Preliminary study on the movement behaviour and home range of golden mahseer (*Tor putitora,* Hamilton 1822) inhabiting Himalayan waters, India

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Abstract

The present study aimed to document the movement behaviour and habitat use of golden mahseers (*Tor putitora*) inhabiting Himalayan waters. A total of nine adult golden mahseers (two males and seven females) were fitted with a VHF radio tag. In results, individuals were found dispersed with the maximum recorded distance of 4231.23 m and 6119.11 m in the Kosi and Kolhu rivers, respectively. Home ranges for males (0.0245 km^2) and larger individuals (0.0697 km^2) exhibited released side fidelity whereas females (0.361 km^2) and smaller individuals (0.459 km^2) moved long distances. The research results successfully identify golden mahseer movements and spatial ecology knowledge, to conserve the fish habitats.

Key Words: Habitat preference, Kernel density, Radio-telemetry, Ramganga river, Spatial ecology.

Introduction

Movement is an essential feature that living organisms exhibit to meet their biological needs. As an aquatic living form, fish move longitudinally and laterally through their habitats to locate and access resources and places crucial to complete their reproductive cycle[1]. Hence, understanding such a crucial life process is essential in explaining the species' ecology by obtaining information on an animal's space use within its habitat [2,3,4,5]. Electrofishing and field observation methods from above and below the water surface have generated spatial biological data for fishes[6.] However, electronic tagging has allowed scientists to expand their understanding of fish behaviour and environmental requirements[7,8].

The golden mahseer, *Tor putitora*, is an emblematic species among the 16 reported species in the genus *Tor*[9.] It has a distribution record in South Asian countries, from Pakistan in the west to India, Nepal, Bhutan, and Myanmar in the east[10, 11]. In India, this species predominantly occurs in the natural running rivers of the Himalayan foothills, up to 1500 m of altitude[12,10,13]. Being a large-sized fish with gaming qualities, the golden mahseer is the most intensively studied among all the "*Tor*" species[14,15,16].

Golden mahseer migrates in phases during different seasons,[14,10] characterised by water currents and optimal water quality conditions. The field observation by Nautiyal[17] and Nautiyal et al.[16] revealed that the movement of the fish gets triggered by water temperature, water velocity and turbidity during the migratory phase, and the mature adult fish ascend the Himalayan river's lower tributaries in rain-fed rivers. Aquatic habitat features such as water velocity, depth, temperature, and other physio-chemical parameters are essential for golden mahseer movement and distribution in these rivers[18,19]. However, very little is known in this regard; being a sensitive fish, even modest disturbances in the golden mahseer habitat might cause the population to decline. As a result, despite several efforts of conservation measures, its distribution in the Indian Himalayan stretch is getting limited. Climate change, overfishing, pollution, habitat modification, sand and boulder mining, and the establishment of hydroelectric power plants have been reported to contribute to the population decline of the golden mahseer in the Himalayan rivers[20,21,22,23].

In the present study, we used the radio telemetry technique to understand the fish species' spatial ecology and their habitat preferences concerning physio-chemical parameters in two potential riverscapes, Kosi and Kolhu, in the western Himalayan foothills of India. We targeted the monsoon and post-monsoon seasons (late June to mid-October) to research the golden mahseer's movement patterns

and home range. The primary goals of this study were to (i) evaluate the movement patterns and home ranges of golden mahseer in the Himalayan rivers and (ii) parameterise environmental variables at the site of their habitat utilisation. We also hypothesised that the golden mahseer migrates upstream during monsoon, and variations in water velocity, volume, and physiological-chemical characteristics influence their movement behaviour.

Materials and methods

Study area

The current study was carried out in the tributaries of the river Ramganga, Kosi, and Kolhu rivers in the state of Uttarakhand (Figure 1). The Kosi (517 m above MSL) is an undammed perennial stream that flows through the Kumaon region of Uttarakhand[24]. The channel meanders through Ramnagar Forests Division (Reserve Forests) and is part of the Corbett Tiger Reserve. River Kolhu, is a rain-fed stream that originates at the confluence of two headwaters and flows through Lansdowne's Forests Division (Reserve Forests). It flows about 16–18 kilometres across the Shivalik's mountainous terrain in Uttarakhand's Pauri-Garhwal district (315 m above MSL).

Field methods

Telemetry tagging

Individuals of the adult golden mahseer (9 females and 2 males) were captured along the Kosi (n = 5) and Kolhu rivers (n = 6) (Figure 1) using the gill net (10 cm X 10cm and kept in a nylon net bag and then brought into shallow water to perform tagging exercises. Cylindrical-shaped VHF radio transmitters (Lotek Wireless Inc., Canada, Model MCFT3-L-TP) 80 mm long, 15 mm wide, and 20 g weight in the air were used. The mass of these transmitters represented <2 % of the fish's body mass ($\bar{x}$ = 2.69978 ± SD=1.245 kg). Each transmitter was used at a frequency of 150.00 MHz with a unique code for individual identification. However, the battery life of the transmitter was programmed to ~ 600 days for "on" for 12 hours and "off" for 12 hours with a signal transmission at an interval of every 2 seconds. A total of eleven telemetry transmitters were externally affixed[25] to the golden mahseer individuals, ranging from 48.0 cm (760.0 g) to 95.0 cm (4500.0 g) in size and 5+ to 12 years of age in

June 2019 (Table 1). The scale samples of the tagged individuals were analysed in the lab to estimate their age. The tags were attached at the dorsal side of the body, close to the dorsal fin area, with the help of a needle, piercing the muscle nearby. The overall tagging exercise took 2-3 minutes per individual. After tagging, the fish were examined for any physical injury. It was ensured that, after being released, all the fish were healthy and able to move smoothly. The necessary approval and authorisation to perform field activities were obtained from the Uttarakhand State Forest authorities, and no harm to individuals was harmed per the guidelines provided. For further analysis, individuals tagged in Kolhu were named KL1, KL2, KL3 and KL4, whereas those tagged in Kosi were assigned KS1, KS2, KS3, KS4 and KS5.

Post-release manual tracking

Tracking of tagged golden mahseer individuals started in late June 2019 and continued till October 2019. After 12–16 hrs of the post-release, detections were made to account for the acclimation period. Individuals were tracked from the bank of the river using an "H" shaped hand-handle antennae and receiver (N = 1, Lotek Company, Canada; Model SRX400). The detection range of the receiver was around <50m radius. Tracking was conducted every fortnight during the study period, upstream and downstream of the rivers, to locate all the tagged individuals. Since the rivers flow through the protected areas and there were other large mammals such as elephants and tigers, all tracking exercises were performed during the daylight. Fish locations were collected using the receiver's automatically recorded latitude and longitude coordinates and a geographic positioning system (GPS; Garmin etrex, 20X, USA).

Physio-chemical parameters

Critical habitat and water quality parameters were assessed during the tracking. We generated nine ecological variables through tracking surveys. The river depth, water velocity, and presence of substrate type were measured at each recorded location of the fish. The telemetry receiver, a depth rod, and a velocity metre were used to record the individuals' water depth and velocity. The composition of each substrate type was quantified based on visual observation. The size classification was done as bedrock

(> 200mm), small boulders (150–200mm), cobbles (50–150mm), gravel (5–50mm), sand-silt (1-2mm), and leaflitter, followed[26,27].

Additionally, the water temperature was recorded on the receiver for each fish habitat. At the same time, total dissolved solids (TDS), pH, salinity (S), and electric conductivity (EC) were all measured using a hand-held probe (Eutech PCS Tester 35 multi-parameter probe). Dissolved oxygen (DO) content was measured for the locations using Wrinkle's method (once per week).

Analytical methods

Movement behaviour

All the collected fish locations (coordinates), were arranged in order in Microsoft Excel 2016 and then imported into the software ArcMap 10.5[2,28]. Individual distances travelled were determined by measuring the distance between two consecutive locations. The total distance travelled was calculated by considering all the daily distances travelled. Also, total displacement was estimated in both upstream and downstream directions as the straight-line distance between the starting point of release and the last observed position of the individuals. We used Arc GIS (10.5) to create trajectories to better understand the downstream and upstream movement patterns. Home Range

Out of the 11 tagged and released golden mahseer individuals, two individuals were lost just two days after their release. Thus, only nine individuals were tracked after that and were considered for analysis. We used the concept of the linear home ranges[2,29,30,31] and kernel density home range estimates[32,33,34,35] for our study in the riverine habitat because the MCP (minimum convex polygon) calculated for different individuals overlapped mostly in the terrestrial habitat. The kernel density home range estimates (95%, 75%, and 50%) were used to determine the habitat utilisation by golden mahseer. To understand the home range of golden mahseer in this study, we considered 95% (KDE) as the total home range of the individuals and 50% (KDE) as the core area. ArcMap 10.5 software created the home range map and calculated the size.

Habitat preference and water quality

To understand the habitat preference of the golden mahseer individuals, we looked for locations inside the 95%, 75%, and 50% KDE in the studied rivers[36] and used kernel density estimates to explain the home ranges and habitat use of individual species in their habitats. To define the association of the physicochemical parameters with the preferred habitat, we investigated the collected six important physicochemical parameters, i.e., water temperature (WT), presence of total dissolved solids (TDS), presence of hydrogen ions, i.e., (pH), electric conductivity (EC), salinity (S), and dissolved oxygen (DO), and three habitat parameters, i.e., water depth, velocity, and substrate type. Regression analysis was performed in R software version 4.1.1 to assess the relationship between habitat selection of stream sites and the water quality data about habitat preference.

Results

Movement behaviour

The nine tagged individuals were located N = 340 times during the tracking. The tagged individuals showed dispersion between 74.53m and 1369.19m ($\bar{x}$ = 347.74 ± SD 41.274 m). The total mean distance travelled for golden mahseer individuals differed significantly (t =2.519, p = 0.0193). Four of the nine individuals, KL2, KL4, KS3 and KS4, travelled long distances ($\bar{x}$ = 4927.88 ± SD 1182.24 m) (Table 2). Similarly, three individuals with code ids KL1, KL3and KS5 travelled short distances ($\bar{x}$=497.96 ± SD 53.82 m), and two individuals, KS1 and KS2, ($\bar{x}$ =287.05 ± SD 63.34 m) exhibited site fidelity behaviour. Individuals with ids KS3 travelled the longest distance upstream (5721.35m), whereas KS4 travelled the maximum distance downstream (6119.11m) (Table2, Figure 2). The average daily distance travelled by female golden mahseer individuals was $\bar{x}$ =324.06 ± SD= 197.4 m, and for male golden mahseer, the figure was $\bar{x}$ = 108.12 ± SD= 29.3 m. We observed that the average total distance travelled by females was larger ($\bar{x}$ =1938.22 ± SD= 226.39 m) than males ($\bar{x}$ =169.22 ± SD=20.126m) during the study period. While considering the upstream and downstream specific movements, a significant difference (p = 0.0012) was recorded between female and male individuals and between different sites.

Home Range

The radio-tracking of golden mahseer produced linear and kernel density estimates of their home range. The average linear home range of the tagged individuals was 347.44 ± SD=41.374 m. The linear home

range for individuals was reported to be significantly different (t =2.519, p = 0.035). The individual KS4 (1369.19 m) occupied the largest linear home range, and the smallest linear home range was reported in KS2 (74.53m) (Table 2). A female individual, KL4 (length = 58cm; weight = 1538g) (Table 2), had the largest estimated total kernel density home range (2.168 km^2), followed by KL2 and KL3 (0.2074 km^2 and 0.1066 km^2), respectively. In the Kolhu River, the mean core area of the tagged individuals was estimated as 0.0599 ± SD=0.095 km^2, while in the Kosi River, it was calculated as 0.00155 ± SD=0.00108 km^2. Individuals of the river Kolhu, with an area of (0.24 km^2) had a higher percentage of 50% KDE (core area home range) than those of the Kosi (0.0077 km^2). Furthermore, individuals' core home ranges varied significantly (t= 1.25, p = 0.0039). Given the smaller number of males present during the study period (n = 2), we could not identify any sex-related changes in the home range. The spatial distribution of each individual with 95%, 75%, and 50% home range analysis is illustrated in (Figure 3).

Habitat preference

Both rivers' ecosystems comprise microhabitats like pools, runs, and riffles. Most individuals were observed in the pool areas of the study stretch. The most common river depth where the individuals were observed was between 0.4 to 2.43m, and the average depth at which the individuals were located in the rivers was ($\bar{x}$ =1.81 ± SD=0.495 m). Throughout the study period, the river flow was reported to vary between 0 m/s and 2.09 m/s and the mean preferred velocity was reported to be ($\bar{x}$ =1.167 ± SD=0.62 m/s). The preferred habitat's riverbed was mostly sandy with large boulders. The average temperature recorded was 25.171 ± SD=0.795 ^oC; average pH was measured to be 8.48 ± SD= 0.20, mean electrical conductivity was 280.80 ± SD= 28.70 µS cm^{-1} and average total dissolved solids, TDS was found 200.1 ± SD=38.55 ppm.

Similarly, the average salinity and dissolved oxygen were measured to be 128.47 ± SD= 25.91 ppm and 8.833 ± SD= 0.29 mg/l, respectively. The regression model results revealed that water velocity (flow), TDS, and salinity were positively related to mahseer habitats among the studied parameters. In contrast, electric conductivity (EC) was negatively related to golden mahseer habitats during the study period. The final selected regression model, including estimates and standard errors for each water quality indicator, is shown in (Table 3). Per week average distance travelled by the fish individuals in the rivers

Kosi and Kolhu (Figure 4) exhibited maximum movements between week 7 and week 12 (early August – mid-September).

Discussion

In the present study, we observed initiation movements by the individuals soon after their release and after the rain commenced. Variations in the movement pattern among individuals were also observed. Not every individual made long-distance movements during the rise in the water, and some showed small movements. We also found that female golden mahseer individuals travelled longer distances than males. Variations in the movement patterns at the individual level have been observed earlier by several studies[37,38,39,40,41].

Golden mahseer, being a rheophilic species migrates during the monsoon and breeds and spawns in the upstream areas[16]. In a recent study conducted in Bhutan, the distance travelled by golden mahseer was reported to be >50 km in 48 hours (Fisheries Conservation Foundation and World Wildlife Fund-Bhutan pers. comm. 2018). This study also reported the utilisation of warmer tributaries for spawning and homing instinct behaviour of golden mahseer individuals. However, in the present study, we have reported a maximum movement of 6.12 km in the foothills of the Western Himalayas. The reason observed is that several factors, including habitat connectivity, water availability and other environmental factors[32,33] that can influence the movement of individuals in their habitats. Hence, this difference in the movement pattern of golden mahseer in the Western Himalayas could be an artefact of difference in the river's physiographic conditions or the environmental parameters. Also, suitable spawning and nursery grounds and resource availability might have provided potential spawning habitats for the individuals, and they only migrated briefly. Moreover, these two rivers are mostly fed by monsoonal rains and groundwater discharge. Thus, the water remains warmer in these rivers than in the typical Himalayan rivers. However, future telemetry studies on the typical Himalayan rivers will give a better answer if there is a migrating and resident population of golden mahseer.

Furthermore, such a difference in the movement pattern could be attributed to the individual's ability or resource availability, which either did not allow such a long-distance movement or facilitated the

individuals in a smaller area by satisfying all their resource needs[42]. Golden mahseers are also considered sensitive to environmental recognition[16]. This could be why some individuals, after their release, stay near the site while others travel a significant distance to find a suitable habitat. Also, we observed that intra and interspecific competition influences such variation in the movement at the individual level.

Regarding sex-biased movement, females in most aquatic habitats generally move longer distances to locate suitable breeding and spawning grounds[43,44]. They often need a comparatively safer site with less competition and abundant resources, which increases their breeding success. We also observed an intra-specific coalition of golden mahseer during the monsoon rains, where individuals prefer to stay together. We frequently observed such phenomena where other non-tagged individuals were spotted along with the tagged ones. Such associations correlate with their breeding successors and might be a defensive behaviour against predators.

Following that, physically tagging fish and releasing them into the habitat puts the fish under stress, and it takes time to acclimate. In our situation, the predator of the golden mahseer (smooth-coated otter) ate up an individual during the telemetry tracking time phase, and we lost the individual due to its slow movement.

Home Range

The estimated golden mahseer's home range in the Kolhu and Kosi rivers is difficult to compare because no similar studies have used kernel density estimates to determine the home ranges. However, we find sufficient rational ground to use kernel density estimates in our study. KDE generates a smooth density estimation for measuring home range and can increase the information content of home range estimation; it is also widely accepted and recommended, particularly in lotic systems, which we chose to use in our study due to the limited study time[45,46,47,48]. However, the individuals' core home ranges had been reported to have some significance in previous studies on the species' ecology, which could be significant for the species' future conservation. Almost every individual's core area (50 % KDE) was in the released site. Females tended to establish a larger home range (95% KDE) than males. The

larger and smaller home ranges in the Kosi and Kolhu rivers are attributable to several reasons, including habitat preferences, inter-and intra-specific competition, and anthropogenic disturbances in individuals[37].

Habitat preference

Deep-water pools characterised the core area (50% KDE) with an average depth (>1.4m). In contrast, the home range (95% KDE) includes the different riverine habitats characterised by cobbles, sand beds, and secondary water channels that connect to the golden mahseer's core area. The core zone of the golden mahseer individuals in the Kosi was restricted to the released site, which had deeper depth and good cover. The presence of sandy bed ponds with large rocks and cobbles characterises the golden mahseer's aquatic habitats in Kosi and Kolhu rivers[10,14,18]. The habitat locations of golden mahseer were shown to be favourably associated with the measured physio-chemical and habitat characteristics[16]. The observed water velocity and temperature were closely associated with earlier studies[10,16,49] and comparable with Bhutan studies[9].

Limitations and future scope of the study

We had certain limitations to our study. Our study had a limited time frame, not covering different seasons; small sample size and less male individuals. Also, we used the radio telemetry equipment, i.e., external tagging and VHF tracking system, to generate information. Manual tracking was done throughout the monitoring phase in undulating rocky terrain and monsoonal floods, utilising a single antenna and receiver. As a result, using modern satellite telemetry to collect more fine-scale data on such endangered species long-term should be highly encouraged. Furthermore, our observation of the mahseer coalition during the monsoon season might be the future scope of research. Though we linked some behavioural phenomena with the species' breeding success, we needed more evidence to prove this.

Implications

The present research focuses on the spatial ecology of golden mahseer individuals in the Kosi and Kolhu rivers of the Indian Himalayas. It revealed the movement pattern, home range, habitat preference, and ecological parameters associated with it, all considered important for the conservation and management of this endangered species. Our research is the first of its nature in Himalayan rivers and might be used as a base to formulate and further understand the ecology of other mahseer species.

Conclusion

In conclusion, our study provides valuable insights into the golden mahseer movement patterns, home-range parameters, and habitat preferences. Furthermore, radio-telemetry data suggested that golden mahseer travelled long and short distances downstream and upstream in search of suitable spawning grounds. It demonstrated the significance of individual behaviour and the differences in fish habitat selection. This information is valuable and should be considered while formulating the conservation measurements and management plans for the golden mahseer individuals. We suggest habitat protection, prohibiting illegal fishing, and public awareness of these essential Himalayan streams and rivers.

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Table 1: Information on the transmitters, tagged fish and release points (GPS locations) in each site during radio telemetry.

[†]cm: centimetres, g: grams, min: minimum, max: maximum, SD: standard deviation

‡ (KL1 to KL4 – represent tagged individuals from Kolhu river; KS1 to KS5 - represent tagged individuals from Kosi River)

Fish Id	Date	Stream	Latitude	Longitude	Fish length (cm)	Fish gender	Fish weight (g)	Fish age (years)
KL1	20.6.2019	Kolhu	29.6916583	78.5272701	95	male	4500	12
KL2	20.6.2019	Kolhu	29.69168611	78.52666667	80	female	4430	6+
KL3	21.06.2019	Kolhu	29.70986111	78.5577778	66	female	2350	5+
KL4	21.06.2019	Kolhu	29.70939722	78.55861111	58	female	1538	7+
KS1	22.06.2019	Kosi	29.45196667	79.14602222	70	male	3100	7
KS2	22.06.2019	Kosi	29.45209444	79.14589444	72	female	3220	7+
KS3	22.06.2019	Kosi	29.45222222	79.14589444	55	female	2100	6+
KS4	22.06.2019	Kosi	29.45207778	79.14586389	61	female	2300	9+
KS5	22.06.2019	Kosi	29.45209167	79.14587778	48	female	760	5+
Mean					67.22		2699.78	
Max					95.00		4500.00	
Min					48.00		760.00	
SD					14.18		1245.98	

Table 2: Description of each tagged individual movement pattern and home range.

† min: minimum, max: maximum, SD: standard deviation

‡ (KL1 to KL4 – represent tagged individuals from Kolhu river; KS1 to KS5 - represent tagged individuals from Kosi River)

Code of transmitter	Number of recorded locations	Distance travelled (m)	Meantime (days) of track	Linear Home Range (m)	Home range (km^2)			
					95% KD area	75% KD area	50% KD area	Total KD area
KL1	39	541.10	54	128.84	0.0216	0.0090	0.0039	0.0227
KL2	40	4231.23	57	264.04	0.1295	0.0507	0.0272	0.1385
KL3	33	437.64	63	139.6	0.0817	0.0181	0.0069	0.0830
KL4	33	3639.81	71	568.56	1.4416	0.5248	0.2017	1.4454
KS1	38	240.14	57	87.39	0.0100	0.0033	0.0014	0.0102
KS2	42	333.96	56	74.53	0.0143	0.0062	0.0019	0.0145
KS3	46	5721.35	60	338.28	0.0003	0.0011	0.0032	0.0003
KS4	48	6119.11	63	1369.19	0.0090	0.0029	0.0009	0.0094
KS5	30	515.15	45	156.53	0.0023	0.0011	0.0004	0.0024
Mean	38.78	2419.94	58.44	347.44	0.1900	0.0686	0.0275	0.1918
Max	48	6119.11	71	1369.19	1.4416	0.5248	0.2017	1.4451
Min	30	240.14	45	74.53	0.0003	0.0011	0.0004	0.0003
SD	6.06	2488.53	7.18	41.374	0.4714	0.1718	0.0659	0.4723

Table 3: Estimates and statistics for the regression model predicting the relation of water quality parameters and tagged golden mahseer individuals.

† SE: standard error

Predictor	Estimate	SE.	*z*-value	*p*-value
Intercept	-3.458750	0.653873	-5.290	1.23e-07

Flow	0.143468	0.079048	1.815	0.06953
TDS	0.008342	0.002836	2.941	0.00327
EC	-0.003612	0.002131	-1.695	0.09010
Salinity	0.007683	0.003033	2.533	0.01130

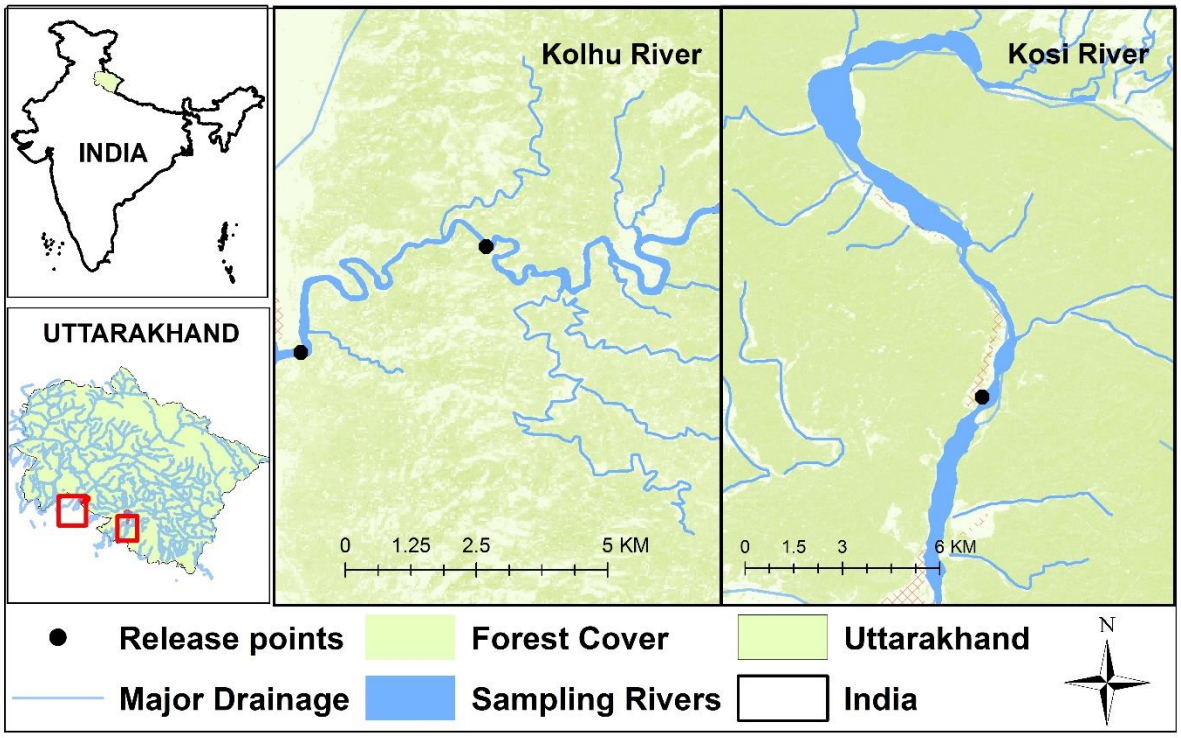
Legend to Figures

Figure 1: Map showing locations of Kolhu and Kosi rivers of Ramganga river basin, Western Himalaya, India (Block dots representing the release locations of the golden mahseer tagged individuals)

Figure 2: Representation of the movement trajectories (colored lines); the upstream and downstream movement (arrow directions) of radio-tagged golden mahseers (n = 9) [KL1 to KL4 – represent tagged individuals from Kolhu river; KS1 to KS5 - represent tagged individuals from Kosi River].

Figure 3: Tracking data and Kernel Density Home Ranges (KD HR) of radio-tracked golden mahseers (n = 9) [KL1 to KL4 – represent tagged individuals from Kolhu river; KS1 to KS5 - represent tagged individuals from Kosi River; KD - Kernel Density].

Figure 4: Graphical representation of the weekly distance travelled by radio-tagged individuals during the monitoring period [KL1 to KL4 – represent tagged individuals from Kolhu river; KS1 to KS5 - represent tagged individuals from Kosi River].



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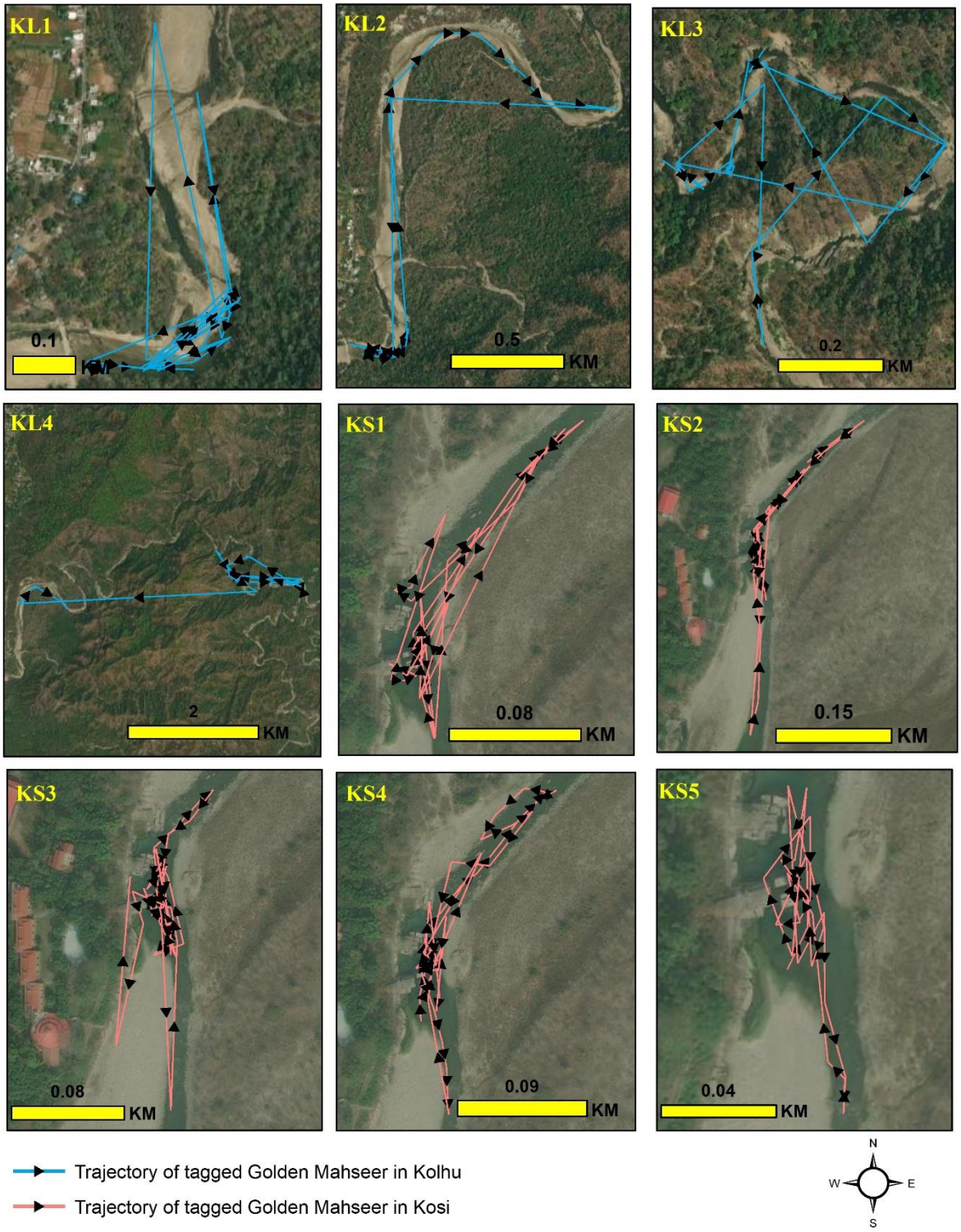

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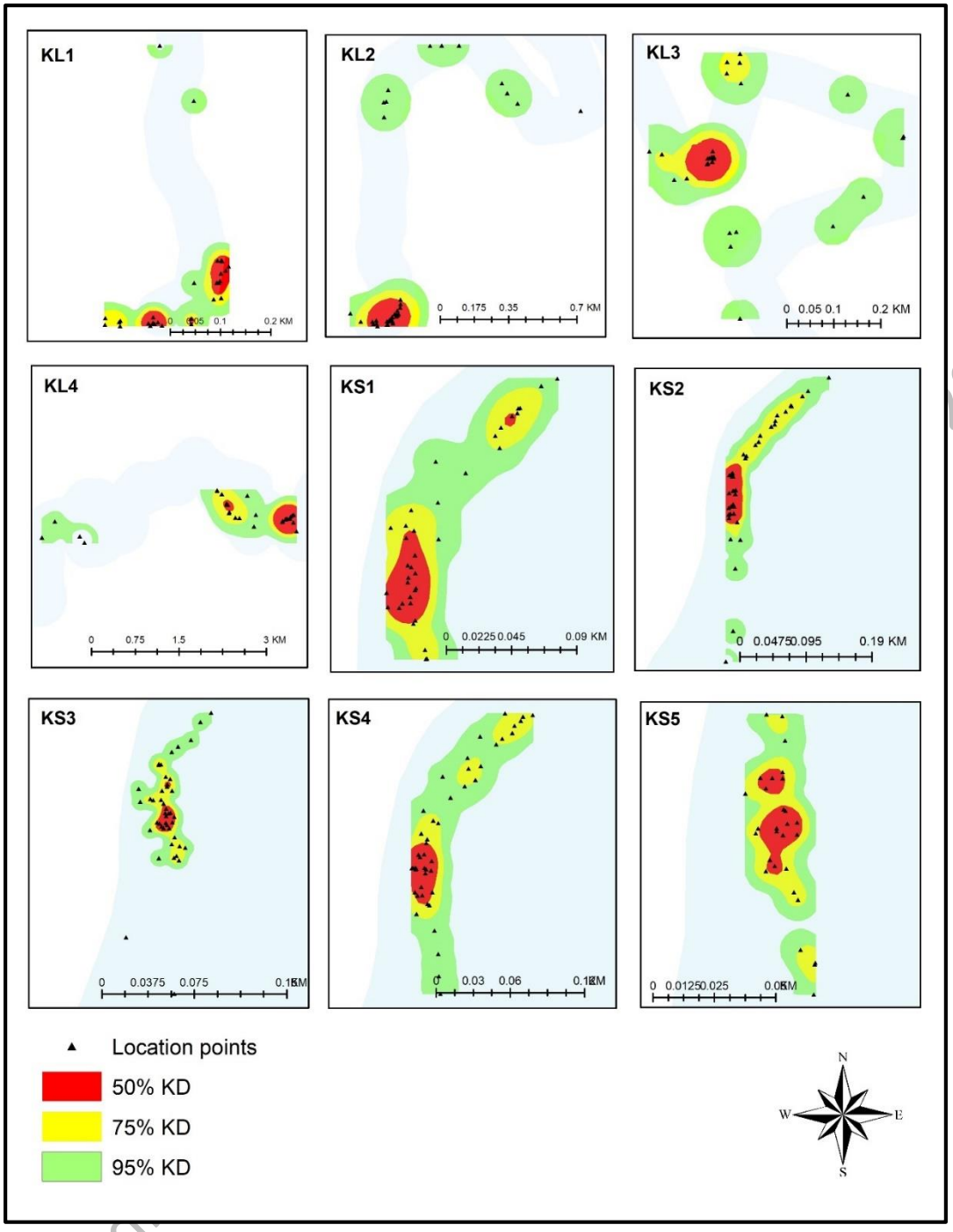

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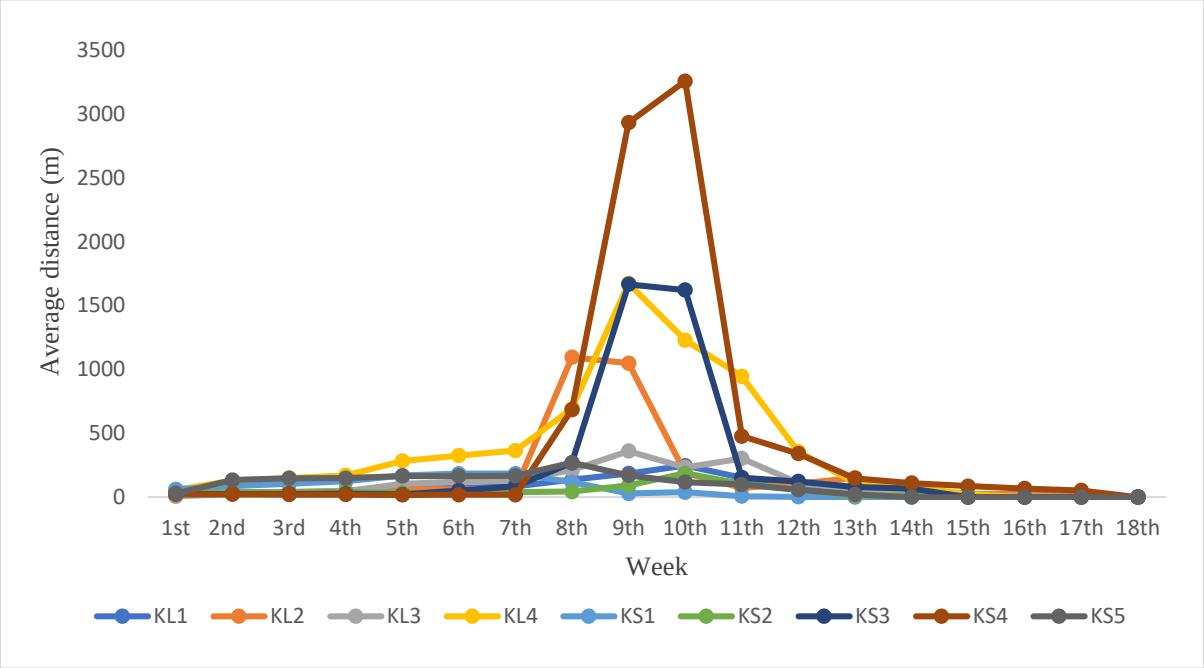

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