et al*., 2005). Tags of different size and use are used to study different ecological aspects of ecology and behaviours of the fishes. According to Faler *et al.*,1988, telemetry is used in conjunction with the mark and recaptures study to gather the information on individual fishes. Telemetry studies have been widely taken as an important tool to locate the habitat use, activity patterns and movements of various species in wildlife ecology. Telemetry in freshwater environments began in the 1950s (Trefethen, 1956; Stasko and Pincock, 1977; Mitson, 1978), and a fairly extensive body of literature has developed since then. Telemetry has been widely used to study the movement, distribution patterns, habitat use and breeding behaviour of salmon in temperate region (Nogro *et al.,* 1985; Nigro and ward, 1985; Faler *et al.,* 1988; Ward *et al.,* 1988; Lariniar *et al.,* 2005). Different types of telemetry tags were used to study the different aspects of ecology and behaviours of freshwater fishes. Faler *et al.* (1988) have used radio telemetry in conjunction with mark and recapture studies to gather information on individual fish and validated the mark-recapture model. Telemetry also widely used to establish the home range of several carnivores' fishes (Lewis and Flickinger, 1967; Malinin, 1969; Winter, 1977;

Doerzbacher, 1980; Ross and Winter, 1981; Mesing and Wicker, 1986). In India, radio telemetry studies were initiated in 1976 by Mech (1983) and this technique has been widely used in free ranging wild animals like Tiger, Asiatic lion, Elephant, Leopard, wolf, bears, Otter, birds etc. (Johnsingh and Sale, 1989; Desai, 1991; Chundawat, 1992; Hussain, 1993; Higuchi *et al.,* 1994; Karanth and Sunquist, 2000; Kalsi, 2004), but no attempt has been made to document the migration and habitat use of fishes, except the recent effort on Whale Shark in Gujarat cost (Whale shark conservation Project, 2011).

Telemetry studies have an important tool to locate the habitat use, activity patterns and movements of various species in wildlife ecology. In golden mahseer, long-distance migrations are an intrinsic part of its life cycle and are under threat of being extinct at least locally in many regions, and we face the risk of losing this charismatic species. The monsoons trigger environmental clues for the Mahseer to migrate upstream for spawning. On the other hand, previous studies report that the young ones of different sizes and classes occur in all seasons in certain streams (Atkore *et al.,* 2011). As Mahseers are considered to be the tigers of the aquatic world in the context of India. This analogy is not just true with reference to the 'charisma', but also the fact that the Mahseers can be observed as an "umbrella species", just like the tiger. Conserving the Mahseers will inevitably lead to the better treatment being met out to rivers and water bodies. This in turn conserves other flora and fauna dependent on these wetlands. The analogy may further be extrapolated and we would see that studying the Mahseers not only helps us understand their biology and ecology but the ecology of the aquatic system as a whole.

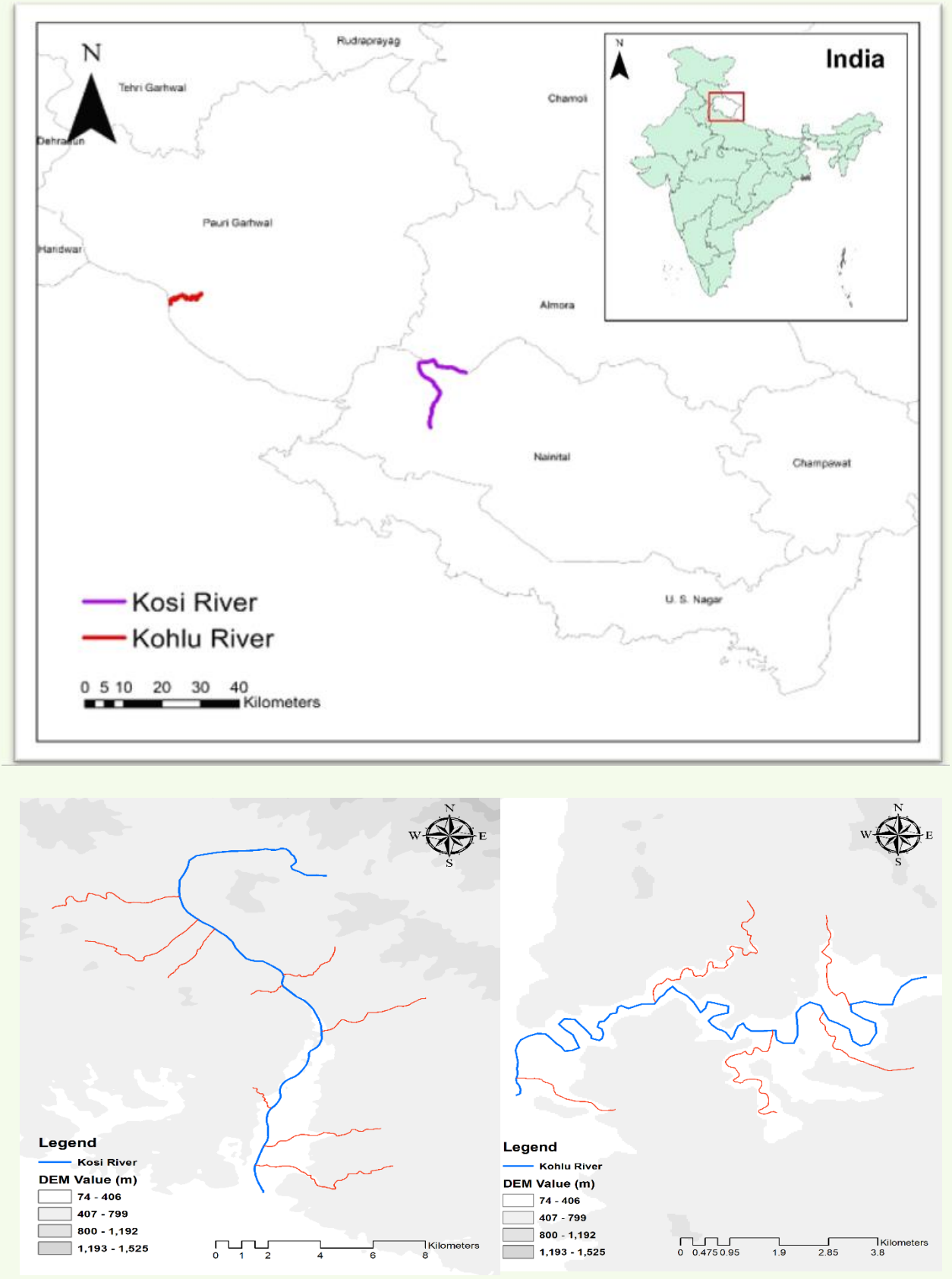
Based on the information on the golden mahseer life cycle, it is believed that monsoonal flood gives environmental clue for mahseer to migrate upstream for spawning, but no idea on how far they migrate in Himalayan river? Further, we observed that young ones of different size classes of golden mahseer are found in all seasons in some of the streams, but no information on how often they undergo spawning in Himalayan waters? In order to answer these questions, we used radio telemetry techniques to understand ecology and migration patterns of golden mahseer in the foot-hills of Himalaya. The present study has the following specific objectives:

I. ***To investigate the breeding migratory patterns of golden mahseer inhabiting in Western Himalaya.***
II. ***Document the habitat uses of golden mahseer during different life history including spawning and growing.***
III. ***Estimate the breeding and non-breeding home ranges of mahseer inhabiting the main river channel.***
IV. ***Estimate the Weighted Usable Area and flow requirement of golden mahseer using PHABSIM model.***

In the present study, only the first two objectives were covered and the objectives 3 & 4 could not get completed due to there is shortage of fund allocation to this project.

Present study was conducted in two dynamic rivers of Uttarakhand known as river Kosi and river Kolhu which flow through the significant landscapes harbouring many terrestrial and aquatic wildlife. The river Kosi (Figure 3; (i, ii)), is an important spring fed tributary of the river Ganga, originating from Dharnapani Dhar in Baramandal region of district Almora (Kumaon, Uttarakhand), Kosi flow through the valleys of Ramnagar covering a total basin area of 2101.83km^2 (Ganie *et al*., 2016) and then it enters the Tarai regions of in Uttar Pradesh, where it joins river Ramganga in the downstream, which ultimately joins river Ganga. Locals of Kumaon region use the water of this river for farming and cultivating different crops. Also, this river harbours a wide variety of fish biodiversity and provides home for some of the conservation significant species like Golden Mahseer and Otters. About 32 km length of the river stretch starting from Kunkhet (upstream) to Ramnagar barrage (downstream) was selected for the present study. The study area lies between latitudes 29^{o}24’2.78” N to 29°48’02.62" N and longitudes 79°07’54.41"E to 79°12’08.43"E (Figure 4). Another important tributary of Ganga, River Kolhu, (Figure 3 (iii, iv)), flow close to the Kotdawar town in Saneh village in Pauri-Garhwal district of Uttarakhand. Kolhu flows through the reserve forests under Lansdowne Forest Division and is home to several small and big wildlife species. This river originates at confluence of two small streams; known by the local names as Noddy and Bhaira streams inside the reserved forest area and flows down to the Saneh village where it meets river Khoh at Uttar Pradesh state border. A total of 15km of the Kolhu river lies between 29° 41' 39.2"-29° 42' 46.3" N and 78° 31' 42.3"-78° 37' 41" E, was selected for present study (Figure 4).

Figure 3. Kosi river (i & ii) flowing the forests of Ramnagar, Nainital and Kolhu river (iii & iv) flowing through Reserved Forest in Saneh, Kotdawar



(A) (B)

Figure 4. Map of Kosi (A) and Kolhu (B) rivers flowing through the Ramnagar and Lansdowne Reserve Forests

5.1 Reconnaissance survey

During the first year, surveys were conducted along the rivers' stretch to locate the sampling points and important mahseer habitats. A detailed site survey was carried out along the rivers to generate information on river habitat types, population status of golden mahseer and to study the critical habitat types of life history stages. During the survey, systematically the rivers were divided into three zones; upper, middle and downstream (200m reach) for further habitat assessment during the three seasons; post-winter, pre-monsoon and post-monsoon. Also, potential golden mahseer habitats were located in both the rivers for the tagging to be performed.

5.2 Inventory; Mahseer habitat

In a running water system, different types of aquatic habitats such as pool, riffle, run and cascades form due to hydraulic force over the bed materials. Adult golden mahseers generally prefer deeper sections of the channel unit with no or less flow, such habitats are called as pools. The formation of pools in natural riverine ecosystems could result due to large rocks and boulders in the bed materials, which hold the flowing water providing a structure of a standing water body. Intensive field studies were performed in the streams to study habitat use (macro and micro habitat) by different life history stages (fingerlings, juveniles and adults). The study was performed for three seasons in a year for two years; Post-winter (March-April), Pre-monsoon (May-early June) and Post-Monsoon (October-November). For the first year, 32 km stretch of the Kosi River was studied; along the stretch, 25 sampling sites (pool habitats) and for Kolhu, 15 km stretch covering 27 sampling sites (pool habitats) were demarcated. For the next two-years, study was executed covering the upper, middle and downstream river stetch (200m reach) to identify available mahseer habitats and their use by different life-history stages.

5.2.1 Measurements of micro-habitats

Fish habitats in the mountain streams comprise of different gradient and levels, different habitats have specific features which defines the particular habitat and its use. It includes depth, water velocity, substrate etc. Information of these micro-habitats in relation to the availability and use by the fish species defines the habitat preference and survival of the fish. The occurrence of golden mahseer and its different life history stages were recorded in different habitat types. This data gives insight into the habitat features that affect the presence of fish.

Followed by number of cross-sectional interval data at every 5m and for each cross-section at every 1-meter interval depth, velocity and substrate type were recorded. The methods for measuring micro-habitat and variables are illustrated in the (Figure 5). Based on the habitat inventory mean habitat

depth, velocity and presence of dominant substrate types were generated. Information on water-velocity and depth distribution were generated using depth finder & measuring rod and hand-held digital Flow probe (3.7-6' Model: FP111). Dominant substrate types (Bedrock (BR)/ small boulder (SB)/ cobbles (Co)/ gravel (Gr)/ sand-silt (S) /leaflitter (LL)) recognized as outlined by (Pusey *et al;* 1993). Composition at each substrate type was quantified on the basis of visual observation.

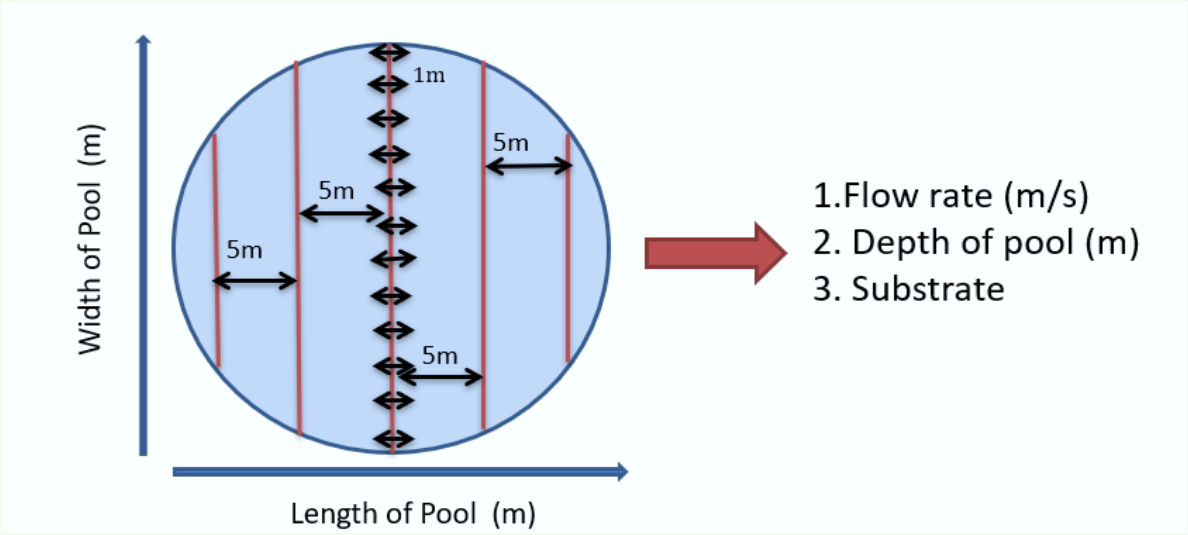


Figure 5. Diagrammatic representation of river cross-sectional data collection method across the pool habitats

5.3 Sampling of mahseer and co-existing fish community

Systematic fish sampling was performed in each habitat using cast nets. For each field site, during all field seasons efforts using the cast nets (10 times) for the half an hour duration was performed. Fish species encountered along with golden mahseer were photographed and their morphometric characteristics recorded. After recording fishes were released back to the river systems.

5.4 Water Quality sampling

In each sampling site, during different seasons information on various water quality parameters were recorded. Measurements for air and water temperature (thermometer); pH (Multimeter-probe), dissolved oxygen (Winkler's method), electrical conductivity, EC (probe) and total dissolved solids TDS (probe) were generated. Data for water sample was collected in triplets and average values were calculated for the further analysis.

Figure 6. Field sampling: Micro-habitat measurements; (i) measuring water velocity, depth and determining available substrate type across the river (ii) measuring environmental parameters with hand probe (iii) DO measurement (iv) Fish sampling by fisherman using cast net

5.5 Telemetry fixing

Telemetry study was conducted in pre-monsoon season (June, 2019). A total of 11 (6+5, in Kolhu and Kosi river) radio telemetry tags (MCFT2-3BM) series, Lotek Company were fixed (Figure 7, i). Fish sampling was done using the gill nets and adult golden mahseer individuals weighing preferably more than 1.5 kg were caught for the tagging. The weight of the tagged golden mahseers was between 1.5 to 8kg. Depending upon the fish catch male and female individuals were identified. On the basis of posterior opening known as vent/cloaca in vertebrates; male and female fish were recognized. In females, cloaca is round in shape and is oval in case of males. After, identified individuals were tagged externally on the dorsal area below the dorsal fin of adult fish individuals in river Kosi and Kolhu followed (Figure 8) (Ward *et al.*, 1988). Fish was examined for any kind of illness or injury and only healthy fish was selected for the radio telemetry tagging. External tag attachment was done by proper handling the fish; total length, weight and sex of the fish was determined, fish scales was preserved to determine the age of individuals. After the field, age of the fish was calculated in laboratory using Scale reader. The age in fish was determined by counting the number of annuli or yearly rings followed (Paget, 1920). Followed by external tag attachment and releasing the fish (Figure 8). The whole process of tag fitment for each individual (after catch) took around five minutes and the fish were released immediately.

5.6 Tracking and collection of fish location and ecological information

Soon after the fish individuals were tagged and released, the fish were tracked to see their movement in water. Followed, a regular manual tracking and monitoring were performed using the receiver and an antenna for the tagged fishes to get GPS location points and to know about their movement during morning and evening hours from June 2019-September 2019. Information related to the habitat-type, depth, velocity, temperature and weather was collected during the complete monitoring period.

5.7 Survey of fish Nursery grounds

Nursery grounds, the ecologically important habitats that enhance the growth and survival of early life-history stages (fingerlings and juveniles) of fish species. Systematically, field studies were performed trailing the complete stretch of river (down, middle and upstream) to study habitat use; macro and micro habitat by (Moore and Gregory, 1988; Pusey *et al.*, 1993) different life history stages including fingerlings and juveniles (Bovee, 1982). Young ones for the study were classified into two types based on the size class (fingerlings, 1.5-10 cm; juveniles 10-30cm based on Kulkarni (1980) and Desai (1973). Studies were conducted to locate the potential nursey grounds of youngs of golden mahseer in classified system as backwater pool, secondary channels, run habitat, associated stream, isolated pools and confluence point (Pusey *et al.*, 1993). Location of each nursery ground was recorded. Later, they were plotted using ArcGIS map.

5.8 Measurement of habitat use information

To understand the ecological principles related to the habitat use by the golden mahseer and to understand the habitat necessities to species communities, the quantification of the habitat was performed for different life-history stages followed (Johnson *et al*., 2010). Habitat quantification and use criteria enumerate how suitable are particular habitats and environmental conditions for specific size or life history stage in respect to the behaviour of the species. Habitat use criteria was developed for each habitat variable from the observations of the presence-absence or relative density of the individuals in specific habitat (Jowett, 2007).

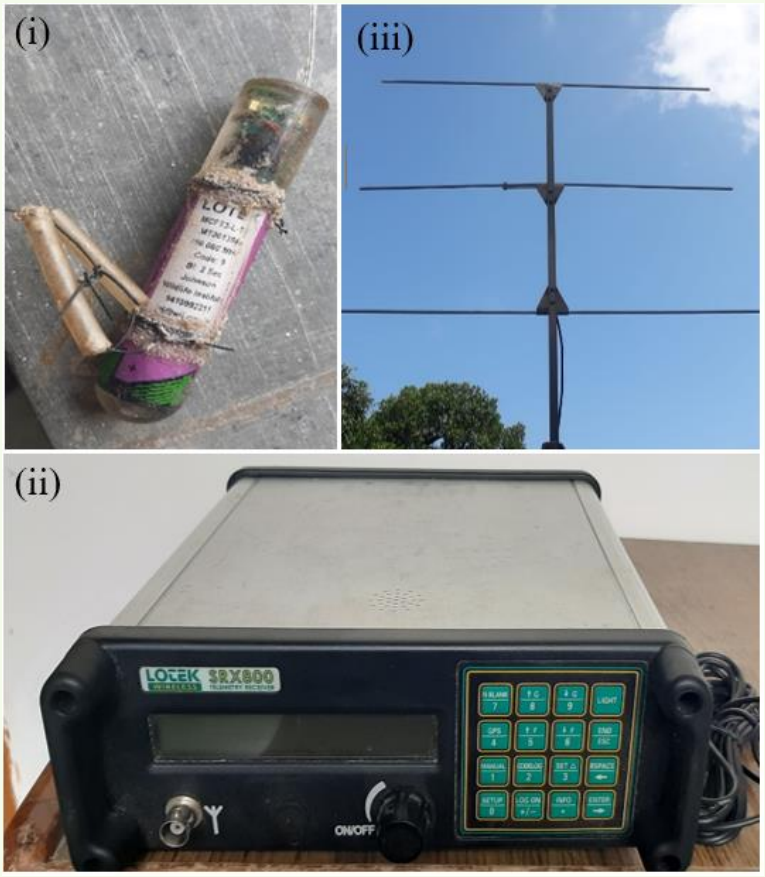


Figure 7. Radio Telemetry equipments (i) Radio telemetry tag (20g) (ii) Receiver (iii) Manual antenna.

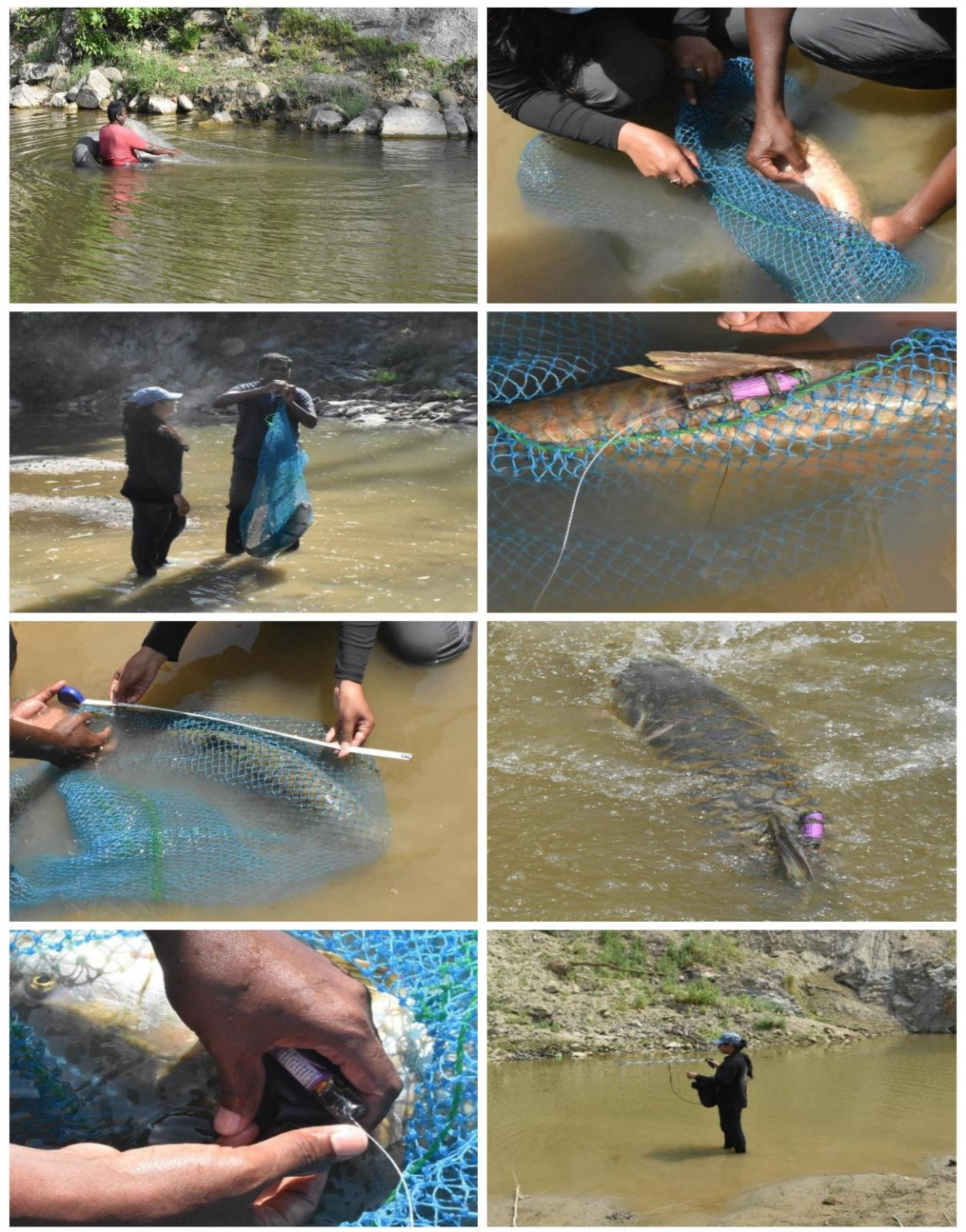


Figure 8. Telemetry fixing process; fish catch, determining weight and length of fish, tracing tagging position to fix tag externally, release of fish, manual tracking of fish to get the location data.

5.9 Threats Analysis

Though fishing in Kosi and Kolhu river is banned by Uttarakhand Forest Department, illegal fishing and other activities are happening along the rivers. Threats to the fish community were observed and classified into five major categories depending upon how these threats adversely affects the golden mahseer population and other fish biodiversity:

(a) Illegal fishing (IF): Fish population decline due to illegal fishing, in selected pools due to the increased demand in the local market.

(b) Destructive fishing (DF): Use of destructive methods such as dynamites, poisoning, electric gears etc.

(c) Habitat Modification (HM): Large scale modification in the river beds, small scale water diversions by local residence and uncontrolled recreational activities in the river channel.

(d) Habitat fragmentation (HF): Due to the developmental activities along the rivers, the natural breeding grounds have been lost due to loss of substrata as rock and sand mining takes place for the construction purposes. During the survey sings of different types of threats operating at each site was recorded and analysed.

5.10 Data Analysis

5.10.1 Inventory study; Habitat Utilization

Macro-habitat and micro-habitat studies are very essential in these river systems as due to the seasonal change there are variations that causes changes in the habitat use of the different life-stages of the fish species. In the case, it is important to do repeated sampling to observe the changes in the habitat use types. Information obtained by performing the field activities during different seasons, data was analysed in the Microsoft Excel using Data analysis tool. The results were depicted in graphs to get the relative frequency of available depth and water-velocity patterns and types of habitats use by youngs (fingerlings and juveniles) and adults of the golden mahseer. For the habitat characterization each category of depth, velocity and substrate was compared throughout the seasonal studies. Also, average and range values for water quality parameters were obtained using simple statistical tools.

5.10.2 Telemetry study

To understand the up-stream movement by the mahseer individuals in the rivers, the location points were plotted to generate maps for each tagged individual. Later, distance between all the obtained location points was generated using ArcGIS tool. The data was further analysed and graph representation was used to show the obtained results of movement and displacement by tagged individuals during the telemetry tracking.

5.10.3 Generation of HSC's (Adults/Youngs)

For the generation of the Habitat Suitability Curves (HSC's), Habitat use were measured on different scales; habitat use from -1 (non-use) of a habitat's types, to +∞ (maximum use) followed (Schlosser,1991)

$$\text{Utilization coefficient} = \frac{\text{Habitat specific density} - \text{Average total density}}{\text{Average total density}}$$

Habitat utilization co-efficient was assessed and habitat suitability criteria curves were developed for the youngs of golden mahseer with respect to the use and availability of microhabitat parameters. The depth and flow measurements were divided into different classes (depth class: 0.1, 0.3, 0.6, 1.0, 1.2, 1.5, 1.8, 2.0 m and <2.0 m; flow class: 0.2, 0.3, 0.5, 0.6, 0.9, 1.2 m/s and <1.2 m/s) (Bovee, 1986). The preference for each class interval of the measured variables was computed from the estimated relative frequencies of utilization and availability as

$$Pi = Ui/Ai$$

Where, *Pi* is the relative preference value, *Ui* the proportion of utilization of a specific interval, *Ai* the proportion of a specific interval of the measured variables. The values were normalized to a preference scale from 0 (unsuitable) to 1 (optimal use) (Waters, 1976).

Results:

6.1 Inventory of golden mahseer habitat

6.1.1 River Kosi

Different macro-habitat types were monitored to recognize the habitat selection by different life-history stages of golden mahseer. Aquatic macro-habitats like riffles, rapids, cascades and deep pools were found more projecting in the river. It was observed that the adult mahseer prefers pools according to the study performed during the post-monsoon and post-winter in 2018 with depth (0.1m to 2m) and velocity (0.2 to 0.5 m/s) (Figure 9). In river Kosi, the results of habitat inventory along the stretch during different seasons in 2019 found the depth availability for adult ranged between (0.1to1.5m) and velocity ranged between 0.5 and >1.2m/s which is favoured by adult mahseer fish. Substrate availability in the study stretch was mostly cobbles followed by sand and gravel. Seasonal variation during the years (2018) in relative proportion of depth and velocity and percent substrate availability in Kosi river has presented in (Figure 9). The volume and water-velocity in Kosi varied greatly between monsoon and dry seasons. At the same time, confluence of secondary channels with the main river channel befalls during monsoon that increased the wet width of the river. Change in the water velocity helps smaller fish to move from secondary channels to the main river channels and adults to migrate. In river Kosi, during 2019 change in the depth and water velocity was seen with the seasonal variations. During the pre-monsoon the depth range found to be less (0.1-1.2 m) (Figure 10). Increase water depth was reported during the post-winter and post-monsoon which ranged from (0.2->2m). The same observation was reported for the velocity which was less during pre-monsoon (0.2-0.6 m/s) and more during the other seasons (0.2->1.2m/s) (Figure 10).

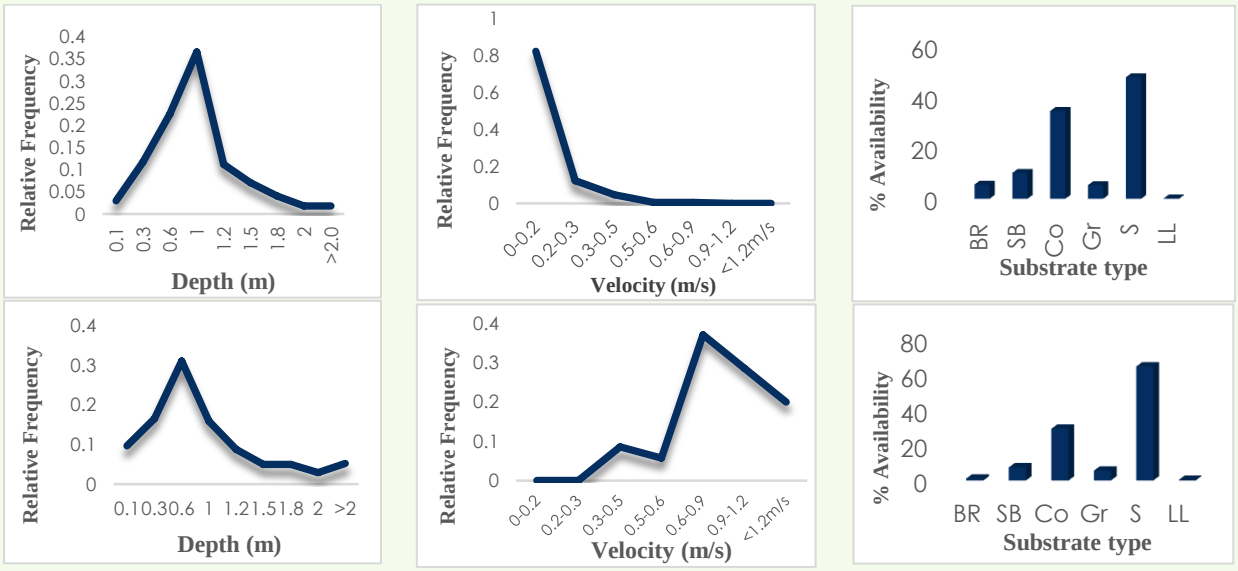


Figure 9. Relative proportion of depth, velocity and % substrate availability in Kosi river; Post-winter 2018 (above) and Post-Monsoon 2018 (down)

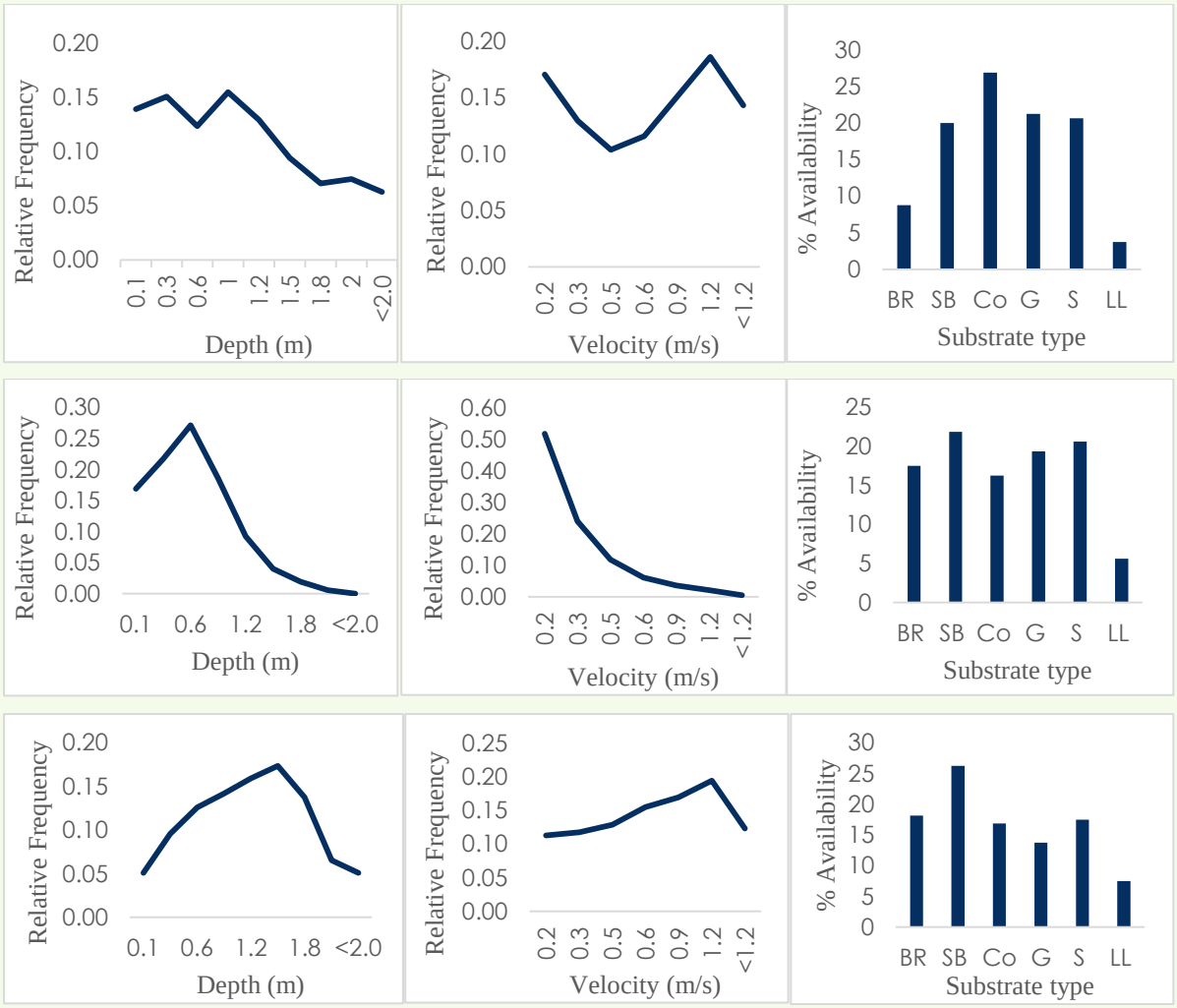


Figure 10. Relative proportion of depth, velocity and % substrate availability in Kosi river; Post-winter 2019 (above), Pre-monsoon 2019 (middle) and Post-Monsoon 2019 (down)

6.1.2 River Kolhu and golden mahseer habitat

Having frequent bends in the whole stretch of Kolhu makes it an active river. Different habitat types; riffle, run, shallow and deep pools get form in the river that changes seasonally. Similar to river Kosi, habitat inventory carried out in Kolhu river in 2018 that inferred the depth and velocity ranged between 0.1m to 1.5m and 0.3 to 1.2 m/s, respectively. The relative proportion of depth, velocity and substrate composition available in Kolhu river (2018) is presented in (Figure 11). During the monsoon season, the river gets turbid and flooded that it becomes difficult to cross the river as depth and width also increases, but during the post-winters, the water remains more clearer with moderate water currents. In Kolhu, more of the sandy pools are there with depth >2m having variety of fish species. In river Kolhu, during 2019 change in the depth and water velocity have been seen with the change in the seasons. During all the three seasons depth range was found to be in a range (0.1-1.8 m) and most of the observations were between 0.2- 0.8m (Figure 12). Increased water depth was reported during post-monsoon season in which more of the observations were in the range (0.6-1.8m). The velocity of water during post-winter ranged (0.2-1.6 m/s). The velocity observations during the other seasons ranged between (0.2->1.2m/s) (Figure 12). The variation in the depth and velocity during the seasonal studies in Kolhu might be due to its curved structure. Water in the deeper sites remained slow with less velocity and in some sites, depth reduced to less than 0.2m observed during the pre-monsoon season.

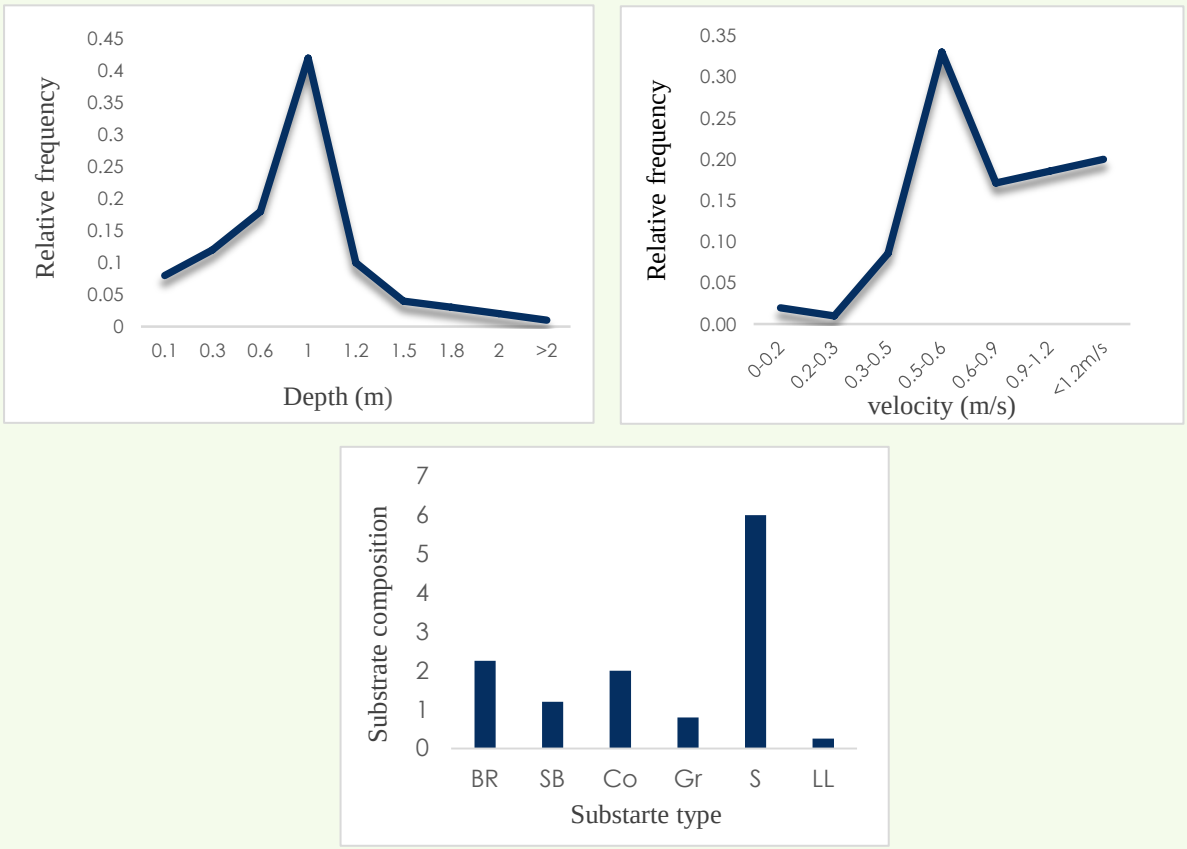


Figure 11. Relative proportion of depth, velocity and substrate composition in river Kolhu; Post winter (2018)

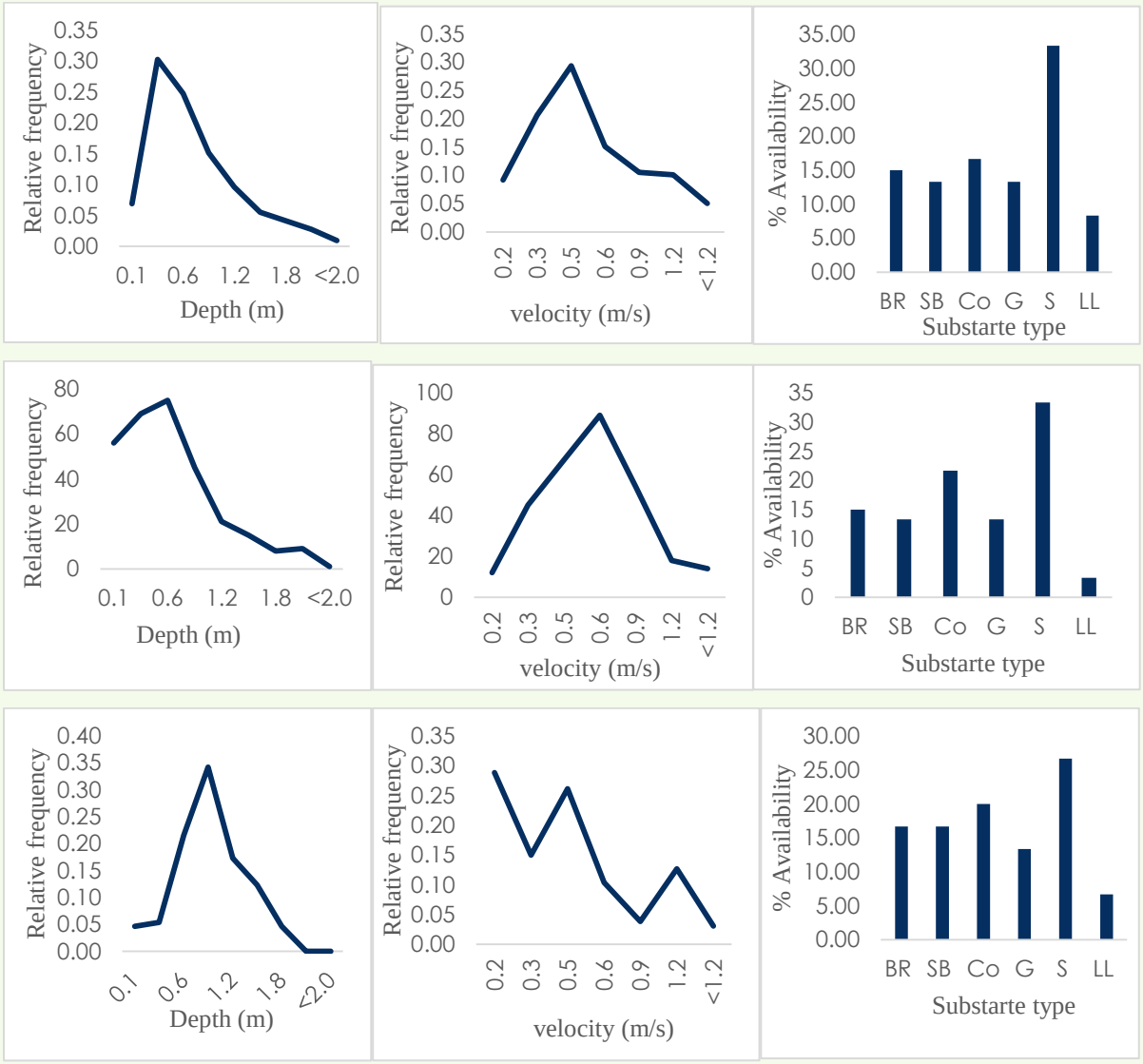


Figure 12**.** Relative proportion of depth, velocity and % substrate availability in Kolhu river; Post-winter 2019 (above), Pre-monsoon 2019 (middle) and Post-Monsoon 2019 (down)

6.2 Fish composition (co-existing fish species) in Kosi and Kolhu

The present study has reported twenty species of fishes belonging to 5 order, 7 families in the studied stretch of River Kosi and Kolhu (Figure 13). Among all species, the Golden Mahseer is an iconic fish from these rivers, which is distributed all across. Along, with the Golden mahseer other big-size native carps such as *Bangana dero*, *Labeo calbasu*, *Labeo pangusia*, *Labeo rohita* and *Chagunius chagunia*, co-exist in most of the habitats. In addition to the large cyprinids, small typical stream fishes like *Garra gotyla*, *Opsarius bendelisis*, *Barilius vagra and Schistura rupicola* are quite common and occupied in entire section of the river. Out of the recorded fish species throughout the study, all of them fall under

four categories of the IUCN Red List, where; *Tor putitora* species is listed as Endangered, *Naziritor chelynoides* is Vulnerable and *Labeo pangusia* is listed in near Threatened species category.

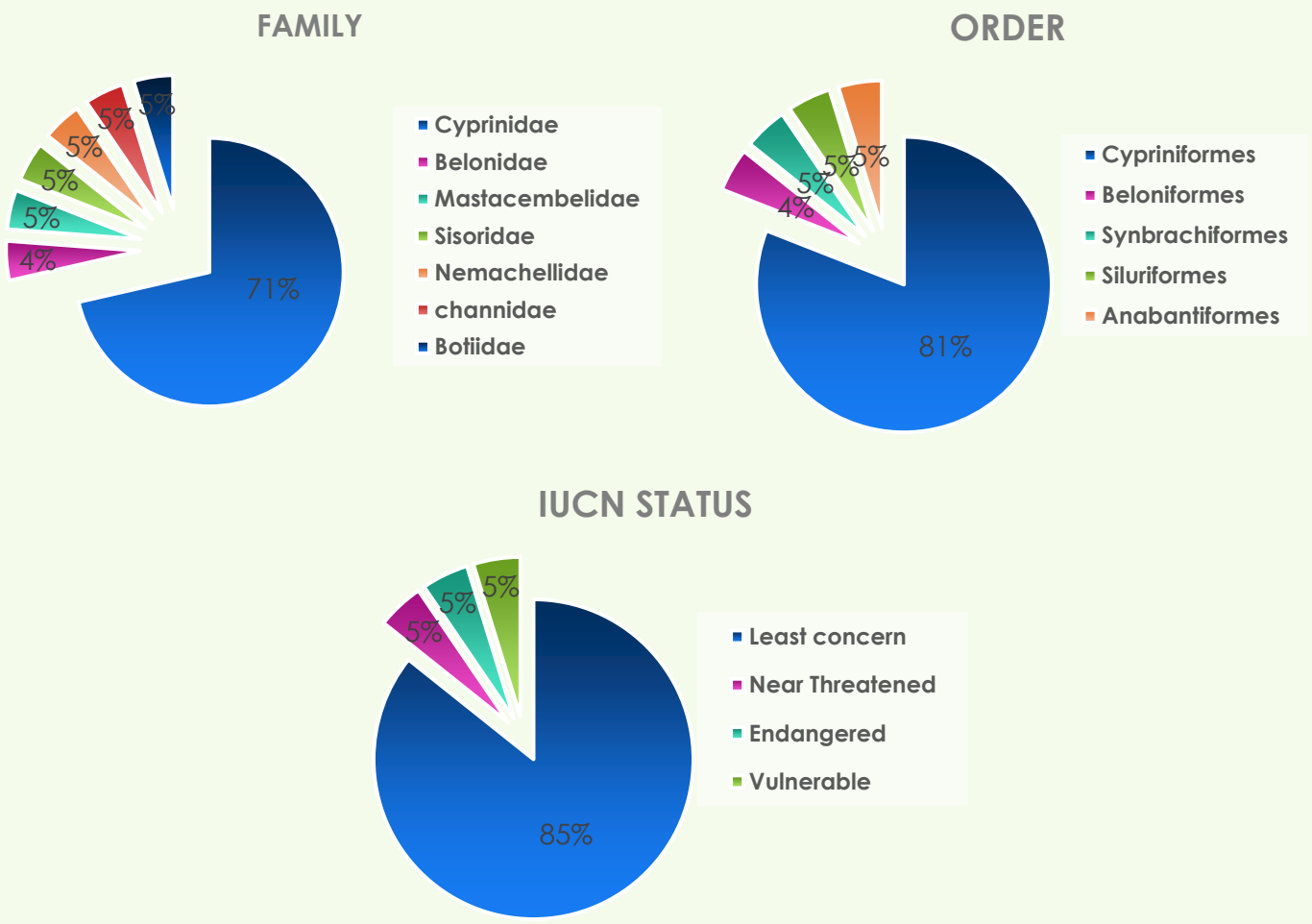


Figure 13. Pie-chart illustrating the composition of recorded fish species' Family, Order and IUCN status

6.3 Water Quality Parameters

The water quality parameters observed in all mahseer habitats during the post-winter and post-monsoon (2018) is presented in (Table 1). Dissolved oxygen content was ranged from 8.01 to 9.78 mg/l, which is ideal for mahseer habitat. Electrical conductivity and total dissolved solids were found increased during the post-winter season. In 2019, the water quality study exhibited increase in the dissolved oxygen level during the post-winter season followed by post-monsoon and pre-monsoon. Other major water quality parameters such as Total Dissolved Solids (TDS), Electrical Conductivity (EC), pH and temperature were also found within the ideal condition, not much difference has been observed along the different study stretch. However, temporal variation in water quality variables was observed in the two rivers. This difference is mainly attributed due to monsoon discharge followed by

presence of sediments and other dissolved solids in the river channel. Electrical conductivity and total dissolved solids were found increased during the pre-monsoon season. It reflects the relation of temperature with EC and TDS. Alkalinity was found almost in the same range for all the studied season in river Kosi (Table 2). In river Kolhu, dissolved oxygen content (8.5-10.5 mg/L) was found high during the post-monsoon season, whereas in the post-winter comparatively low values (8.1-9.9 mg/L) were recorded. High water velocity and river replenishment during the monsoons can cause increase in the dissolved oxygen content. Alkalinity was found little high during the Pre-monsoon (181.67-262.67 ppm) season. Electric conductivity was high during post-monsoon and pre-monsoon time (Table 3). These parameters varied with the change in the temperature and water level during the different seasons.

Table 1. Environmental parameters observed during the seasonal study in Kosi river in 2018

River Kosi (2018)		**Post-Winter**		**Post-monsoon**	
S. No.	Parameters	Range	Mean± SD	Range	Mean± SD
1.	**DO (mg/L)**	8.01-9.81	9.31±0.48	8.10-9.11	8.64±0.4
2.	**pH**	8-8.9	9.11±0.457	8.18-8.88	8.64±0.23
3.	**Water temp (°C)**	22-28	23.91±1.57	21.13-28.80	23.35±2.32
4.	**EC (µ/S)**	220-417	280.62±45.90	220.67-251.00	155.93±8.11
5.	**TDS (ppm)**	147-300	177.92±36.67	157-184.33	232.24±9.72

Table 2. Environmental parameters observed during the seasonal study in Kosi river in 2019

River Kosi (2019)		**Post-Winter**		**Post-monsoon**		**Pre-monsoon**	
S. No.	Parameters	Range	Mean± SD	Range	Mean± SD	Range	Mean± SD
1.	**DO (mg/L)**	7.93-9.38	8.73±0.549	8.90-9.38	9.192±0.2	7.58-8.3	7.99±0.26
2.	**pH**	8.83-9.39	9.122±0.216	8.74-9.46	9.122±0.28	8.89-9.65	9.37±0.32
3.	**W temp (°C)**	22.36-26.53	24.42±1.36	23.66-28.5	26.09±1.56	26.56-29.45	28.011±0.979
4.	**EC (µ/S)**	231.667-296.33	264.75±27.2	248.66-314.33	282.58±21.4	222.33-290	268.46±23.87
5.	**TDS (ppm)**	172-212.33	185.75±14.9	169.66-276.33	208.58±43.9	181.67-262.67	218.75±30.7

Table 3. Environmental parameters observed during the seasonal study in Kolhu river in 2019

River Kolhu (2019)		Post-Winter		Post-monsoon		Pre-monsoon	
S. No.	Parameters	Range	Mean± SD	Range	Mean± SD	Range	Mean± SD
1.	DO (mg/L)	8.1-9.9	9.02±0.91	8.5-10.5	9.32±1.07	8-8.88	8.28±0.25
2.	pH	9-9.5	9.13±0.2	8.7-9.27	8.97±0.26	8-8.7	8.34±0.37
3.	W. temp (°C)	18-22.1	19.6±2.18	19.6-23.2	21.68±1.89	26-28.1	26.96±0.99
4.	EC (µ/S)	323-389	365.55±37	359-395.3	380.66±18.66	382.33-405	393.11±11.47
5.	TDS (ppm)	222.6-279.3	257.55±30.5	268-279	275.22±6.3	279.67-299.3	292.67±11.26

6.4 Telemetry tagging

A total of 11 VHF telemetry tags were tagged on 11 individuals in Kolhu and Kosi river. Six individuals were tagged in Kolhu and five in Kosi. Out of the 11 individuals, eight were found to be female and three were males. The body sizes of the tagged fishes were ranged from 48cm to 106cm and weight ranged between 2100 to 7595g. The age of smallest tagged individual was about 5+ years old and the largest induvial was about 13+ years old. Information on fish catch locations, body measurement and age details are presented in (Table 4).

Table 4: Locations and morphometric characters of the tagged golden mahseer individuals;

Tag code	River	Latitude	Longitude	Total Length (cm)	Standard length (cm)	Sex	Weight (g)	Age (in years)
1	Kolhu	29°41’31” N	78°31'35"E	106	95	male	7595	13+
2	Kolhu	29°41’30” N	78°31'35"E	95	67	male	4500	12
3	Kolhu	29°41’30” N	78°31'36"E	71	57	female	4195	8
4	Kolhu	29°41’30” N	78°31'36"E	80	67	female	4430	6+
5	Kolhu	29°42.257' N	78°33.867'E	66	54	female	2350	5+
6	Kolhu	29°42.257' N	78°33.867'E	58	47	female	1538	7+
7	Kosi	29°27‘08.39"N	79°08'45.54"E	70	58	male	3100	7
8	Kosi	29°27‘08.39"N	79°08'45.54"E	72	59	female	3220	6+/7+
9	Kosi	29°27‘08.39"N	79°08'45.54"E	55	46	female	2100	6+
10	Kosi	29°27‘08.39"N	79°08'45.54"E	61	51	female	2300	9+
11	Kosi	29°27‘08.39"N	79°08'45.54"E	48	39	female	760	5+

The tagged individuals monitored for their movement and location from (June to September, 2019) (Figure 14). The point locations obtained for tagged fishes were represented in maps using ArcGIS (Figure 14 & 15) to determine the distance covered by the tagged fishes. Considering all the observations, more than 300 location points have been generated for all the tagged individuals. The movement of each individual fish was recorded. Results of tracking data were analysed and graphs were generated (Figure 16) to display their movement activity during the monsoon season. Among the tagged individuals, females were reported for large movement in comparison to males in both the river systems. Maximum movement was observed in the tagged individuals in Kosi river; individual with tag10 was reported to show upstream movement of >6kms followed by individual with tag9 with upstream movement of 5.75 kms. In Kolhu, individuals with tag2 and tag4 were reported to move upstream movement covering a distance of 4 and 4.2 kms after the onset of monsoon. Also, we lost our two individuals; tagged with (tag1 and tag3) after few days of tagging due to the natural causes (fish eaten up the otters). Kolhu, being a river with numerous bends in the upper stretch, a long-distance migration was not observed during the monitoring period.

Simultaneously, during the telemetry monitoring period the micro-habitat data and data of environmental parameters was collected and it shown that individuals used both deep and shallow habitats (0.29- > 6.5m) throughout the tagging period. The velocity observed during the monitoring

ranged between (0-5.8m/s) (Table 5). With the onset of monsoonal rains, water-level rises up and due to heavy flow the adult mahseers migrate upstream. The same have been observed in case of tagged mahseers which migrated up stream.

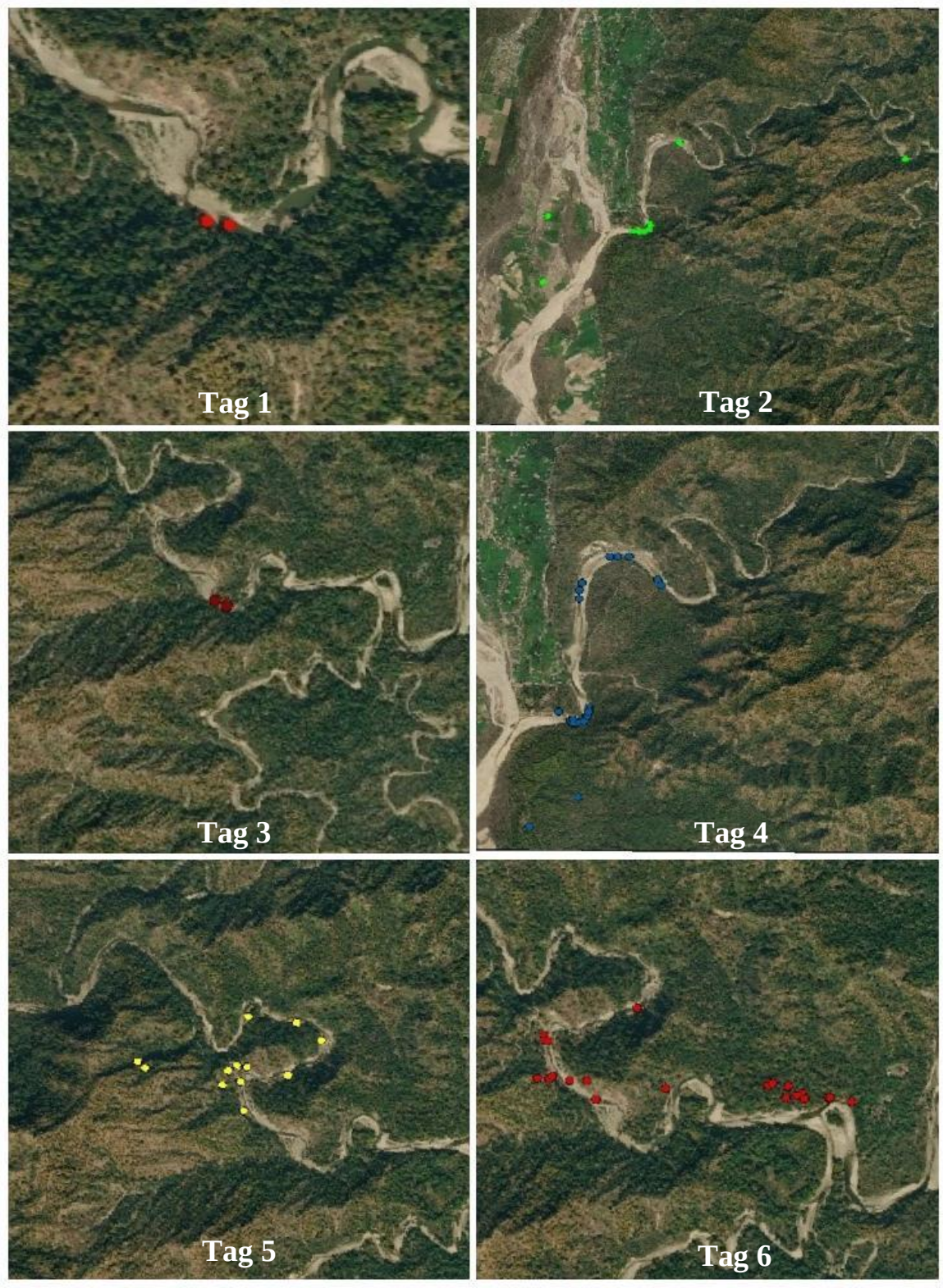


Figure 14. Location points of the tagged individuals (Tag 1 to 6) monitored during the study in Kolhu

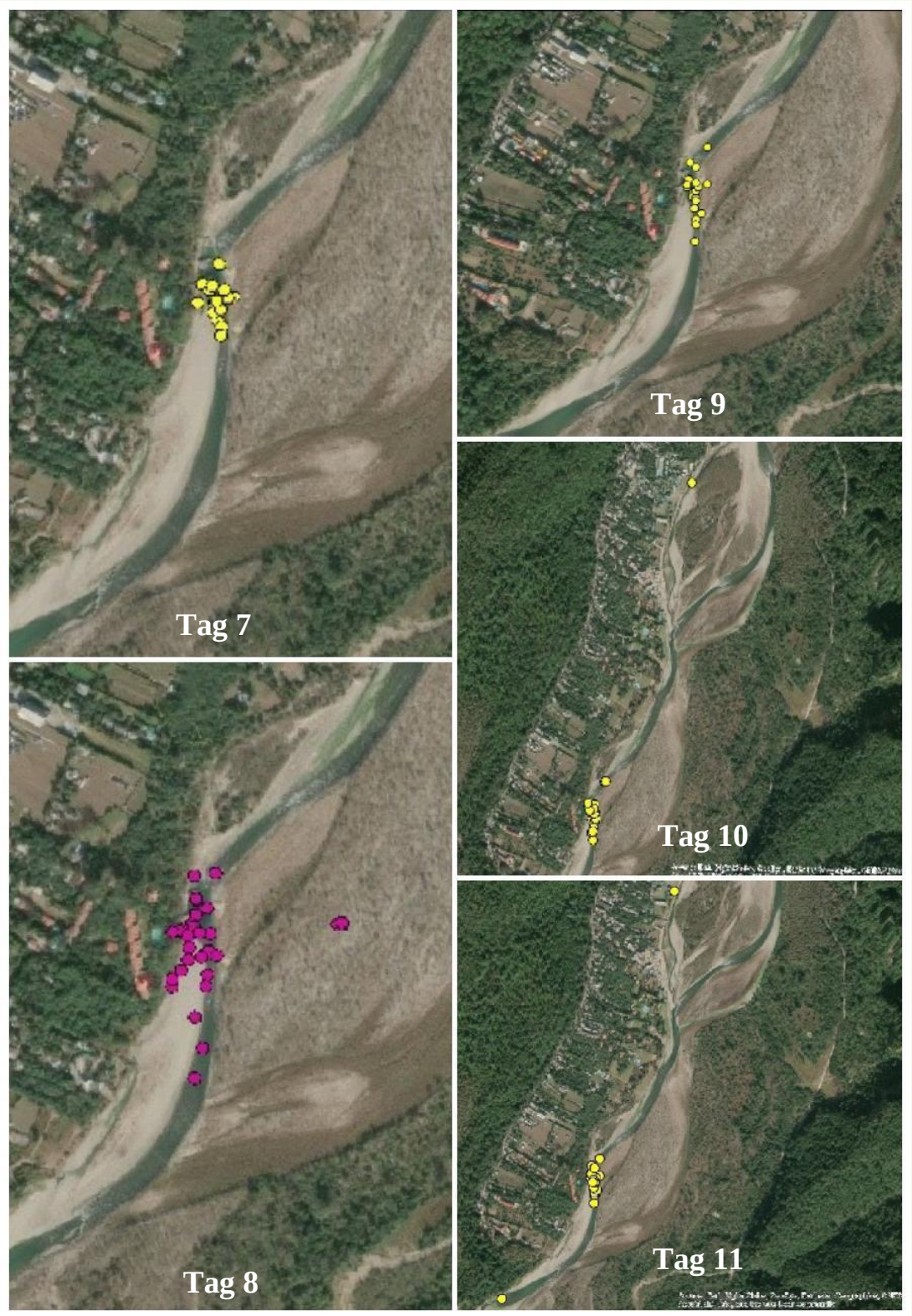
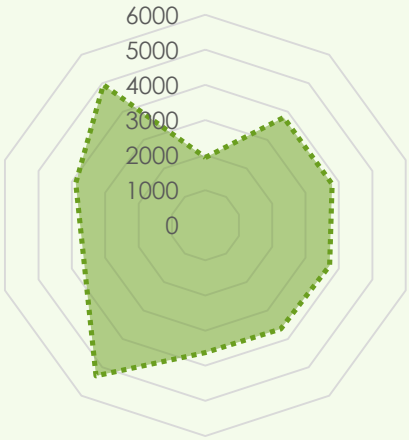
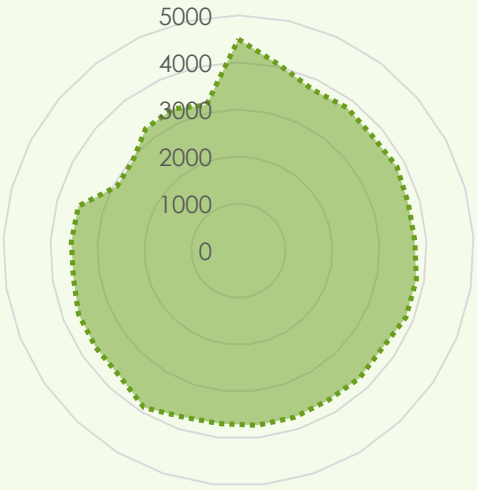


Figure 15. Location points of the tagged individuals (Tag 7 to 11) monitored during the study in River Kosi

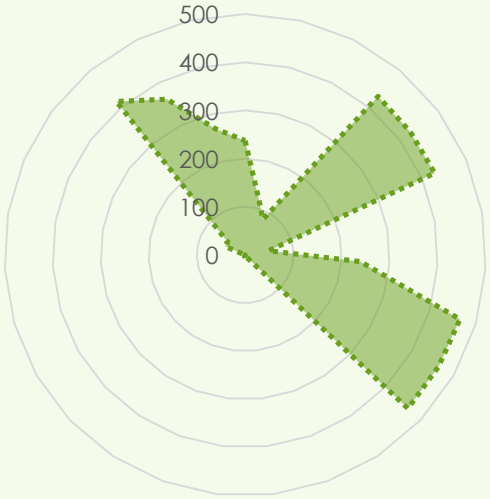
TAG 2



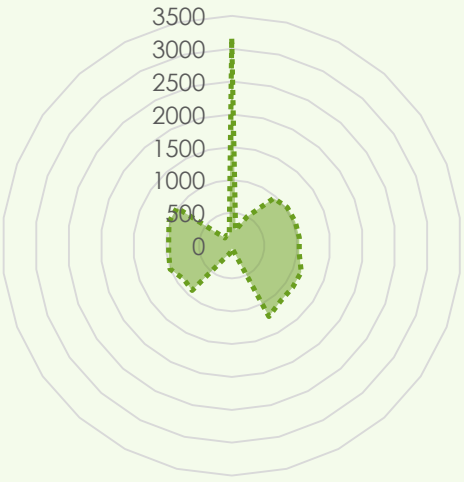
TAG 4



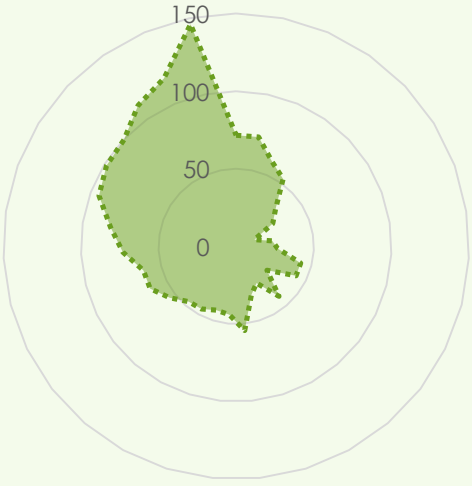
TAG5



TAG6



TAG7



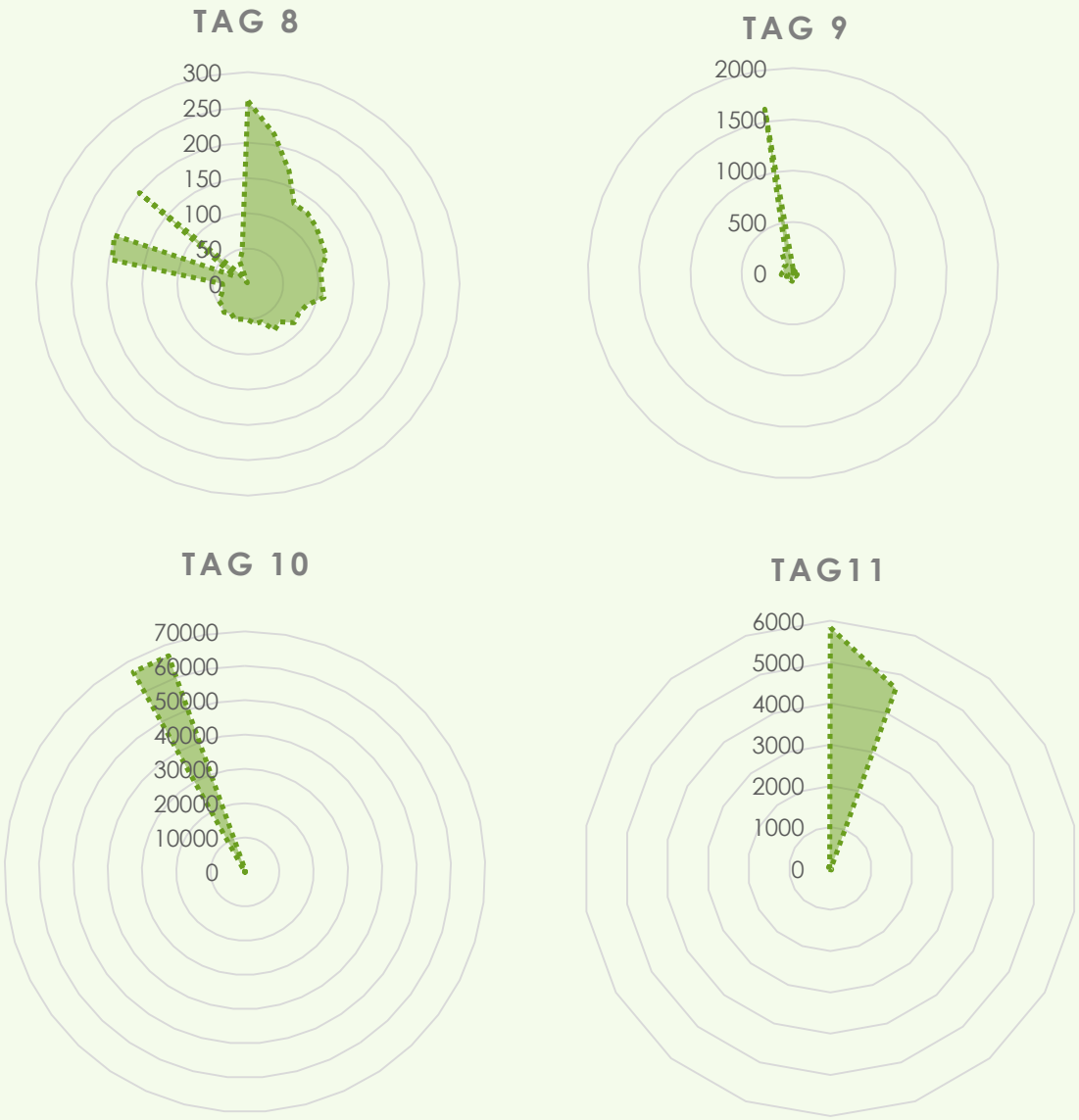


Figure 16. Graphical representation of the movement (values in meters) of tagged individuals during the telemetry studies

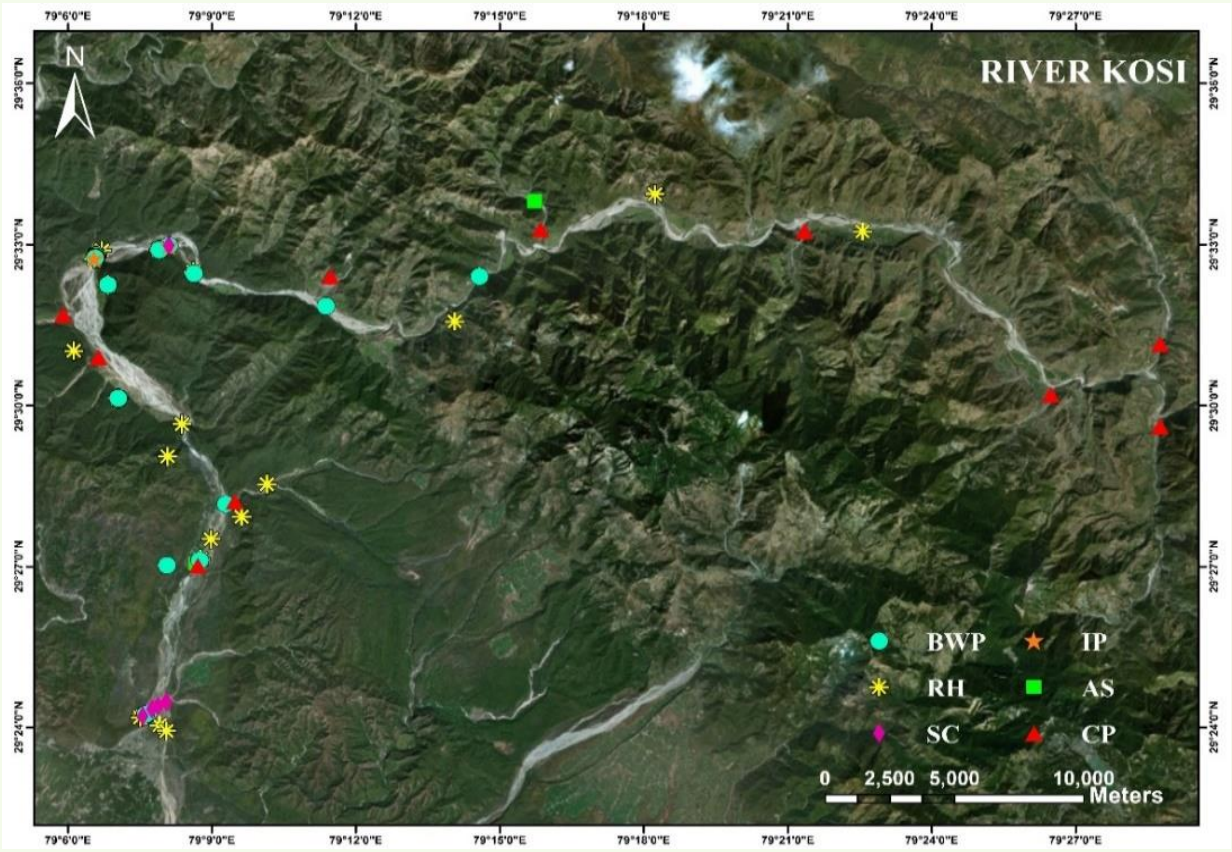
Figure 17. Picture of the tagged fishes recorded during different phase of tracking

Table 5. Observed depth, velocity, pH and temperature in River Kosi and Kolhu during the telemetry studies.

		River Kosi		River Kolhu	
S. No.	Parameters	Range	Mean ± SD	Range	Mean ± SD
1.	**Depth (m)**	0-7.94	2.29±2.15	0.29-2.54	1.55±0.90
2.	**Velocity (m/s)**	0-1.6	0.217±0.48	0-1.4	0.307±0.47
3.	**Water temp (°C)**	22.13-29.23	26.38±1.99	22.98-29.2	25.74±1.59
4.	**pH**	7.8-9.1	8.36±0.331	7.72-8.92	8.26±.26

6.5 Nursery grounds (Fingerlings and Juveniles)

In the study, distribution of young mahseer (fingerlings and juveniles) was surveyed during the post-monsoon season. It was observed that the juveniles occur in run habitats, whereas fingerlings were distributed in flow refuge areas in the river channel i.e., back-water pools and secondary channels. Based on the distribution of young individuals, important nursery grounds along the rivers were identified and mapped (Figure 18). Distribution of young mahseers was recorded in backwater pools, secondary channels and run habitats along and in Kosi and Kolhu rivers. Habitat study for the depth, velocity and substrate preference were analysed for both fingerlings and juveniles. The water quality parameters in both the rivers were recorded during the three seasons and the combined results with range of seasonal variation are shown in the (Table 6a & b).



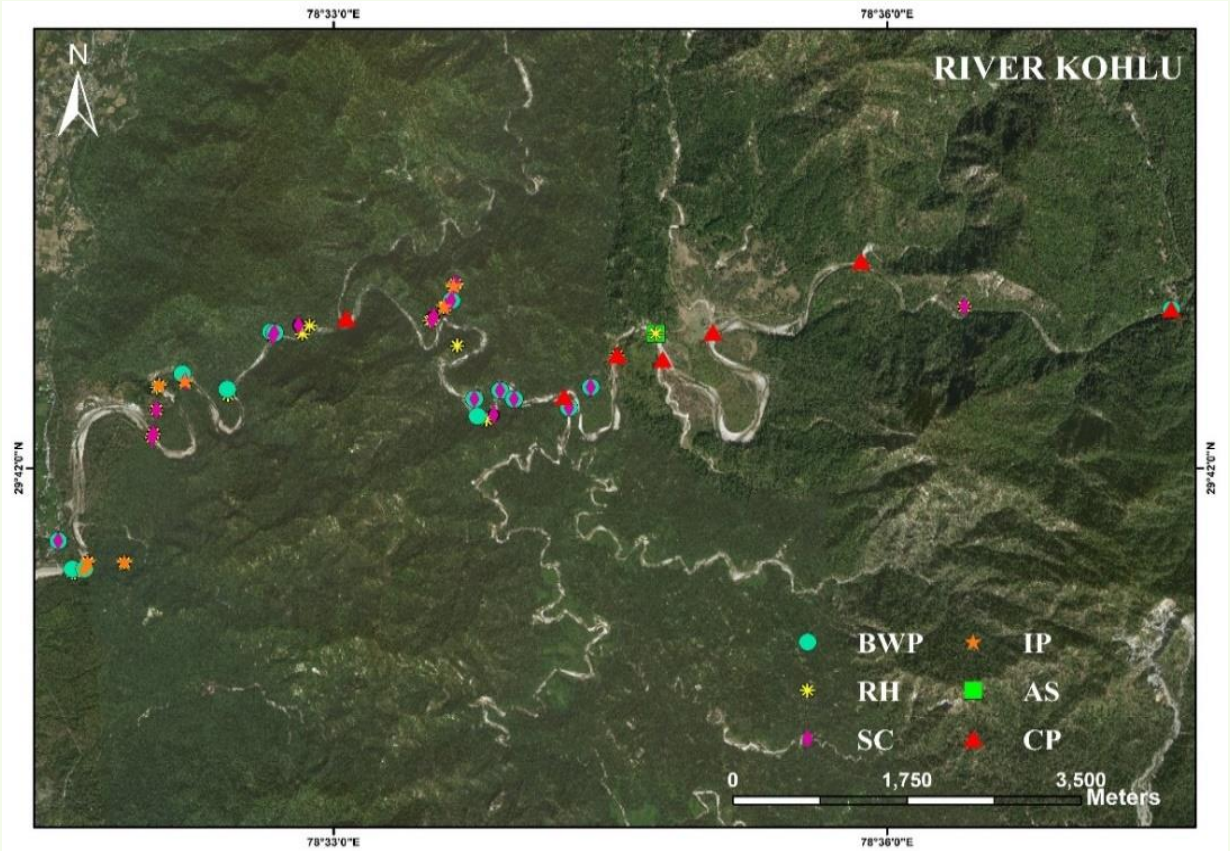


Figure 18**.** Maps showing the location of golden mahseer nursery grounds in Kosi and Kolhu Rivers

Table 6(a). Environmental parameters observed during seasonal study of youngs of golden mahseer, Kosi River

River Kosi (2019)		Post-Winter		Post-monsoon		Pre-monsoon	
S. No.	Parameters	Range	Mean± SD	Range	Mean± SD	Range	Mean± SD
1.	**DO (mg/L)**	7.93-9.38	8.73±0.549	8.90-9.38	9.192±0.2	7.58-8.3	7.99±0.26
2.	**pH**	8.83-9.39	9.122±0.216	8.74-9.46	9.122±0.28	8.89-9.65	9.37±0.32
3.	**W. temp (°C)**	22.36-26.53	24.42±1.36	23.66-28.5	26.09±1.56	26.56-29.45	28.011±0.979
4.	**EC (µ/S)**	231.667-296.33	264.75±27.2	248.66-314.33	282.58±21.4	222.33-290	268.46±23.87
5.	**TDS (ppm)**	172-212.33	185.75±14.9	169.66-276.33	208.58±43.9	181.67-262.67	218.75±30.7

Table 6(b). Environmental parameters observed during seasonal study of youngs of golden mahseer, Kolhu

River Kolhu (2019)		Post-Winter		Post-monsoon		Pre-monsoon	
S. No.	Parameters	Range	Mean± SD	Range	Mean± SD	Range	Mean± SD
1.	**DO (mg/L)**	8.1-9.9	9.02±0.91	8.5-10.5	9.32±1.07	8-8.88	8.28±0.25
2.	**pH**	9-9.5	9.13±0.2	8.7-9.27	8.97±0.26	8-8.7	8.34±0.37
3.	**W temp (°C)**	18-22.1	19.6±2.18	19.6-23.2	21.68±1.89	26-28.1	26.96±0.99
4.	**EC (µ/S)**	323-389	365.55±37	359-395.3	380.66±18.66	382.33-405	393.11±11.47
5.	**TDS (ppm)**	222.6-279.3	257.55±30.5	268-279	275.22±6.3	279.67-299.3	292.67±11.26

6.6 Habitat Use and Suitability of youngs of Golden mahseer

To investigate the habitat preference of natural life-history stages of golden mahseer, present study was formulated to assess the habitat use and suitability of youngs of golden mahseer in Kosi and Kolhu streams in Uttarakhand during the post-monsoon, post-winter and pre-monsoon time (2018-2019). Availability of depth ranges between (0-1m) and velocity (0-1.2 m/s) for fingerlings (Figure 19). For juveniles it was reported between (0-1.2m) and (0->1.2m/s) respectively (Figure 20). Fingerlings were mostly found at depth between (0.1-0.6m) and velocity between (0-1.0m/s). Reported dominant substratum for fingerling habitats were gravel, small cobbles and sand. Similarly, depth ranged between (0.3->1.8 m), high velocity between (0.3->1.5 m/s) and habitats with cobbles, bed rock and gravel as dominant substratum were reported preferred habitats by juveniles. From the study, it was resulted that backwater pools, secondary channels and run habitats were reported to be highly used habitats among fingerlings whereas run habitats were mostly used by juveniles in these rivers in both the seasons (Figure 21&22). Further, habitat suitability curves (HSCs) were generated with respect to the use and availability of microhabitat parameters (Figure 23&24) depicting suitable depth and velocity rate for the youngs in these rivers. The habitat preference of fingerlings in both the rivers falls in range of (0.1-1.5m) throughout different seasons. For the observed points fingerlings found abundantly in-depth range of (0.1-1.2m) and prefer low water-velocity. Maximum depth where

fingerlings were found was 1.8m during the post-winter season. Juveniles used wide range of water-depths from (0.1-1.8m) and velocity ranged (0.1>1.2m/s), although most of the preferred depth range was found to be between (0.1-1.2m) and moderate water velocity.

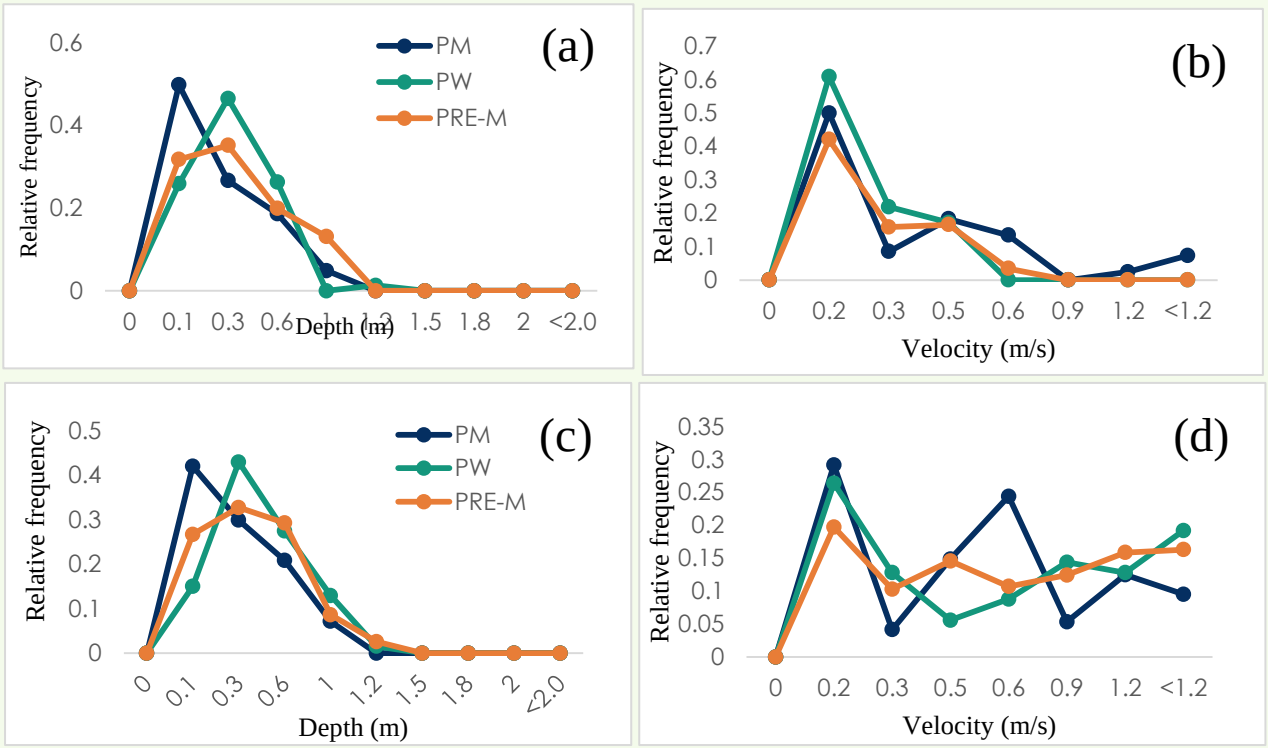


Figure 19. Seasonal variation in availability of depth and velocity for fingerlings (a) & (b) and juveniles (c) & (d)in Kolhu river; PM-Post Monsoon, PW-Post Winter and PRE-M-Pre-Monsoon

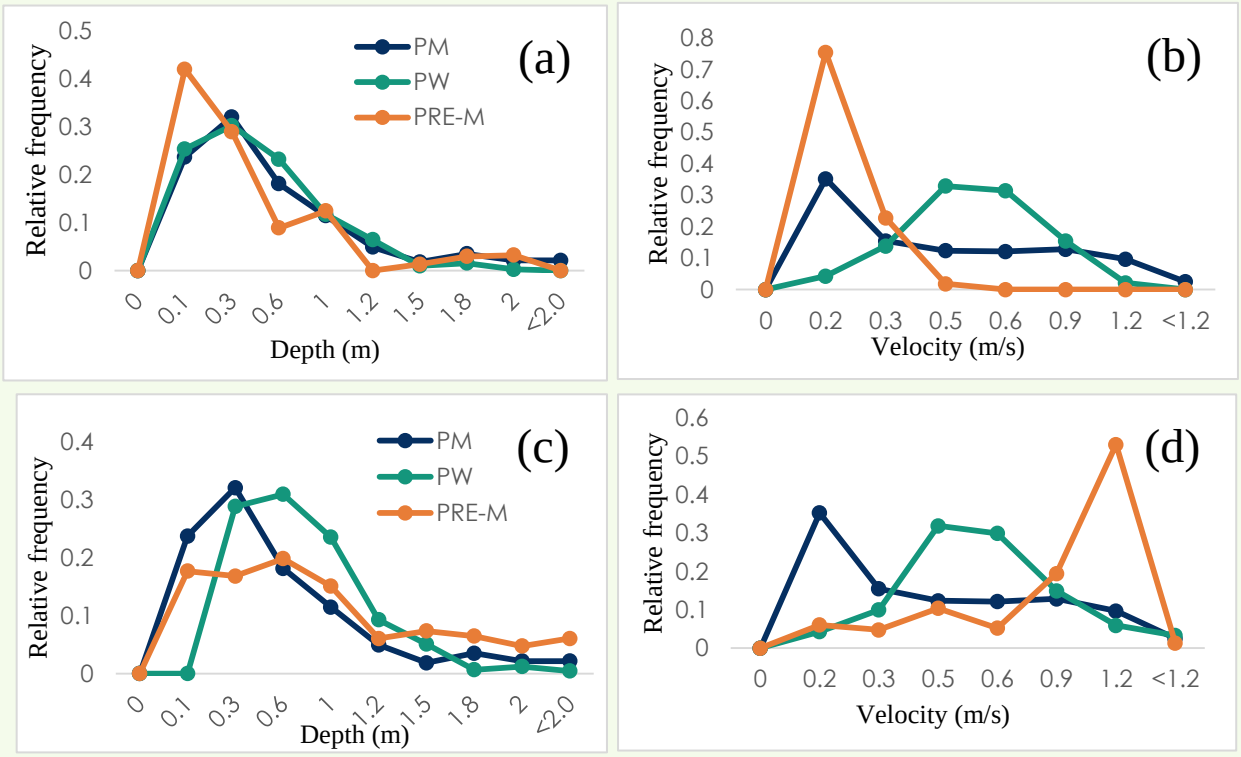


Figure 20. Seasonal variation in availability of depth and velocity for fingerlings (a) & (b) and juveniles (c) & (d) in Kosi river; PM-Post Monsoon, PW-Post Winter and PRE-M-Pre-Monsoon

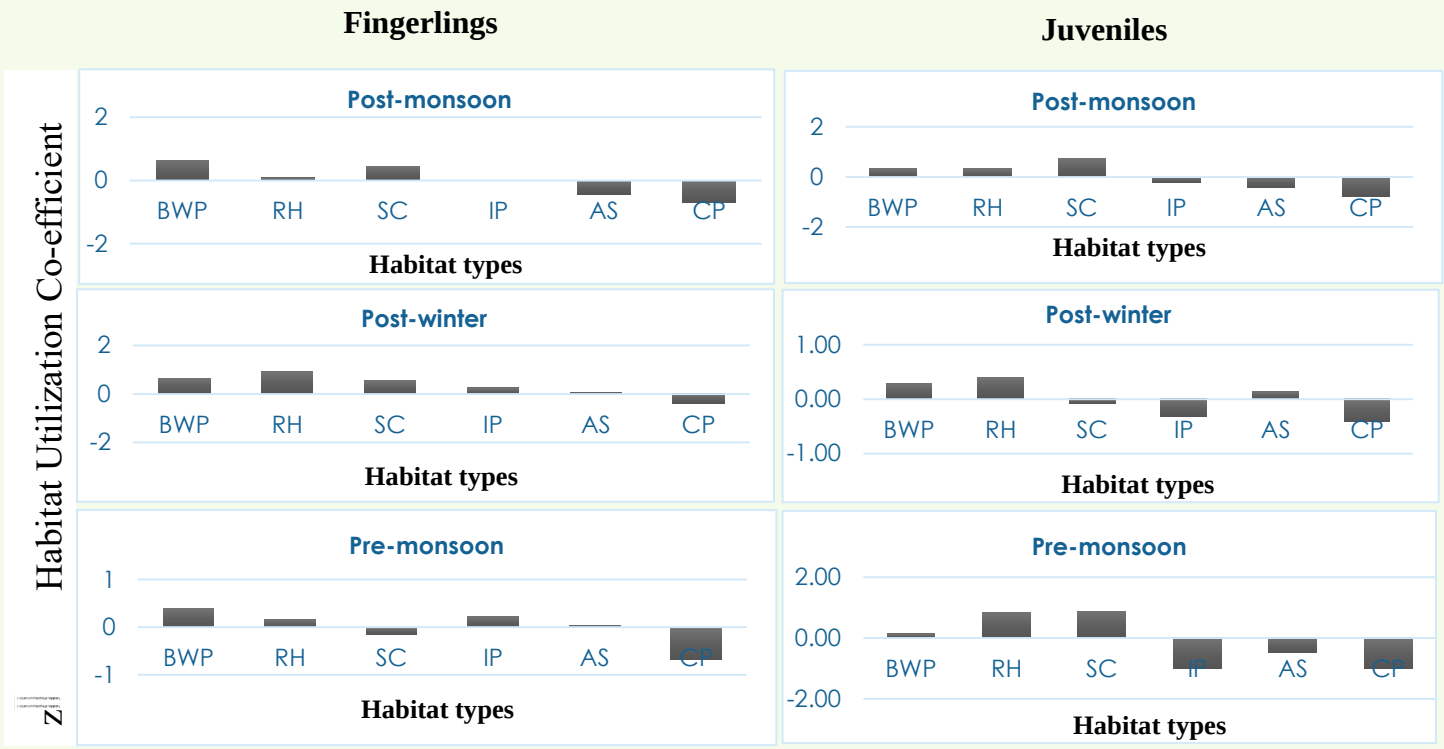


Figure 21**.** Habitat Utilization by Fingerlings and Juveniles in river Kosi

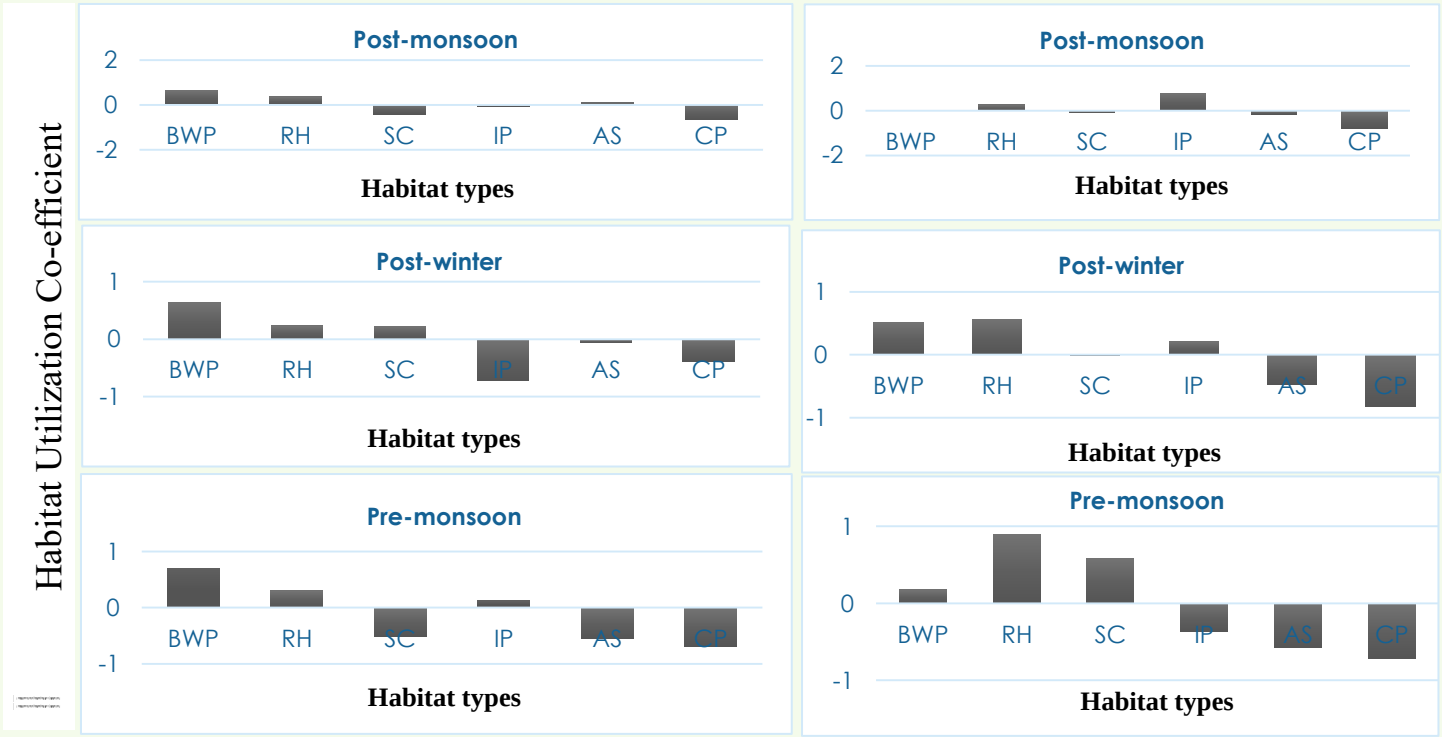


Figure 22. Habitat Utilization by Fingerlings and Juveniles in river Kolhu

Figure 23. Habitat Suitability Criteria (HSC) Curves of the Fingerlings and Juveniles in Kosi River

Figure 24: Habitat Suitability Criteria (HSC) Curves for the fingerlings and juveniles in Kolhu River

6.7 Threats

In the present study, different types of threats that harm the fish community have been observed. As per the threat classification done on observation basis: **(a) Illegal fishing (IF) (b) Destructive fishing (DF) (c) Habitat Modification (HM) and (d) Habitat fragmentation (HF).** On the basis of density-proportion analysis, it was observed that in Kosi, the major threat was related to the over-fishing and destructive fishing (use of bleach and dynamiting) (Figure 25). In case of Kolhu River, major threat is same as in Kosi, illegal fishing activities. During the study, it was found that in the mahseer habitats, fish population was found generally increasing from the lower reaches to the head waters suggesting less population distribution in disturbed (human settlement) areas. Factors like human activities, sewage effluent release from the city, overfishing were found responsible for less fish number (Figure 26). Also, it was found that there has been extraction of gravels, boulders and sand near the river banks accountable for the habitat fragmentation. It may increase the levels of suspended solids in these rivers and that factors can have negative effects on the fish population. Illegal fish catch was found more in the down streams' areas unlike unprotected areas where there is restriction and some control has been observed as per the conservation of the golden mahseer and other fish species.

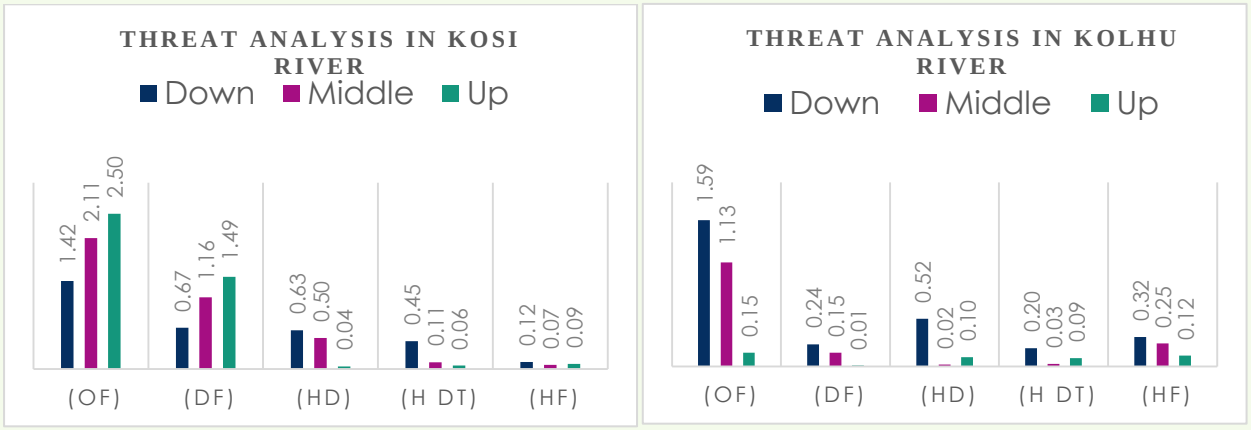


Figure 25. Graph depicting the relative threat proportion analysed for river Kosi and Kolhu

Figure 26. Activities illustrating the fish threats in River Kosi and Kolhu; (i) sand and boulder mining (ii) illegal fishing (iii) fish catch without legal means in Kosi market

1. Present study resulted about the current status and habitat use of golden mahseer population (different-life history stages) in Kosi and Kolhu River for different seasons.
2. Seasonal variability has been reported related to habitat assessment, aquatic environmental/water quality conditions and availability of co-existing fish biodiversity.
3. From the telemetry monitoring data, >300 location points have been located for all the tagged fishes for a period of four months along with the information related to habitat use.
4. Telemetry analysis had shown results related to the movement patterns of golden mahseer in Kosi and Kolhu during the monsoons.
5. Golden mahseers' presence was found positively co-related to the dissolved oxygen content, water currents, depth and clean water.
6. Adult golden mahseer population was found distributed in deep pools with depth range (>1.5m – 5.9m) and low water current but higher during the post-monsoon.
7. Information on the nursery grounds of the youngs of the golden mahseer have been generated. Backwater pools, secondary channels and run habitats were highly used habitats of fingerlings. But, run habitats were mostly used by juveniles in these rivers. Fingerlings were mostly seen at shallow depth with moderate water flow. Run habitats and backwater pools depth (0.3- >1.8m), flow (0.3->1.2m/s) were found preferred habitats of juveniles. Dominant substratum found was gravel, cobbles and sand.
8. Twenty fish species from Kosi and Kolhu have been recorded and major threats prevailing in mahseer habitats were documented.

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