Research Article

Bird-habitat associations at Maidi Lake and adjacent wetlands, Kaski, Nepal

Mohan Bucha Magar[1,2], George Vernon Byrd[3,4*], Richard Goodwin Storey[3,5]
[1]Tribhuvan University, Institute of Forestry, Pokhara, Nepal
[2]Ministry of Forests and Environment, Bagmati Province, Subdivision Forestry Office, Ranibas, Sindhuli, Nepal
magarmohanbucha@gmail.com
[3]Kathmandu University, Dhulikhel, Nepal
[4]University of the Nations, 75-5851 Kuakini 129, Kailua Kona, Hawaii USA
[5]1/22 Methuen Rd, Avondale, Auckland 0600, New Zealand

Abstract
Bird-habitat relationships were evaluated at Maidi Lake, Nepal, one of nine lakes in the Lake Cluster of Pokhara Valley Ramsar Site. Eleven distinct habitats were identified within the lake and its immediate surroundings, and the frequency of use of each habitat by different bird species was recorded across all four seasons during repeated surveys along a fixed route that facilitated views of the entire lake area. All surveys were conducted during the morning peak of bird activity. Forty species of birds used at least one wetland habitat, with the highest seasonal species richness in winter and spring. Every habitat was used by multiple species in each season. This appears to be the first study in Nepal to examine bird-habitat relationships at such a fine scale in a wetland ecosystem. The results show the critical link between bird conservation and habitat protection, helping to focus conservation planning and achieve the goals of the Ramsar management plan.

Keywords: bird-habitat relationships, waterbirds, wetlands, wetland conservation

Introduction
Wetlands provide unique habitats for wildlife and deliver critical ecosystem services, yet they are continuing to be lost at an alarming rate (United Nations, 2018). To address this, the international "Ramsar" treaty was initiated in 1971 with the objective "protect wetlands and promote their wise use" (IUCN Nepal, 2004; Matthews, 1993). The Ramsar site designations highlighted the importance of wetlands for biodiversity conservation (Gauli et al. 2016). Among the wetland biota, birds are one of the most visible elements, and many species are wetland dependent and vulnerable to decline when these wetlands are lost or degraded (Li et al., 2024). The occurrence and abundance of these wetland birds are closely related to vegetation structure and composition among other attributes of habitats (Adhikari et al., 2022), and wetland birds are dependent on healthy wetlands for survival (Ma et al., 2010; Weller, 1999). Several publications have emphasized the importance of wetlands in Nepal (Baral 2009; Bhandari 2008; Siwakoti & Karki 2010; Thagunna et al. 2023), with major threats including loss or modification to wetland habitats. Nepal currently hosts 10 Ramsar sites, including the Lake Cluster of Pokhara Valley (LCPV) (Gauli et al., 2016). The management plan for the LCPV aims to "conserve and sustain the ecology, hydrobiology, geology, and biodiversity" of these lakes (MoFE, 2018). Within this cluster, Maidi Lake has been identified as a priority site, with the expected outcomes including the conservation of biodiversity and critical habitats, enhancement of ecosystem services and processes, assessing biodiversity and critical habitats, and establishing a long-term monitoring system (MoFE, 2018). The plan, which is overseen by the Maidi Lake Conservation Committee, also promotes eco-tourism development, particularly bird watching. Because birds are highly visible elements of biodiversity that reflect changes in lake ecosystems, they are appropriate subjects for long-term monitoring as called for in the management plan. Maidi Lake was chosen for this study because of its relatively small size, which made habitat mapping feasible, the recent modification to expand its ecosystem services, which made this an ideal time for a baseline study, and its suitability as a model ecosystem for similar studies of other lakes in the LCPV.

Bird-habitat relationships were assessed in 2023 and 2024, with the aim of providing a baseline from which the significance of future changes in the Maidi Lake ecosystem may be assessed, as called for in the management plan. This information will be valuable for conservation planning and lake management.

Materials and Methods
Study Area
Physical Characteristics
Among the lakes of LCPV, Maidi Lake is one of the smaller lakes (Fig. 1). It lies at an elevation of approximately 672 m and has a catchment area of 1.6 km² (Pathak et al., 2020). The lake underwent changes due to a "rehabilitation" project that was initiated in 2019. A dam was constructed, and much of the "thick grassy mat that covered 90% of the lake" was removed to create more areas of open water interspersed with robust emergent vegetation (Joshi, 2020). Consequently, the lake expanded from about 1 ha (0.01 km²) to the current size of 27 ha (0.27 km²) by 2021 with a 3.2 km boundary trail.

Corresponding author: vernonbyrd@uofnkona.edu

TU-CDES

Water Physicochemical Measurements

Relative water levels were measured on most field visits by stretching a tape measure to the water level from a bridge at the southwestern edge of the lake. In mid-June 2023, water depths were measured across the largest contiguous area of open water. These measurements were made from a boat by extending a graduated rod from the water level to the lakebed at 10-20 m intervals along a transect. Periodically between December 2021 and December 2022, water temperature was measured with a handheld thermometer, water clarity was measured using a Secchi disc, water color on the Forel-Ule scale was estimated using a mobile phone app called Eye on Water, and chlorophyll-a in water samples were measured in a laboratory using APHA method 10200H (acetone extraction followed by spectrophotometric determination; APHA, 1999). These measurements were taken from a boat in the middle of the lake.
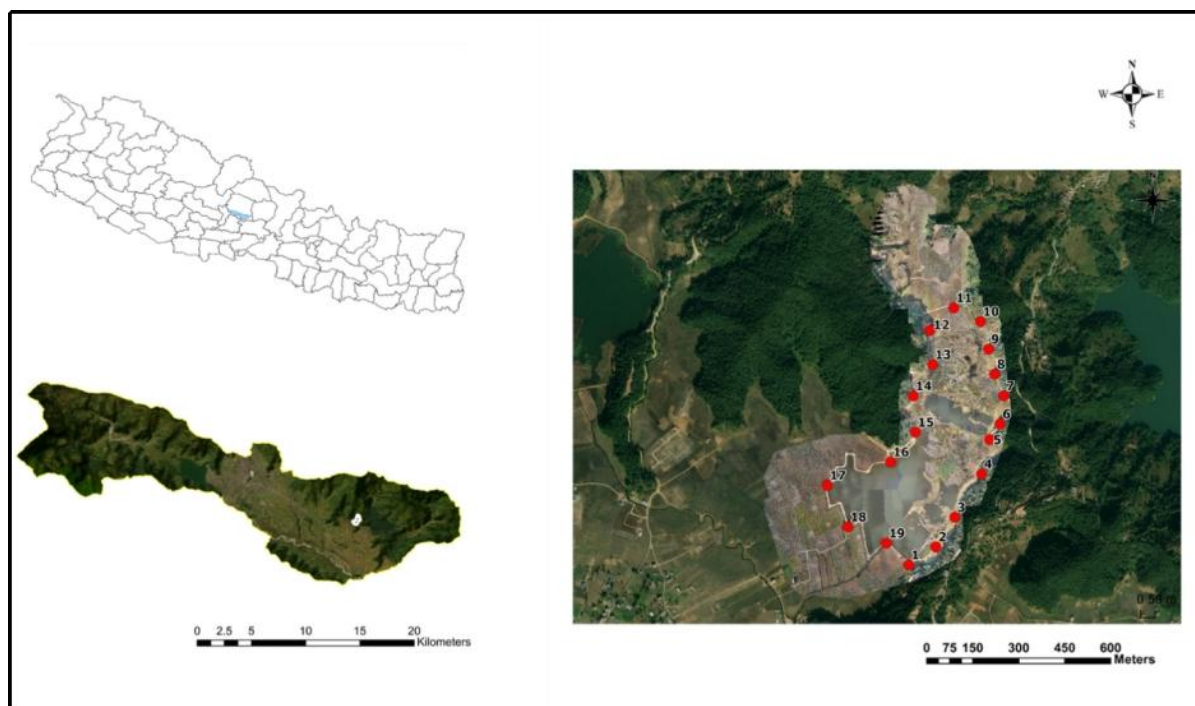

Figure 1. Location of Maidi Lake, including the location of observation points around the lake

Vegetation

The lake is surrounded by forest and agricultural land. On the western side, it is bordered by Sal (*Shorea robusta*) forest, while the eastern boundary is characterized by a mixed open forest dominated by Chilaune (*Schima wallichi*) and Katus (*Castanopsis indica*) as primary species. At the time of our surveys, scattered planted bamboo (*Dendrocalamus spp*) were recorded, along with subsequent plantations of other species. Wetland vegetation is described in detail in the habitat section.

Vertebrate Wildlife

Fish species that occurred in Maidi Lake have been documented (Timilsina et al., 2019). Commercially valuable species included Rohu *(Labeo rohita),* Grass Carp *(Ctenopharyngodon idella),* Bighead Carp *(Hypophthalmichthys nobilis),* Silver carp *(Hypophthalmichthys molitrix),* Tilapia (*Oreochromis niloticus),* and Magur (*Clarias magur*), which have been the primary focus of lake management (see below).

Maidi Lake supports rich avifaunal diversity. Approximately 200 species of birds have been recorded (Poudel et al., in press), including the wetland-associated species addressed in this study. Although the LCPV management plan (MoFE, 2018) provides general information about mammals, reptiles, and amphibians in the wider lake cluster, no published records specific to Maidi Lake of LCPV exist.

Human Uses

Commercial fishing started in 2018 with the registration of the Maidi fishery and co-operative, coinciding with the release of fingerlings into the lake. Normally, fish are harvested twice per week. Surrounding fields are actively used for growing rice and other cereal crops. Local people regularly cut grass from the floating grass mat in the lake and from rush beds at the lake edge to feed livestock. Goats and cattle often graze in the paddies and adjacent wetland areas. Agricultural vehicles also use the road on the western side of the lake.

The lake is a focal point for local recreation. Local people and visitors frequently walk and drive around the lake, and picnicking occurs along the shore of the lake. Since the expansion of the lake, the site has been designated as a "hotspot" on eBird (Sullivan et al., 2009), and bird observation postings have been steadily increasing since 2022.

TU-CDES

Habitat Classification

Besides the area that is enclosed by the lake berm, the study area included the paddy field to the south and the agricultural land, including additional paddies, to the north. The distribution of major habitats is illustrated in Fig. 2, and detailed descriptions of all habitats are provided below.
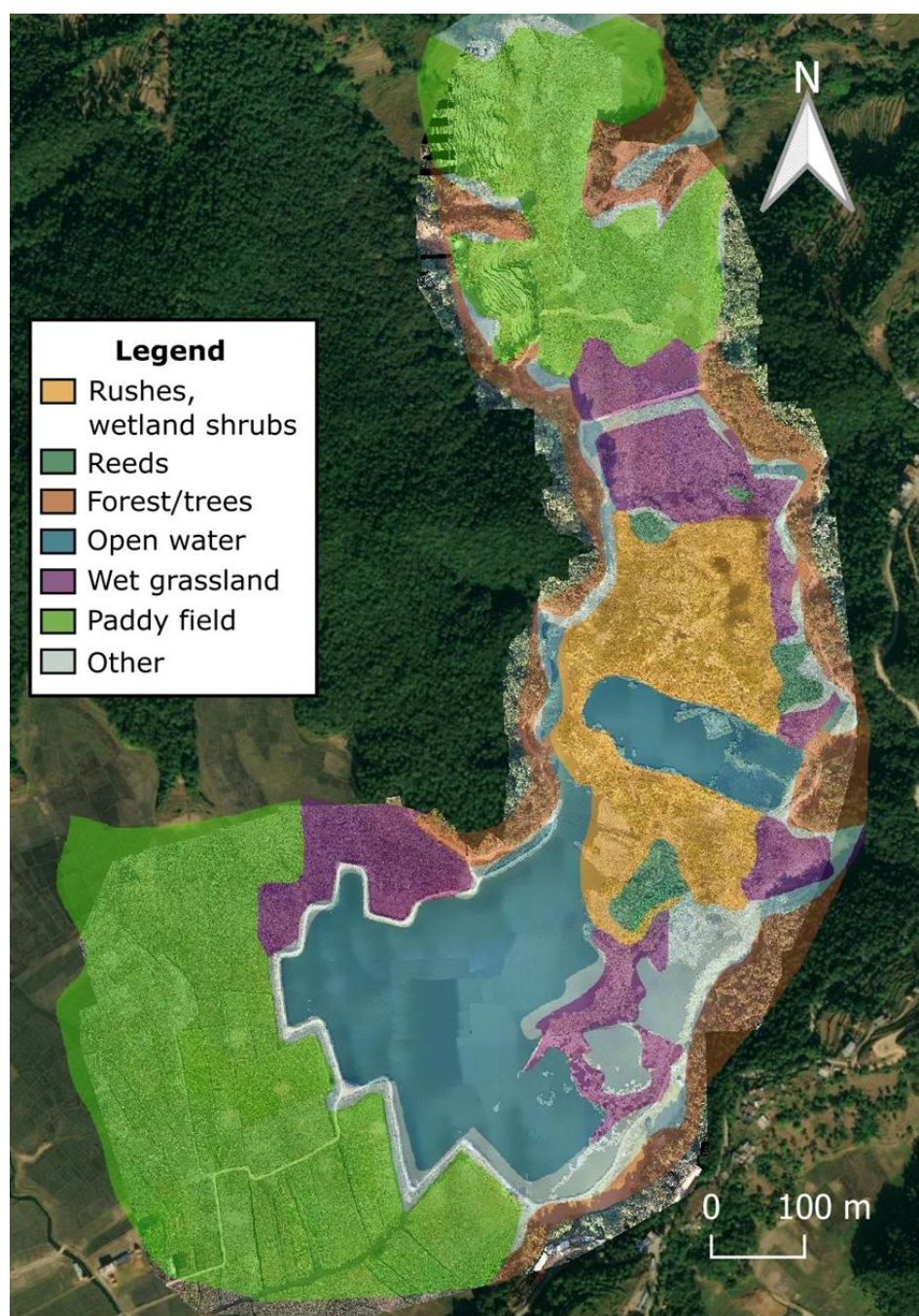

Figure 2. Map of Maidi Lake with approximate habitat distributions

Open Water and Mud Banks: This category included open water areas without emergent vegetation, including shallow water nearshore. Unvegetated mud banks formed a limited habitat along the water's edge, and the extent of this habitat fluctuated with water level.

Wet Grassland: This habitat included wet areas, which were poorly drained and remained wet most of the year, both inside and outside the perimeter of the lake. Vegetation included dense Navo, wild rice (*Oryza rufipogon*), and other plants such as Pirre Jhar (*Polygonum recumbens)* and *Floscopa scandens* rooted in soil.

Grass Mat and Wetland Shrubs: This habitat consisted of a floating dense grassy layer dominated by Karaute (*Leersia hexandra*) within the lake. Wetland shrubs were

found in wet areas at the edge and inside the lake boundary, often growing on grass mats. Shrubs included Angeri (*Osbeckia nepalensis*) with small patches of *Rubus moluccanus, Chromolaena odorata, Rubus ellipticus,* Vede Kuro *Biden pilosa,* and seedlings of Champ (*Schima wallichii*). At the time of study, most of the shrubs were 1 to 1.5 m tall, but several clusters were taller.

Roadside Shrub: This habitat consisted of scattered clumps of primarily *Bambusa* spp. planted before this study along the trail that surrounded the lake. These were the tallest shrubs in this habitat, reaching up to 3 m.

Rush and Reed: Dense and robust emergent plants were dominant features of the wetland area. Rushes were predominantly *Juncus articulatus* with sparsely scattered Mothe (*Cyperus exaltantus*). The plants were typically 1 to 1.5 m high and often grew on grass mats. Several dense clusters of reeds (Narkat, *Phragmites karka*) also occurred within the lake, the tallest stand reaching up to 6 m.

Paddy field: These fields were used to grow rice, other grains, and potatoes, and they are located outside the trail around the lake. The habitat varied along the stages of production. During the early monsoon (mid-June), the paddy field consisted of open water, which gradually transformed from seedlings to a complete cover of mature rice. The fields were mostly bare after harvest (usually by the end of November), with only stubble remaining.

Canal: There was a canal about 3 m wide along the peripheral road on the southern side of the lake (Fig. 9). It consisted of open water and emergent vegetation, particularly Besram (*Ipomea fistula),* and floating vegetation such as water chestnut (*Trapa natans*).

Artificial: These man-made structures included the road and trail, water control structures, and wooden stakes inside and outside the lake.

Data Collection and Analysis
Between January 2023 and July 2024, observations were conducted to document bird use of various wetland habitats at Maidi Lake. Sampling effort was greatest in winter (7 surveys) and spring (11 surveys) (Magar, 2023), but funding limitations resulted in only a few surveys in summer (2 surveys) and autumn (4 surveys). A team of four people, all trained together on the methods, were responsible for all the surveys. A series of observation points along the trail encircling the lake were used to ensure full coverage of the lake and adjacent habitats. At each point (Fig. 1) along the trail, about 5-10 minutes were spent recording all birds seen. Binoculars and a field guide (Grimmet et al., 2016) aided identification. The habitat type was recorded for each bird or group of birds. All surveys were conducted during the morning activity period (usually from first light to 10:30 am). Additional observations were added between points. This method resulted in a survey of the entire study area on each observation day. Care was taken to avoid duplicate observations of birds that moved between areas.

Spatial distributions of the most common species of wetland birds were mapped on a high-resolution aerial image of Maidi Lake in winter using the Qfield application (OPENGIS.ch, 2023) on a tablet. However, the distribution data was limited to winter because after that the tablet with the Qfield application malfunctioned and could not be repaired.

To quantify habitat associations, the frequencies of occurrence were calculated for all wetland species (which we defined as any species seen using a wetland habitat). Each location with the observation of one or more birds in the wetland habitat was treated as a data point. For example, a flock of Eastern Cattle Egrets perched on a group of nearby posts in the lake was recorded as an observation of that species using the artificial habitat. Observations were summarized by season: winter (Dec.-Feb.), spring (Mar.-May), summer (Jun.-Aug.), and autumn (Sep.-Nov.).

Results and Discussion
Water physicochemical characteristics
In mid-June 2023, water depths on a transect across the largest contiguous area of open water were relatively uniform, ranging from 0.8 to 1.0 m. Due to being after the onset of monsoon rains, the mid-June water level was the highest of all levels measured between February and June 2023. Relative to mid-June, the water level was 0.4 m lower in February, 0.3 to 0.15 m lower in March, 0.1 to 0.2 m lower in April, and 0.05 m lower in May. Water temperatures between December 2021 and December 2022 were 14.7 °C to 19.5 °C in winter (Dec.-Feb.), 18.1 °C to 27.3 °C in spring (data for March only), 28.4 °C to 31.3 °C in summer (Jul.-Aug.), and 23.2 °C to 28.4 °C in autumn (Sept. and Nov. samples). From December 2021 to December 2022, water clarity ranged from 0.7 to 1.0 m, water color on the Forel-Ule scale was 16-18 (greenish brown), and chlorophyll-a concentrations ranged from 2 to 20 mg/m³.

Relative Abundance of Habitats
Paddy field was identified as the most common habitat in the study area, followed by open water and wet grassland (Table 1).

Seasonal Habitat Use
In winter, a total of 35 species of wetland birds were observed using one or more wetland habitats (Table 2). Of the 9 species observed on water, most were in shallow water near the shore, except for the Great Cormorant, which fed in deeper water. Mud banks were seldom used (once by Gray Wagtail), whereas wet grasslands supported the highest number of species (14 species). Other habitats were used by 6 to 9 species each (Fig. 3A).

In spring, 40 species were documented using wetland habitat (Table 3). Wet grasslands and reeds were the most frequently used habitats overall. Ten species occurred on water, although most (except cormorants) were usually seen in shallow water nearshore. Ducks, lapwings, and Green Sandpiper often utilized mud

banks, while grass mats were used by only the Medium Egret. Other habitats were used by 6-13 species (Fig. 3A).

In summer, only 22 species were recorded in wetland habitats (Table 4). Paddies and wetland shrubs supported the highest number of species, while mud banks, wet grasslands, grass mat, and reeds were used by

3-5 species each. All the other habitats were used by just 1 or 2 species (Fig. 3B).

In autumn, 31 species were recorded in the wetlands (Table 5). Mud banks and artificial habitats supported the highest number of species, while most other habitats were used by 3-5 species (Fig. 3B).

Table 1. Area and relative abundance of wetland habitats at Maidi Lake.

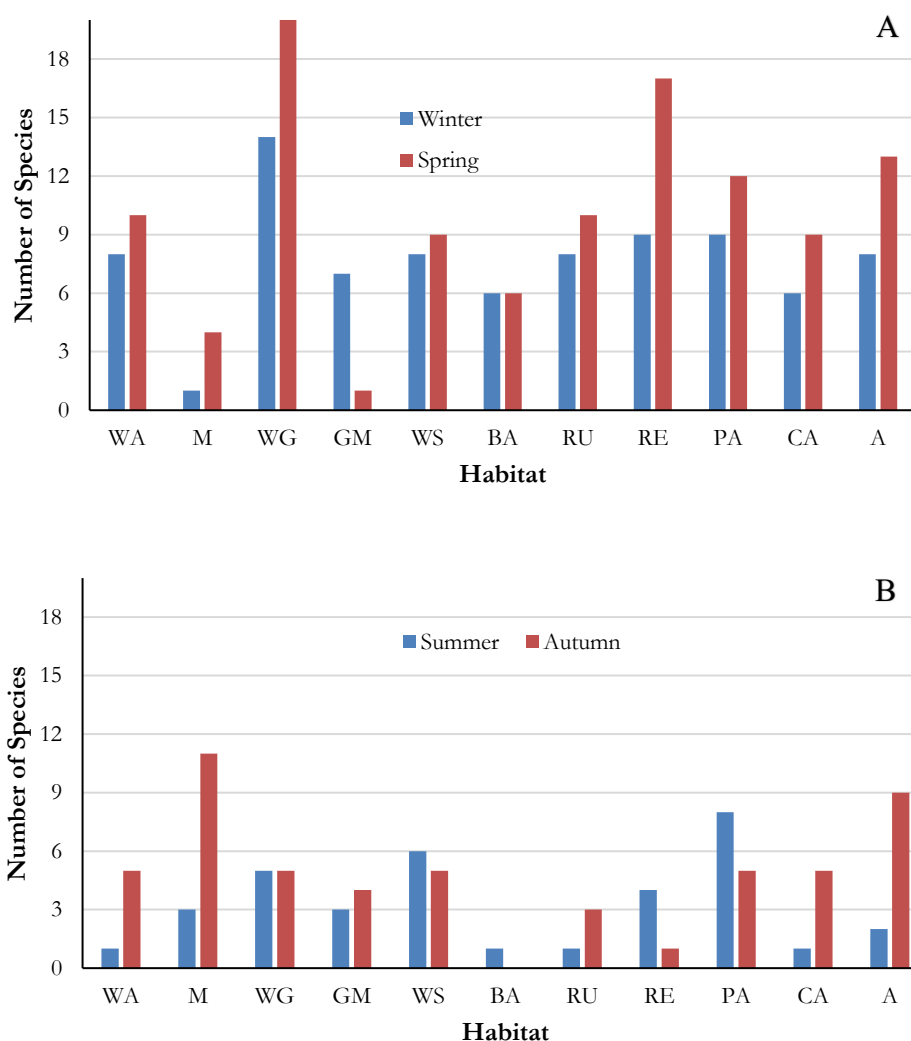| Habitat	Approximate Area (ha)	Relative Proportion	Comments
Rushes/Wetland Shrubs	7.02	0.13	Wetland shrubs often grew among beds of rushes
Reeds	0.72	0.01	
Open Water	10.96	0.21	
Wet Grassland	9.12	0.17	
Paddy	19.31	0.36	
Other	6.19	0.12	Grass mat, canal, mud, roadside shrub, and artificial
Total	53.3	1.00	

Figure 3. Numbers of species using different habitats in winter, spring (A), and summer and autumn (B) at Maidi Lake. Habitat codes are: WA=open water, M=mud banks, WG=wet grassland, GM=grass meadow, WS=wetland shrub, BA=bamboo (roadside shrubs), RU=rush, RE=reed, PA=paddy, CA=canal, A=artificial

Table 2. Winter habitat associations of birds based on proportions of observations in each habitat at Maidi Lake

Species	Scientific name	Water	Mud	Wet Grass	Grass Mat	Wetland Shrub	Bamboo	Rush	Reed	Paddy	Canal	Artificial
Mallard	*Anas platyrhynchos*	85		8	7							
Green-winged Teal	*Anas crecca*	100										
Gray-headed Swamphen	*Porphyrio poliocephalus*							25	75			
White-breasted Waterhen	*Amaurornis phoenicurus*			13	12			25	25	13	12	
Grey Headed Lapwing	*Vanellus cinereus*	25		50	25							
Red-wattled Lapwing	*Vanellus indicus*									83	17	
Common Snipe	*Gallinago gallinago*			100								
Green Sandpiper	*Tringa ochropus*	100										
Black Stork	*Ciconia nigra*			100								
Asian Woolly-necked Stork	*Ciconia episcopus*			40		10		10		40		
Great Cormorant	*Phalacrocorax carbo*	75			12							13
Cinnamon Bittern	*Ixobrychus cinnamomeus*			100								
Little Egret	*Egretta garzetta*	11		33	5				6		6	39
Indian Pond Heron	*Ardeola grayii*	14		29						57		
Eastern Cattle Egret	*Bubulcus coromandus*			44	4	8			4	8	4	28
Medium Egret	*Ardea intermedia*			70	10				5	10	5	
Grey Heron	*Ardea cinerea*	37		63								
Steppe Eagle	*Aquila nipalensis*											100
Black Kite	*Milvus migrans*						25			25		50
Common Kingfisher	*Alcedo atthis*			67			34					
White-throated Kingfisher	*Halcyon smyrnensis*					25	25	4	4			42
Black Drongo	*Dicrurus macrocercus*											
Long-tailed Shrike	*Lanius schach*					20	40	20				20
Gray-backed Shrike	*Lanius tephronotus*					50			50			
Zitting Cisticola	*Cisticola juncidis*							100				
Red-vented Bulbul	*Pycnonotus cafer*								100			
Himalayan Bulbul	*Pycnonotus leucogenys*							100				
Dusky Warbler	*Phylloscopus fuscatus*						100					
Gray-sided Bush Warbler	*Cettia brunnifrons*					100						
Siberian Stonechat	*Saxicola maurus*			4		8	12	48	24	4		

Species	Scientific name											
Pied Bushchat	*Saxicola caprata*				100							
Gray Wagtail	*Motacilla cinerea*		100									
White Wagtail	*Motacilla alba*										100	
Paddyfield Pipit	*Anthus rufulus*										100	
Olive Backed Pipit	*Anthus hodgsoni*											100
Number of species		8	1	14	7	8	6	8	9	9	6	8

Table 3. Spring habitat associations of different species based on proportions of observations in each habitat at Maidi Lake.

Species	Scientific name	Water	Mud	Wet Grass	Grass Mat	Wetland Shrub	Bamboo	Rush	Reed	Paddy	Canal	Artificial
Lesser Whistling Duck	*Dendrocygna javanica*	60	27	13								
Mallard	*Anas platyrhynchos*	73	9	18								
Spotted Dove	*Spilopelia chinensis*								67	33		
Eurasian Coot	*Fulica atra*	100										
Gray-headed Swamphen	*Porphyrio poliocephalus*			27				45	28			
Watercock	*Gallicrex cinerea*			50							50	
White-breasted Waterhen	*Amaurornis phoenicurus*	5		57				11	11	8	8	
Baillon's Crake	*Zapornia pusilla*									100		
Red-wattled Lapwing	*Vanellus indicus*		6	33					7	47	7	
Common Snipe	*Gallinago gallinago*			100								
Common Sandpiper	*Actitis hypoleucos*										100	
Green Sandpiper	*Tringa ochropus*	67	33									
Black Stork	*Ciconia nigra*			33						67		
Asian Woolly-necked Stork	*Ciconia episcopus*			78						22		
Little Cormorant	*Microcarbo niger*	20							60			20
Great Cormorant	*Phalacrocorax carbo*	50				50						
Cinnamon Bittern	*Ixobrychus cinnamomeus*			23		5		19	29		14	
Yellow Bittern	*Ixobrychus sinensis*								100			
Little Egret	*Egretta garzetta*	20		49				4	10	6	7	4
Indian Pond Heron	*Ardeola grayii*			32				4	11	18	32	3
Eastern Cattle Egret	*Bubulcus coromandus*			53					25	14		8
Medium Egret	*Ardea intermedia*	6		64	2			3	11	11		3
Grey Heron	*Ardea cinerea*	20		60								20

Species	Scientific name	Water	Mud	Wet Grass	Grass Mat	Wetland Shrub	Bamboo	Rush	Reed	Paddy	Canal	Artificial
Common Kingfisher	*Alcedo atthis*			14								86
White-throated Kingfisher	*Halcyon smyrnensis*					8	17		10			65
Black Drongo	*Dicrurus macrocercus*						50			25		25
Long-tailed Shrike	*Lanius schach*								50			50
Zitting Cisticola	*Cisticola juncidis*			20		20		20		20	20	
Red-vented Bulbul	*Pycnonotus cafer*											
Himalayan Bulbul	*Pycnonotus leucogenys*			50					50			
Dusky Warbler	*Phylloscopus fuscatus*					80	20					
Jungle Myna	*Acridotheres fuscus*						100					
Small Niltava	*Niltava macgrigoriae*					100						
Rusty-tailed Flycatcher	*Ficedula ruficauda*					100						
Siberian Stonechat	*Saxicola maurus*			9		22	9	34	13			13
Scaly-breasted Munia	*Lonchura punctulata*					25			75			
White-rumped Munia	*Lonchura striata*					20			80			
White browed Wagtail	*Motacilla maderaspatensis*											100
Paddyfield Pipit	*Anthus rufulus*							20		80		
Olive Backed Pipit	*Anthus hodgsoni*			67				33				
Rosy Pipit	*Anthus roseatus*											100
Number of species		10	4	20	1	9	6	10	17	12	9	13

Table 4. Summer habitat associations of birds based on proportions of observations in each habitat at Maidi Lake.

Species	Scientific name	Water	Mud	Wet Grass	Grass Mat	Wetland Shrub	Bamboo	Rush	Reed	Paddy	Canal	Artificial
Lesser Whistling Duck	*Dendrocygna javanica*	25	50		25							
Oriental Turtle-Dove	*Streptopelia orientalis*									100		
Spotted Dove	*Spilopelia chinensis*						100					
Gray-headed Swamphen	*Porphyrio poliocephalus*								50			
Watercock	*Gallicrex cinerea*			100								
White-breasted Waterhen	*Amaurornis phoenicurus*			75					25			
Little Cormorant	*Microcarbo niger*								100			
Cinnamon Bittern	*Ixobrychus cinnamomeus*			50						50		
Little Egret	*Egretta garzetta*			25	25				25	25		
Indian Pond Heron	*Ardeola grayii*							100				
Eastern Cattle Egret	*Bubulcus coromandus*			33	33					33		

Species	Scientific name	Water	Mud	Wet Grass	Grass Mat	Wetland Shrub	Bamboo	Rush	Reed	Paddy	Canal	Artificial
Medium Egret	*Ardea intermedia*		50							50		
Common Kingfisher	*Alcedo atthis*											100
White-throated Kingfisher	*Halcyon smyrnensis*					50						50
Long-tailed Shrike	*Lanius schach*					100						
Common Tailorbird	*Orthotomus sutorius*					100						
Zitting Cisticola	*Cisticola juncidis*					50				50		
Red-vented Bulbul	*Pycnonotus cafer*					100						
Himalayan Bulbul	*Pycnonotus leucogenys*					100						
Common Myna	*Acridotheres tristis*									100		
Jungle Myna	*Acridotheres fuscus*									100		
White browed Wagtail	*Motacilla maderaspatensis*		100									
Paddyfield Pipit	*Anthus rufulus*									100		
Number of species		1	3	5	3	6	1	1	4	8	1	2

Table 5. Autumn habitat associations of birds based on proportions of observations in each habitat at Maidi Lake.

Species	Scientific name	Water	Mud	Wet Grass	Grass Mat	Wetland Shrub	Bamboo	Rush	Reed	Paddy	Canal	Artificial
Lesser Whistling Duck	*Dendrocygna javanica*	75	25									
Mallard	*Anas platyrhynchos*	100										
Green-winged Teal	*Anas crecca*	100										
Gray-headed Swamphen	*Porphyrio poliocephalus*			50								
White-breasted Waterhen	*Amaurornis phoenicurus*	14	29	28				29				
Grey Headed Lapwing	*Vanellus cinereus*		100									
Common Snipe	*Gallinago gallinago*		100									
Common Sandpiper	*Actitis hypoleucos*		100									
Green Sandpiper	*Tringa ochropus*		100									
Black Stork	*Ciconia nigra*		100									
Little Cormorant	*Microcarbo niger*											100
Great Cormorant	*Phalacrocorax carbo*	50										50

Common Name	Scientific Name											
Cinnamon Bittern	*Ixobrychus cinnamomeus*										100	
Little Egret	*Egretta garzetta*			14	14					14	29	29
Indian Pond Heron	*Ardeola grayii*				20					20	40	20
Eastern Cattle Egret	*Bubulcus coromandus*				34					33		33
Great Egret	*Ardea alba*		100									
Medium Egret	*Ardea intermedia*		12	50	25					13		
Grey Heron	*Ardea cinerea*		100									
Common Kingfisher	*Alcedo atthis*											100
White-throated Kingfisher	*Halcyon smyrnensis*			19					5			76
Long-tailed Shrike	*Lanius schach*					100						
Gray-backed Shrike	*Lanius tephronotus*											100
Common Tailorbird	*Orthotomus sutorius*							100				
Zitting Cisticola	*Cisticola juncidis*					100						
Dusky Warbler	*Phylloscopus fuscatus*					100						
Rusty-tailed Flycatcher	*Ficedula ruficauda*					100						
Scaly-breasted Munia	*Lonchura punctulata*					100						
White-rumped Munia	*Lonchura striata*							100				
Gray Wagtail	*Motacilla cinerea*											100
White browed Wagtail	*Motacilla maderaspatensis*										100	
White Wagtail	*Motacilla alba*		50								50	
Paddyfield Pipit	*Anthus rufulus*									100		
Number of species		5	11	5	4	5	0	3	1	5	5	9

Species Use Compared to the Availability of Habitats

Table 1 provides estimates of the habitat coverage within the Maidi Lake area. Forest is not included because we sampled only the forest fringe adjacent to the lake, and bird species recorded solely in the forest were included in a companion manuscript (Poudel et al., in press).

Among the wetland habitats, paddy and open water were relatively common. We had more surveys in spring than in other seasons, so those data were used to illustrate how habitat is used related to habitat availability (Fig. 4). Notably, reed and paddy fields were used disproportionately to their coverage, reeds relatively high and paddy fields relatively low.
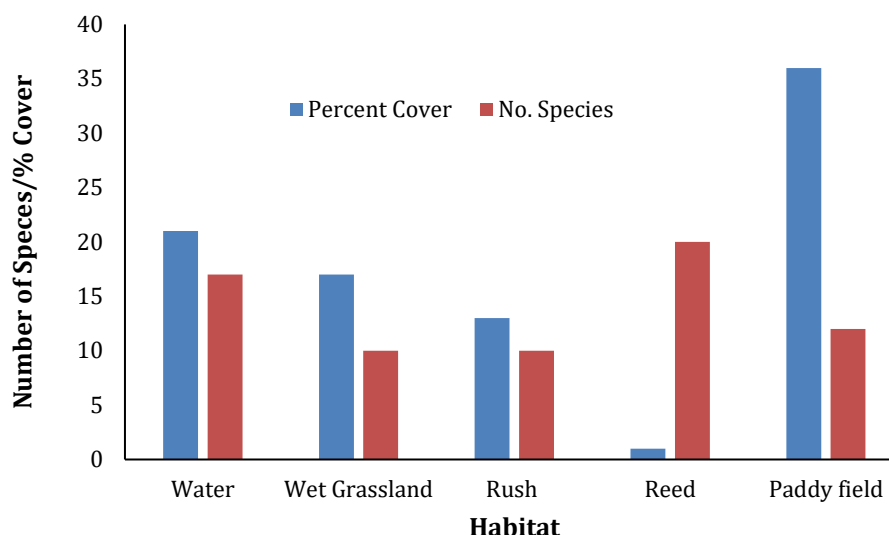
Figure 4. Number of bird species using primary wetland habitats at Maidi Lake compared to their area of coverage.

Habitat Use by Wetland Species Groups

Waterfowl (Anseriformes), including Lesser Whistling Ducks, Mallards, and Green-winged Teal, were most frequently recorded in open water (usually near shore if not disturbed), on mud banks, or in wet grasslands (Tables 2-5). They were typically seen near the northern end of the lake where open water and vegetation interspersed (Fig. 5). Rails (Gruiformes) commonly used reeds and rushes, while White-breasted Waterhen occurred across most wetland habitats (Fig. 6). Shorebirds (Charadriiformes) were generally observed in shallow water or on mud, though Red-wattled Lapwing was frequently seen in paddy fields as well (Fig. 7) and snipe were usually found in wet grasslands. Storks (Ciconiformes) were most often seen in wet grasslands and paddy fields (Fig. 7). The cormorants (Suliformes) showed distinct habitat preferences: Great Cormorants are usually being found in open water, whereas Little Cormorant was primarily seen in reeds, roosting in the heron and egret breeding colony. Bitterns, herons, and egrets (Pelecaniiformes) used a variety of habitats. Cinnamon Bittern occurred mainly in more open habitats (wet grassland, paddy, and canal), but sometimes in dense rushes and reeds like the Yellow Bittern (Fig. 8). Pond herons used most of the habitats but concentrated in reeds in spring, where they breed alongside egrets (primarily Eastern Cattle Egrets) in a mixed colony. In other seasons, egrets utilized a wide range of habitats (Fig. 9). Gray Herons were mostly seen in shallow water, on mud banks, or in wet grasslands. Both species of kingfishers (Coraciiformes) used artificial habitats extensively as perches. However, Common Kingfishers used wet grasslands frequently, whereas White-throated Kingfishers often perched in wetland shrubs. Among Passeriformes, wagtails and pipits were primary wetland users. Wagtails were seen mostly on mud banks, along canals, or perched on artificial habitats. Paddy field Pipits were recorded mainly in paddy fields, while Olive-backed Pipit and Rosy Pipit were occasionally observed in other habitats.

Habitat Use by Wetland-Associated Species

Birds of Prey (Accipitriformes) were mostly recorded as individuals flying over Maidi Lake. However, Steppe Eagle and Black Kite were observed perched in wetland habitats, with the eagle utilizing an artificial habitat (a pole) and the kite using multiple habitat types. Wetland habitat associations were recorded for 15 species of perching birds (Passeriformes) and 2 species of doves (Columbiformes). Most of these species were primarily associated with adjacent forests, using wetland shrubs or other perches in the wetland only occasionally. In contrast, Zitting Cistacola, Dusky Warbler, Siberian Stonechat, and Pied Bushchat were seen only in wetland habitats. Cistacolas predominantly occupied wetland shrubs, rushes, and paddy fields. Dusky Warblers were found in wetland shrubs and bamboo, whereas Pied Bushchat was restricted to wetland shrubs. Siberian Stonechat used the most habitats, but was most frequently seen in wetland shrubs, rushes, and reeds.

Use of Individual Habitats

Deep open water was used occasionally by ducks and rails, where they were most often resting or swimming between other habitats. The only species that appeared to feed in deep water were cormorants and coots. Other species using this habitat (dabbling ducks, egrets and herons, and shorebirds) were mostly in shallow water near shore, where they rested and fed. Mud flats were used by herons and egrets for resting, but these habitats were mostly used by ducks (roosting), shorebirds, and wagtails (both roosting and feeding).
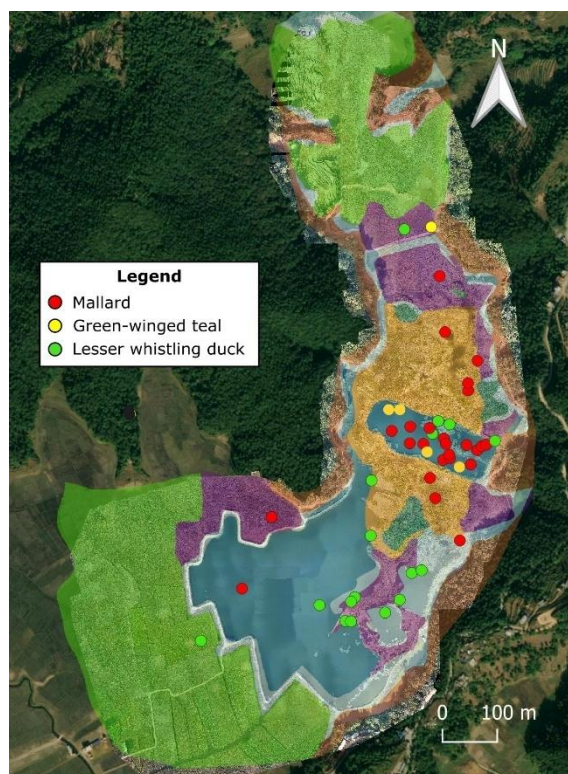
Figure 5. Distribution of waterfowl in winter and spring at Maidi Lake (each dot represents 1 or more birds that were observed together). Habitat types (shown by color) as in figure 2.
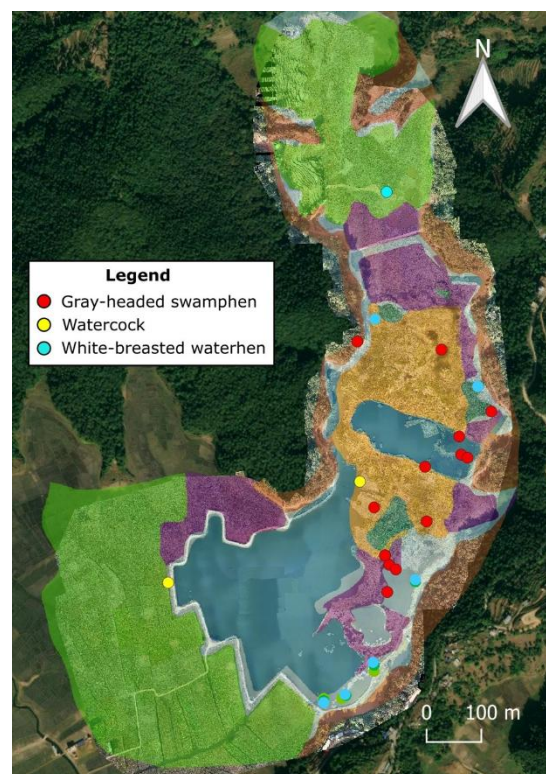

Figure 6. Distribution of rails in winter and spring at Maidi Lake (each dot represents 1 or more birds that were observed together). Habitat types (shown by color) as in figure 2.
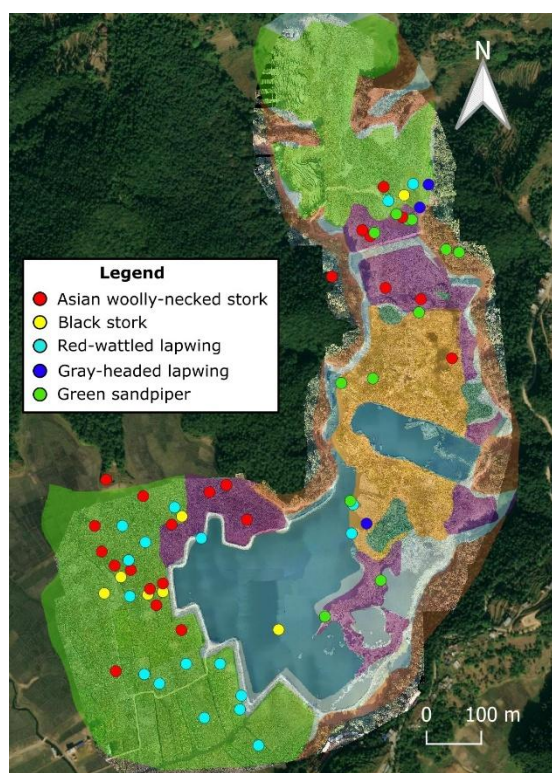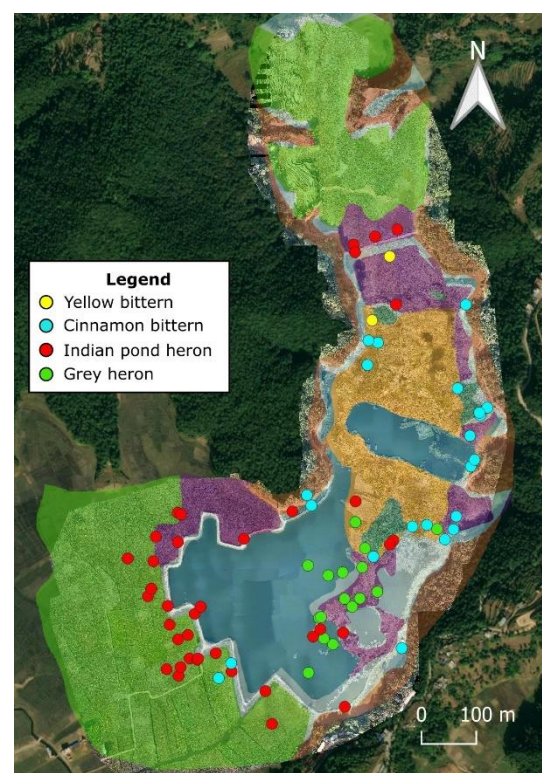

Figure 7. Distribution of shorebirds and storks in winter and spring at Maidi Lake (each dot represents 1 or more birds that were observed together). Habitat types (shown by color) as in figure 2.
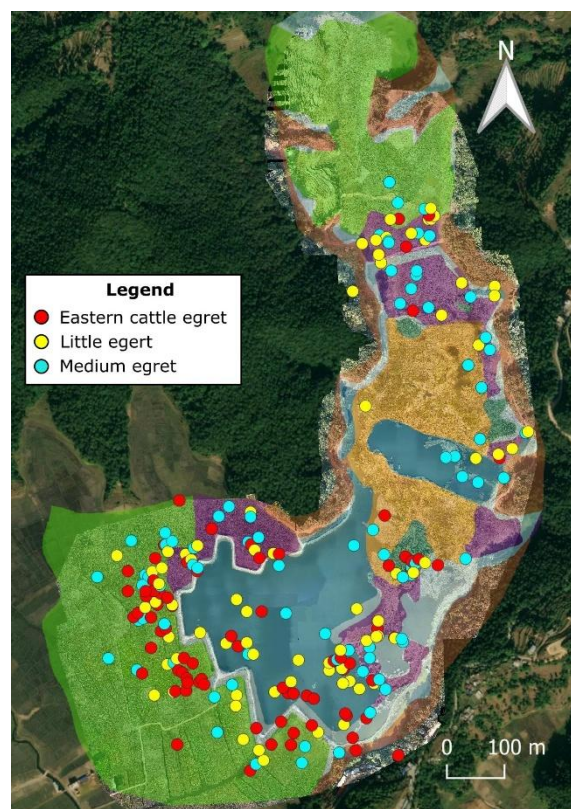

Figure 8. Distribution of bitterns and herons in winter and spring at Maidi Lake (each dot represents 1 or more birds that were observed together). Habitat types (shown by color) as in figure 2.

Figure 9. Distribution of egrets in winter and spring at Maidi Lake (each dot represents 1 or more birds that were observed together). Habitat types (shown by color) as in Fig. 2.

Wet grasslands supported many obligate wetland species, and particularly storks, herons, and egrets that fed as well as rested in this habitat. Snipes were also recorded in this habitat, though more were likely present but not detected because surveys did not involve walking through grassland to flush these difficult-to-see birds. Grass mats and wetland shrubs along the water's edge were used by a variety of mostly perching birds for resting; shrikes and Siberian Stonechats being among the more frequent. The scattered clumps of roadside shrubs were used by kingfishers and occasionally by larger birds like kites and cormorants, and they also provided perching sites for smaller perching bird species like Black Drongo.

The rush and reed habitats were mainly frequented by swamphens, waterhens, and bitterns, which were almost certainly undercounted due to the thick vegetation. Also, perching birds were sometimes observed in these habitats, and one particularly dense "island" of reeds served as habitat for a nesting colony of herons and egrets.

Use of paddy fields varied seasonally, but these areas were especially important for Red-wattled Lapwings, wagtails, and pipits. The adjacent canal was frequented by pond herons, rails, and bitterns, which apparently fed there. Artificial habitats, including stakes within the lake and around its periphery, were used by kingfishers, herons, egrets, and shrikes.

Comparisons With Other Studies
Bird studies have been conducted in several wetlands in Nepal (Adhikari et al., 2018; Baral, 2005; Basaula et al., 2023; Bhusal et al., 2020; Dhakal et al., 2020; Gautam & Kafle, 2008; Giri & Chalise, 2008; Kharel, 2018; Khatri et al., 2019; Lamsal et al., 2014; Pant et al., 2024; Parajuli, 2022; Shrestha et al., 2023; Subedi, 2006). Most of these studies reported species richness and commonly applied one or more diversity indices at the species or family level. A few also examined seasonal abundances, and many incorporated surveys of local communities to get a sense of threats to the wetland birds. Other studies have addressed wetland habitat characteristics for plants (e.g., Pathak et al., 2020; Pathak et al., 2021). Nevertheless, none of these publications have analyzed bird-habitat relationships. Therefore, this study appears to be the first of its kind in Nepal for wetland birds.

Publications documenting species richness and relative abundance of birds in wetlands in Nepal provide valuable baseline information on species using these sensitive areas. However, understanding bird-habitat relationships often provides stronger guidance for wetland conservation planning, particularly in managed wetlands (Ma et al. 2010) with water control dams like Maidi Lake.

As noted in Section 2.3, surveys were more frequent in winter and spring than in summer and autumn, so habitat associations are best represented for these seasons. Even

so, it was evident that all the habitats were utilized by multiple species across seasons.

Habitat Modification and Threats

Maidi Lake has changed substantially since the rehabilitation project was completed in 2021. The characterization of bird-habitat associations presented in this study provides a foundation for assessing the potential impacts of management options that balance human use with wetland and bird conservation.

As summarized in "Study Area: Human Uses" and reported by Magar (2023), potential threats to Maidi Lake include commercial fishing in open water, agriculture in the paddy areas, livestock grazing in wet grasslands, and harvesting plants for fodder in the wet grasslands, grass mats, and rushes. These activities are likely to cause temporary disturbance to birds. However, the wetland is large enough to offer alternative sites when birds are flushed. Agricultural areas adjacent to the lake provide a potential buffer against other encroachment, such as housing developments, while simultaneously offering seasonal bird habitat. Livestock grazing in wet grasslands may not have negative impacts if overgrazing is avoided, as these areas are not known to be important bird nesting areas. Similarly, fodder collection at the level observed in Maidi Lake does not appear to permanently damage vegetation.

Magar (2023) noted that a reduction in floating grass mats, whether through physical removal to increase open water or through root damage caused by grass carp, could lead to significant losses of this important habitat. Besides providing bird habitat directly, floating grass mats likely provide cover for juvenile fish and serve as a substrate for wetland shrubs and reeds. Interspersion of vegetation types such as floating grass mats, reeds, and rushes with open water is recognized as critical for wetland birds (Weller & Spatcher 1965). Thus, maintaining a mosaic of open water and vegetation is desirable.

Visitors walking or riding motorbikes around the lake occasionally create temporary disturbance to birds near the edge of the lake, including birds in wetland shrubs and bamboo habitats. Nevertheless, current visitation levels appear low. Hunting of birds has also been reported (Magar, 2023), but the extent of its negative impact remains unknown.

Encroachment from developments that replace the buffer areas or directly reclaim wetland habitats is likely the most serious threat to Maidi Lake. Development within the surrounding watershed could further increase risks of pollution, agricultural runoff, and siltation, in addition to causing more disturbance. These challenges are already evident at other LCPV sites, such as Phewa (Khatri et al., 2019; Basaula et al., 2021) and Begnas (Basaula et al., 2023). Invasive plants are a concern in some LCPV lakes (Basaula, 2023), though they have not yet become a problem at Maidi Lake.

Understanding bird-habitat relationships provides critical insight into the potential consequences of increasing threats to wetlands in Nepal. Similar studies are recommended at other LCPV Ramsar sites to support efforts to maintain the biological integrity of these ecosystems for both wildlife and local communities that depend on them.

Conclusions

This comprehensive study conducted at Maidi Lake from 2023 to 2024 provides a crucial baseline for understanding the current role of wetland habitats in supporting bird species. The mosaic of open water and vegetated habitats in and surrounding the lake, which has been present since the 2019-21 lake rehabilitation, is used by a variety of birds in all seasons. This study demonstrates that each of the habitats present in the lake is valuable for sustaining the current diversity of birdlife at Maidi Lake. Therefore, conservation of the lake's birdlife depends on maintaining or enhancing the diversity of habitats. Habitat quality at Maidi Lake has not yet been severely affected by the problems observed at other wetland areas, providing a valuable opportunity to manage the area in a way that supports livelihoods and wildlife, including wetland birds. The baseline data generated in this study supports the objectives of the Ramsar management plan and provides a foundation for both conservation planning and long-term monitoring of changes in habitats and use of those habitats by birds. Conducting bird-habitat association studies at other LCPV sites would expand the understanding of the importance of specific habitats for various wetland birds, thereby highlighting the important linkages between bird conservation and habitat conservation across all the lakes in the Pokhara Valley. It is recommended that the nomenclature for wetland habitats be consistent in future studies to facilitate comparisons.

Author Contributions: All authors contributed to conceptualization and planning the study, Magar and Byrd collected bird habitat data, Storey collected water quality data, all authors contributed to analysis and writing.

Conflicts of Interest: The author declares no conflicts of interest.

TU-CDES

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Adhikari, J.N., Bhattarai, B.P., & Dhakal, D.N. (2018). Conservation value of Beeshhazari Lake: an insight into diversity and abundance of wetland birds. *Our Nature,* 16, 17–26. https://doi.org/10.3126/on.v16i1.21563.

Adhikari, J.N., Khatiwada, J.R., Adhikari D., Sapkota S, Bhattari B.P., Rijal D., & Sharma L.N. (2022). Comparison of bird diversity in protected and non-protected wetlands of western lowland of Nepal. *Journal of Threatened Taxa,* 14, 20311. https://doi.org/10.11609/jott.2022.14.1.20311-20538.

APHA. (1999). Standard Methods for the Examination of Water and Wastewater. 20th edition. American Public Health Association.

Baral, H. S. (2005). *Birds of Koshi (1st ed)*. DNPWC, Kathmandu.

Baral, H.S. (2009). Status of Nepal's wetland birds. *Banko Janakari*, 19(3), 30-35. https://doi.org/10.3126/banko.v19i3.2209.

Basaula, R. (2023). Effects of water hyacinth on fish diversity and abundance in the lake cluster of Pokhara Valley, Nepal. *Global Ecology and Conservation,* 46, e02565.

Basaula, R., Singh, O., & Gautam, R. (2021). Seasonal variation on the abundance and diversity of waterbirds in Phewa wetland Pokhara, Nepal. *ZOO Journal,* 6, 24-34. https://doi.org/10.3126/zooj.v6i1.58702.

Basaula, R., Singh, O., & Dahal, B. (2023). Abundance and diversity of waterbirds around the Begnas Lake of Pokhara Valley, Nepal. *Global Journal of Ecology,* 8, 11–18. https://doi.org/10.17352/gje.000076.

Bhandari, B.B. (2008). Wise use of Wetlands in Nepal. *Banko Janakari,* 19(3), 10-17. https://doi.org/10.3126/banko.v19i3.2206.

Bhusal, K., Rana, D., Joshi, A., Chaudhary, P., Ghimire, P., & Pandey, M. (2020). Diversity and abundance of winter wetland birds in Jagdishpur Reservoir Ramsar Site, Kapilvastu, Nepal. *Danphe,* 29(1), 1-13.

Dhakal, H., Ghimire, M., Poudel, A., Ghimire, P., & Bhusal, K. (2020). Avian diversity of Khaste Lake Complex, Pokhara Valley, Nepal. *Minivet* 3, 17–25.

Gauli S., Dhakal M., Khanal R. (2016). Lake Cluster of Pokhara Valley. Department of National Parks and Wildlife Conservation and IUCN Nepal. Kathmandu.

Gautam, R., & Kafle G. (2008). A preliminary survey of waterbirds in Phewa Lake, Kaski. *Bird Conservation Nepal.* Newsletter, 6-8.

Giri, B., & Chalise, M. (2008). Seasonal diversity and population status of waterbirds in Phewa Lake, Pokhara, Nepal. *Journal of Wetland Ecology*, 1(1), 3-7. https://doi.org/10.3126/jowe.v1i1.1568.

Grimmett, R., Inskipp, C., Inskipp, T., & Baral, H. (2016). Birds of Nepal. Bloomsbury Publishing.

IUCN Nepal. (2004). A review of the status and threats to wetlands in Nepal. IUCN Nepal.

Joshi, D. (2020). Knowledge and learning documentation of Lake Cluster of Pokhara Valley (LCPV). *Final Report.* World Wildlife Fund. Kathmandu.

Kharel, M. (2018). A preliminary study on birdlife of Betana Wetland, Belbari, Morang District, SE-Nepal. *SOJ Veterinary Sciences,* 4, 1–6. https://doi.org/10.15226/2381-2907/4/3/00162.

Khatri, N.D., Neupane, B., Timilsina, Y.P., & Ghimire, S. (2019). Assessment of avifaunal diversity and threats to them in Phewa Wetland, Nepal. *Journal of Institute of Forestry,* 16, 31–47.

Lamsal, P., Pant, K.P., Kumar, L., & Atreya, K. (2014). Diversity, uses, and threats in the Ghodaghodi Lake Complex, a Ramsar Site in Western Lowland Nepal. *ISRN Biodiversity* 2014, 1–12. https://doi.org/10.1155/2014/680102.

Li, L., Liu, Y., Wang, H., Zhu, Y., Li, Y., Xu, C., & Teng, S.N. (2024). Effects of surrounding landscape context on threatened wetland bird diversity at the Global Scale. *Diversity*, 16(12), 738. https://doi.org/10.3390/d16120738.

Ma, Z., Cai, Y., Li, B., & Chen, J. (2010). Managing wetland habitats for waterbirds: An international perspective. *Wetlands,* 30, 15–27. https://doi.org/10.1007/s13157-009-0001-6.

Magar, M. (2023). *Assessment of bird habitats, use preference, and threats in Maidi Lake Area, Pokhara, Nepal.* Bachelor's Thesis. Tribhuvan University, Pokhara.

Matthews, G.V.T. (1993). *The Ramsar Convention on wetlands: its history and development.* Ramsar Convention Bureau, Gland, Switzerland. ISBN: 2-940073-00-7.

MoFE. (2018). *Integrated Lake Basin Management Plan of Lake Cluster of Pokhara Valley, Nepal (2018-2023).* Ministry of Forests and Environment, Kathmandu.

OPENGIS.ch (2023). Qfield (version 2.5.7). Accessed 2 Jan 2023 from https://qfield.org.

Pant, S.R., Bhattarai, B.P., Baral, H.S., & Thapa, T.B. (2024). Diversity, species richness, and community composition of wetland birds in the lowlands of western Nepal. *Ecological and Evolution,* 14(12), e70538. https://doi.org/10.1002/ece3.70538.

Parajuli, K. (2022). Assessment of bird diversity and abundance in Karra River Basin, Hetauda, Makawanpur. *International Research Journal of MMC,* 3, 18–33. https://doi.org/10.3126/irjmmc.v3i3.48630.

Pathak, H., Shrestha, B., Bhuju, D.R., & Bhandari, P. (2020). Floristic diversity in the Lake Cluster of Pokhara Valley, Central Nepal. *Journal Natural History Museum,* 31(1), 1–32. https://doi.org/10.3126/jnhm.v31i1.39371.

Pathak, H.N., Bhuju, D.R., Shrestha, B.B., & Ranjitkar, S. (2021). Impacts of invasive alien plants on ecosystem services of Ramsar lake cluster in middle mountain Nepal. *Global Ecology and Conservation,* 27, e01597. https://doi.org/10.1016/j.gecco.2021.e01597.

Poudel A.K., Magar M.B., & Byrd G.V. *in press*. Seasonal abundance, species richness and diversity of birds at Maidi Lake, Nepal. *Nepalese Journal of Zoology.*

Shrestha, S., Dahal, A., Joshi, A.B., Thapa, V.K., & Shrestha, M.B. (2023). Assemblage of waterbirds in wetlands of Kathmandu Valley. *Danphe,* 3, 1–8.

Siwakoti, M., & Karki, J.B. (2010). Conservation status of Ramsar sites of Nepal tarai: an overview. *Botanica Orientalis: Journal of Plant Science,* 6, 76–84. https://doi.org/10.3126/botor.v6i0.2914.

Subedi, B. (2006). Wetland bird diversity of Rupa Lake. MS Thesis, Tribhuvan University, Kathmandu.

Sullivan, B.L., Wood, C.L., Iliff, M.J., Bonney, R.E., Fink, D., & Kelling, S. (2009). eBird: A citizen-based bird observation network in the biological sciences. *Biological Conservation,* 142, 2282–2292. https://doi.org/10.1016/J.BIOCON.2009.05.006.

Thagunna, R.S., Subedi, R., & Koirala, R. (2023). Ecological significance and conservation issues of internationally important wetlands of Nepal: A Review. *Journal of Forest and Natural Resource Management,* 3, 35–52. https://doi.org/10.3126/jfnrm.v3i1.60108.

Timilsina, G., Bastola, S., Gurung, S., & Pokharel, K. (2019). Diversity, distribution and conservation of fishes in Lakes of Pokhara Valley, Nepal. *ZOO Journal,* 5, 32–40.

United Nations. (2018). Wetlands disappearing three times faster than forests. *Climate Change News.* Retrieved 05 June 2025 from https://unfccc.int/news/wetlands-disappearing-three-times-faster-than-forests.

Weller, M., & Spatcher, C.S. (1965). *Role of habitat in the distribution and abundance of marsh birds.* Special Report # 43, Iowa State University, Ames.

Weller, M.W. (1999). *Wetland birds: Habitat resources and conservation implications.* Cambridge University Press.