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Invasive Water Hyacinth Limits Globally Threatened Waterbird Abundance and Diversity at Lake Cluster of Pokhara Valley, Nepal

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Abstract: Invasive species alter ecosystem structure and functioning, including impacts on native species, habitat alteration, and nutrient cycling. Among the 27 invasive plant species in Nepal, water hyacinth (*Eichhornia crassipes*) distribution is rapidly increasing in Lake Cluster of Pokhara Valley (LCPV) in the last several decades. We studied the effects of water hyacinth on threatened waterbird abundance, diversity, and physico-chemical parameters of water in the LCPV. We found areas with water hyacinth present (HP) had reduced threatened water bird abundance relative to areas where water hyacinth was absent (HA; $p = 0.023$). The occurrence of birds according to feeding guilds also varied between water hyacinth presence and absence habitats. Piscivorous birds were more abundant in HA areas than HP areas whereas insectivorous and omnivorous birds had greater abundance in HP areas than in HA areas. Threatened waterbird abundance and richness were greater in areas with greater water depth and overall bird abundance but declined in HP areas. Degraded water quality was also identified in HP areas. Our findings can be used as a baseline by lake managers and policy makers to develop strategies to remove or manage water hyacinth in LCPV to improve waterbird conservation.

Keywords: abundance; physicochemical; threatened; waterbirds; wetland

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1. Introduction

Biological invasions have adverse effects on ecosystem structure and functioning in terrestrial and aquatic ecosystems [1–5]. Major impacts of alien invasions include the loss of native species, habitat alteration, and deterioration of ecosystem productivity and nutrient cycling [6–9]. For example, mikania (*Mikania micrantha*) covers about 44% of the habitat of Greater one-horn rhino (*Rhinoceros unicornis*) in Chitwan National Park, Nepal, and has reduced the growth of primary grass and tree species resulting in limited forage for this species [4,5,10]. Other invasive plant species in Nepal alter ecosystems, including parthenium (*Parthenium hysterophorus*) in grasslands and residential areas, blue billygoat weed (*Ageratum houstonianum*) in agro-ecosystems, and water hyacinth (*Eichhornia crassipes*) in wetlands [5,8]. The effects of invasive species on native flora and fauna [11], including endemic species [12–14], are increasing in Nepal.

In Nepal, of 182 alien flowering plants, 27 species are considered invasive [11]. Among these invasive species, four species, siam weed (*Chromolaena odorata*), lantana (*Lantana camara*), mikania, and water hyacinth, are considered among the World's 100 invasive species with the greatest negative impacts [15]. Water hyacinth is a perennial, mat-forming, and rooted macrophyte native to Brazil and can proliferate rapidly as an invasive species, limiting the growth of native species in polluted water bodies [16]. Its distribution outside of Brazil includes Africa, North America, New Zealand, and Southeast Asia, including Nepal [17], and is facilitated by human trade as an ornamental [18]. Water hyacinth was first reported in western Nepal in 1972 [18] and was likely introduced from India [19]. Water hyacinth has a high reproductive rate and can double in numbers within seven days [20]. Water hyacinth can degrade aquatic ecosystems displacement of native species and decreased water quality [16,21,22]. Decreased photosynthesis of phytoplankton, decreased dissolved oxygen, and increased water temperature can occur in areas with abundant water hyacinth [16,23,24], resulting in anoxic conditions with elevated concentrations of ammonia, iron, manganese, and sulphide [25].

Waterbirds are wetland dependent species, with wetlands providing habitat for many residential and migratory birds for foraging [26], nesting, and reproduction [27]. However, wetlands are highly vulnerable ecosystems, with the greatest loss of wetlands occurring in portions of Asia due to habitat degradation, habitat fragmentation, and biological invasion [22,27–29]. The invasion of water hyacinth in wetlands can reduce water quality and limit open water areas needed by some threatened bird species [22]. Consequently, many waterbirds populations are declining [29]. For example, migratory birds were absent in Lake Chapala Mexico when the lake surface was covered by water hyacinth [22].

Of the 886 bird species occurring in Nepal, 200 species are classified as waterbirds [30]. Waterbird populations in Nepal have declined in recent years, and about 25% of these species are at high risk for extinction [29]. Water hyacinth can decrease water quality and access to threatened waterbirds [22], which are critical to aquatic food webs [31–33]. However, we have little knowledge of the effects of water hyacinth on threatened waterbird distributions and abundance and the corresponding water quality, which is pre-requisite for developing invasive wetland species management strategies for the LCPV. We quantified the effects of water hyacinth on the abundance of waterbirds and the physicochemical parameters of water in the LCPV, Nepal, emphasizing globally threatened waterbirds.

2. Materials and Methods

2.1. Study Area

Pokhara Metropolitan City is one of the most rapidly urbanizing cities in Nepal and occurs within the Seti River watershed. The city encompasses the LCPV, which includes nine lakes (Phewa, Begnas, Rupa, Kamal Pokhari, Gunde, Khaste, Niureni, Dipang, and Maidi) of ecological importance and is identified as a Ramsar Site (Figure 1). The LCPV comprises 262 km^2 with the lakes covering 9 km^2. Among these lakes, Phewa is meso-eutrophic (i.e., moderate nutrient loading), Begnas is oligo-mesotrophic (i.e., low nutrient loading with clear, deep water), and the seven remaining lakes are eutrophic (i.e., high nutrient loading); all lakes contain diverse aquatic plants and animals [34]. Aquatic plant species in the LCPV include white cheesewood (*Alstonia scholaris*); yellow grass orchid (*Apostasia wallichii*); champak (*Michelia champaca*), satawari or asparagus (*Asparagus racemosus*), bulbophyllum (*Bulbophyllum plyrhiza*); cymbidium (*Cymbidium iridioides*), pineapple orchid (*Dendrobium densiflorum*), fringe-lipped dendrobium (*D. fimbriatum*), tree fern (*Cyathea spinulosa*), elephant's foot (*Dioscorea deltoidea*), oberonia or Nepal's orchid (*Oberonia nepalensis*), Sikkim's orchid (*O. iridifolia*), Indian trumpet flower (*Oroxylum indicum*), terete vanda (*Papilionanthe teres*), malabar gulbel (*Tinospora sinensis*), and common hornwort (*Ceratophyllum demersum*); and water chestnut (*Trapa natans*) and lesser Bulrush (*Typha angustifolia*) [34]. Bird species in the LCPV include spiny babbler (*Turdoides nepalensis*), Nepal wren babbler (*Pnoepyga immaculate*), comb duck (*Sarkidiornis melanotos*), Baer's pochard (*Aythya baeri*), ferruginous duck (*Aythya nyroca*) [35], and numerous other waterbirds.

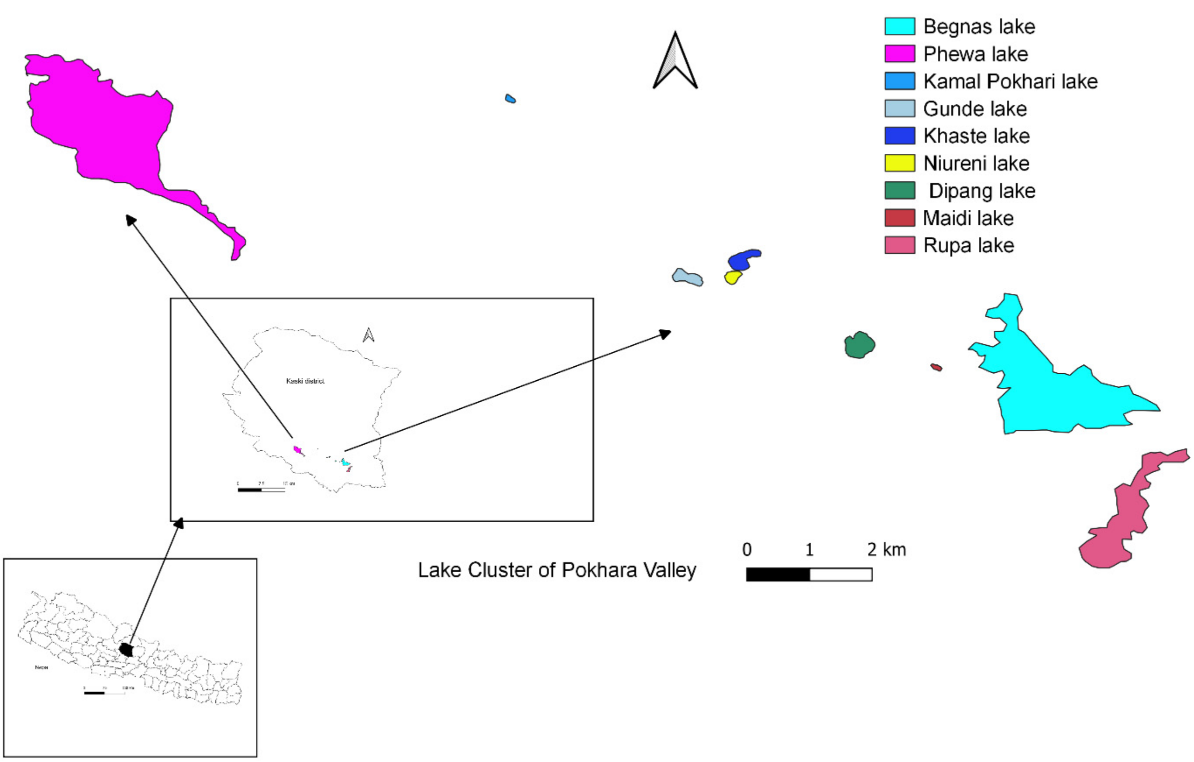

Figure 1. Lake Cluster of Pokhara Valley, Nepal.

2.2. Methods

Based on lake size and water hyacinth occurrence in lakes in the LCPV, we identified areas with water hyacinth presence (HP) and absence (HA). In larger lakes (i.e., Phewa, Begnas, and Rupa), we established three HP and three HA areas, and in each of the smaller remaining lakes, we established one HA area. In Phewa, Begnas, and Rupa, the distance between water hyacinth presence and absence areas was $\geq$500 m. During this study, water hyacinth coverage in HP areas was >90%, whereas water hyacinth was completely absent in HA areas in the last 10 years, confirmed through consultation with lake management committees. In HP and HA areas, we established a total of 24 samling plots each of 50-m radius and demarcated each to facilitate observations.

We recorded the coordinates of each plot center and measured the distance to the nearest lake edge and human settlement using a measuring tape. We conducted bird surveys during 7.00–11.00 h., using binoculars to record bird species composition and abundance at 5-min intervals for 30 min [36]. We initiated counts at each plot 5 min after arrival to reduce potential disturbance effects of observers. We observed birds on four occasions during winter (November 2019–February 2020) and summer (May–August 2020). We used the greatest number of birds and bird species counted during each observation period each season for analyses. We identified birds using field guides [28], and when uncertain, confirmed our observations through consultations with experts in bird identification.

At each plot, we measured physicochemical water parameters including depth, transparency, temperature, pH, total dissolved solids (TDS), turbidity, dissolved oxygen (DO), free carbon dioxide (CO_2), total alkalinity, and nitrate (NO_3). We established five 1- × 1- m^2 subplots, four along each plot edge and one at each plot center. We measured the water parameters in each subplot and averaged plot values for analyses. We determined water depth (cm) using a measuring tape and water transparency (cm) using a 20-cm diameter Secchi disc. We measured surface water temperature using a standard thermometer with 0.1 °C precision. We measured pH (4500-B, APHA), total dissolved solids (mg/L) (Instrumental), and turbidity (NTU) (3130 B, APHA, 1998). We measured dissolved oxygen (mg/L) using Winkler's method, free carbon dioxide (mg/L), total alkalinity (mg/L), and nitrate (mg/L) (4500-NO_3^- B, APHA) via the titrimetric method [37]. Laboratory work was performed at the Department of Zoology, Prithvi Narayan Campus, and Laboratory of Federal water Supply and Sewerage Management Project, Pokhara.

2.3. Data Analysis

We calculated Shannon–Weiner diversity (H′) [38], Pielou's species evenness (J) [39], and species richness (S) of waterbirds in HP and HA areas. We categorized waterbird species into four feeding guilds: piscivorous, insectivorous, omnivorous, and herbivorous [28,29]. We compared bird abundance, threatened bird abundance, feeding guilds of birds, and physicochemical parameters of water between HP and HA area using Mann–Whitney tests because our data were not normally distributed. We used generalized linear mixed models with Poisson distribution and lake as a random factor in the lme4 Package [40] in Program R [41] to identify factors affecting waterbird abundance and species richness at LCPV. We conducted model averaging using competing models with Akaike Information Criteria scores adjusted for small samples <2, estimated 95% confidence intervals for each variable, and accepted statistical significance at $\alpha = 0.05$.

3. Results

3.1. Abundance

We observed 4114 individual waterbirds overall, representing 32 species and 11 families (Figure 2, Table 1). Anatidae comprised the greatest number of species (35%, n = 11) followed by Ardeidae (16%, n = 5) and Rallidae (10%, n = 3).

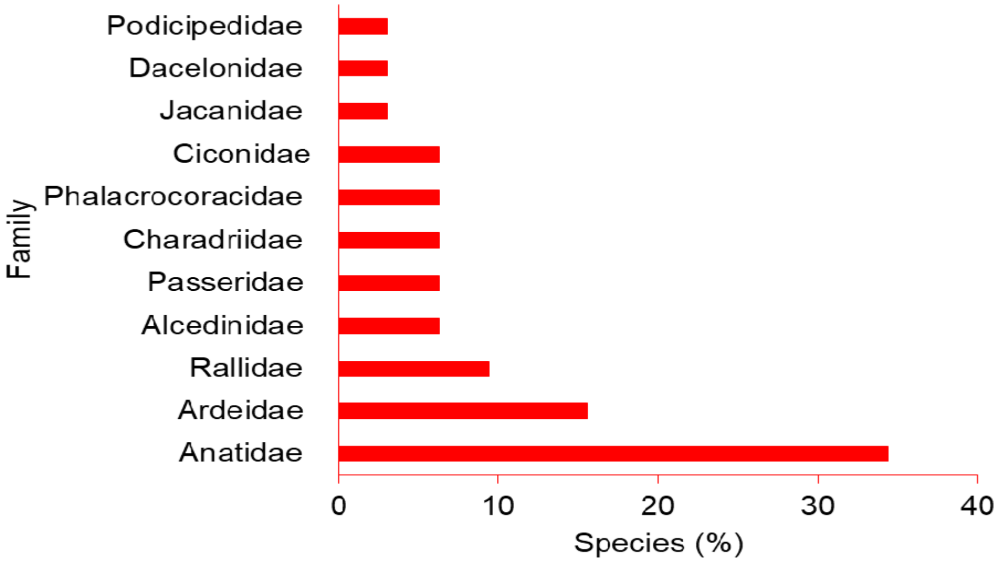

Figure 2. Families of waterbirds by species percentage, Lake Cluster of Pokhara Valley, Nepal, 2019–2020.

Bird abundance differed between the HP and HA habitats ($p = 0.03$; Table 2). The great cormorant, common pochard, ruddy shelduck, tufted duck, and lesser whistling duck were most abundant in HA areas, whereas purple swamphen, bronze wing jacana, cattle egret, Indian pond heron, and common moorhen were more abundant in HP areas. Among the birds observed, 73% were residential and 27% were migratory, with more residential birds in HP areas ($p = 0.004$; Table 1).

Table 1. Waterbirds recorded in Lake Cluster of Pokhara Valley, Nepal, 2019–2020. IUCN status: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concerned (LC).

S.N.	Scientific Name	Common Name	Family	IUCN Status	Feeding Guild
1	*Phalacrocorax carbo* Linnaeus, 1758	Great Cormorant	Phalacrocoracidae	LC	Piscivore
2	*Aythya baeri* Güldenstädt, 1770	Baer's Pochard	Anatidae	CR	Omnivore
3	*Aythya ferina* Linnaeus, 1758	Common Pochard	Anatidae	VU	Omnivore
4	*Anser indicus* Latham, 1990	Bar-headed Goose	Anatidae	LC	Herbivore
5	*Mareca penelope* Linnaeus, 1758	Eurasian Wigeon	Anatidae	LC	Herbivore
6	*Aythya nyroca* Güldenstädt, 1770	Ferruginous Pochard	Anatidae	NT	Omnivore
7	*Anas platyrhynchos* Linnaeus, 1758	Mallard	Anatidae	LC	Omnivore
8	*Anas acuta* Linnaeus, 1758	Northern Pintail	Anatidae	LC	Omnivore
9	*Spatula clypeata* Linnaeus, 1758	Northern Shoveler	Anatidae	LC	Omnivore
10	*Tadorna ferruginea* Pallas, 1764	Ruddy Shelduck	Anatidae	LC	Omnivore
11	*Aythya fuligula* Linnaeus, 1758	Tufted Duck	Anatidae	LC	Omnivore
12	*Ciconia nigra* Linnaeus, 1758	Black Stork	Ciconiidae	LC	Piscivore
13	*Ciconia episcopus* Boddaert, 1783	Woolly Necked Stork	Ciconiidae	VU	Piscivore
14	*Ardea cinerea* Linnaeus, 1758	Grey Heron	Ardeidae	LC	Piscivore
15	*Dendrocygna javanica* Horsfield, 1821	Lesser Whistling duck	Anatidae	LC	Omnivore
16	*Tachybaptus ruficollis* Pallas, 1764	Little Grebe	Podicipedidae	LC	Insectivore
16	*Phalacrocorax niger* Gmelin, 1789	Little Cormorant	Phalacrocoracidae	LC	Piscivore
18	*Bubulcus ibis* Linnaeus, 1766	Cattle Egret	Ardeidae	LC	Insectivore
19	*Ardeola grayii* Sykes, 1832	Indian pond Heron	Ardeidae	LC	Insectivore
20	*Ardea intermedia* Wagler, 1829	Intermediate Egret	Ardeidae	LC	Insectivore
21	*Egretta garzetta* Linnaeus, 1766	Little Egret	Ardeidae	LC	Insectivore
22	*Fulica atra* Linnaeus, 1758	Common Coot	Ardeidae	LC	Omnivore
23	*Gallinula chloropus* Linnaeus, 1758	Common Moorhen	Rallidae	LC	Omnivore
24	*Porphyrio porphyrio* Linnaeus, 1758	Purple Swamphen	Rallidae	LC	Omnivore
25	*Metopidius indicus* Latham, 1790	Bronze-winged Jacana	Jacanidae	LC	Omnivore
26	*Alcedo atthis* Linnaeus, 1758	Common Kingfisher	Alcedinidae	LC	Piscivore
27	*Alcedo meninting* Horsfield, 1821	Blue-eared Kingfisher	Alcedinidae	LC	Piscivore
28	*Halcyon smyrnensis* Linnaeus, 1758	White Throated Kingfisher	Dacelonidae	LC	Piscivore
29	*Motacilla maderaspatensis* Gmelin, 1789	White-browed Wagtail	Passeridae	LC	Insectivore
30	*Motacilla alba* Linnaeus, 1758	White Wagtail	Passeridae	LC	Insectivore
31	*Charadrius dubius* Scopoli, 1786	Little Ringed Plover	Charadriidae	LC	Insectivore
32	*Vanellus indicus* Boddaert, 1783	Red Wattled Lapwing	Charadriidae	LC	Insectivore

Table 2. Comparison of bird abundance between water hyacinth presence (HP) and absence (HA) habitats of Lake Cluster of Pokhara Valley, Nepal, 2019–2020. Range of reported values are in parentheses. Bolded values are significant.

Parameters	HP Habitat	HA Habitat	Statistics
Abundance	Median = 33.5(9–160)	Median = 25.5(3–205)	Mann–Whitney test, U = 805.5; *p* = 0.038
Resident birds	Median = 33.5(9–131)	Median = 23(3–116)	Mann–Whitney test, U = 700.5; *p* = 0.004
Threatened birds	Median = 0(0–7)	Median = 0(0–14)	Mann–Whitney test, U = 1275; *p* = 0.023
Omnivore birds	Median = 15(0–82)	Median = 6(0–112)	Mann–Whitney test, U = 817; *p* = 0.046
Insectivore birds	Median = 20(7–58)	Median = 16(2–58)	Mann–Whitney test, U = 772.5; *p* = 0.020
Piscivore birds	Median = 4(1–21)	Median = 4.5(1–41)	Mann–Whitney test, U = 1064; *p* = 0.906

Bird diversity and evenness were greater in HA areas (H′ = 3.01; *J* = 0.86) than HP areas (H′ = 2.68; *J* = 0.84). The greatest species richness was found in HA areas (29 species) compared to HP areas (21 species). Using foraging niches, 41% of birds were omnivores, followed by insectivores (28%), carnivores (25%), and herbivores (6%) (Figure 3). The abundance of piscivorous birds was similar between HP and HA areas ($p = 0.90$), however, more insectivorous ($p = 0.01$) and omnivorous species ($p = 0.04$) birds were observed in HP areas.

Four observed species are threatened globally, including the critically endangered Baer's pochard (*Aythya baeri*), the vulnerable common pochard (*Aythya ferina*) and woolly necked stork (*Ciconia episcopus*), and near threatened ferruginous pochard (*Aythya nyroca*) (Table 1). More threatened birds occurred in HA areas than HP areas ($p = 0.023$; Table 2)

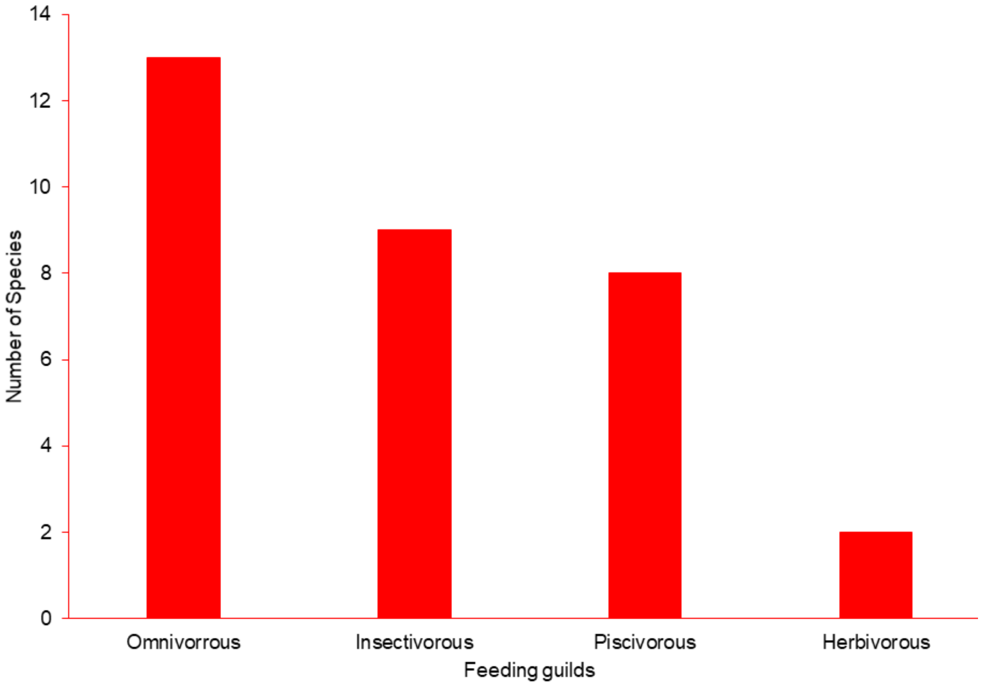

Figure 3. Number of waterbird species by feeding guild, Lake Cluster of Pokhara Valley, Nepal, 2019–2020.

3.2. Physicochemical Parameters

The water depth, transparency, pH, turbidity, total dissolved solid, dissolved oxygen, free carbon dioxide, total alkalinity, and nitrate differed between the HP and HA areas ($p < 0.001$; Table 3). The water temperature was similar between the HP and HA areas ($p > 0.05$).

Table 3. Comparison of physicochemical parameters of water in areas with water hyacinth present (HP) and absent (HA). Lake Cluster of Pokhara Valley, Nepal, 2019–2020. Bolded values are significant.

Parameters	HP Habitat	HA Habitat	Statistics
Depth (m)	Median = 3	Median = 4	Mann–Whitney test, U = 1817; p = <0.001
Temperature (°C)	Median = 25	Median = 24.5	Mann–Whitney test, U = 850.5; p = 0.082
Transparency(m)	Median = 0.77	Median = 1.4	Mann–Whitney test, U = 2057; p = <0.001
pH	Median = 6.6	Median = 7.4	Mann–Whitney test, U = 1825; p = <0.001
Turbidity (NTU)	Median = 3.05	Median = 3.05	Mann–Whitney test, U = 949; p = 0.323
TDS (mg/L)	Median = 23.5	Median = 19	Mann–Whitney test, U = 602; p = <0.001
DO (mg/L)	Median = 4	Median = 6.6	Mann–Whitney test, U = 1997; p = <0.001
Free CO_2 (mg/L)	Median = 11.85	Median = 6.8	Mann–Whitney test, U = 96.5; p = <0.001
Total alkalinity (mg/L)	Median = 126.5	Median = 149.5	Mann–Whitney test, U = 1677; p = <0.001
Nitrate (mg/L)	Median = 1.25	Median = 2.05	Mann–Whitney test, U = 1766; p = <0.001

3.3. Factors Affecting Waterbirds Abundance and Richness

Threatened water bird abundance was greater in HA areas and decreased with increasing distance to settlements (Table 4). Threatened waterbird abundance increased during winter and with increasing overall bird abundance. Bird species richness decreased with decreasing temperature.

Table 4. Model-averaged parameter estimates and 95% confidence limits (CL) describing the abundance of the waterbird species in Lake Cluster of Pokhara Valley, Nepal, during winter 2019–summer 2020. Model parameters include water hyacinth presence and absence, seasons (winter and summer), depth of water (m), temperature (°C), transparency of water (m), distance to lake edge (m) and distance to settlement (m), bird abundance and threatened bird abundance, and bird richness as response variables. Estimates were averaged from all models. Bolded values are significant.

	Parameters	Estimate	Lower CL	Upper CL	z	p
Threatened waterbird abundance	(Intercept)	−19.600	-5.27×10^{3}	5.23×10^{3}	−0.006	0.995
	Depth	0.447	0.00346	0.692	2.610	**0.009**
	Distance to settlement	2.70×10^{-5}	-2.23×10^{-3}	8.32×10^{-4}	0.022	0.982
	Bird abundance	1.23×10^{-2}	4.19×10^{-3}	2.18×10^{-2}	3.560	**0.000**
	Distance to edge	-1.01×10^{-3}	-2.23×10^{-3}	8.32×10^{-4}	−0.774	0.439
	Winter season	20.4000	-5.23×10^{3}	5.27×10^{3}	0.006	0.995
	Water hyacinth	−1.450	−3.170	0.185	−2.126	**0.033**
	Transparency	−1.380	−2.580	0.304×10^{-1}	−1.893	0.058
	Temperature	-6.25×10^{-2}	-2.16×10^{-1}	2.80×10^{-2}	−1.113	0.266
Threatened waterbird richness	(Intercept)	−22.200	-8.23×10^{3}	8.19×10^{3}	0.005	0.996
	Bird abundance	9.89×10^{-3}	2.19×10^{-3}	1.76×10^{-2}	2.517	**0.012**
	Depth	3.54×10^{-1}	9.06×10^{-2}	6.18×10^{-1}	2.633	**0.008**
	Winter season	20.400	-8.20×10^{3}	8.24×10^{3}	0.005	0.996
	Temperature	-9.80×10^{-2}	-2.67×10^{-1}	7.11×10^{-2}	1.136	0.256
	Water hyacinth	−0.631	−2.130	0.870	0.824	0.410
	Transparency	4.29×10^{-2}	−1.640	1.730	0.050	0.960
	Distance to settlement	1.96×10^{-4}	-1.67×10^{-3}	2.06×10^{-3}	0.205	0.837
	Distance to edge	2.70×10^{-4}	-1.67×10^{-3}	2.21×10^{-3}	0.273	0.785

4. Discussion

The LCPV supported abundant waterbird species with high species richness. High species diversity could be attributed to the wetlands providing shelter and foraging opportunities [22,42–44]. The community composition of waterbird in LCPV was dominated by the family Anatidae during winter in HA areas and purple swamphen, egrets and herons in HP areas during winter and summer. Similar dominant species composition including cormorants, herons, and egrets was observed in the Pulau Rambut Wildlife Sanctuary, Jakarta, Indonesia [27]. The high occurrence of Anatidae in the LCPV during winter is likely due to their migratory behavior and specific use of the LCPV as a wintering area. Anatidae were also the numerically dominant family in Lake Chapala, Mexico [22], and Beeshhazari Lake, Nepal [43]. The Anatidae, Ardeidae, and Jacanidae families were more abundant in HP areas than in HA areas, probably due to their respective migratory patterns, insectivorous foraging, and resident status, respectively. These families were also prevalent in other areas, including Phewa Lake Pokhara, Nepal, [35,45], Lake Chapala, Mexico [22], Beeshhazari Lake [43], and in the Khaste Lake Complex, Nepal [46].

In this study, threatened waterbird abundance was less in water hyacinth areas. This could be due to variation in vegetation structure, habitat heterogeneity, food resources, and foraging behavior of threatened waterbird species [16,22,47]. The greater abundance of these birds in HA habitats is probably due to open areas facilitating movement, swimming, and foraging. Generally, winter migratory birds such as ducks, geese, and cormorant species avoid dense emergent vegetation due to increased cover restricting movements and reduced foraging efficiency [26,33,48]. However, greater abundance of residential birds such as herons, common coots, common moorhens, and purple swamphens in HP habitat is probably due to their omnivorous feeding because HP habitat provides abundant insects and vegetation as potential food [22,48]. Most residential birds were insectivores and omnivores and the roots and leaves of water hyacinth support many macro-invertebrates including insects, mollusks, and worms [31,49]. In addition, the dense mats formed by water hyacinth are used by invertebrate prey, and we suggest can facilitate supporting the occurrence of more omnivorous bird species. Water hyacinth also likely provides nest sites and refugia for some species [22,50,51]. For example, the number of purple swamphens has increased in the LCPV, probably due to secure breeding in and around water hyacinth areas [52–54]. The number of migratory waterbirds has deceased in the LCPV during recent years [31], possibly due to increased water hyacinth presence in these lakes, which has altered the habitat. Similarly, fewer migratory birds were recorded in Lake Chapala, Mexico, corresponding with increased water hyacinth prevalence [22].

Threatened waterbird abundance and their richness were influenced by the overall bird abundance in the study area, possibly due to security afforded by other birds and higher availability of forage. Generally, the more-individuals hypothesis states that higher available energy supports the occurrence of individuals of species in a community, which in turn can increase the overall species richness [55]. The degraded water quality we detected in HP areas may also have contributed to the observed differences in threatened waterbird abundance and richness. Threatened water bird abundance and richness was greater in areas without water hyacinth, possibly due to greater water depth in areas without water hyacinth as these areas contain less detritus. In addition, the overall waterbird occurrence increased with increasing water depth in our study area. The greater abundance of wintering waterbirds in HA areas could be due to the presence of open shallow water areas [56] where they can dive and more easily catch fish. Furthermore, the abundance and diversity of waterbirds was greater in areas with reduced water hyacinth coverage [57], which could be attributed to reduced coverage, providing foraging areas for waterbirds. The decay of water hyacinth and accumulation of detritus likely resulted in lower observed pH, dissolved oxygen, low water transparency, short light penetration, and greater CO_2 and turbidity [21–23,58,59]. pH values greater than 9 and lower than 5 may kill aquatic life [44]. Thapa and Saund [44] found that pH and dissolved oxygen were positively associated with the abundance of birds; the higher abundance of waterbirds in HA areas of LCPV might be due to in part to the low free carbon dioxide and greater pH and dissolved oxygen in HA areas. Threatened waterbird abundance and richness decreased with increased temperature because these birds are migratory and more abundant during winter.

5. Conclusions

We were unable to monitor bird use of all catchment areas of the LCPV. However, the extent of water hyacinth coverage had demonstrable adverse effects on waterbird abundance as well as the physicochemical parameters of water in the LCPV. We expect more species of waterbirds to occupy the LCPV and improved water quality if managed to emphasize habitat restoration, particularly through removal of water hyacinth. We recommend that habitat restoration be integrated with a multidisciplinary research and monitoring strategy to further our understanding of the effects of water hyacinth and other invasive plant species on waterbird populations.

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