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Ichthyodiversity and conservation importance of the Jakhor Taal Lake in Kailali district, far western Nepal

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Abstract

Jakhor Taal is an ox-bow perennial lake, situated in Dhangadhi sub-metropolitan city in Kailali district, Nepal. The present study focuses on the factors determining fish diversity, socio-economic status of fishing communities and conservation challenges of Jakhor Taal. Fish sampling was done by gill net, cast net and other local fishing techniques such as Helka and Tiyari nets and Dhadiya trap. A total of 24 fish species (8 exotic and 16 native) were recorded belonging to 7 orders, 14 families and 22 genera. The order Cypriniformes was found to be highest, obtaining 41.66% of the total fish species recorded and 65.38% of total fish caught during the study period (February 2019 - August 2019) followed by Siluriformes (20.33%) and Perciformes (16.67%), respectively. The Shannon-Weiner diversity index was found highest (2.93) in winter (February) and lowest (2.76) in summer (July). Similarly, the Simpson and Evenness values were also found slightly higher during winter (February) in comparison to summer (July). The Shannon-Weiner diversity index was found highest (2.73) at station II in comparison to station I, III, and IV where it was 2.31, 2.09, and 2.04, respectively. Results from the Redundancy analysis (RDA) revealed that the environmental variables such as water temperature, depth and dissolved oxygen were found to be highly significant to most of the fish species at different stations and months. However, pH and free CO_2 was not shown to have any relationship or significance. Altogether, 22 clusters were formed in which exotic species show highly significant clustering in comparison to native species. The socio-economic status of the local fishing communities is below the poverty line and the lake and its fishing resources play vital roles in their diet and income source. In the context of conservation challenges and implications, this lake is highly neglected by both governmental and local communities and this negatively affects its natural properties through habitat destruction, illegal fishing, urbanization, invasive species, and a general lack of awareness.

Key words: Fish conservation, Jakhor Taal, lowland, redundancy analysis, species, wetlands

Introduction

Wetlands are considered one of the most threatened ecosystems among all major natural ecosystems, and in Nepal they range from the torpid ponds of the Terai region to the glacial lakes of the high Himalayas; which all support diverse wildlife species (KC et al., 2013). Among high biodiversity ecosystems, wetlands occupy only about 1% of the Earth's surface, but provide habitat for about 20% of the world's species (Dudgeon et al., 2006). Wetlands offer ecological, economic and social benefits providing habitat for various species of plants, invertebrates, fishes, amphibians, reptiles, birds and mammals (KC et al., 2013). The wetlands of Nepal cover a total of 819, 277 ha, which is 5.57 % of the total landmass of the country (DoFD, 2012) and constitute an important ecosystem that harbors 42 globally threatened species (IUCN Nepal, 2004; 2019). These wetlands harbor 252 fish species belonging to 104 genera, 35 families and 15 orders (Shrestha, 2019). They also have a large number of endemic wildlife species, including resident species, migratory species and uncommon and rare passage migrant species (Shrestha, 2019).

The National Lake Conservation Development Committee (NLCDC) has listed 5,358 lakes in Nepal during its map-based inventory program conducted in 2011 and the estimated area of these lakes is 5000 ha, about 0.7% of the total existing water areas of Nepal. The lakes can be categorized into 3 types based on their origin: I) Glacial, II) Tectonic and III) Ox-bow, and there are more than two dozen ox-bow lakes in Nepal (Sharma, 1977). The availability, distribution and composition of the fish species in each habitat are closely related to various factors such as food, breeding sites, water current, water depth, topography and physiochemical properties of water (Harris, 1995). The interaction of both the physical and chemical properties of water that affect these environmental variables play a significant role in the composition, distribution, abundance, movements and diversity of aquatic organisms (Shinde and Singh, 2014).

Nepal is less explored and poorly studied regarding fish diversity relative to that of other fauna (Shrestha et al., 2008). As wetlands are among one of the richest ecosystems of the country, providing ecological, economic and social benefits is a crucial life support for much of humanity. Wetland-dependent communities account for more than 17% of the country's population, out of which more than 90% are of Terai origin (KC et al., 2013). As a result, a close interaction takes place between the local community and the biological resources of the wetlands. Therefore, the present study was conducted to assess the fish diversity, factors determining fish diversity, socio-economic status of the local community and conservation challenges and implications of the Jakhor Taal.

Material and Methods

Study area

The present study was carried out in Jakhor Taal (February 2019- August 2019), a large perennial ox-bow lake that lies in Dewariya-7, Dhangadhi, Kailali District, Nepal. *Taal* means lake in the Nepali language. It covers a total area of 13.49 ha and is situated at 165 m above sea level with a latitude of 28º 42' 23.08"N and longitude of 80º 37' 21"E (IUCN Nepal, 2004; DoF, 2017). This lake is surrounded by a community forest (Chamraiya Forest) in the North-western part, farmland and settlements on the east and Dewariya Botanical Garden towards its south, which contains a total area of 149.50 ha and plays an important role in *in-situ* and *ex-situ* conservation. The study area map with different land cover (Fig. 1a) and the location of four sampling stations (Fig. 1b) was prepared by using ArcGIS 10.7. The land cover map of the study area was obtained from ICIMOD (ICIMOD, 2013) and the land cover presented in the station map was obtained from Esri's World Imagery map (ESRI, 2020).

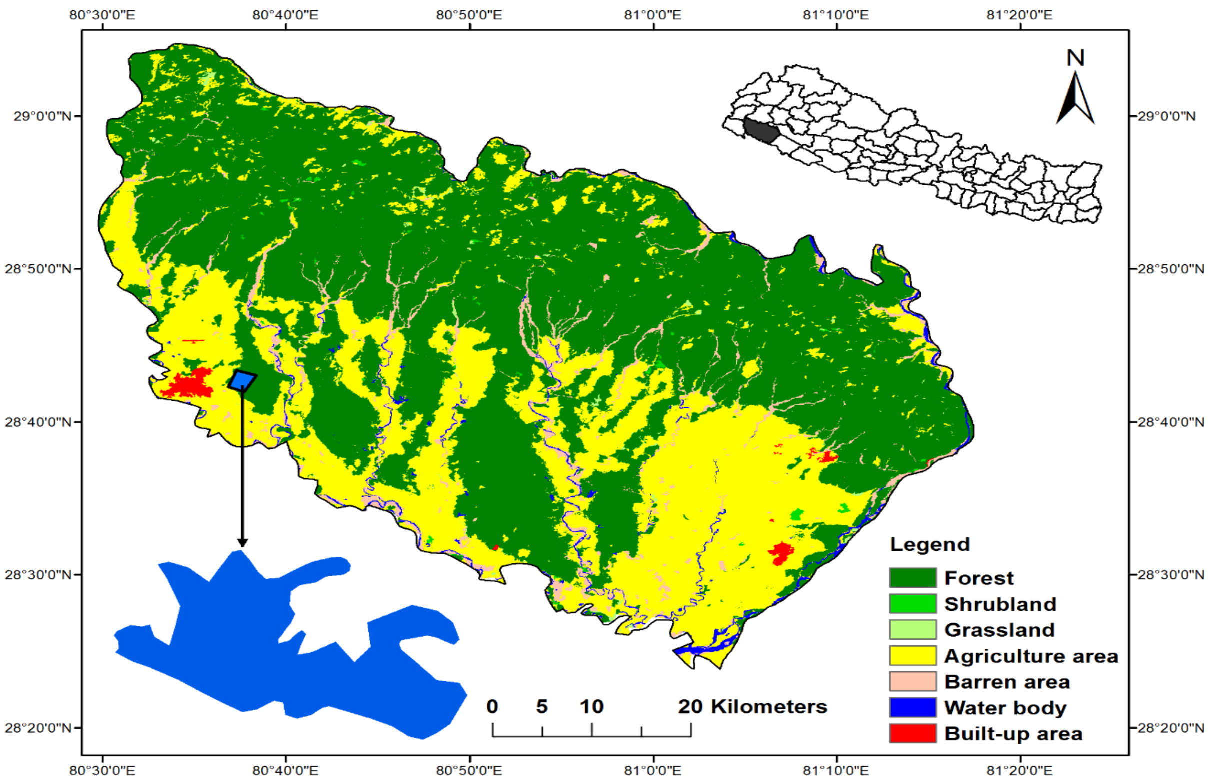

Figure 1a: Map of the study area showing the Jakhor Taal and the land cover of associated areas.

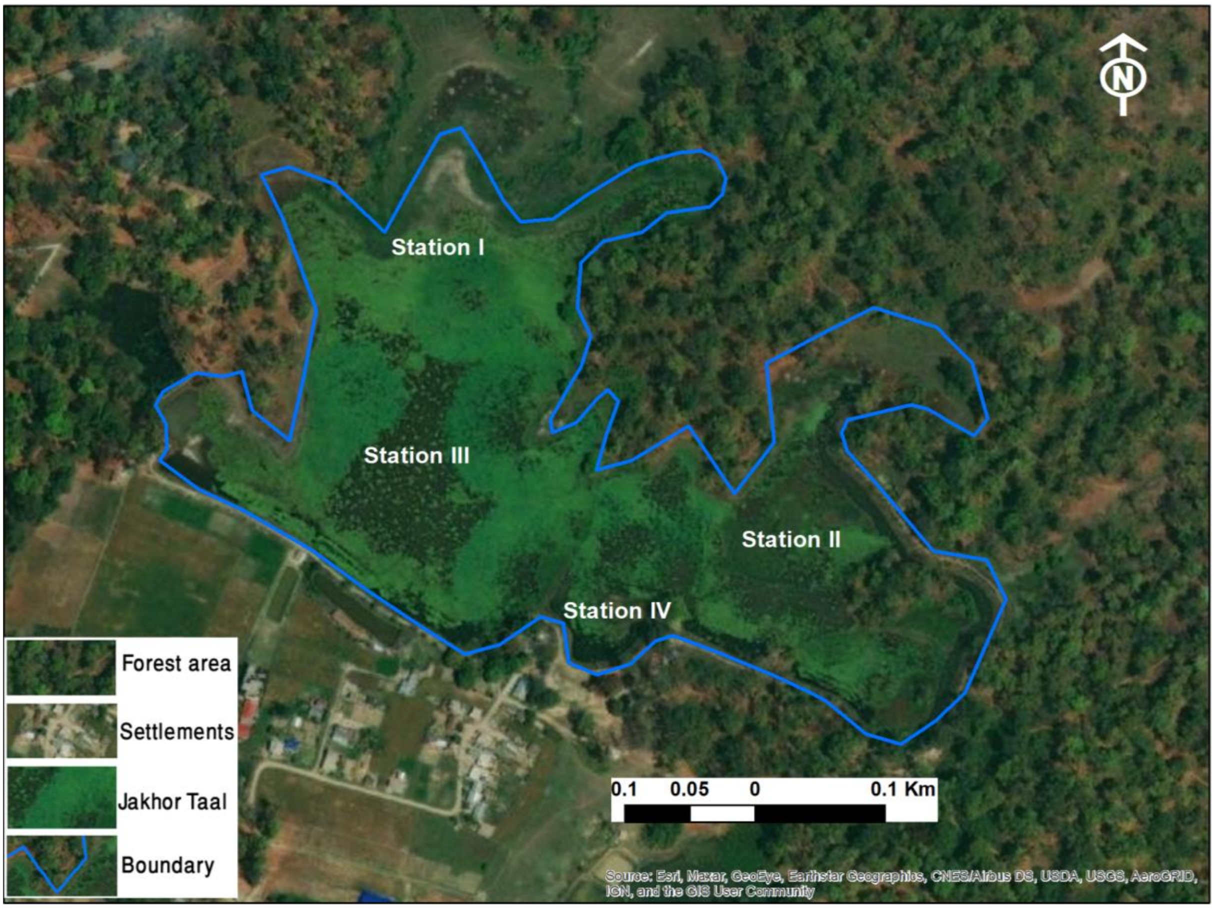

Figure 1b: Map of the study area showing water coverage and sampling stations (I-IV) in the Jakhor Taal during the rainy season (July 2019).

Figure 1c: Photographs of the study area showing four sampling stations (I-IV) in the Jakhor Taal during the rainy season (February 2019).

Data collection

The present study was carried out from February 2019 to August 2019 covering two major seasons i.e., winter and summer. We selected four sampling stations based on water depth, aquatic vegetation cover, peripheral areas of human-disturbed sites and water outlet. The peripheral areas of the lake with high disturbance and shallow water were taken as Station I, high vegetation covered area was taken as Station II, middle and deep areas of the lake was taken as Station III and any outlet areas were taken as Station IV (Fig. 1b, 1c). The primary, or basic, source of data is based on direct field observations, but a questionnaire survey and photographs were also used.

Various kinds of locally available fishing gear such as cast nets (mesh size of 0.5 cm, 1 cm and 2 cm) and gill nets (mesh size of 3 cm, 5 cm and 6 cm) of 15 m, 18 m, and 25 m length were used for catching fish. Cast net fishing was done randomly at 3 stations, except for station II (due to its dense aquatic vegetation), twice a day (morning 7–9 am and evening 4–6 pm) using CPUE method (Catch per Unit Effort) (Lauridsen et al., 2008). However, gill nets were placed in all four stations, left overnight and observed the next morning and evening all throughout the study period. Scoops nets and Helka (local hand-made, semi-circular nets) were also used for capturing larvae, fingerlings, and small fishes. All the collected fish samples were carefully preserved in 10% formalin solution for further study and the specimens were taken to the laboratory of the Central Department of Zoology (CDZ), Tribhuvan University for identification.

The identification was carried out with the help of taxonomic references (Shrestha, 2008; Jayaram, 2010; Froese and Pauly, 2019; Shrestha, 2019). Water samples were collected from all four sampling stations of the lake and the following parameters measured: pH, temperature (HI-8314 water-resistant hand-held pH, mV and Temperature Meter, Hanna, Italy) and depth (using a rope with a weight to determine the depth of the lake). Physical parameters, such as dissolved oxygen and free carbon dioxide, were analyzed by titration methods in the laboratory of Drinking Water Supply Corporation, Dhangadhi, using standard procedures (Trivedy and Goel, 1984).

Data analysis

The Shannon-Weiner diversity index (Shannon and Weiner, 1963) was calculated by the following equation (1):

$$H = -\sum_{i=1}^{s} p_i \ln p_i \qquad (1)$$

Where S is the total number of species and Pi is the relative cover of ith of species.

The dominance index (Harper, 1999) was calculated by using the following equation (2):

$$D=\sum_i\left(\frac{ni}{n}\right)\sum_i\left(\frac{ni}{n}\right)^2 \qquad (2)$$

Where ni is number of individuals of species i.

The Pielou Evenness index (J) = H/H_{max} (Pielou, 1966)

Where H is the calculated Shannon-Wiener diversity index and H_{max} is species diversity under maximum equitability conditions. The temporal (season-wise) variation in diversity was analyzed separately. However, spatial (station-wise) variation in diversity was analyzed using the sum of species number and abundance data obtained from both seasons.

The correlation between fish assemblage structure and physio-chemical parameters was first done by selection of appropriate tests, a Detrended Correspondence Analysis (DCA). The axis length and eigenvalue obtained from the DCA suggested that the linear model of the Redundancy analysis (RDA) was more applicable. Therefore, a direct multivariate ordination method (Ter Braak, 1986) based on a linear response of species to environmental gradients was applied by using vegan library in R (Oksanen et al., 2007; Oksanen et al., 2015).

Fish species were analyzed into different assemblage clusters based upon abundances of each fish species by utilizing *pvclust* package in R (Ryota and Hidetoshi, 2016; Suzuki et al., 2019). Species codes were used further in the figures and RDA analysis for showing the relationship between species and parameters among different stations (Table 1).

Results

Fish diversity

A total of 24 fish species were reported from the Jakhor Taal during this study period from all four stations that included 7 orders, 14 families and 22 genera. Among them, 16 species were native and 8 species were exotic fishes in which 19 are of Least Concern (LC), 3 are Vulnerable (VU), 1 Near Threatened (NT), and 1 Not Evaluated (NE) on the IUCN Red List of Threatened Species (IUCN, 2019) (Table 1; Appendix 1, 2).

Among the total fish caught during this study period, order Cypriniformes was found to predominate and constituted 41.66 % of the total collected fish fauna; followed by Siluriformes and Perciformes which constituting about 20.33% and 16.67%, respectively. However, the frequency of fish catch was slightly different to that of the species composition where the order Perciformes showed the high numbers of fish caught followed by the order Siluriformes (Fig. 2).

A total of 14 families were recorded in which Cyprinidae showed the highest number of fish diversity, forming nearly 64.27% (9 species) of total fish diversity followed by Clariidae and Channidae forming 14.28% (2 species) each. Similarly, the frequency of fish caught per family showed Cyprinidae with the highest number (61.18%) which was more than half of the total fish caught during the study period. However, the frequency of fish caught in other families was slightly different to that of the species composition, where the family Cichlidae showed the second highest number of fish caught followed by the families Channidae and Clariidae, which constituted two fish species each (Fig. 3).

Table 1: Fish species diversity of the Jakhor Taal, Nepal.

S.N.	Order	Family	Scientific Name	Species code used in analysis	Local Name	Origin / IUCN Status
1	Cypriniformes	Cyprinidae	*Amblypharyngodon mola* (Hamilton, 1822)	C16	Mada/Mahila	Na / LC
			Catla catla (Hamilton, 1822)	C2	Vakur	Ex / LC
			Cirrhinus mrigala (Hamilton, 1822)	C8	Mrigal/Naini	Ex / LC
			Ctenopharyngodon idella (Valenciennes, 1844)	C7	Grass carp	Ex / NE
			Cyprinus carpio Linnaeus, 1758	C5	Common carp	Ex / VU
			Hypophthalmichthys molitrix (Valenciennes, 1844)	C6	Silver carp	Ex / NT
			Labeo rohita (Hamilton, 1822)	C1	Rohu	Ex / LC
			Puntius sophore (Hamilton, 1822)	C17	Sidhra/pothi	Na / LC
			Rasbora daniconius (Hamilton, 1822)	C20	Dedhan	Na / LC
		Corbitidae	*Lepidocephalichthys guntea* (Hamilton, 1822)	C18	Guitna	Na / LC
2	Siluriformes	Bagridae	*Mystus vittatus* (Bloch, 1794)	C13	Tegna	Na / LC
		Siluridae	*Wallago attu* (Bloch and Schneider, 1801)	C9	Lachea	Na / VU
		Clariidae	*Clarias batrachus* (Linnaeus, 1758)	C10	Mangur	Na / LC
			Clarias gariepinus (Burchell, 1822)	C4	Mangur	Ex / LC
		Heteropneustidae	*Heteropneustes fossilis* (Bloch, 1794)	C11	Singi	Na / LC
3	Perciformes	Ambassidae	*Chanda nama* Hamilton, 1822	C19	Cahnerbijuwa	Na / LC
		Gobiidae	*Glossogobius giuris* (Hamilton, 1822)	C21	Vulvule	Na / LC
		Channidae	*Channa orientalis* Bloch and Schneider, 1801	C22	Bhoti	Na / VU
			Channa punctata (Bloch, 1793)	C23	Charanga	Na / LC
4	Synbanchiformes	Mastacembelidae	*Macrognathus pancalus* Hamilton, 1822	C12	Bam	Na / LC
		Synbranchidae	*Monopterus cuchia* (Hamilton, 1822)	C24	Andho Bam	Na / LC
5	Cichliformes	Cichlidae	*Oreochromis niloticus* (Linnaeus, 1758)	C3	Tilapia	Ex / LC
6	Osteoglossiformes	Notopteridae	*Notopterus notopterus* (Pallas, 1769)	C15	Kauwa	Na / LC
7	Anabantiformes	Osphronemidae	*Trichogaster lalius* (Hamilton, 1822)	C14	Theski	Na / LC

(Ex: Exotic, Na: Native, LC: Least Concern, NE: Not Evaluated, VU: Vulnerable and NT: Near Threatened). Species names verified from Froese and Pauly (2019).

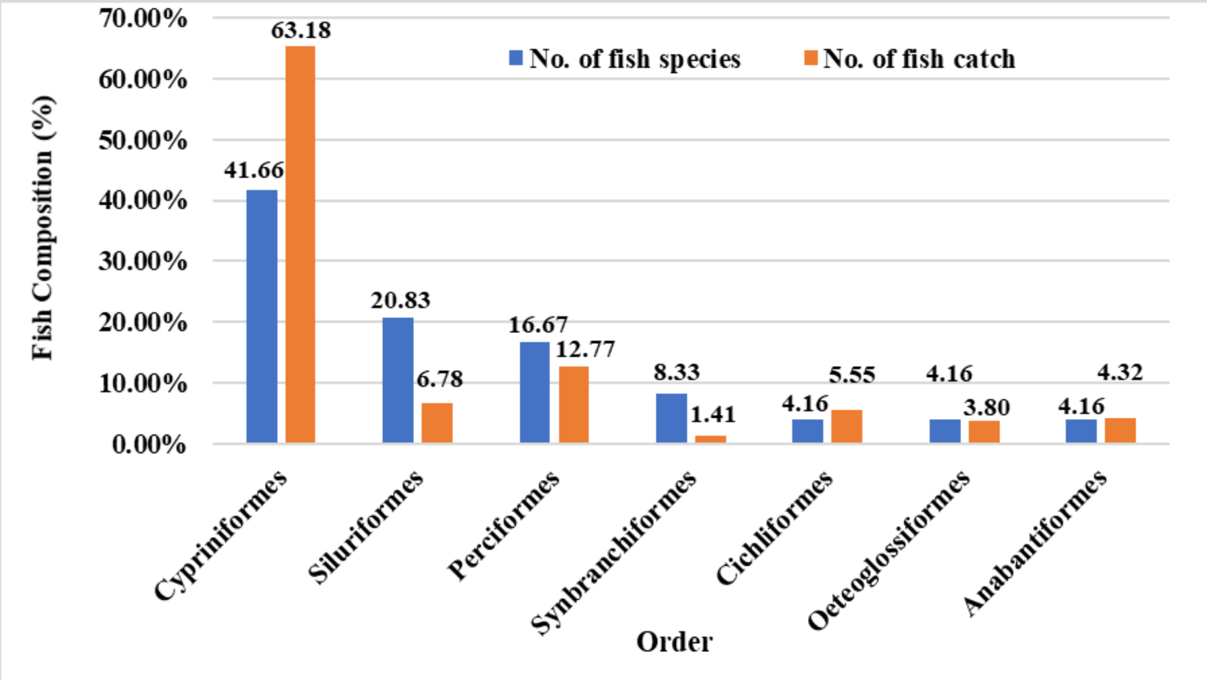

Figure 2: Order-wise fish species composition (%) in the Jakhor Taal, Nepal.

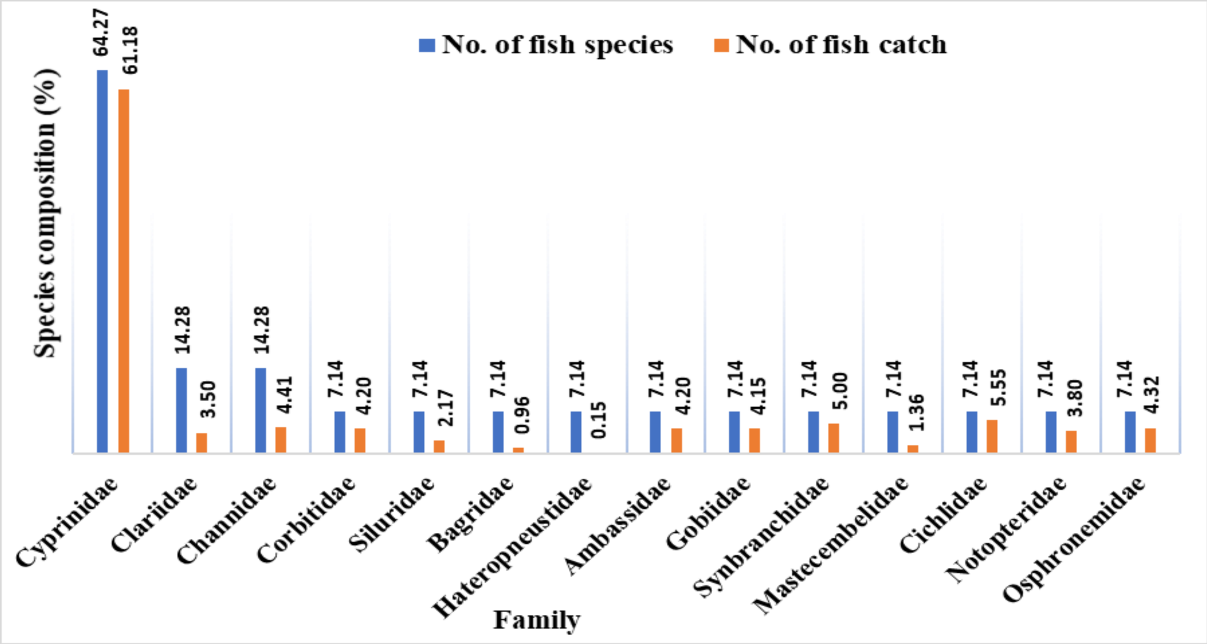

Figure 3: Fish species composition by family in the Jakhor Taal, Nepal.

Spatio-temporal variation in fish diversity

The values of the Shannon-Weiner diversity index (H'), Simpson index (D), and Pielou's evenness index (J) were calculated according to seasons (winter and summer) and stations (I, II, III and IV). In the case of seasons, the Shannon-Weiner diversity index was found highest (2.93) in winter (February) and lowest (2.76) in summer (July). Similarly, the Simpson and Evenness values were also found slightly higher in winter (February) in comparison to summer (July) (Fig. 4).

In the case of sampling stations, the Shannon-Weiner diversity index was found highest (2.73) at station II, as compared to the station I, station III and station IV which were 2.31, 2.09 and 2.04, respectively. Similarly, Simpson and Evenness values were also found slightly higher at station II in comparison to station I, station III and station IV (Fig. 5a). Station II possessed the highest number of species with the highest number in winter (Fig. 5b).

Factors determining fish diversity

During the study period, the pH of the water showed slight changes between the different stations. The average pH of the water was found more suitable or optimal, with the value ranges from 6.2 at station II in February to 8.2 at station IV in July. The water temperature ranged from 12 ºC– 25 ºC according to seasonal variation. The water temperature was recorded as 12 ºC (lowest) in February at station II and at 25 ºC (highest) in June at station I. The depth of the lake varies between the different stations. The deepest depth was recorded as 457 cm during the month of July at station III and the shallowest depth was recorded as 28 cm in February at station IV. Dissolved oxygen varied between different stations. The highest dissolved oxygen value recorded was 7.7 mg/l at station IV in July and the lowest value was 4.7 mg/l recorded at station II in February. Similarly, free carbon dioxide differed significantly. The highest value of free carbon dioxide observed was 6.51 mg/l during the month of February at station III and the lowest value was 1.74 mg/l during the month of July at station IV.

Fish species, stations, season and environmental variable relationship

The axial length of the first axis of the Detrended Correspondence Analysis (DCA) was found to be 2.9 standard deviation units (SD unit) and that was followed by 1.2 for the second DCA axis. The overall variance explained by the data matrix was 67%. Thus, the application of the RDA was justified.

The result obtained after the RDA was plotted is shown in Figure 6. This result showed that dissolved oxygen and water temperature were found positively correlated to station I and the species, *Amblypharyngodon mola*, *Chanda nama*, *Glossogobius giuris*, *Macrognathus pancalus*, *Mystus vittatus*, *Puntius sophore*, *Rasbora daniconius*, *Trichogaster lalius*, and *Wallago attu*. Similarly, water depth was found positively correlated with station III and the species, *Catla catla*, *Cirrhinus mrigala*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *Labeo rohita, and Oreochromis niloticus*. The only species found positively correlated with station IV (an outlet region with very low water levels) was *Lepidocephalichthys guntea*. *Notopterus notopterus* was the only one species that showed a positive correlation with station II (dense aquatic vegetated habitat) where the dissolved oxygen and temperature showed a negative correlation.

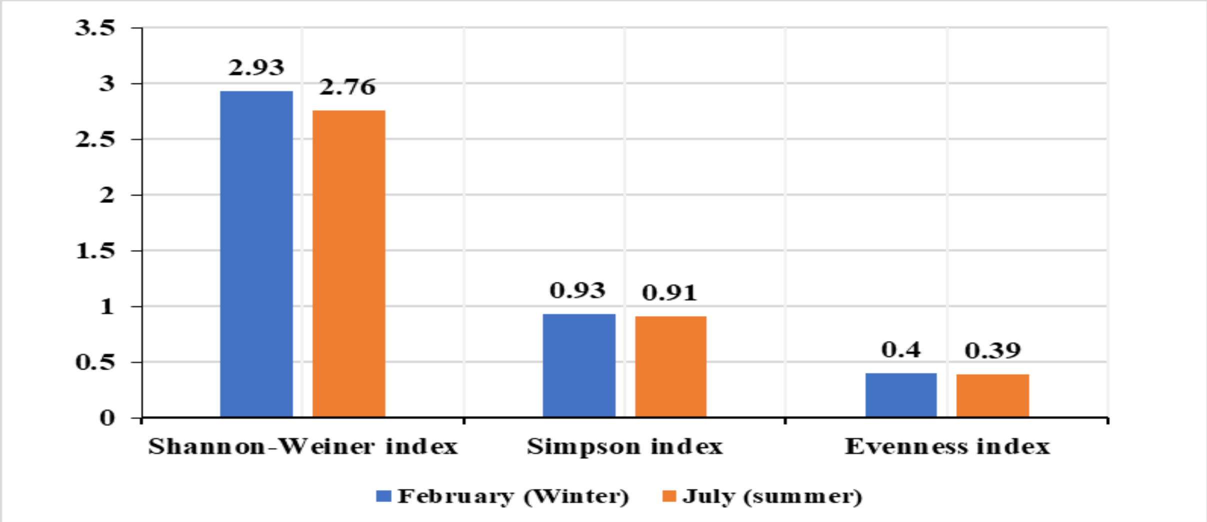

Figure 4: The Shannon-Weiner diversity, Simpson, and Evenness indices of two seasons for fishes of the Jakhor Taal, Nepal.

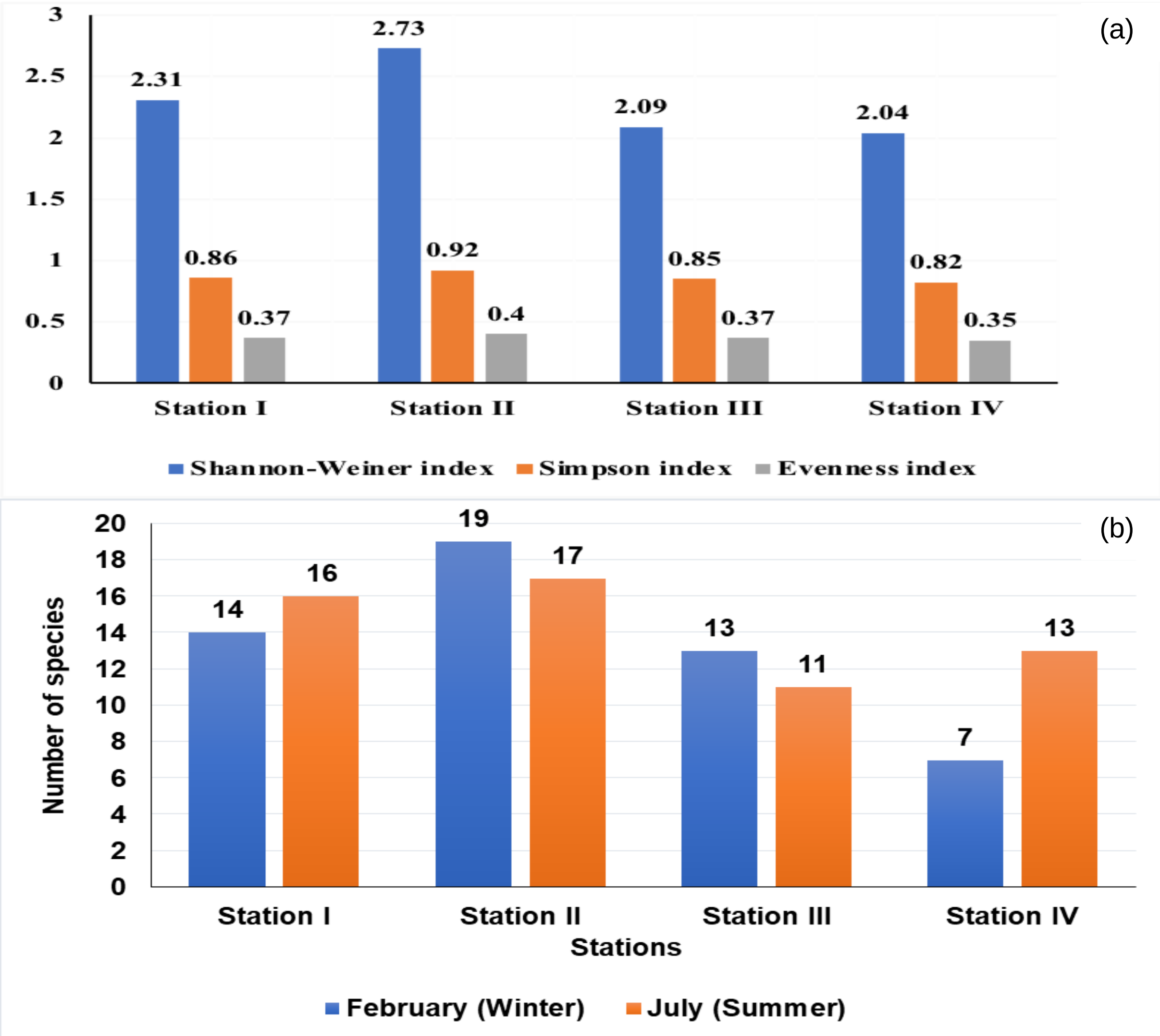

Figure 5: (a) Spatial variation of the Shannon-Weiner, Simpson and Evenness indices of all four stations in two seasons (winter and summer), (b) Number of species recorded at all four stations in two seasons (winter and summer), in the Jakhor Taal, Nepal.

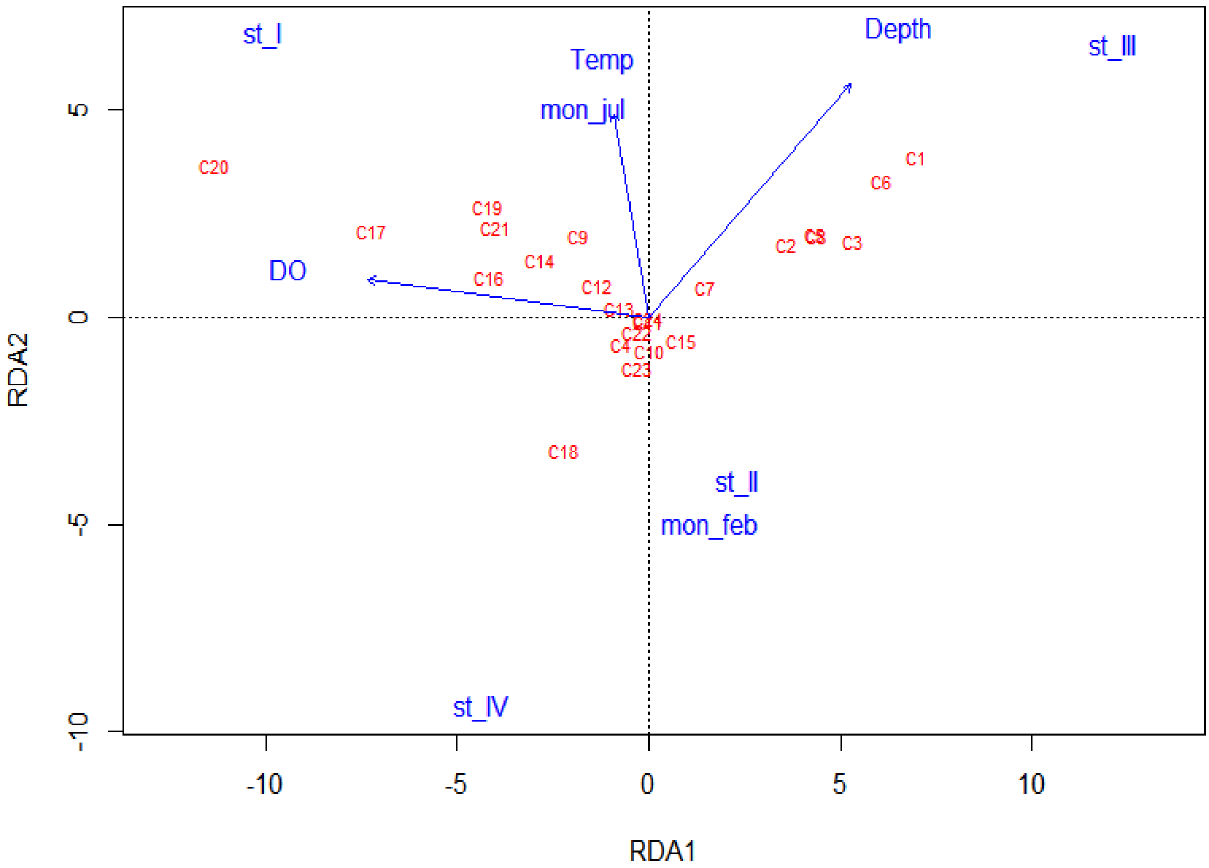

Figure 6: Redundancy analysis (RDA) ordination of fish species in relation to sites, seasons and other environmental variables (for species code see Table 1, st_I= Station I, st_II= Station II, st_III= Station III, st_IV= Station IV, DO= Dissolved oxygen, Temp= Temperature, Depth= Water depth, mon_feb= sample taken in February 2019, mon_jul= sample taken in July 2019) in the Jakhor Taal, Nepal.

Fish community structure

There were 22 clusters of fish species found in the Jakhor Taal that live in mutual coordination with each other (Fig. 7). On the right side of the figure, the cluster numbers 2, 3, 8, 9, 10 and 15 form a highly significant cluster group which inhabits a similar type of habitat (significant water depth and middle of the lake). The exotic fishes, such as *Labeo rohita* (C1), *Catla catla* (C2), *Oreochromis niloticus* (C3), *Cyprinus carpio* (C5), *Hypophthalmichthys molitrix* (C6), *Ctenopharyngodon idella* (C7), and *Cirrhinus mrigala* (C8) all form a separate highly significant cluster group. Similarly, the cluster groups on the left and center, such as 4, 5, 6, 7, 11, 12, 13, 16, 17, and 18 also form significant clustering according to their habitat preferences (peripheral lake and high vegetation). Whereas on the right, cluster number 1 (*Chanda nama* (C19), and *Glossogobius giuris* (C21)) together, form a significant cluster with *Macrognathus pancalus* (C12) which is the cluster number 5. *Lepidocephalichthys guntea* (C18) formed a significant cluster group with all the groups in the center and left with cluster number 21, which are the native species who are found in the Jakhor Taal.

Socio-economic status of local fishing community

The economic condition of the fishermen living around Jakhor Taal (Far-Western Development Region) is very poor and they usually fall below the poverty line i.e. less than 19,261 Nepalese rupees per person/year (CBS, 2011). The standard of living of fishermen appears to be low, both in absolute terms and by comparison to the living standards of other rural inhabitants (non-fishing community). Therefore, the level of education is low and awareness of living, personal hygiene and general health are also low, leading to many incidences of various health hazards. The average family size of the fishermen is 5–6 persons and nearly 70 percent of males and females are engaged in fishing during the rainy season (June-July). But, during the off-season males either work as laborers or they drive local and electric auto-rickshaws. Fishermen of the Jakhor Taal are locally known as "Majhi" and generally inhabit near or around the Jakhor Taal. They belong to different ethnic castes i.e., Tharu, Rana, Sunar, Magar, Gurung, and Chhetri. Usually, Tharu, Rana and Sunar communities are the majority of inhabitants living around the Jakhor Taal since pre-historic times.

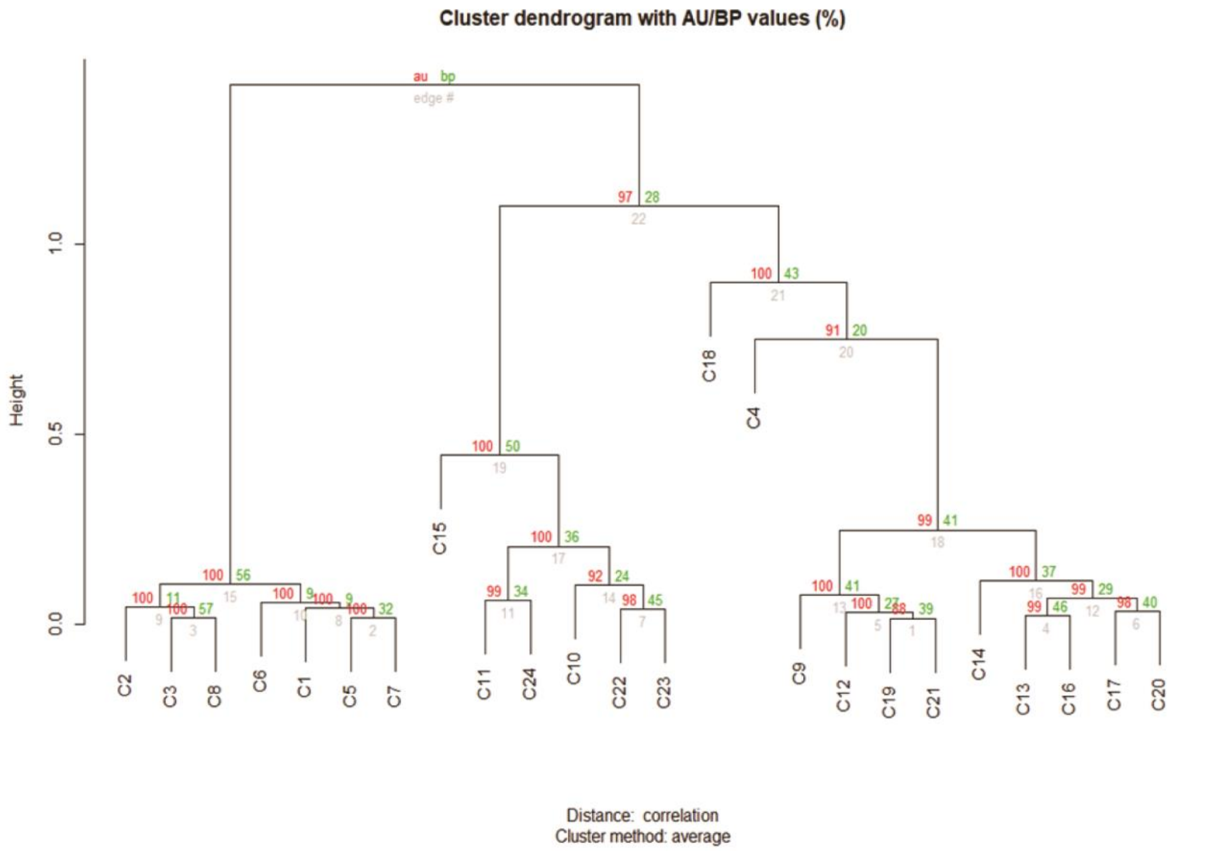

Figure 7: Dendrogram of cluster analysis comparing fish species on the basis of fish assemblage (C1-C24, fish species code mentioned in Table: 1) of the Jakhor Taal, Nepal. Dark Black code name represents the fish species. Soft or light Black numbers represent the cluster number. Red numbers represent the probability of the Automatic Unbiased (AU) value. Green numbers represent the Bootstrap Probability (BP) value. AU value > or = 95 represents a significant cluster.

The literacy rate of fishermen is very low with about 80 percent of the total fishermen being illiterate (unable to read and write) and only 20 percent are educated up to high school (+12). Local fishermen make different types of fishing equipment, especially during leisure periods, with the help of locally available plant fibers (bamboo) and nylon strings. The commonly used fishing equipment are cast nets, gill nets, and local fishing gear like Helka and Tiyari nets, and Dhadiya (hand-made, cone-shaped basket traps). The best timing for fishing is from mid-August to October after the completion of the breeding season of most of the native and exotic fishes (Appendix 3).

Conservation challenges

Our observations, in and around the Jakhor Taal, show that there are various challenges regarding fish conservation and management of wetlands. These challenges include habitat destruction, illegal poaching and fishing, urbanization, invasive plants (Water hyacinth, Water cabbage, Tropical hornwort) and a lack of awareness about habitat degradation and pollution. Habitat destruction by human activity is mainly to harvest natural resources for individual use, industrial purposes, and urbanization. Clearing habitat for agriculture is the principal cause of habitat destruction, which is drastically increasing day by day to meet local food demand. Due to the increase in human population in recent decades, the lands around the lake are being legalized by the government for personal and commercial purposes; which further causes agricultural runoff of nitrogenous fertilizers and other various chemicals, and pollution caused by the anthropogenic activities. The Water hyacinth (*Eichhornia crassipes*) and Water cabbage (*Pistia stratiotes*) are the major invasive plants that cause severe negative impacts to the whole lake, almost destroying its natural habitat.

Discussion

The findings of this study reveal a total of 24 fish species belonging to 7 orders, 14 families and 22 genera. The results for ichthyodiversity are consistent with the findings of some of the previous studies. For instance, IUCN Nepal (1998) recorded 27 species from the Ghodaghodi Lake Complex. Similarly, DNPWC and WWF Nepal (2003) reported 29 fish species from the Ghodaghodi Lake Complex. Kafle et al. (2007) identified 25 species from the same area (Ghodaghodi Lake), including *Amblypharyngodon* *mola*, *Chanda nama*, *Clarias batrachus*, *Channa striatus*, *Puntius sophore*, *Trichogaster lalius*, and *Rasbora daniconius*; which shows that the fish diversity of lowland ponds and lakes are similar. More recently, Gautam et al. (2016) and Joshi and Bijaya (2017) have also reported similar results supporting this study where the family Cyprinidae was found dominant from the Rupa Lakes and Ghodaghodi lake, respectively.

The diversity status of the different fish species in the Jakhor Taal shows slight variations, both spatially and temporally. In the case of spatial condition (Fig. 5), the Shannon-Weiner diversity index was found highest (2.73) at station II in comparison with the other stations. This is due to station II being occupied by dense vegetation, which provides suitable habitat, such as shelter, food and breeding grounds, for some fish species. Cheng et al. (2012) recorded high fish species richness in those areas which are occupied by vegetation. Moreover, Tang et al. (2015) and Ayub et al. (2018) stated that eutrophication leads to an increase in phytoplankton and zooplankton, thus increasing food and prey availability for many fish species. In the temporal condition (Fig. 4), the Shannon-Weiner diversity index was found highest (2.93) in February and lowest (2.76) in July, which is similar to the findings of Muhammad et al. (2018), where they recorded high diversity during the winter. Our values show that Jakhor Taal has less effect on diversity in terms of seasonal variation, which might be due to its stagnant water properties that provide a similar kind of habitat, or environmental conditions, throughout the year. This would favor the habit and habitat of the current fish species that were recorded during this study period. Jones and West (2005) had similar outcomes where their study of intermittently closed lakes showed less seasonal diversity of species than more open coastal lakes.

Environmental variables, such as hydrogen ion concentration, temperature, water depth, dissolved oxygen, and free carbon dioxide, all play vital roles in fish diversity (Bastola, 2017; Joshi and Bijaya, 2017). In the ordination plot, it was found that species such as *Amblypharyngodon mola*, *Chanda nama*, *Glossogobius giuris*, *Macrognathus pancalus*, *Mystus vittatus*, *Puntius sophore*, *Rasbora daniconius*, *Trichogaste lalius*, and *Wallago attu* were positively correlated with station I. This is because, most of these small native fish species show preference for the peripheral area of the lake along the edges, which is a shallow habitat with favorable dissolved oxygen and temperature (Sharma, 2008). Similarly, the centermost and deepest part of the lake (station III) had some large exotic species, such as *Labeo rohita*, *Hypothalmichthys molitrix*, *Oreochromis niloticus*, *Cirrhinus mrigala*, *Catla catla*, and *Ctenopharygodon Idella*, as they prefer larger, deeper water bodies (Ali et al., 2006; Miranda, 2011). The only species found highly correlated with station IV, which is the outlet region of the lake from where excessive water was driven out of the lake, was *Lepidocephalus guntea*. In case of station II, *Notopterus notopterus* was the only species that showed a positive correlation with this dense vegetation habitat. This may be due to their preference for aquatic vegetation that provides proper shelter (protection), food (feed on insects, small fish, crustaceans and some young roots of aquatic plants), and breeding grounds for better survival.

The socio-economic status of fisherman inhabiting the Jakhor Taal seems to be below the poverty line, where levels of education are inadequate and awareness of personal hygiene and general health is low. The literacy rate of fishermen is very low with nearly 80 percent of fishermen being illiterate and only 20 percent have any education, which is similar to the findings of Hafijur et al. (2017). The United Nations Development Program (UNDP) has launched Sustainable Community Development Programs (SCDP) in the study area which provides loans to the local fishing community living near the Jakhor Taal, especially Tharu, Rana, Majhi families.

At Jakhor Taal, there are many challenges to fish diversity conservation and management of wetlands, including habitat destruction, illegal fishing, urbanization, invasive plants and a general lack of awareness of these major threats. Presently, the condition of the lake is threatened by human encroachment, annual siltation, eutrophication, seasonal microphytic coverage, and the introduction of exotic, as well as invasive, species. Due to the increase in the Nepalese population in recent decades, the lands around the lake are being legalized by the government for personal agriculture and commercial purposes which causes the agricultural runoff of nitrogenous fertilizers and other pollution caused by the anthropogenic activities (Decker et al., 2016). The Water hyacinth (*Eichhornia crassipes*) and the water cabbage (*Pistia stratiotes*) are major invasive plants that cause severe negative impacts to the whole lake, almost destroying its natural habitat (Smith, 2003; Babourina and Rengel, 2011).

Conclusion

A total of 24 fish species were recorded from different stations of Jakhor Taal belonging to 7 orders, 14 families and 22 genera. The dominant order and family in this lake were Cypriniformes and Cyprinidae, respectively. Fish diversity is significantly correlated with the environmental parameters of Jakhor Taal. The RDA revealed that the environmental variables of water, such as temperature, depth and dissolved oxygen, were found highly significant for most species with respect to different sites and months, however pH and free CO_2 did not show any significance. The socio-economic status of the local fishing communities seems to be below the poverty line and the lake, and its resources, play a very important role in their diet and income source. Despite rich fish and other aquatic biodiversity, this lake is highly neglected by both government and local communities. Some of the major factors affecting the study area are habitat destruction, illegal fishing, infrastructure development around the Taal, urbanization, people pressure and invasive alien plant species.

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Conflict of interest

The authors declare that there are no conflicting issues related to this research article.

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Appendix 1: Photographs of native fish species of Jakhor Taal, Kailali, Nepal.

Puntius sophore (Hamilton, 1822)

Amblypharyngodon mola (Hamilton, 1822)

Rasbora daniconius (Hamilton, 1822)

Lepidocephalichthys guntea (Hamilton, 1822)

Mystus vittatus (Bloch, 1794)

Wallago attu (Bloch and Schneider, 1801)

Heteropneustes fossilis (Bloch, 1794)

Chanda nama Hamilton, 1822

Glossogobius giuris (Hamilton, 1822)

Channa punctata (Bloch, 1793)

Channa orientalis Bloch and Schneider, 1801

Trichogaster lalius (Hamilton, 1822)

Macrognathus pancalus Hamilton, 1822

Monopterus cuchia (Hamilton, 1822)

Notopterus notopterus (Pallas, 1769)

Clarias batrachus (Linnaeus, 1758)

Appendix 2: Photographs of exotic fish species of Jakhor Taal, Kailali, Nepal.

Catla catla (Hamilton, 1822)

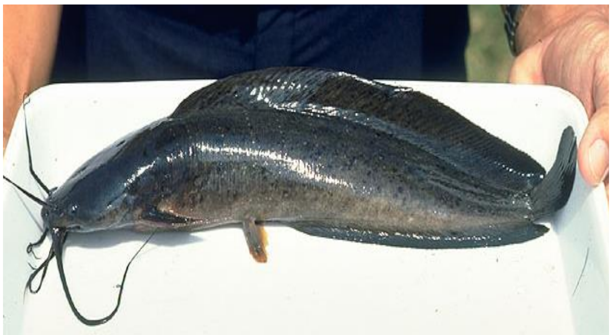
Cirrhinus mrigala (Hamilton, 1795)

Ctenopharyngodon Idella (Valenciennes, 1844)

Cyprinus carpio Linnaeus, 1758

Labeo rohita (Hamilton, 1822)

Hypophthalmichthys molitrix (Valenciennes, 1844)



Clarias gariepinus (Burehell, 1822)

Oreochromis niloticus (Linnaeus, 1758)

Appendix 3: Photographs of the study area showing socio-economy of the local people around Jakhor Taal, Kailali, Nepal.

Local people fishing at Jakhor Taal

Typical mud-house of Majhi community

Paddy fields adjoining to Jakhor Taal

Fish caught: main source of livelihood of local people