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ORIGINAL RESEARCH ARTICLE

The Invasion of Water Hyacinth and Its Impact on Diversity of Macro-Invertebrates in the Lake Cluster of Pokhara Valley, Nepal

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ABSTRACT
Invasion of Alien Invasive Plant species (IAPs) is one of the major drivers for the wetland ecosystem degradation and aquatic biodiversity loss. Among the wetland ecosystems, the freshwater habitats including lakes and streams are more susceptible to species extinction. In the Lake Cluster of Pokhara Valley (LCPV), many aquatic species have been threatened by an abundant occurrence of water hyacinth (Eichhornia crassipes). Thus, this study aims to identity an association of the water hyacinth with different water parameters, diversity and abundance of macro-invertebrates. Water hyacinth is not only correlated with depth, transparency, pH and dissolved oxygen negatively, it is also correlated with temperature and free carbon dioxide positively. A total of 29 species and 26 genera from 21 families and 15 orders of macro-invertebrates were recorded. Among the macro-invertebrates, haplotaxida and diptera were found to be less abundant in the water hyacinth presence (HP) habitat than the water hyacinth absence (HA) habitat. However, the macro-invertebrates were found more abundant and diverse in the HP habitat than the HA habitat (Ranged: HP: 177 to 666; HA: 46 to 483). The abundance of orders like ephemeroptera, odonata, coleoptera, sphaeriida and caenogastropoda was significantly higher in the HP habitats. The direct and indirect effect of water hyacinth on the occurrence of macro-invertebrates and abundance can change the faunal structure of LCPV. Therefore, it is recommended to develop a plan of LCPV to manage the water hyacinth.
KEYWORDS: Eichhornia crassipes, habitats, IAPs, invasion, physico-chemical

INTRODUCTION
The invasion of Alien Invasive Plant species (IAPs) causes the wetland habitat degradation, which is now a global problem for conservationists (Coetzee et al., 2014; Lamelas-López et al., 2021; Pathak et al., 2021). Basically, IAPs modify the ecosystem

of invaded areas, and reduce the abundance and diversity of native floral and faunal species. Due to high competition, predation and hybridization, they change in the community structure (Blackburn et al., 2011; Gentili et al., 2021). Among the various ecosystems, the freshwater ecosystems including lakes and streams are more susceptible to species extinction due to the habitat change and its IAPs invasion (Havel et al., 2015; Shrestha, 2016; Shrestha & Shrestha, 2021). Out of six aquatic invasive plant species of Nepal (Shrestha, 2016; Shrestha & Shrestha, 2021), five species: water hyacinth (*Eichhornia crassipes*), bush morning-Glory (*Ipomoea cornia*), southern cut grass (*Leersia hexandra*), water lettuce (*Pistia stratoides*) and alligator weed (*Alternanthera philoxeroides*) are reported from the lakes of Pokhara valley (Pathak et al., 2021). According to Lowe et al. (2000), the water hyacinth is under the category of 100 worst invasive species in the world.

The water hyacinth is widely distributed in freshwater bodies of about 50 countries in the regions of tropic and subtropic (Bartodziej & Weymouth, 1995; Brendonck et al., 2003; Villamagna, 2009), generally in eutrophic lakes having 30°C of average water temperature, which is suitable for water hyacinth (Harun et al., 2021). It is abundantly found in Africa, North America, Nigeria, New Zealand and Southeast Asia (Ndimele et al., 2011). Probably, the water hyacinth was introduced in Nepal from India, which was first reported in Nepal in 1972 in the western part (Khatri et al., 2018). Its distribution out of its native range was facilitated by human activities such as decoration in gardens, trade and transportation (Villamagna, 2009). The free-floating invasive water hyacinth is native in Brazil and South America; it has a massive reproductive output and rapid growth in polluted water bodies due to lack of natural enemies (Khatri et al., 2018). Due to the rapid proliferation capacity of water hyacinth, its number could be doubled within a week at high temperature (25°C-35°C) (Gunnarsson & Petersen, 2007; Villamagna, 2009). The invasion of water hyacinth in freshwater ecosystem is one of the major causes for the degradation of aquatic ecosystem, deterioration of water quality and the decline of native species (Hailu et al., 2020; Villamagna, 2009; Villamagna et al., 2012). Furthermore, the water hyacinth causes serious ecological and socio-economic problems including water quality degradation and difficulties in recreational activities like boating, swimming and water transport, and obstructing in fisheries as well as agricultures (Assefa & Yigermal, 2019; Njiru et al., 2007; Villamagna & Murphy, 2010).

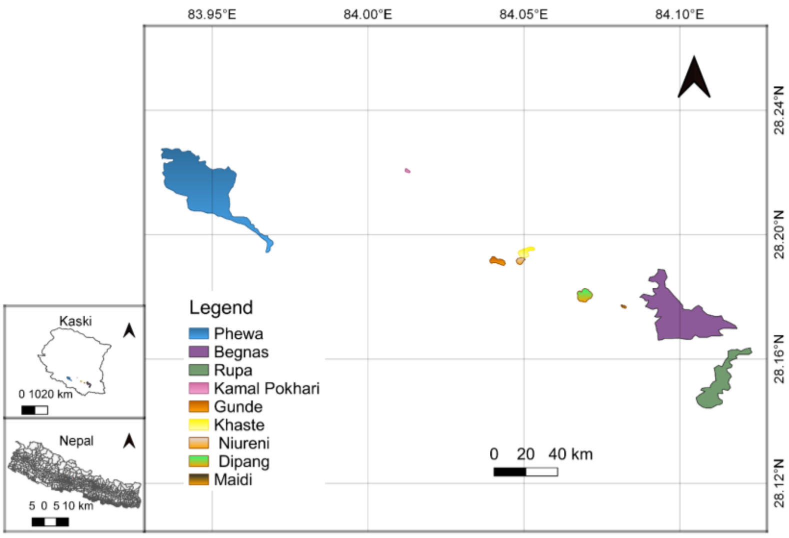
The decreased rate of photosynthesis by the phytoplankton under the dense mat of water hyacinth results in a decrease in dissolved oxygen and an increase in water temperature (Mangas-Ramírez & Elías-Gutiérrez, 2004; Mironga et al., 2012; Villamagna, 2009). Consequently, the aquatic system changes to anoxic conditions with increasing the concentration of ammonia, iron, manganese and sulphide, and change the whole aquatic ecosystem in terms of structure and function (Yongo & Outa, 2015). However, the varying length and complex structure of root of invasive water hyacinth (Gopal, 1987) forms the dense mats of interlocking roots and provides a novel habitat heterogeneity for many epiphytic macro-invertebrates such as amphipods (Rocha-Ramírez et al., 2007; Toft et al., 2003), snails and arachnids (Brendonck et al., 2003). Furthermore, the macro-invertebrates like insects, crustaceans and fish get benefited from the mat of water hyacinth as a nursery ground (Brendonck et al., 2003; Villamagna, 2009). Bailey and Litterick (1993) reported a higher density of macro-invertebrates within six metres of open water from the water hyacinth edge other than that of the non-vegetated habitat. Similarly, more abundant and diverse macro-invertebrates were reported from the water hyacinth edge than that of the rooted emergent vegetation in Lake Victoria (Masifwa et al., 2001). Further, the habitat complexity may be altered due to the introduction of invasive species in the freshwater lakes and streams resulting in a shift in the macro-invertebrate community structure (Wahl et al., 2021). Moreover, the larger lakes of LCPV (Phewa, Begnas and Rupa) are exceedingly invaded by the water hyacinth and had adverse effects on the occurrence and abundance of threatened water birds (Basaula et al., 2021). Similar effects can be found in other faunal species including the macro-invertebrates in LCPV due to a presence of the water hyacinth. The macro-invertebrates are one of the major components in the ecological process to transfer energy from the detritus to consumers. However, little knowledge is available on the invasion effect of water hyacinth on diversity and abundance of macro-invertebrates in LCPV; therefore, this study aimed to explore the invasion effects of water hyacinth on the diversity and abundance of macro-invertebrates in LCPV, which have provided the baseline data for developing a plan.

MATERIALS AND METHODS

Study Area

Figure 1

The Lake Cluster of Pokhara Valley



Pokhara, the largest and speedily urbanizing Metropolitan City of Nepal, is located in Kaski District of Gandaki Province in the watershed of Seti River. The area of LCPV is expanded from Pokhara Metropolitan City to a small portion of Rupa and Annapurna Village Municipalities. It consists of three large lakes (Phewa, Begnas and Rupa) and six small lakes (Kamal Pokhari, Gunde, Khaste, Niureni, Dipang and Maidi) (Figure 1). On 2 February 2016, the LCPV was listed as the tenth Ramsar site with an area of 262 kilometres, including 9 kilometres of the water body, which is the largest Ramsar site of Nepal. Among these lakes, the Phewa lake, the largest lake of the cluster, fluctuates between mesotrophic and eutrophic while the Begnas lake, the second-largest lake of the cluster, fluctuates between oligotrophic and mesotrophic, and the remaining are eutrophic lakes (MoFE, 2018). The LCPV is regarded as the hotspot of biodiversity; its southern part is covered with sub-tropical to the tropical broad-leaved forest of Sal (*Shorea robusta*) whereas the northern and western parts are covered with the forest of Chilaune-katus (*Schima-Castanopsis*). More than 360 species (plants), 32 species (mammals), 140 species (birds), 24 species (reptiles), 27 species (fish) and 11 species (amphibians) are found in LCPV (MoFE, 2018). The globally threatened fauna such as clouded leopard (*Neofelis nebulosa*) and leopard (*Panthera pardus*), yellow-breasted bunting (*Emberiza aureola*), baer's pochard (*Aythya baeri*), common pochard (*Aythya ferina*), woolly necked stork (*Ciconia episcopus*) and ferruginous pochard (*Aythya nyroca*) were reported from LCPV (MoFE, 2018; Basaula et al., 2021). In addition, some invasive animals and plants are found in LCPV. For examples, tilapia (*Tilapia nilotica*), African cuttlefish (*Clarias gairiepinus*), giant African land snail (*Achatina fulica*) parthenium (*Parthenium hysterophorus*), mikania (*Mikania micrantha*), water hyacinth, cut grass and water lettuce (MoFE, 2018; Adhikari et al., 2020).

Methods

A total of 24 sampling plots, each of 50 m × 50 m, were established based on the size of the lakes and the presence of water hyacinth (HP) or absence of water hyacinth (HA) areas in the lakes of LCPV. Three HP and three HA plots were established in the larger lakes (Phewa, Begnas and Rupa) and a single HA plot was established in each of the smaller lakes. During the study period, the water hyacinth coverage percentage in HP areas was > 90%, but the water hyacinth was completely absent in HA areas in the past ten years, which was confirmed through the personal communication with the members of fishing community and lake management committees. The distance between HP and HA plots in large lakes was ≥500 m. The coordinates of each plot were recorded using GPS (Garmin eTrex Touch 35). The data collection was carried out seasonally during the autumn 2019 (September to November), the winter 2020 (December to February), the spring 2020 (March to May) and the summer 2020 (June to August).

Macro-Invertebrates Survey

Each 50 m × 50 m plot was again divided into 1 m × 1 m of sub-plot for the study of macro-invertebrates. Five sub-plots (four at the corners and one at the center) were selected from each plot to collect the macro-invertebrates. Peterson's Grab Sampler (0.0289 m) was used to collect the samples from each sub-plot. All the contents of Grab samples were collected in the polythene bags and were screened by using a standard sieve of 40 mesh size/inch. The water hyacinth plants from each subplot were taken out and the epiphytic macro-invertebrates found in stem and leaf were manually picked up using entomological forceps and brush, but the root was combed in a bucket containing 70% ethanol. The sieved samples and manually picked samples were transferred to plastic bottles containing 5% formalin and kept the details of sampling site and date following Toft et al. (2003). The samples of macro-invertebrates were taken to the laboratory and poured into a white enamel tray. All the macro-invertebrate taxa were identified up to possible taxonomic level (species) following the taxonomic manuals (Budha, 2016; Edmondson, 1959; Macan, 1977; Pennak, 1953; Subramanian & Sivaramakrishnan, 2007; Tonapi, 1980). All the individuals were counted from each sub-plot and its average was calculated for analysis. The abundance of macro-invertebrate taxa was expressed as individuals per square meter.

The Parameters of Water

The water samples were collected from a 1m × 1m sub-plot (four from the edge and one from the center of each plot). A measuring tape was used to measure the depth (m) and then Sechhi disc of 20 cm diameter was used to measure the transparency (cm). The disc was immersed from the water surface downward till it disappeared and the depth was noted. Then, the disc was lifted upward till it reappeared and again the depth was noted. The water temperature of the lake was measured in the field using a standard mercury thermometer graduated as 0-50°C, having a precision of 0.1°C. The pH was measured using (4500- B, APHA), total dissolved solids (mg/l) were measured

(Instrumental) and turbidity (NTU) was measured using (3130 B, APHA). In addition, the titration method APHA (1998) was used to measure the dissolved oxygen (mg/l), free carbon dioxide (mg/l), total alkalinity (mg/l) and Nitrate (mg/l).

Data Analysis

Diversity indices (H'), species evenness (J) and species richness (S) of macro-invertebrates were calculated following Shannon-Wiener et al. (1949) and Pielou (1966). Our data were not normally distributed. We compared the abundance of macro-invertebrates between HP and HA areas using Mann–Whitney U test. The association between water hyacinth coverage with physico-chemical parameters was measured. A simple linear regression was performed between macro-invertebrate abundance and species richness with dissolved oxygen, free carbon dioxide and water hyacinth coverage percentage. In addition, a multivariate ordination analysis was used between biological variables (most abundant 14 macro-invertebrate taxa) and environmental variables (physico-chemical parameters and water hyacinth coverage). Detrended Correspondence Analysis (DCA) was applied to find whether our data support for Canonical Correspondence Analysis (CCA) or Redundancy Analysis (RDA). Our data supported RDA because the lengths of all four axes were less than two in DCA (Yang et al., 2020) to identify the variation in the dominant macro-invertebrates compared with the environmental variables. Moreover, Monte-Carlo permutation test under the reduced model of 999 permutations at ($\alpha = 0.05$) (Powell, 2019) was used to perform the significance testing of ordination. The function decorana was used for DCA and the function rda was used for RDA in the vegan package of R statistical software. The data analysis was carried out using program R (R Core Team, 2020).

RESULTS

Abundance and species diversity of macro-invertebrates

The researchers identified 29 species and 26 genera of macro-invertebrates belonging to 21 families, 15 orders and three phyla (Annelida, Arthropoda and Mollusca) during the study period in LCPV (Table 1 and Table 2). The highest relative abundance of macro-invertebrates 16.47% (n=4644) was found in HP habitat in autumn 2019 and 16.25% (n=4583) in HA habitat in the spring 2020. Similarly, the lowest relative abundance 9.85% (n=2776) was found in HP habitat and 10.57% (n=2981) in HA habitat during the winter 2020 (Table 1). The highest mean abundance of macro-invertebrates (102.35±7.04) was recorded in bottom sediments, followed by (50.38±3.67) in the root of water hyacinth and the lowest abundance (7.47±0.33) was in the stem of water hyacinth and sand (Figure 2).

Table 1

Seasonal abundance of Macro-Invertebrates in Water Hyacinth Presence Habitat (HP) and Water Hyacinth Absence Habitat (HA) of Lake Cluster of Pokhara Valley between 2019 and 2020.

Seasons	HP	Relative abundance%	HA	Relative abundance%
Autumn 2019	4644	16.47	3889	13.79
Winter 2020	2776	9.85	2981	10.57
Spring 2020	3860	13.69	4583	16.25
Summer 2020	3006	10.66	2457	8.71

Figure 2

Mean Abundance of Macro-Invertebrates in Different Habitats of Lake Cluster of Pokhara Valley between 2019 and 2020

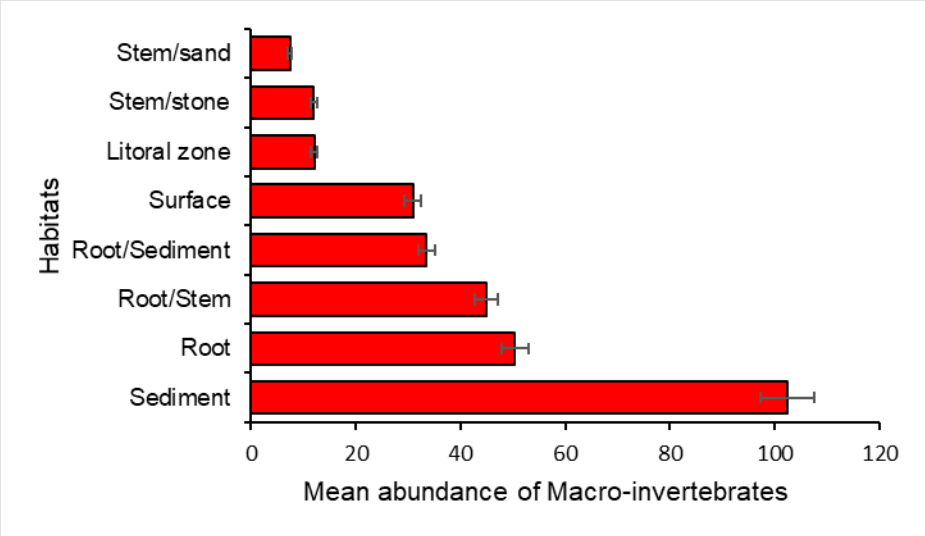


Table 2

Mean Abundance ± Standard Error of the Macro-Invertebrates Recorded in Water Hyacinth Presence Habitat (HP) and Water Hyacinth Absence Habitat (HA) of Lake Cluster of Pokhara Valley between 2019 and 2020

SN	order	Family	Scientific name	Mean ± SE (HP)	Mean ± SE (HA)
1	Haplotaxida	Tubificidae	*Limnodrilushoffmeisteri*Claparède, 1862	11.42±1.15	20.93±2.41
2			*Branchiurasowerbi*Beddard, 1892	13.25±1.47	21.27±2.14
3		Naididae	*Tubifextubifex* Mueller, 1774	5.61±0.94	16.95±1.75
4			*Stylarialacustris* Linnaeus, 1767	5.83±0.55	13.47±1.72
5	Hirudinida	Hirudinidae	*Hirudinaria granulosa* Lucknow, 1941	2.64±0.4	2.75±0.59
6			*Hirudomedicinalis*Linnaeus, 1758	5.33±0.67	3.55±0.45
7	Rhynchobdellida	Glossiphonidae	*Helobdellastagnalis*Linnaeus, 1758	6.81±0.97	2.95±0.47
8			*Placobdellaparsitica*Say, 1824	5.36±0.77	2.18±0.4
9	Diptera	Chironomidae	*Chironomus* sp. Meigen, 1803	21.69±4.44	37.52±4.07
10	Ephemeroptera	Leptophlebiidae	*Leptophlebia marginata* Linnaeus, 1767	39.92±2.95	11.75±0.92
11	Odonata	Libellulidae	*Diplacodes*sp.Rambur, 1842	13.67±0.98	4.85±0.83
12			*Brachythemiscontaminata*Fabricius, 1793	15.69±0.98	4.23±0.71
13		Gomphidae	*Gomphidia*sp. Selys, 1854	10.31±0.8	4.03±0.68
14		Hemiphlebiidae	*Schnuraheterosticta*Burmeister, 1842	15.75±1.09	8.77±0.69
15	Hemiptera	Gerridae	*Aquarius remigis*Say, 1824	31.81±2.19	30.3±1.92
16		Nepidae	*Nepa cinerea* Linnaeus, 1758	0.08±0.08	1.67±0.48
17	Coleoptera	Dytiscidae	*Thermonectus* sp. Dejean,1833	72.69±4.79	16.67±1.66
18	Araneae	Pisauridae	*Dolomedestenebrosus*Hentz, 1844	2.08±1.07	0.25±0.1
19	Decapoda	Paleomonidae	*Paleomon*Weber, 1795	1.89±0.56	0.53±0.23
20	Sphaeriida	Sphaeriidae	*Sphaerium* sp. Scopoli, 1777	64.06±3.53	15.2±1.99

21	Acroloxoidea	Acroloxidae	*Acroloxuslacustris*Linnaeus, 1767	12.64±1.03	2.03±0.49
22	Unionoida	Unionidae	*Lamellidens* sp. Simpson, 1900	3.08±0.76	2.3±0.46
23		Veneridae	*Radiatula s*p.Simpson, 1900	0.75±0.37	1.17±0.35
24	Basommatophora	Planorbidae	*Helisoma* sp.Brown, 1967	1.64±0.91	
25			*Segmentina* sp. Fleming, 1817	0.97±0.35	0.28±0.12
26	Caenogastropoda	Thiaridae	*Thiararequeti*Grateloup, 1840	1.47±0.86	
27			*Thiaratuberculata* Mueller, 1774	10.97±1.52	2.05±0.35
28			*Thiaragranifera* Lamarck, 1822	6±1.51	1.25±0.41
29		Viviparoidae	*Bellamya bengalensis* Lamarck, 1822	13.42±1.39	2.93±0.42

The highest mean abundance for *Chironomus* sp. (37.52±4.07) was recorded in the study and was followed by *Aquarius remiges* (30.30±1.92) in the HA habitat whereas the lowest abundance was found for *Dolomedes tenebrosus* (0.25±0.10). Similarly, the highest mean abundance for *Thermonectus* sp. (72.69±4.79) was recorded in the HP habitat, followed by *Sphaerium* sp. (64.06±3.53) whereas the lowest abundance was found for *Nepacenerea* (0.08±0.08) (Table 2). The abundance of macro-invertebrate was varied between HP and HA habitats (Ranged: HP: 177 to 666; HA: 46 to 483, $p < 0.001$). The abundance of orders ephemeroptera, odonata, coleoptera, sphaeriida and caenogastropoda was significantly higher in the HP habitats whereas orders haplotaxida and diptera were lower in the HA habitat (Table 3).

Table 3

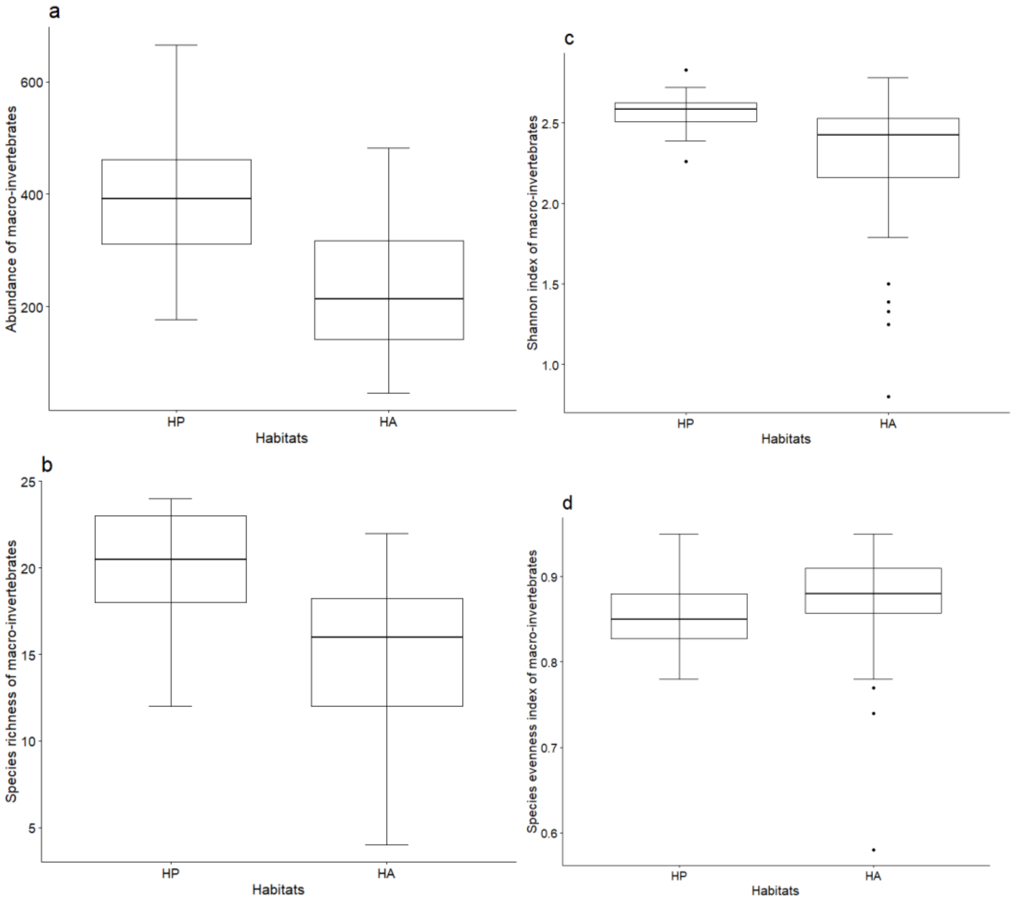
Comparison of Different Variables in Water Hyacinth Presence Habitat (HP) and Water Hyacinth Absence Habitat (HA) of Lake Cluster of Pokhara Valley between 2019 and 2020

Variables	HP habitat	HA habitat	Statistics
Abundance	Median = 392	Median = 231	Mann Whitney test, U = 358, p = <**0.001**
Orders			
Haplotaxida	Median = 27.5	Median = 66	Mann Whitney test, U = 1390, p = **0.01**
Diptera	Median = 10.5	Median = 26.5	Mann Whitney test, U = 1499.5, p = **0.001**
Ephemeroptera	Median = 37	Median = 11	Mann Whitney test, U = 92, p = <**0.001**
Odonata	Median = 52.5	Median = 13	Mann Whitney test, U = 263.5, p =<**0.001**
Coleoptera	Median = 68.5	Median = 18	Mann Whitney test, U = 65.5, p = <**0.001**
Sphaeriida	Median = 60.5	Median = 14	Mann Whitney test, U = 64.5, p = <**0.001**
Caenogastropoda	Median = 23.5	Median = 5	Mann Whitney test, U = 110, p = <**0.001**

Macro-invertebrate diversity and species richness were greater in the HP habitat (H' = 2.58; S = 24) than the HA habitat (H' = 2.42; S = 22). Greater species evenness was found in the HA habitat (J = 0.87) than in the HP habitat (J = 0.85) (Table 3, Figure 3).

Figure 3

Abundance and Species Diversity of Macro-Invertebrates in HP and HA Areas in Lake Cluster of Pokhara Valley between 2019 and 2020. HP=Water Hyacinth Presence Habitat and HA=Water Hyacinth Absence Habitats



Relation of water hyacinth with physico-chemical parameters

The water hyacinth coverage had a significant moderate negative correlation with depth, transparency, pH, dissolved oxygen and nitrate ($r = -0.51$, $r = -0.73$, $r = -0.63$, $r = -0.77$ and $r = -0.63$, respectively, $p < 0.001$) while it had a significant positive correlation with the water temperature and free carbon dioxide ($r = 0.86$ and $r = 0.84$, respectively, $p < 0.001$) (Table 4).

Table 4

Correlation Matrix among the Environmental Variables of Lake Cluster of Pokhara Valley between 2019 and 2020, Bold Values Represent Significant ($P < 0.05$)

Variables	Depth	Temp	Transp	pH	DO	Free CO_2	Total Alk	Nitrate	Whcov
Depth	1								
Temp.	-0.62	1							
Transp.	**0.82**	-0.76	1						
pH	0.68	-0.64	0.75	1					
DO	0.69	**-0.80**	0.78	0.61	1				

Free CO_2	-0.78	**0.80**	**-0.93**	**-0.81**	-0.74	1			
Total Alk	0.30	-0.30	0.30	0.48	0.27	-0.40	1		
Nitrate	0.45	-0.67	0.61	0.58	0.66	-0.61	0.51	1	
Whcov	**-0.51**	**0.86**	**-0.73**	**-0.63**	**-0.77**	**0.84**	-0.46	**-0.63**	1

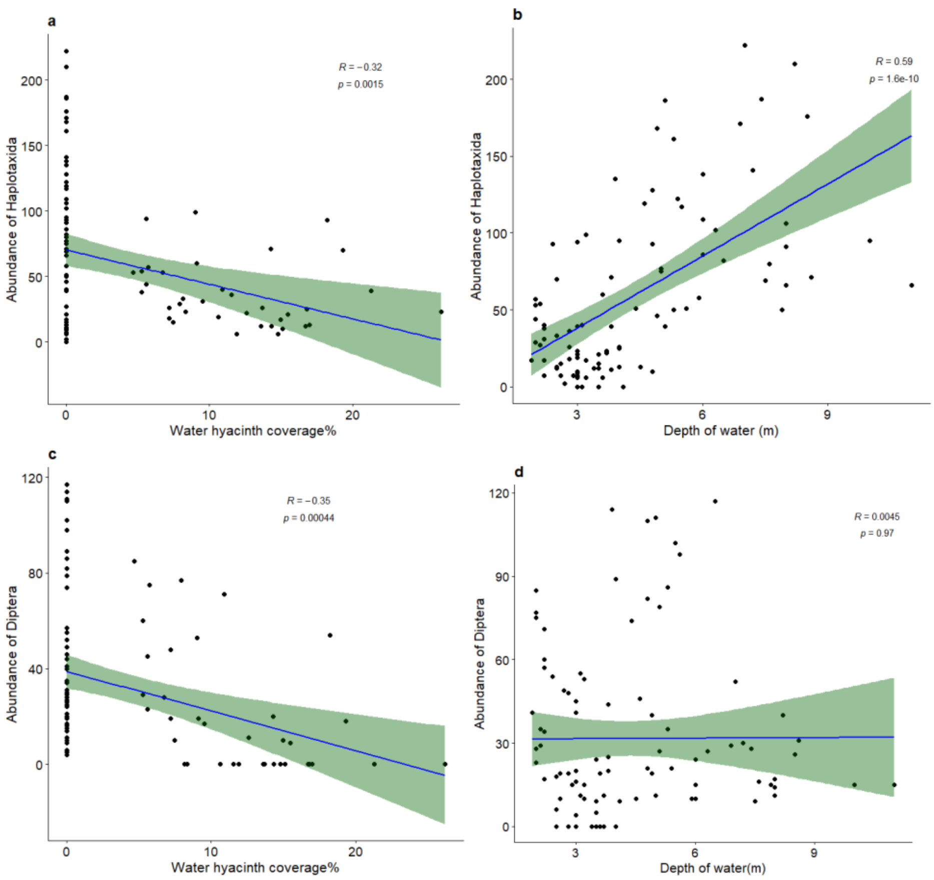
*Temp. = Water temperature, Transp. = Transparency, Alk. = Alkalinity and Whcov = Water hyacinth coverage.

Correlation of Macro-Invertebrates with Environmental Variables

The correlation of order haplotaxida's abundance with the water hyacinth coverage was negative and significant ($r = -0.32$, $p < 0.001$) whereas positive and significant with depth ($r = 0.59$, $p < 0.001$). Similarly, the abundance of order diptera was negative, but significantly correlated with the water hyacinth coverage ($r = -0.3$, $p < 0.001$) and positively correlated with depth ($r = 0.0045$, $p = 0.09$) (Figure 4). Except these two orders, the researchers performed RDA analysis.

Figure 4

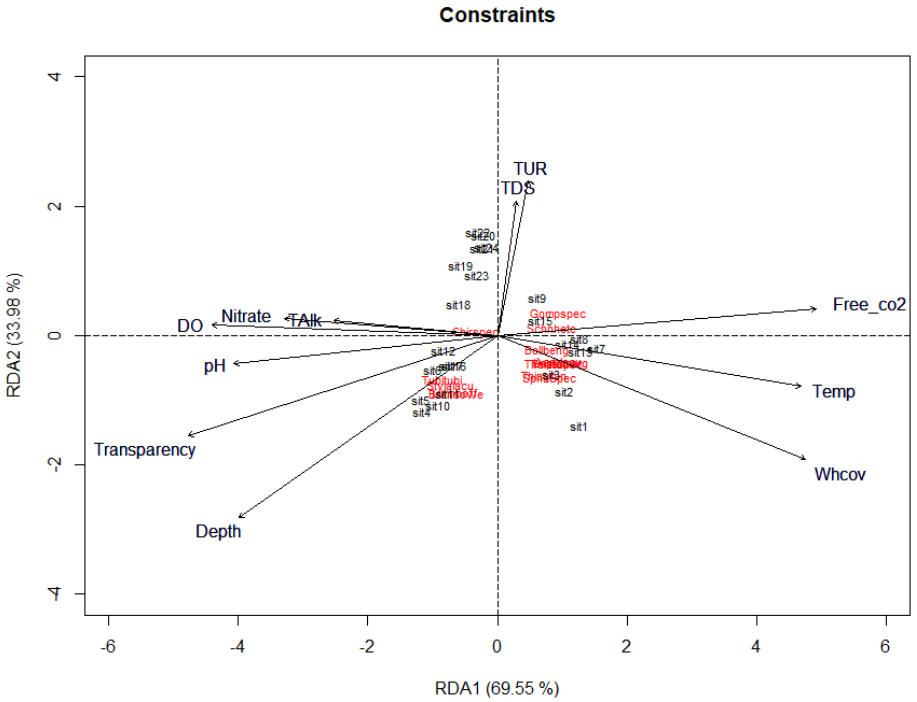
Abundance of Haplotaxida and Diptera with Water Hyacinth Coverage and Depth of Water



The temperature and free carbon dioxide were closely associated with the water hyacinth coverage whereas other variables were negatively correlated (Figure 5). Similarly, the macro-invertebrates such as *Leptophlebia marginata*, *Gomphidia* sp., *Schnurahete rosticta*, *Thermonectus* sp. and *Sphaerium* sp. were closely associated with the water hyacinth coverage, but *Limnodrilus hoffmeisteri*, *Branchiura sowerbi*, *Tubifex tubifex*, *Stylariala custris* and *Chironomus* sp. were negatively associated (Figure 5). The canonical axes of RDA analysis explained the variance in the macro-invertebrates and environmental variables interaction (F = 5.83, p = 0.001), and the first and second axis accounted for 69.55% and 33.98%, respectively (Figure 5).

Figure 5

RDA of Macro-Invertebrates after Constraining Variation by Environmental Variables



DISCUSSION

The present study identified the effect of water hyacinth invasion on the diversity and abundance of macro-invertebrates in the Lake Cluster of Pokhara valley. Marginally, more macro-invertebrates and higher abundance were recorded in the water hyacinth presence habitat than the absence habitat. Higher diversity of maco-invertebrates in the HP habitat might be due to the presence of substrate structures such as roots, stem and leaves (da Silva & Henry, 2020; Hansen et al., 1971; O'Hara, 1967; Toft et al., 2003; Villamagna & Murphy, 2010). The diversity and abundance of macro-invertebrates were varied according to the season in the HP and HA habitat. In the winter season, the low abundance of macro-invertebrates in the study area might be due to low water temperature, which will not be suitable for the seasonal invertebrates especially for mayfly and other ephemeroptera. The wetland vegetation along with the water hyacinth start to grow during the summer and become dense during late summer and autumn, and provide suitable habitats for the macro-invertebrates. Therefore, the researchers assumed abundant macro-invertebrates and water hyacinth coverage in the autumn season in the study area, which have a positive relationship. Not only in the study area, the macro-invertebrates and water hyacinth had a positive relation in the reservoir of the western part of Ecuador (Thi Nguyen et al., 2015). At the time of higher abundance of water hyacinth, the body structure of plants becomes flat, cover a larger area and provides a shelter for more species such as larvae of mayfly, dragonfly and diving beetles (Villamagna, 2009); therefore, the researchers assume abundant macro-invertebrates in the summer and autumn seasons. The morphological characteristics and structural complexity of plants determine the abundance of macro-invertebrates (Villamagna, 2009; da Silva and Henry, 2020). The root and leaves of floating water hyacinth offer the complex habitat for the colonization of macro-invertebrates like snails, arachnids and amphipods (Brendonck et al., 2003; Toft et al., 2003; Villamagna, 2009). The greater abundance of macro-invertebrates including mayfly, arachnids and snails in the HP areas might be due to the presence of water hyacinth for providing spaces. However, an abundance of macro-invertebrates was reported higher in the artificially constructed HA habitats than the HP habitats (Coetzee et al. 2014). It might be due to the substrate variation and age of habitats.

The higher abundance of omnivore and insectivore waterbirds in the HP habitat of LCPV was reported by Basaula et al. (2021), which could be due to the higher abundance of macro-invertebrates in the HP areas of LCPV. However, the abundance of macro-invertebrates from two orders haplotaxida (*Limnodrilus hoffmeisteri*, *Branchiura sowerbi*, *Tubifex tubifex*, *Stylariala custris*) and diptera (*Chironomous sp*.) were found significantly lower in the HP habitats than in the HA habitats. The abundance of haplotaxida and diptera decreased with the increasing water hyacinth coverage, indicating that the water hyacinth has negative effects on the macro-invertebrates in LCPV. The taxa in these orders have a high tolerance to the toxic substances (Mandaville, 2002). The higher abundance of haplotaxida and diptera in the HA habitat at LCPV was found in higher depth in the large lakes and the bottom sediments of small lakes where decomposed/sediment materials were found. The water hyacinth is floating and buoyant and move from one location to another, and their deposition of parts may not be in the same location of lake. Additionally, oligochaetes and chironomid larvae were abundantly found in the HA habitats, having a higher decomposition of organic materials, which were high tolerance taxa (Shah et al., 2011). Furthermore, the HP habitat was more diversified than the HA habitat in LCPV. In this way, all three indices were consistently higher at the HP habitats (Brendon et al., 2003). Moreover, these studies supported that the water hyacinth can provide a suitable and novel habitat for the macro-invertebrates when it is in a fragmented patch in waterbodies.

The analysis of physico-chemical parameters revealed that all the parameters were found significantly different in the HP and HA habitats except water temperature and turbidity; however, it was also slightly more in the HP habitats (Basaula et al., 2021). This slight increase in temperature in the HP habitats might be due to the prevention of sunlight penetration by the mats of water hyacinth. Consequently, the rate of photosynthesis will be decreased below the dense mat of water hyacinth by the phytoplankton, resulting a decrease in dissolved oxygen and an increase in water temperature (Mangas-Ramírez & Elías-Gutiérrez, 2004; Mironga et al., 2012; Villamagna, 2009). The pH of the water was found higher in the HA habitat in all seasons, which indicated that the water hyacinth makes the habitat slightly acidic (Dersseh et al., 2019; Mironga et al., 2012) probably due to higher production of free carbon dioxide in the HP habitat. The eutrophic level of the lake is increased due to the secondary pollution and due to the decay of dead water hyacinth, and finally it may cause the serious problems in the lake ecosystem (Chen et al., 2021). Consequently, the aquatic system changes to anoxic conditions with increasing the concentration of ammonia, iron, manganese and sulphide, which change the whole aquatic ecosystem in terms of structure and function (Yongo & Outa, 2015). A depth of water was recorded higher in the HA habitat than in the HP habitat because the water hyacinth cannot grow in the water more than six-meter depth (Dersseh et al., 2019). The water hyacinth can absorb the nutrients including nitrates from the water body (Masifwa et al., 2001; Villamagna et al., 2010), and therefore the low content of nitrate was found in the HP habitat than the HA habitat. The low value of dissolved oxygen in the HP habitat with high free carbon dioxide might be due to the metabolic activities of the epiphytic organism (Masifwa et al., 2001; Villamagna et al., 2010). The correlation matrix showed that the water temperature and free carbon dioxide increased with the increase of water hyacinth coverage, but it was opposite to depth, transparency, dissolved oxygen, etc. The multivariate RDA ordination showed that the species like *Leptophlebia marginata*, *Gomphidia*sp., *Schnurahete rosticta*, *Thermonectus* sp. and *Sphaerium* sp. were found as dominant species in the water HP habitats and these species were closely associated with the water hyacinth coverage percentage, free carbon dioxide and water temperature, but the species like *Limnodrilus hoffmeisteri*, *Branchiura sowerbi*, *Tubifex tubifex*, *Stylariala custris* and *Chironomus* sp. were found as dominant species in the HA habitats.

CONCLUSION

In conclusion, the variation on the diversity and abundance of macro-invertebrates in LCPV between the HP and HA habitat is mainly due to changes in the structural composition and physico-chemical properties. The increased in water temperature and carbon dioxixe with decreased disssolved oxygen in the increased water hyacinth coverage indicates the probability of macro-invertebrate variation, which was reported in this study. The water hyacinth supports the occurrence of some species with higher abundences while it has negative effects on others including haplotaxida and diptera. The consequences of increased water hyacinth coverage is noticed in some water birds. Therefore, based on these findings, the researchers recommended multidisciplinary research approaches in the field of effects of invasive water hyacinth and other weeds on the structure and function of aquatic ecosystem, and implementation of an integrated approach to managing the water hyacinth to conserve aquatic biodiversity in LCPV.

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