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Original article

Drivers of fisheries and their management in the lakes of Pokhara Valley, Nepal

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Abstract
Inland fisheries provide food security, livelihood and well-being to community. Fisheries management of lakes is a complex process, influenced by many drivers. In this study the driver of fisheries of lakes of Pokhara Valley were determined through interview of *Jalari* fishers, key informants and field visits from July 2016 to June 2017. Key drivers were illegal fishing, siltation, loss of fish habitat, water pollution and accelerated eutrophication, intensification of agriculture, biological invasion and developmental works. These drivers have played a key role in changing lake characteristics including lake size, water quality, water depth and natural food availability which subsequently affected the cage aquaculture and capture fisheries of the lake. This paper included an insight of these drivers along with strategy to mitigate them to ensure sustainable fisheries.

Key words: Drivers of fisheries; lake management; illegal fishing; capture fisheries; non-native fish; biological invasion; *Jalari* fishers; Pokhara Valley

1 | INTRODUCTION

Inland fish and fisheries are important in providing food security, nutrition, human wellbeing and ecosystem [illegible] lion peoples engaged in the capture fisheries and aquaculture (FAO 2018). Inland fisheries provide cultural and recreational services and contribute to human health (Lynch *et al.* 2016). Valuation of inland fisheries is difficult and the governance structures for water are often complex (Bartley *et al.* 2016; Youn *et al.* 2016). Small-scale fisheries are important for supporting livelihoods and food security globally (Mills *et al.* 2011; Hall *et al.* 2013). Lake and reservoir management are complex and dynamic ecosystems that have shifted towards integrated, community-driven management. With the increasing human population, the pressures exerted on lakes and reservoirs have become intolerable and freshwaters have become contaminated, which in turn has resulted in dete[illegible]eries (Cowx, 2002). Co-management is the best way to find a solution for the majority of the problems facing in global fisheries (Gutiérrez *et al.* 2011; Bhuiya 2014).

Nepal is rich in fish biodiversity, a home to 230 native fish species (Rajbanshi 2012). Livelihood of 24 ethnic communities depends on the capture fisheries in Nepal. Pokhara Valley encompasses nine cluster lakes (Phewa, Begnas, Rupa, Dipang, Maidi, Khaste, Neurani, Kamalpokhari and Gunde) of ecological importance listed as the 10th Ramsar Site / Wetland (No. 2257) (IUCN 2018). These lakes have been providing multipurpose services to local communities including fisheries, tourism, irrigation, electricity, bathing, washing clothes and drinking water. Livelihood of approximately 200 families of *Jalaris*, a deprived ethnic fisher community, is dependent on the fisheries of these lakes (Gurung and Bista 2003; Gurung *et al.* 2005; Wagle *et al.* 2007). The major fisheries activities in these lakes involve capture fisheries and aquaculture (cage aquaculture, pen aquaculture). The fish species cultured in the cages and pens includes bighead carp (*Aristichthys nobilis*), silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*), rohu (*Labeo rohita*) and naini (*Cirrhinus mrigala*). Previous studies on the fisheries of Phewa, Begnas and Rupa lakes (e.g. Gurung *et al.* 2005; Husen *et al.* 2016) have speculated that the fisheries of these lakes are being affected by some drivers but no further studies are available. In this paper a comprehensive detail of those drivers are given that would be of help in developing a sustainable management strategy for these lakes.

2 | METHODOLOGY

2.1 | Study sites

The lakes of Pokhara Valley are situated in the Kaski districts of Gandaki rovince of Nepal (Figure 1). Phewa Lake is the largest lake, with an area of 443 ha, situated at 28.1°N and 82.5°E and 742 m above mean sea level (Figure 1). Begnas Lake is the second biggest lake (area: 328 ha) situated at 28°10’26.2”N and 84°05’50.4”E, 650 m above mean sea level whereas Lake Rupa (area: 100 ha) is the third biggest lake located 600 m above mean sea level between 28°08’N – 28°10’N and 84°06’E – 84°07’E.

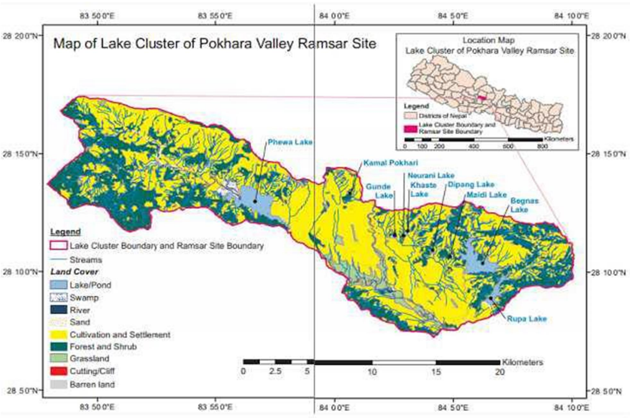

FIGURE 1 Lakes of Pokhara Valley (map adopted from IUCN).

Of these lakes, the Phewa Lake has the widest catchment area of 110 km^2 followed by Rupa Lake (30 km^2) and Begnas Lake is the narrowest (19 km^2). Phewa Lake is the deepest lake with maximum depth of 23 m followed by Begnas Lake (10 m) whereas Rupa is the shallowest with 6 m water depth (Ferro and Swar 1978; Rai *et al.* 1995). The Rupa Lake is categorized as eutrophic, Phewa Lake fluctuates between mesotrophic and eutrophic depending on seasons while Begnas Lake fluctuates between oligotrophic and mesotrophic in different seasons (Husen and Dhakal 2009; Husen *et al.* 2012a).

2.2 | Data collection and analysis

The field data collection and interviews for this study were conducted from July 2016 to June 2017. Daily fish catch records were collected from the fish landing sites of Phewa, Begnas and Rupa in order to determine the fish species contributions to total harvest. Fish sampling was carried out in each of the lakes by gill net (mesh 10–50 mm, size 350–450 m^2) cast net and hook and line with the help of *Jalari* fisher. In addition, fish landing sites were monitored regularly to determine the fish species diversity. Fishes were identified following the descriptions and photographs in Shrestha (1981) and Shrestha (2008).

Fishers of the communities were interviewed to collect information about drivers of fisheries and their impacts on associated lakes (e.g. Phewa, Begnas and Rupa lakes) and community. A total of 80 respondents (equivalent to 40% of the total households) and key informants (President of Phewa and Begnas fish entrepreneur committee, Rupa Lake cooperative, and women’s fisher groups) were interviewed. Monthly field visits were carried out to each lake to find out the present status of fisheries activities, aquaculture (cage and pen aquaculture) and any other factors of interest. The number of cages and pens and their volume were recorded during field visits. Information regarding sources of water pollution such as drainage canal of city, households/hotels on the bank of the lakes, use of pesticides due to intensification of agriculture and other residues that enters to the lake were also recorded. The inlets of each lake were monitored for sedimentation and its effects. The fish breeding and nursing areas in each lake were monitored with the help of fisher community. The coverage of water hyacinth (*Eichhornia crassipes*) in each lake was also monitored. In addition, developmental works (road and bridge construction) were also monitored. Information regarding conservation and management of the lakes were collected from relevant stakeholders including government officials, INGO and NGO personnel. Collected data were summarized in Microsoft Excel 2013 and analysed by using SPSS (version 16).

3 | RESULTS AND DISCUSSION

3.1 | Fish species and production

A total of 26 fish species have been recorded including 20 native and 6 non-native species (Table 1). The amount of the total fish harvested from three lakes of Pokhara Valley in 2016/17 was 118.5 metric tons (MT). The fish production was higher in Phewa Lake followed by Rupa Lake and Begnas Lake (Figure 2).

TABLE 1 Fish species of Phewa, Begnas and Rupa lakes appeared in the catches in 2016–17.

Sl.	*Scientific name*	*Local name*
Native fish species		
1	*Tor putitora*	Sahar
2	*Neolissochilus hexagonolepis*	Katle
3	*Cirrhinus reba*	Rewa
4	*Barilius barna*	Lam Fageta
5	*B. bola*	Fageta
6	*B. vagra*	Fageta
7	*B. bendelisis*	Fageta
8	*Puntius sarana*	Kande
9	*P. sophore*	Bhitte/Bhitta
10	*P. titius*	Bhitte/Bhitta
11	*P. ticto*	Bhitte/Bhitta
12	*Cirrhinus mrigala*	Naini
13	*Catla catla*	Bhakur
14	*Labeo rohita*	Rohu
15	*Mastacembelus armatus*	Chuche Bam
16	*Xenentodon cancila*	Dhunge Bam
17	*Clarias batrachus*	Magur
18	*Mystus bleekeri*	Junge
19	*Channa orientalis / C. gachua*	Bhoti
20	*Channa punctatus*	Bhoti
Exotic fish species		
21	*Aristichthys nobilis*	Bighead carp
22	*Hypophthalmichthys molitrix*	Silver carp
23	*Ctenopharyngodon idella*	Grass carp
24	*Cyprinus carpio*	Common carp
25	*Clarias gariepinus*	African magur
26	*Oreochromis niloticus*	Nile tilapia

Seasonal variations in the catches from three lakes showed that the highest catch was obtained during winter months. Species contribution to the total catch of each lake varied greatly. The per cent contribution of exotic fish species to the total catch of Phewa (88.9%), Begnas (78.9%) and Rupa (86.1%) lakes was much higher than native species. Of non-native species, Nile tilapia (*Oreochromis niloticus*) contributed the biggest proportion, 71.3%, 51.9 % and 42.8 % to the total exotic fish of Phewa, Begnas and Rupa lakes respectively. Previous study reported establishment of Nile tilapia in these lakes and its influence in shifting the catch composition in these three lakes (Husen *et al.* 2016). Other major exotic species in these lakes were bighead carp, silver carp, common carp and grass carp. Among native species, Bhitta (*Puntius* spp.) contributed the highest to the catch made in Phewa and Begnas while Naini (*Cirrhinus mrigala*) dominated the catches of Rupa Lake. The fish production of Rupa Lake was found higher (489.1 kg ha^{-1}) followed by Phewa Lake (132.1 kg ha^{-1}) and Begnas Lake (34.8 kg ha^{-1}; Figure 3). The fish production was positively related to trophic status of lakes.

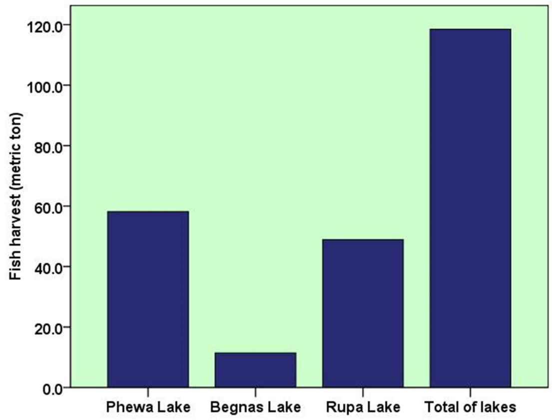

FIGURE 2 Fish harvest (metric ton) from Phewa, Begnas and Rupa lakes in year 2016–17.

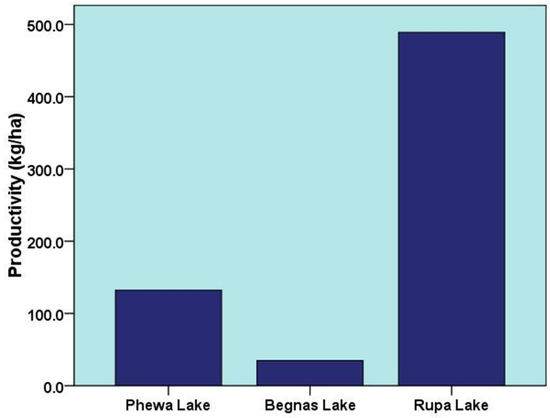

Figure 3 Fish production (kg ha^{-1}) of Phewa, Begnas and Rupa lakes in year 2016–17.

3.2 | Drivers of fisheries and their impacts

Following drivers were recorded, illegal fishing, water pollution, siltation, loss of fish habitat, accelerated eutrophication, exotic fish, agricultural cropping intensification, shrinkage of lake-area and encroachment, developmental works (road and bridge construction) and invasive water hyacinth (Figure 4). Aquaculture and fisheries activities in these lakes were being negatively affected by these factors. Negative impacts on water quality, area, fish habitat, spawning and nursing ground and natural food (phytoplankton and zooplankton compositions) availability were also recorded.

According to *Jalari* fishers, illegal fishing methods, siltation and loss of fish breeding and nursing grounds were the major drivers (Figure 4). Illegal fishing method included use of poison, explosive and electric current during breeding season of native fish species which has caused decline of native fish population. Harvesting of *Tor putitora* and *Neolissochilus hexagonolepis* during breeding migration was recorded. Degradation of studied lakes were also due to lack of active participations of the stakeholders and ownership conflict.

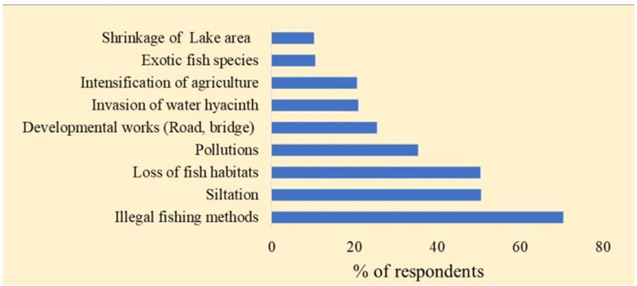

FIGURE 4 Drivers of fisheries in the lakes of Pokhara Valley, recorded during interview of the respondents (as % of respondents reported).

Several areas of Khapudi of Phewa Lake are still available for the fishes to breed but most of the breeding and nursery grounds have decreased drastically in these lakes. The Lake Cluster of Pokhara Valley (LCPV) falls within one of the highest rainfall zones in Nepal (MOFE 2018), which causes natural disasters like landslides, erosion and sediments from the catchment areas and carried heavy sediment load to the lakes through feeding rivers or channels. Slow growth of planktivorous species in cage culture of Phewa Lake have been reported by *Jalari* fishers. Increased abundance of toxic phytoplankton (e.g. *Microcystis aeruginosa*) in Lake Phewa is also affecting the food availability for fishes (Husen *et al.* 2015). Changes in composition of plankton and its density have been documented earlier in these lakes (Husen and Dhakal 2009; Husen *et al.* 2013, 2015). It is also speculated that the food availability became scarce for caged fishes due to presence of Nile tilapia in the lakes, i.e. outside cages. Present survey of fish species showed that the population of Nile tilapia has been increased in recent times since its first record in the catches in 2003 (Husen *et al.* 2016). However, once established it is very difficult to eradicate tilapia completely because of their prolific breeding (Imteazzaman and Galib 2013).

The Pokhara flat valley floors are intensely being used for cultivation of rice, maize, finger millet and vegetables and a large amount of residuals of fertilize, manure and pesticide find their way into Phewa Lake by the feeding streams (MOFE 2018). Due to heavy pollution in lake water, increased level of mercury in fish of Phewa Lake has already been reported which can pose a significant health threat to local people or consumers (Sharma *et al.* 2013; Thapa *et al.* 2014). Metabolites of DDT and endosulfan sulfate were also reported in the muscle of fishes from the lake (Basnet 2011).

Every year, Phewa Lake turns into murky after receiving sediment loads from the surrounding environments. Currently, Phewa Lake area has been decreasing at the rate of 2 ha year^{-1} due to sediment deposition as a result of anthropogenic activities in adjacent areas such as rural road construction, improper and inappropriate land use pattern in both upstream and downstream directions (Heyojoo and Takhachhe 2014). It has been predicted that, due to sediment influx, the Phewa Lake will lose 80% of its storage capacity in the next 110–347 years (Watson *et al.* 2019). Lakes of Pokhara Valley are facing wider problems due to encroachment, siltation, pollution and invasion by non-native species; however, the encroachment is higher in Phewa and Rupa lakes (MOFE 2018). In 1995, the Phewa Lake area was 523 ha (Rai *et al.* 1995) but reduced to only 4.11 ha (Heyojoo and Takhachhe 2014). Likewise, area of Rupa Lake also reduced from 128 ha (Rai *et al.* 1995) to 1.07 ha (Dhakal and Dixit 2013). The natural processes of sedimentation, biological invasion or any kind of destruction become favourable for the encroachment (Bhuju *et al.* 2012). Due to shrinkage of area and decrease in depth of Phewa and Rupa lakes, the carrying capacity of lake for fisheries production has now decreased and it will directly impacts the sustainable fisheries production.

Cage aquaculture in Phewa Lake has been affected and *Jalari* fisher experienced mass mortality of caged fish (10–30%) due to heavy silt deposition in the inlets during rainy season. Cage numbers have been reduced in Phewa Lake over time by 83% in 2018 as compared to 2011 (Figure 5). Water quality of Phewa became more eutrophic due to the addition of nutrient rich municipal sewage into the lake (Fleming and Fleming 2009; Gurung *et al.* 2010; Husen *et al.* 2012a). However, Begnas Lake turns into an oligotrophic to mesotrophic lake (Husen *et al.* 2009) due to damming near the outlet which increased lake depth. Cage numbers have been reduced in Begnas Lake by 88% in between 2011 and 2018 (Figure 5) because of changes in water quality of Begnas Lake (Husen *et al.* 2009; Husen et al. 2012a), which resulted in decreased natural food to caged fish. Rupa Lake water also became more eutrophic and causing fish mortality during overturn (Husen *et al.* 2012a). Poor waste treatment has already been reported from this part of the world where untreated waste products are being dumped directly into nearby waters that often caused mass mortality of aquatic biota (e.g. Galib *et al.* 2018).

Water hyacinth (*Eichhornia crassipes*) has rapidly colonized into the lakes, especially during during rainy seasons. During this time, nearly 25 to 60% of the lake surface remains covered by water hyacinth in Phewa and Begnas lakes. It also affects fishing operations (e.g. gill net operation), boat rowing and sometimes, the beauty of lake. To control rapid unexpected growth of this vegetation huge manpower (*Jalari* fishers) and money are being spent by local government offices (e.g. municipality, district agricultural offices) and local NGOs every year.

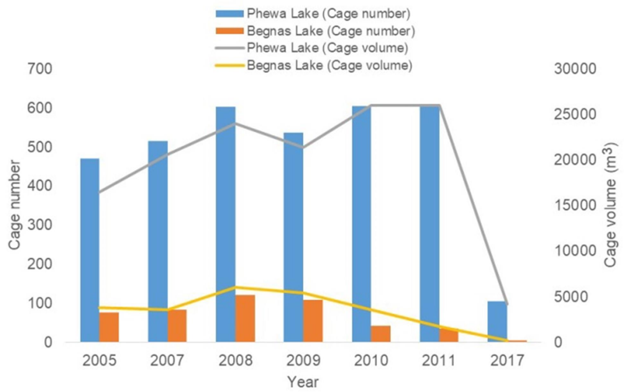

FIGURE 5: Cage number and volume (m^3) in Phewa and Begnas lakes over time.

Species contribution to the total harvest has been changed over time. *Puntius sarana* and *Neolissochilus hexagonolepis* were not recorded in the Begnas Lake (Husen *et al.* 2012b). Declined catches of *N. hexagonolepis* and *Tor putitora* in Phewa and Rupa lakes has also been observed. Increasing trends of Nile tilapia production from these lakes of Pokhara Valley has been reported (Husen *et al.* 2016). A reduction by 42% in *Puntius* spp. and *Mystus* spp. catch was reported due to presence of non-native species in Lake Begnas (Swar and Gurung 1998). African cat fish (*Clarias gariepinus*) has also established in these lakes.

3.3 | Efforts to protect native fish species

Jalari fisher communities were organized to form fish entrepreneurs committee and fish cooperative for the better management of fisheries. They were sensitised for the conservation of native fish species with the technical support from the Fishery Research Station (FRS), Pokhara (Gurung *et al.* 2005; Wagle *et al.* 2007; Gurung 2007; Husen *et al.* 2012c). Women group of *Jalari* community were mobilised for the protection of native fish by patrolling of the breeding ground during the spawning season and campaigning for native fish protection (Gurung *et al.* 2005; Nepal *et al.* 2011; Husen *et al.* 2012c). Manual removal of water hyacinth has been continuously done every year by *Jalari* community. Placement of hording board in different protected places and campaign for the conservation of native fish on the wetland day by FRS, Pokhara have contributed in building awareness among local people towards the conservation of native fish species. Stock enhancement of native fish species, *T. putitora*, *L. rohita*, *C. mrigala*, *C. catla* and *L. dero* have been done every year by FRS, Pokhara as well as by fish entrepreneurs committee and cooperatives of these lakes.

3.4 | Possible approaches to mitigate negative impacts

To keep up the native fish diversity intact and maintain sustainable fisheries, impacts of drivers identified need to be mitigated by applying suitable strategy and coordinated approach and laws enforcement. The illegal fishing methods should be discouraged by making coordination with local government and fisher communities and developing awareness. The spawning ground of fish species should be restored and declared as protected area. Regular monitoring of breeding ground should be continued primarily at the river–lake confluences during breeding season.

Landslides should be controlled by improvements in vegetation in the catchment areas of lakes and adaptation of improved agricultural practices. Sediment load in the inlet water could be lessen by construction of diversion canal, check dams and retaining structures for the reduction of sediment load in lake water and eco-zoning of lake shoreline. The urban pollution could be controlled by prohibiting direct discharge to the lakes and by ensuring prior treatment at waste treatment plants. Mandatory provision of roadside bio-engineering and drainage system has to be developed (GoN/EbA/UNDP 2015) to control the further degradation of lakes. Lake shrinkage could be mitigated by managing landslide and sediment transport to the watershed (Watson *et al.* 2019).

Manual removal of water hyacinth is laborious and costly. Therefore, biological control of water hyacinth using beetles *Neochetina eichhorniae* and *N. bruchi* could be an ecofriendly approach (Jayanth 1988; Firehun *et al.* 2015; Akers *et al.* 2017). The potential use of water hyacinth should be promoted to reduce the cost of management for water hyacinth removal from Pokhara valley lakes. Several studies showed that water hyacinth have various uses such as phyto remediation, paper, organic fertilizer, biogas production, biofuels, briquette, fibre and animal fodder (Jafari 2010; Guna *et al.* 2017; Rezania *et al.* 2017; Sindhu *et al.* 2017).

Continuous and regular monitoring of the fish population, fish catch, limnological studies should be continued to provide updated information relevant to fisheries management. Populations of Nile tilapia must be controlled in these lakes to ensure sustainable yield. Vulnerability of native fish species could be reduced by regular stocking of native fish species and intentional harvesting of Nile tilapia by using selective fishing gears (Husen *et al.* 2016). The introduction and invasion of exotic fish in the natural waters should be controlled to avoid further invasion in uninvaded lakes.

Drivers of fisheries should be regulated by suitable policies, strategy and law enforcement. Formation of an umbrella institution by including different stakeholders could help better manage the lakes, not only fisheries but also tourism. Proper implementation of Integrated Lake Basin Management Plan of Lake Cluster of Pokhara Valley, Nepal would be more fruitful (MOFE 2018).

The development of fishing tourism in these lakes could be of help in generating additional income to fisher communities and their livelihood and it will reduce the emerging risk of reduced fish production from the lakes. The fishing tourism has been a part of international and global concern (Cowx *et al.* 2010; Travis *et al.* 2014). The fishing tourism will provide an ample job and income opportunities for poor fishers. Promoting tourism based recreational fisheries could be one of the safeguarding approaches for fish conservation by providing other livelihood options to traditional fishers through fishing tourism (Gurung and Thing 2016).

The past efforts for fisheries management in the lakes of Pokhara Valley should be continued and it should be managed with its changing context. Drivers, identified in this study, should be addressed as soon as possible to ensure sustainable fish yields. Enforcement of fisheries and lake management strategy by government authority along with involvement of local communities may be the best option in this regard.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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MAH data collection, data analysis and visualisation;
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