7-26-2023

Babesa sewage treatment plant as a vital artificial wetland habitat for a multitude of avian species

Pelden Nima

Mahendra Timsina
Edith Cowan University

Tenzin Jamtsho

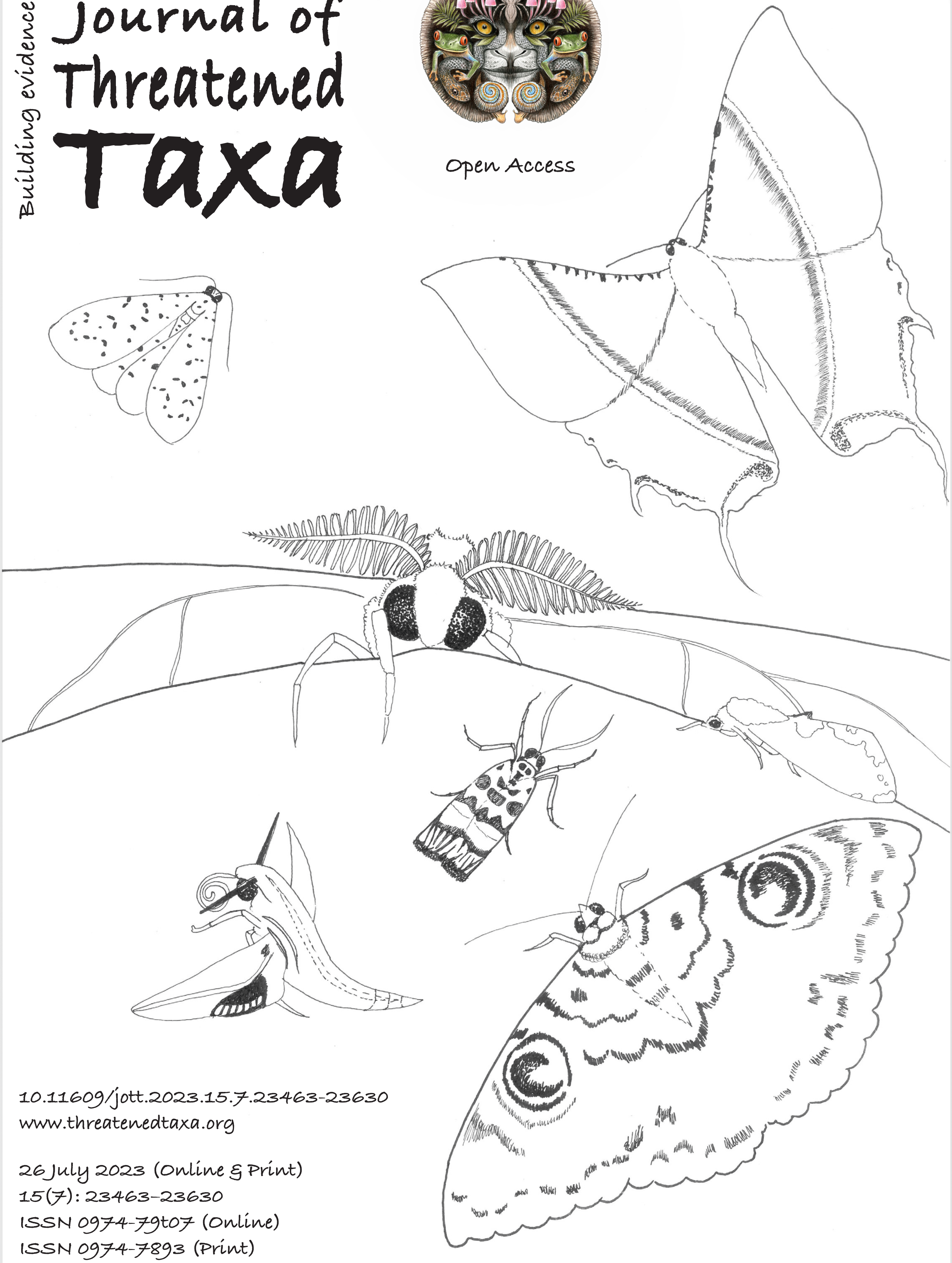
Pema Khandu

10.11609/jott.8467.15.7.23472-23486
Nima, P., Timsina, M., Jamtsho, T., & Khanda, P. (2023). Babesa sewage treatment plant as a vital artificial wetland habitat for a multitude of avian species. Journal of Threatened Taxa, 15(7), 23472-23486. https://doi.org/10.11609/jott.8467.15.7.23472-23486

Building evidence for conservation globally

Journal of Threatened Taxa

Open Access



10.11609/jott.2023.15.7.23463-23630
www.threatenedtaxa.org

26 July 2023 (Online & Print)
15(7): 23463–23630
ISSN 0974-7907 (Online)
ISSN 0974-7893 (Print)

ISSN 0974-7907 (Online); ISSN 0974-7893 (Print)

Publisher
Wildlife Information Liaison Development Society
www.wild.zooreach.org

Host
Zoo Outreach Organization
www.zooreach.org

43/2 Varadarajulu Nagar, 5th Street West, Ganapathy, Coimbatore, Tamil Nadu 641006, India
Registered Office: 3A2 Varadarajulu Nagar, FCI Road, Ganapathy, Coimbatore, Tamil Nadu 641006, India
Ph: +91 9385339863 | www.threatenedtaxa.org
Email: sanjay@threatenedtaxa.org

For Focus, Scope, Aims, and Policies, visit https://threatenedtaxa.org/index.php/JoTT/aims_scope
For Article Submission Guidelines, visit https://threatenedtaxa.org/index.php/JoTT/about/submissions
For Policies against Scientific Misconduct, visit https://threatenedtaxa.org/index.php/JoTT/policies_various

continued on the back inside cover

Cover: Celebrating the unsung heroes—moths, our nocturnal pollinators. © Priyanka Iyer.

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 July 2023 | 15(7): 23472–23486

OPEN ACCESS

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.8467.15.7.23472-23486

#8467 | Received 02 April 2023 | Final received 31 May 2023 | Finally accepted 18 July 2023

ARTICLE

Babesa Sewage Treatment Plant as a vital artificial wetland habitat for a multitude of avian species

Pelden Nima [1], Mahendra Timsina [2], Tenzin Jamtsho [3] & Pema Khandu [4]

[1] Department of Science, Wangbama Central School, Ministry of Education and Skills Development, Thimphu 11001, Bhutan.
[2] Edith Cowan University, 2 Bradford Street, Mount Lawley WA 6050, Australia.
[3] Centre for Molecular Therapeutics, Australian Institute of Tropical Health and Medicine, James Cook University, Cairns campus, Smithfield, QLD 4878, Australia.
[4] Department of Biology, Texas State University, San Marcos, Texas 78666, USA.
[1] nimapelden@gmail.com (corresponding author), [2] mtimxena@gmail.com , [3] jamtshooo@gmail.com, [4] pksesay@gmail.com

Abstract. This study aimed to glean basic ecological aspects on diversity and abundance, temporal variation and guild composition of the birds at Babesa Sewage Treatment Plant (STP). The line transect method was used as the sampling technique from November 2021 to October 2022. A total of 80 species belonging to 58 genera, 29 families, and 11 orders were detected, of which three, namely, River Lapwing *Vanellus duvaucelii*, Falcated Duck *Mareca falcata*, and Ferruginous Duck *Aythya nyroca*, are 'Near Threatened' with the remaining being 'Least Concern'. The highest species richness was recorded in the winter (6.29), the highest species diversity in the spring (2.73), and the highest evenness in the summer (0.76). There was not any statistically significant difference between non-waterbirds and waterbirds, or between feeding guilds. However, based on a permutational multivariate analysis of variance (PERMANOVA), the bird composition was significantly different among seasons. Subsequently, pairwise comparisons revealed a significant difference between autumn & winter (P = 0.006), autumn & summer (P = 0.006), autumn & spring (P = 0.018), winter & summer (P = 0.006), winter & spring (P = 0.006) as well as spring & summer (P = 0.006). The non-metric multidimensional scaling (NMDS) biplot showed most bird species overlap occurred between autumn and spring as well as summer and spring, respectively. Taken together, the present results suggest that the Babesa STP holds significant potential as a habitat for diverse avian populations and underscores the ecological significance of artificial wetlands.

Keywords: Artificial wetland, avian population, feeding guilds, non-waterbirds, species diversity, waterbirds.

Editor: H. Byju, Coimbatore, Tamil Nadu, India. **Date of publication:** 26 July 2023 (online & print)

Citation: Nima, P., M. Timsina, T. Jamtsho & P. Khandu (2023). Babesa Sewage Treatment Plant as a vital artificial wetland habitat for a multitude of avian species. *Journal of Threatened Taxa* 15(7): 23472–23486. https://doi.org/10.11609/jott.8467.15.7.23472-23486

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interests: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author details: P. Nima currently works as a biology teacher at Wangbama Central School under the Ministry of Education and Skills Development (MoESD), Thimphu Bhutan. He holds an MS in Agriculture from Nagoya University, Japan, where he studied about the neuroendocrine mechanism of mammalian reproduction. Additionally, his research interests encompass behavioral and reproductive ecology of waterbirds. M. Timsina is currently pursuing his master's degree in education from Edith Cowan University, Western Australia. He served as a biology and environmental science teacher for 10 years with the MoESD. His research interest includes bird ecology and conservation, and is passionate about nature and wildlife. T. Jamtsho is currently pursuing his PhD at the Centre for Molecular Therapeutics, Australian Institute of Tropical Health and Medicine, James Cook University. His research interest includes biodiversity, pharmacognosy, medicinal chemistry, ethnobotany and phytochemistry. P. Khandu, a wildlife biologist, specializes in avian ecology, particularly focusing on the rare White-bellied Heron and its conservation. He is currently pursuing a PhD in Aquatic Resources and Integrative Biology at Texas State University, USA. Through birding expeditions and seminars, he inspires the younger generation to meaningfully engage in science-based conservation programs.

Author contributions: PN conceived the study design, carried out field study, data collection, data tabulation, statistical analysis and prepared the whole manuscript. MT carried out field study, data collection, data tabulation and helped in revision. TJ provided critical comments on the whole manuscripts and helped in revision. PK critically commented and revised the whole manuscript, and provided comments on statistical analysis. All authors read and approved the final manuscript.

Acknowledgements: All authors remain indebted to IDEA WILD for the grant of the equipment (Police Binocular).

IDEA WILD

INTRODUCTION

Accumulating evidence suggest that wetlands are indispensable for the conservation of many waterbirds and migratory species as well as for mammals, fishes, invertebrates, reptiles and amphibians (Airoldi et al. 2008; Kedleck & Wallace 2008; Engle 2011). This is because wetlands are primarily considered to be abundant in food (Rajpar et al. 2010) and water resources that sustain various lifeforms. Particularly for waterbirds, they are thought to provide breeding, stopover and wintering sites for diverse migratory species (Rendon 2008; Ma et al. 2009), and have been shown to help in the accumulation of critical energy reserves (Catry et al. 2022; Liu et al. 2022), which is inevitable for the wetland-dependent birds to complete a long migration (Alerstam et al. 2003). Wetlands are also considered to enhance landscape biodiversity, control floods, provide recreation (Hansson et al. 2005) and remove pollutants (Vymazal 2010).

However, due to the burgeoning human population, wetlands have been imperilled (Zedler & Kercher 2005). For example, anthropogenic-induced pressures such as water pollution, surplus use of pesticides in adjoining agricultural habitats and human settlements have caused 50% of natural wetlands to be degraded and altered globally (Mitsch & Gosselink 2015). Likewise, human dependence on wetlands for various ecosystem services has intensified and mounted pressures on these ecologically delicate ecosystems (Molur et al. 2011), which may further deteriorate in the future.

Consequently, it has placed wetland inhabitants in a perilous state (Soderquist et al. 2021) often culminating in fewer resources for wetland-dependent species such as waterbirds (Forcey et al. 2011). As a result, avifaunal diversity has diminished. Thus, waterbirds have become progressively reliant on alternative and artificial wetlands (Murray & Hamilton 2010) such as small agricultural ponds, paddy fields and water treatment plants to meet their needs (Lawler 2001; Sebastián-González et al. 2010; Hsu et al. 2011).

Though artificial wetlands cannot fully replace the operationality of natural wetland habitats (Li et al. 2013), wastewater treatment ponds have been reported to increasingly play an important role in supporting regional population of waterbirds (Kalejta-Summers et al. 2001) mainly due to abundance of food resources such as zooplankton (Hamilton et al. 2005). Further, such artificial wetland habitats have been reported to form key staging sites and breeding grounds for migratory bird species (Donahue 2006). Indeed, Breed et al. (2020) showed that wastewater treatment plant is a crucial refuge site for several species of ducks and waders. Similarly, several other studies have also shown that sewage treatment plant (STP) provide habitat supplements and occasional alternative sanctuaries for waterbirds (Attuquayefio & Gbogbo 2001; Gbogbo 2007; Harebottle et al. 2008; Murray & Hamilton 2010). As a consequence, attempts have been made globally to safeguard the wetlands of significance (Tiéga 2011; Ibrahim & Aziz 2012), several of which encompass artificial wetlands (Zedler & Kercher 2005). For instance, a few sewerage habitats, such as Phakalane sewage lagoons in Botswana and Samra sewage in Jordan, are internationally acknowledged as an important bird area (Orlowski 2013).

However, despite the global recognition of STPs as valuable habitat for many bird species, studies pertaining to it are limited (Murray & Hamilton 2010). As such, there is not a single report from Bhutan regarding the role of STP in bird conservation, and in general, studies concerning bird diversity and conservation are sparse and limited only to protected areas (Gyeltshen et al. 2020; Dendup et al. 2021), non-protected areas (Norbu et al. 2021) and freshwater ecosystems (Passang 2018; Nima & Dorji 2022). Therefore, there is a paucity of information and a knowledge gap concerning the role of STPs on the conservation of waterbirds in Bhutan.

To this end, the present systematic study aimed to glean basic ecological aspects on i) diversity and abundance, ii) temporal variation and iii) guild composition of the birds found in Thimphu's only STP. This study will also provide the opportunity to form a basis for formulating national and local policies for the conservation of waterbird species (Wang et al. 2018) and proper management of their essential habitats such as the STP. Documenting the avian diversity of this habitat will advance our understanding of the utilization of sewerage treatment plants by the different avian communities.

MATERIALS AND METHODS

Study site

The present study was conducted at Babesa STP (27.4367^{0}N, 89.6521^{0}E) (Figure 1), Thimphu, Bhutan. The study site spans an area of 13 acres of land with the design capacity of 1.75 million l/day and 325 mg/l five-day biological oxygen demand (BOD_5) removal (Phuntsho et al. 2016). There are three ponds with varying areas and depth. The first one, anaerobic pond covers 1.85

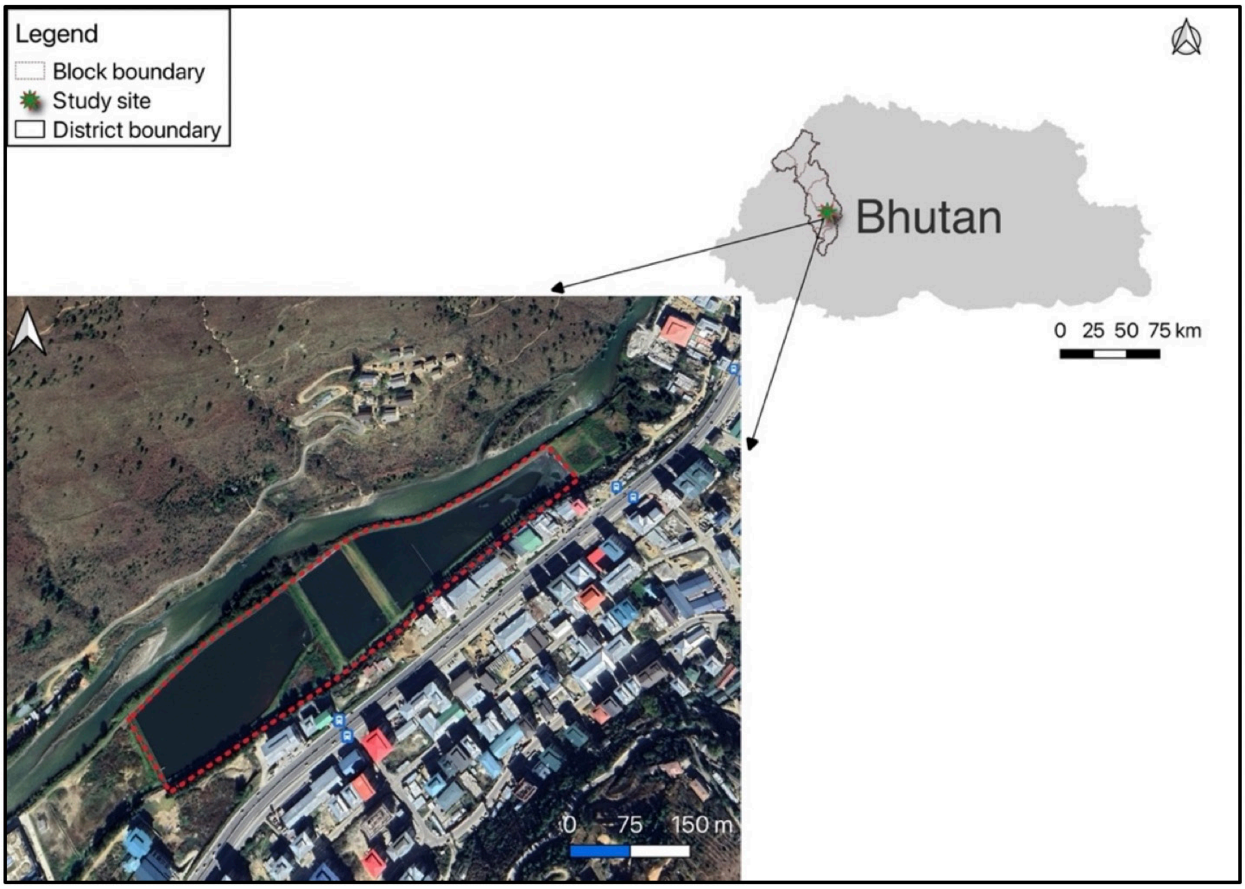


Figure 1. Map showing the location of the study site. The boundary of the STP is marked with red dotted lines.

ha with a depth of 3 m, while the second, facultative pond covers 0.71 ha with a depth of 2 m, and the third, maturation pond covers 1.71 ha with a depth of 1.5 m, respectively. The banks of all the three ponds have flat upper surfaces lined with rocks, mostly covered by *Cynodont dactylon,* and features steep vertical slopes approximately measuring 0.45 m. Other sparsely populated herb species such as *Rumex nepalensis* is also found along the edges of the pond. The surrounding vegetation is mostly dominated by tree species such as *Salix babylonica*, sparsely populated *Silax* and *Populus* species along with the shrub *Rosa brunonii* and the herb *Fagopyrum* species.

It is situated about 40 m away from Babesa-Thimphu expressway and lies to the immediate south of Wangchhu (chhu = river) while heading towards the main town. The nearest human settlement is about 15 m away from the study site. The site has moderate summer, cool spring and autumn, and a cold winter season with an annual average temperature of 13.8°C, and an annual average rainfall of 48.3 mm (NCHM 2013). The STP uses wastewater stabilization ponds alone (Phuntsho et al. 2016).

Bird counts

A reconnaissance study was carried out in the last week of October 2021 to identify vantage points and a suitable position for a transect lines. The actual study commenced from the first week of November 2021, considered to be the ideal time for studying wintering and resident birds in the sub-Himalayan region (Salewski et al. 2003; Mazumdar et al. 2007), through to the end of October 2022.

We divided the time of the day into two intervals: 0800–1000 h in the morning and 1500–1700 h in the evening for 23 bird count surveys along the 650-m transect line. So, in a day we traversed for four hours along the 1,300 m transect line. For the remaining 14 bird surveys, in a day we surveyed the birds only once for 2 h in the evening along the 650 m transect line. Altogether, we spent 120 h surveying the birds along the 39,000 m of transect line. All the surveys were performed on weekends.

Prior to entering the designated study site, we observed and recorded all the birds sighted in the open sewerage pond from a vantage point to make a quick estimate of the actual birds present and help validate the counts made from the line transect. Before we traversed the preset transect line by foot and recorded the sightings, we spent about 10 min to settle so that the birds did not feel disturbed and stressed. Concurrently, care was taken to maintain a proper distance between the observer and birds. At a certain randomly identified points marked along the transect, we stopped for about 15 min and recorded additional visible species and estimated the number of each species (Webb et al. 2010). We included all the observed bird species either wandering on the bank or resting on the bank or trees as long as they were within 50 m radius from the transect (Hutto et al. 1986). We did not consider flying birds in order to avoid repeated counting of the same individuals. Moreover, to reduce the impact of inclement weather on results of sightings, observations were not taken during snowfall or rainfall.

Birds were recorded using direct observations with the help of binoculars namely Police (7 x 50, Steiner, Germany), and Nikon (7 x 50), and immediately noted in the field journal. Where a bird species could not be confirmed, photos were taken using Canon 7d Mark II paired with Tamron G2 telephoto zoom lens (150–600 mm) and Nikon D850 paired with Nikkor telephoto zoom lens (200–500 mm) for further identification.

Bird identification, nomenclature, feeding guild, and conservation status

We followed Grimmett et al. (2019) for avifauna identification and nomenclature. Further, birds were categorized as per their residency pattern as Altitudinal Migrant (AM), Passage Migrant (PM), Resident (R), Summer Visitor (SV), Vagrant (V), and Winter Visitor (WV) (Ali et al. 1996; Feijen & Feijen 2008; Grimmett et al. 2019). Likewise, feeding guilds were ascribed based on the observation made in the field (Kumar & Sharma 2018; Singh et al. 2020). Additionally, we followed Ali & Ripley (1987) to assign the feeding guild: granivorous if they fed on grains, omnivorous if they fed on both plants and animals, insectivorous if they fed on insects, carnivorous if they fed on non-insects' invertebrates and vertebrates, frugivorous if they fed on fruits and nectarivorous if they fed on floral nectar. Birds were also categorized as water and non-waterbirds. The conservation status of the identified bird species was categorized as per International Union of Conservation for Nature (IUCN 2022).

Species accumulation curve

Species accumulation curve as a function of sampling adequacy was performed to determine if the probability of sighting new species increased with increase in sampling days. The function 'specaccum' from R package 'vegan' (Oksanen et al. 2019) was employed to discover the expected species accumulation curve by means of sample-based rarefaction (Chiarucci et al. 2008).

Bird abundance and rank abundance curve

We followed Bull (1974) to describe the bird abundance. If more than 1,000 individuals were seen in a day, it was classed as very abundant (VA), those between 201–1,000 individuals as abundant (A), between 51–200 individuals as very common (VC) and those between 21–50 as common (C). Likewise, those between seven to 20 were classed as fairly common (FC) and between one to six as uncommon (UC). For birds with one to six individuals per season, it was classed as rare (Ra) and those with infrequent occurrence as very rare (VR) species.

The season-wise rank abundance curve was graphed with abundance rank and relative abundance. For interpretation purpose, a horizontal rank abundance indicated a community with a complete even distribution, whereas a steeper slope indicated a community with a less even distribution of species (Akinnifesi 2010). Subsequently, a rank abundance curve was plotted to analyse dominance patterns and species evenness across different seasons.

Data analysis

The relative diversity (RDi) of families was computed following La Torre-Cuadros et al. (2007), where:

$$RDi = \frac{\text{Number of species in a family}}{\text{Total number of species}} * 100.$$

For species evenness (E), we followed Pielou's index (Pielou 1966):

$$E = \frac{H'}{LnS}$$

Where:

E: Pielou's index

H': Shannon diversity index

Ln: natural logarithm

S: number of species observed

If E is close to 0, species evenness is considered low and if E is close to 1, evenness is considered to be relatively uniform.

For richness index (R), we followed Margalef's equation (Margalef 1968):

$$R = \frac{(S-1)(1)}{Ln(N)}$$

Where:

R: index of species richness.

S: number of species observed.

N: number of individuals of all species observed.

Ln: natural logarithm.

If R <2.5, the species richness is considered low, medium if R >2.5 but <4 and high if R >4.

For species diversity, Shannon-Weaver index (H') (Shannon & Weaver 1949) was used as follows:

$$\text{Shannon - Weaver index } (H') = -\sum_{i=1}^{n} Pi \ln Pi$$

Where:

H': Shannon-Weaver diversity index.

n: number of individual species.

Pi: proportion of individual species belonging to the i^{th} species of the total number of individuals.

If H' <1, the diversity index is considered low, medium if H' >1 but <3 and high if H' >4.

Data was checked for normality using Shapiro-Wilk test. As it did not conform to a normal distribution, a non-parametric Kruskal-Wallis test was performed to evaluate the statistical significance in the feeding guilds of the birds. Likewise, to assess the statistical significance between waterbirds and non-waterbirds, a Mann-Whitney test was computed. Waterbirds included Anatidae, Ardeidae, Charadriidae, Cinclidae, Ibidorhynchidae, Motacillidae (White Wagtail *Motacilla alba*, White-browed Wagtail *Motacilla maderaspatensis*, Water Pipit *Anthus spinoletta*, Citrine Wagtail *Motacilla citreola*), Muscicapidae (White-capped Redstart *Phoenicurus leucocephalus*, Plumbeous Redstart *Phoenicurus fuliginosus*), Podicipedidae, Phalacrocoracidae, Rallidae, and Scolopacidae.

NMDS was applied to visualize and compare species composition across seasons using the function 'ordihull' in vegan (Tojo 2015) and the results were presented as two-dimensional plots. The function 'ordihull' creates neat and convex outlines to further depict group segregation for visual clarity (Moskowitz et al. 2020).

We removed species whose frequency of observation was only once. NMDS is an ordination technique that uses rank-order dissimilarity of multivariate data to ordinate sites and species, in which similar communities are placed closer together (Duchardt et al. 2018). To this end, we used Bray-Curtis dissimilarity, which factors in species abundance, using vegan package (Bray & Curtis 1957).

The statistical difference in species composition across seasons was computed by PERMANOVA using 'adonis' function from the vegan package (Oksanen et al. 2020). Subsequently, to evaluate which seasons significantly differed from each other, pairwise 'adonis' function in R with Bonferroni correction was used (Arbizu 2020). Abundance values were square root-transformed to lower the influence of abundant species on rare species prior to executing multivariate analysis method (Zar 2010).

All analyses were performed by using R Statistical Computing Software, version 4.0.2. P <0.05 was considered statistically significant for all analyses.

RESULTS

Sampling adequacy and Species composition

Sampling adequacy was tested based on the number of bird species sighted during the study period, which indicated that an asymptote was not reached. Hence, it is plausible that a greater number of unrecorded bird species might be present at the site (Figure 2).

During a period spanning from November 2021 to October 2022, the present study recorded a total of 7661 individual birds belonging to 80 species, 58 genera, 29 families and 11 orders (Table 1). The greatest number of bird species detected were from order Passeriformes (52.50%) with 42 species, followed by Anseriformes (18.75%) with 15 species, Charadriiformes (7.5%) with six species, Gruiformes (5%) with four species, Pelecaniformes (3.75%) with three species, Accipitriformes, Columbiformes, Coraciiformes, Podicipediformes with two species (2.50%) each, and Bucerotiformes and Suliformes with only one species (1.25%) each.

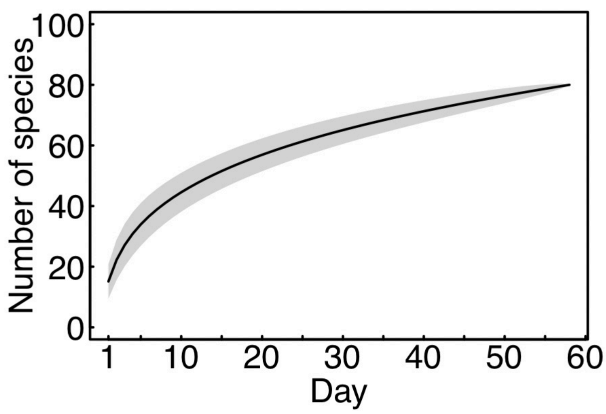


Figure 2. Species accumulation as a function of number of sampling days. The grey shade indicates the 95% confidence interval.

Table 1. Family, order and species recorded from November 2021 to October 2022 from the study site.

Family	Order	Common name	Scientific name
Muscicapidae	Passeriformes Passeriformes Passeriformes Passeriformes Passeriformes Passeriformes Passeriformes Passeriformes	Plumbeous Redstart Hodgson's Redstart Aberrant Bush-warbler White-capped Redstart Slaty-backed Flycatcher Common Stonechat Chestnut-bellied Rock-Thrush Verditer Flycatcher	*Phoenicurus fuliginosus* *Phoenicurus hodgsoni* *Horornis flavolivaceus* *Phoenicurus leucocephalus* *Ficedula erithacus* *Saxicola maurus* *Monticola rufiventris* *Eumyias thalassinus*
Motacillidae	Passeriformes Passeriformes Passeriformes Passeriformes Passeriformes Passeriformes Passeriformes	White Wagtail Olive-backed Pipit White-browed Wagtail Grey Wagtail Water Pipit Rosy Pipit Citrine Wagtail	*Motacilla alba* *Anthus hodgsoni* *Motacilla maderaspatensis* *Motacilla cinerea* *Anthus spinoletta* *Anthus roseatus* *Motacilla citreola*
Leiothrichidae	Passeriformes Passeriformes Passeriformes Passeriformes	Chestnut-crowned Laughingthrush Rufous Sibia Red-billed Leiothrix Chestnut-tailed Minla	*Trochalopteron erythrocephalum* *Heterophasia capistrata* *Leiothrix lutea* *Chrysominla strigula*
Corvidae	Passeriformes Passeriformes	Large-billed Crow House Crow	*Corvus macrorhynchos* *Corvus splendens*
Turdidae	Passeriformes Passeriformes Passeriformes Passeriformes Passeriformes	Blue Whistling-thrush Black-throated Thrush Alpine Thrush White-collared Blackbird Red-throated Thrush	*Myophonus caeruleus* *Turdus atrogularis* *Zoothera mollissima* *Turdus albocinctus* *Turdus ruficollis*
Zosteropidae	Passeriformes Passeriformes	Indian White-eye Whiskered Yuhina	*Zosterops palpebrosus* *Yuhina flavicollis*
Paridae	Passeriformes Passeriformes	Green-backed Tit Coal Tit	*Parus monticolus* *Periparus ater*
Passeridae	Passeriformes Passeriformes	Eurasian Tree Sparrow Russet Sparrow	*Passer montanus* *Passer cinnamomeus*
Phylloscopidae	Passeriformes Passeriformes	Common Chiffchaff Sulphur-bellied Warbler	*Phylloscopus collybita* *Phylloscopus griseolus*
Pycnonotidae	Passeriformes	Himalayan Black Bulbul	*Hypsipetes leucocephalus*
Aegithalidae	Passeriformes	Rufous-fronted Bushtit	*Aegithalos iouschistos*
Cettiidae	Passeriformes	Aberrant Bush Warbler	*Horornis flavolivaceus*
Emberizidae	Passeriformes	Little Bunting	*Emberiza pusilla*
Fringillidae	Passeriformes	Yellow-breasted Greenfinch	*Chloris spinoides*
Cinclidae	Passeriformes	Brown Dipper	*Cinclus pallasii*
Laniidae	Passeriformes	Grey-backed Shrike	*Lanius tephronotus*
Prunellidae	Passeriformes	Rufous-breasted Accentor	*Prunella strophiata*
Anatidae	Anseriformes Anseriformes Anseriformes Anseriformes Anseriformes Anseriformes Anseriformes Anseriformes Anseriformes Anseriformes Anseriformes Anseriformes Anseriformes Anseriformes Anseriformes	Ruddy Shelduck Common Shelduck Common Merganser Mallard Red-crested Pochard Eastern Spot-billed Duck Common Teal Falcated Duck Northern Pintail Northern Shoveler Gadwall Eurasian Wigeon Ferruginous Duck Tufted Duck Garganey	*Tadorna ferruginea* *Tadorna tadorna* *Mergus merganser* *Anas platyrhynchos* *Netta rufina* *Anas zonorhyncha* *Anas crecca* *Mareca falcata* *Anas acuta* *Spatula clypeata* *Mareca Strepera* *Mareca penelope* *Aythya nyroca* *Aythya fuligula* *Spatula querquedula*
Alcedinidae	Coraciiformes Coraciiformes	Crested Kingfisher Common Kingfisher	*Megaceryle lugubris* *Alcedo atthis*
Charadriidae	Charadriiformes Charadriiformes Charadriiformes	River Lapwing Long-billed Plover Grey-headed Lapwing	*Vanellus duvaucelii* *Charadrius placidus* *Vanellus cinereus*
Scolopacidae	Charadriiformes Charadriiformes	Common Sandpiper Green Sandpiper	*Actitis hypoleucos* *Tringa ochropus*

Family	Order	Common name	Scientific name
Ibidorhynchidae	Charadriiformes	Ibisbill	*Ibidorhyncha struthersii*
Columbidae	Columbiformes Columbiformes	Oriental Turtle-dove Rock Pigeon	*Streptopelia orientalis* *Columba livia*
Accipitridae	Accipitriformes Accipitriformes	Long-legged Buzzard Himalayan Buzzard	*Buteo rufinus* *Buteo refectus*
Rallidae	Gruiformes Gruiformes Gruiformes Gruiformes	Eurasian Coot Eurasian Moorhen White-breasted Waterhen Black-tailed Crake	*Fulica atra* *Gallinula chloropus* *Amaurornis phoenicurus* *Zapornia bicolor*
Ardeidae	Pelecaniformes Pelecaniformes Pelecaniformes	Indian Pond-Heron Cattle Egret Little Egret	*Ardeola grayii* *Bubulcus ibis* *Egretta garzetta*
Podicipedidae	Podicipediformes Podicipediformes	Black-necked Grebe Great Crested Grebe	*Podiceps nigricollis* *Podiceps cristatus*
Phalacrocoracidae	Suliformes	Great Cormorant	*Phalacrocorax carbo*
Upupidae	Bucerotiformes	Common Hoopoe	*Upupa epops*

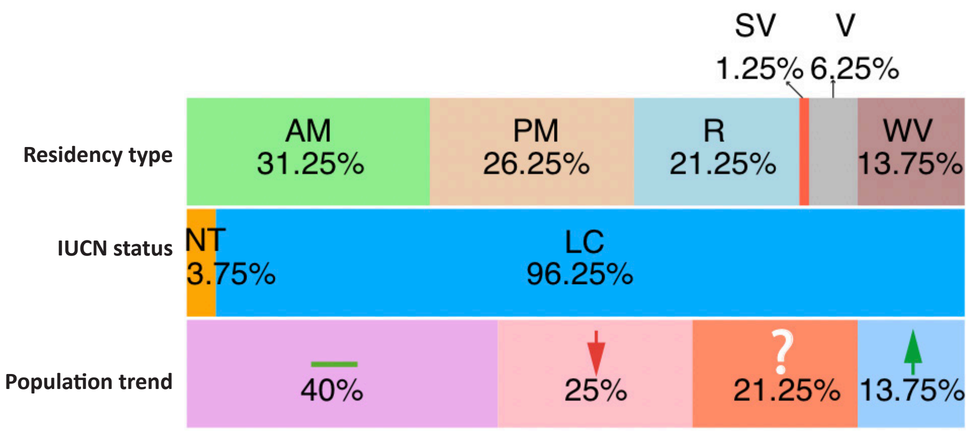


Figure 3. Graph showing residential status, IUCN status and population trend of the species in percentage: AM—Altitudinal Migrant | PM—Passage Migrant | R—Resident | SV—Summer Visitor | V—Vagrant | WV—Winter visitor | NT—Near Threatened | LC—Least Concern. — - Stable | ↓—Decreasing| ?—Unknown| ↑—Increasing.

Global population trends and residential status

Of the 80 recorded bird species, only three birds namely River Lapwing, Falcated Duck, and Ferruginous Duck were 'Near Threatened' species classified based on the IUCN Red List category. The remaining birds were species of 'Least Concern'. Further, the present study found out that sewerage treatment plant hosted 32 species (40%) of birds known to have a stable population trend, 11 increasing (13.75%), 20 decreasing (25%) and 17 (21.25%) unknown on the global population trends as per the IUCN. The study also recorded the residential status of the birds and found 31.25% (AM), 26.25% (PM), 21.25% (R), 1.25% (SV), 6.25% (V), and 13.75% (WV), respectively (Figure 3).

Relative diversity, Bird abundance, and Rank abundance

Table 2 shows the relative diversity of the bird families. Subsequently, Anatidae (15 species, RDi = 18.75) was found to be the most dominant of the total 29 families followed by Muscicapidae (eight species, RDi = 10), Motacillidae (seven species, RDi = 8.75), Turdidae (five species, RDi = 6.25), Leiothrichidae and Rallidae (four species each, RDi = 5), Ardeidae and Charadriidae (three species each, RDi = 3.75), Accipitridae, Alcedinidae, Columbidae, Corvidae, Paridae, Passeridae, Phylloscopidae, Podicipedidae, Scolopacidae and Zosteropidae (two species each, RDi = 2.50). The poorly represented families were Ibidorhynchidae, Aegithalidae, Cettiidae, Cinclidae, Emberizidae, Fringillidae, Laniidae, Phalacrocoracidae, Prunellidae, Pycnonotidae and Upupidae (one species each, RDi =

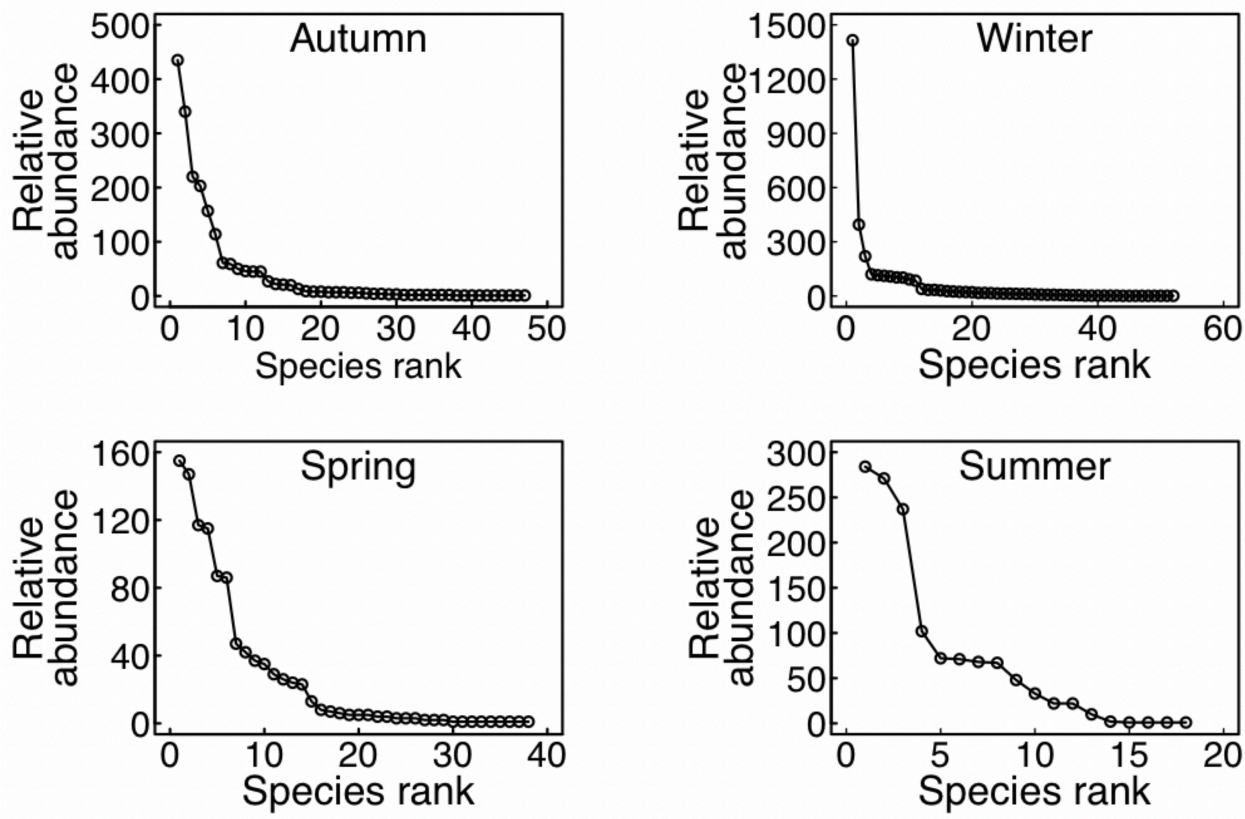


Figure 4. Rank abundance curve for bird species in autumn, winter, spring and summer.

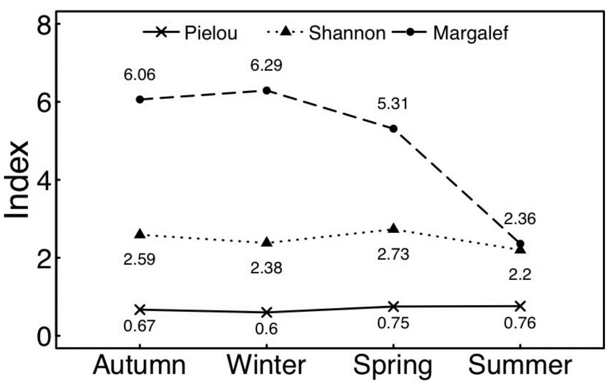


Figure 5. Seasonal variation in Pielou's evenness, Shannon-Weaver diversity index and Margalef's richness index.

1.25). Assessment of the bird abundance showed that three species were VC, eight species (C), 12 species (FC), eight species (UC), 13 (Ra) and 36 species (VR).

The rank-abundance curve had a steep gradient for winter, autumn and spring season, respectively, denoting low evenness of bird species (Figure 4). During winter, Ruddy Shelduck *Tadorna ferruginea* ranked first followed by White Wagtail, Common Merganser *Mergus merganser*, Common Sandpiper *Actitis hypoleucos*, and River Lapwing *Vanellus duvaucelii*. In the autumn season, White Wagtail ranked first followed by Ruddy Shelduck, Oriental Turtle-Dove *Streptopelia orientalis*, River Lapwing, and Common Sandpiper. Spring season had White Wagtail ranked first followed by River Lapwing, Oriental Turtle-Dove, House Crow *Corvus splendens* and Common Sandpiper. By contrast, the curve for summer season was shallower in comparison to the other seasons. Subsequently, summer witnessed higher even distribution of the birds with Oriental Turtle-dove ranked first followed by River Lapwing, White Wagtail, Himalayan Black Bulbul *Hypsipetes leucocephalus* and Eurasian Hoopoe *Upupa epops*. Moreover, the curve length of summer and autumn season are shorter compared to the winter and spring season.

Richness index and Species diversity

Figure 5 shows season-wise Margalef's richness index (R), Shannon-Weaver diversity index (H') and Pileou's evenness index. Winter had the highest species richness (6.29), followed by autumn (6.06), spring (5.31) and summer (2.36), respectively. Similarly, the highest species diversity was recorded for the spring season (2.73), followed by autumn (2.59), winter (2.38) and summer (2.20), respectively. The highest evenness was recorded for summer (0.76), followed by spring (0.75), autumn (0.67) and winter (0.60), respectively.

Feeding guilds of birds and difference between waterbirds and non-waterbirds

Figure 6 shows the abundance of birds in different feeding guilds. A non-parametric Kruskal-Wallis test was carried out to check for statistically significant difference between the guilds. Result revealed that there was no statistically significant difference between the feeding guilds (x^2 = 2.14, df = 3, P = 0.543). However, insectivores were higher (median = 17.0, Q1–Q3 = 1.0–45.0) than granivores (median = 12.0, Q1–Q3 = 8.5–126.5), omnivores (median = 8.5, Q1–Q3 = 1.0–40.25) and carnivores (median = 4.0, Q1–Q3 = 1–7.00).

Likewise, Figure 7 shows the relative abundance of waterbirds and non-waterbirds. A Mann-Whitney test found that there was no statistically significant difference between the relative abundance of waterbirds and non-waterbirds (Z = -0.2769, P = 0.78), although non waterbirds were higher (median = 10.0, Q1 – Q3 = 1–42.50) than the waterbirds (median = 7.0, Q1–Q3 = 2–41.0).

Comparisons of bird species composition across seasons

The NMDS analysis revealed a stress value of 0.146 and suggested a good fit (Clarke & Warwick 2001). The NMDS biplot showed that most bird species overlap occurred between autumn and spring seasons as well as summer and spring, respectively. However, the overlap did not occur between winter and spring, winter and summer as well as between autumn and summer (Figure 8).

To check for statistically significant difference in the bird species composition across seasons, a PERMANOVA test was computed and found that there was a statistically significant difference ($F_{3, 56}$ =16.732, P = 0.001).

Subsequently, pairwise comparisons revealed a statistically significant difference between autumn and winter (R^2 = 0.347, P = 0.006, df = 1), autumn and summer (R^2 = 0.242, P = 0.006, df = 1), autumn and spring (R^2 = 0.148, P = 0.018, df = 1), winter and summer (R^2 = 0.706, P = 0.006, df = 1), winter and spring (R^2 = 0.502, P = 0.006, df = 1) as well as spring and summer (R^2 = 0.197, P = 0.006, df = 1), respectively.

Table 2. The number of species in each avian family and their relative diversity.

Avian families	Number of species	Relative diversity (RDi)
Accipitridae	2	2.50
Aegithalidae	1	1.25
Alcedinidae	2	2.50
Anatidae	15	18.75
Ardeidae	3	3.75
Cettiidae	1	1.25
Charadriidae	3	3.75
Cinclidae	1	1.25
Columbidae	2	2.50
Corvidae	2	2.50
Emberizidae	1	1.25
Fringillidae	1	1.25
Ibidorhynchidae	1	1.25
Laniidae	1	1.25
Leiothrichidae	4	5.00
Motacillidae	7	8.75
Muscicapidae	8	10.00
Paridae	2	2.50
Passeridae	2	2.50
Phalacrocoracidae	1	1.25
Phylloscopidae	2	2.50
Podicipedidae	2	2.50
Prunellidae	1	1.25
Pycnonotidae	1	1.25
Rallidae	4	5.00
Scolopacidae	2	2.50
Turdidae	5	6.25
Upupidae	1	1.25
Zosteropidae	2	2.50

DISCUSSION

To our knowledge, this is the first study that reported on the avifaunal composition concerning species diversity, relative abundance, feeding guilds and temporal variation from the Babesa STP, Bhutan. Despite the rapid urban sprawl over the years, a substantial number of avian species was observed at the study site.

In total, 80 species of birds, representing about 12.05% of the country's total bird species, belonging to 58 genera, 29 families and 11 orders were detected accounting for a total of 7661 individuals. The most notable and the relatively abundant bird species

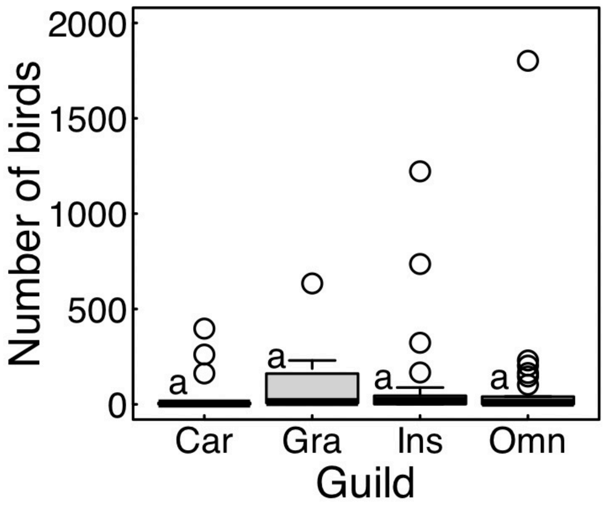


Figure 6. Relative abundance of the birds based on the various feeding guilds. The horizontal black lines in the box indicates the median. The top and bottom edges of each box represent the 75th and 25th percentiles, respectively. The whiskers of the box plot encompass the data within a range of 1.5 times the interquartile range, spanning the upper and lower quartiles. Outliers are indicated by open circles. Identical letters on the box plot signify statistical significance was not found based on non-parametric Kruskal-Wallis test.
Car—Carnivorous | Gra—Granivorous | Ins—Insectivorous | Omn—Omnivorous.

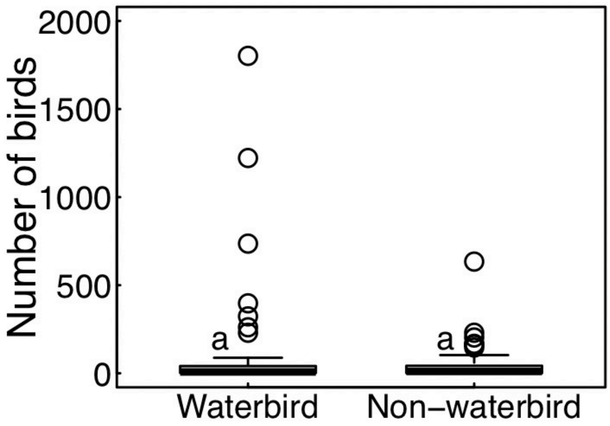


Figure 7. Relative abundance of waterbird and non-waterbird found at the study site. The horizontal black lines in the box indicates the median. The top and bottom edges of each box represent the 75th and 25th percentiles, respectively. The whiskers of the box plot encompass the data within a range of 1.5 times the interquartile range, spanning the upper and lower quartiles. Outliers are indicated by open circles. Identical letters on the box plot signify statistical significance was not found based on non-parametric Mann-Whitney test.

were Ruddy Shelduck (Anatidae), followed by White Wagtail (Motacillidae), River Lapwing (Charadriidae), Oriental Turtle-dove (Columbidae), Plumbeous Redstart (Muscicapidae) and Common Sandpiper (Scolopacidae). The findings imply that the site is relatively rich in avian diversity and richness as evidenced by the detection of birds that belonged to various migration status. Therefore, the Babesa STP holds great potential as a habitat for a diverse population of birds including vagrant, resident and migratory waterbird species.

The family Anatidae, which includes wintering birds such as Ruddy Shelduck, Common Shelduck *Tadorna tadorna*, Common Merganser, Mallard *Anas platyrhynchos*, Red-crested Pochard *Netta rufina*, Eastern Spot-billed Duck *Anas zonorhyncha*, Common Teal *Anas crecca*, Falcated Duck *Mareca falcata*, Northern Pintail *Anas acuta*, Northern Shoveler *Spatulal clypeata*, Gadwall *Mareca Strepera*, Eurasian Wigeon *Mareca penelope*, Ferruginous Duck *Aythya nyroca*, Tufted Duck *Aythya fuligula*, and Garganey *Spatula querquedula*, was found to have the highest RDi value, as previously reported by Tak et al. (2010) and Kumar et al. (2016), which reported a high abundance of the Anatidae family among wetland avifauna communities.

These findings further support the significance of the study site as an important area for avian biodiversity. In the present study, the wintering ducks were mostly seen to inhabit open water and avoided thick vegetation presumably because of limited space and minimal foraging scope (King & Wrubleski 1998; Benoit & Askins 1999).

We observed a large flock of Ruddy Shelduck foraging, resting and roosting at the study site. We also observed Common Merganser foraging in the treatment plant twice. Some conceivable reasons for the substantial number of wintering ducks could be the availability of food resources and size of the wetland (Afdhal et al. 2012; Murray 2014), minimal interference, physical features of wetland habitats (Chatterjee et al. 2020), lack of hunting zones and predators (Kloskowski et al. 2009) at the study site. However, we cannot dismiss the role that the fresh water ecosystem might have played in attracting these birds, especially Ruddy Shelduck, given its close proximity to the STP, or vice versa, as we observed them shuttling between the two during our field visits.

Further, high invertebrate production has also been suggested as one of the key drivers for the occurrence and abundance of waterbirds (Augustin et al. 1999), which could have provided favorable foraging opportunities. Similarly, shorebirds and waders such as Common Sandpiper, Green Sandpiper *Tringa ochropus*, River Lapwing, Grey-headed Lapwing *Vanellus cinereus* and Long-billed Plover *Charadrius placidus* were seen confined to the edges of the STP and on the banks either

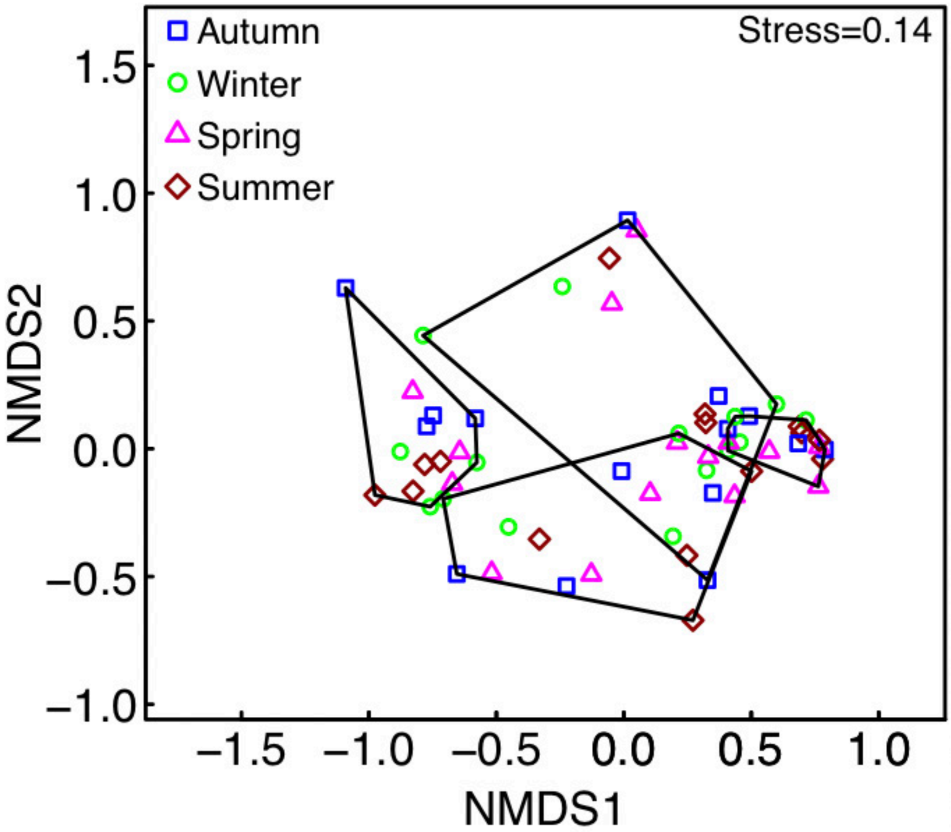


Figure 8. Non-metric multidimensional scaling (NMDS) plot showing dissimilarity in bird species composition across autumn, winter, spring and summer based on the Bray-Curtis dissimilarity matrix of species abundance data with square root transformation. Stress = 0.14.

resting or exploring food resources such as insects, invertebrates, worms and seeds.

The aforementioned findings are in congruence with previous literatures (Muhammad et al. 2018; Luo et al. 2019; Holbech & Cobbinah 2021). Taken together, the results highlights that the Babesa STP is a critical stopover ground and wintering site for many migratory birds which spends as long as six months at the site prior to their summer migration. Perhaps, artificial wetlands have been acknowledged as important migration routes for numerous diving ducks (Kennedy & Mayer 2002). Altogether, that the artificial wetlands hold potential value and can be of importance for migratory waterbird species was reported by Giosa et al. (2018).

Moreover, three 'Near Threatened' waterbird species, namely River Lapwing, Falcated Duck, and Ferruginous Duck, occurred at the study site. The River Lapwing occurred throughout the study period while the Falcated and Ferruginous ducks occurred only during winter (February) and spring (March) months. This indicates that constructed wetlands such as Babesa STP play an indispensable role in conservation and provide important sanctuaries even for threatened species.

Regarding the non-waterbirds, the richness and diversity could be attributed to resources, surrounding habitat and cover along with availability of food (van Biervliet et al. 2020). Indeed, on many occasions we observed non-waterbirds, especially Grey-backed Shrike *Lanius tephronotus* and Common Stonechat *Saxicola maurus*, feed on insects, seeds and fruits, and Eurasian Hoopoe *Upupa epops* forage on edges of the STP as it afforded easy availability of prey.

Likewise, availability of the trees and plants within the vicinity of the study site could have been central to their large assemblages because we observed many of them roost on the branches of the trees and plants. Consistent with this, plant diversity has been shown to exert a positive influence on the bird richness and diversity (Fontana et al. 2011) as it affords microhabitats for roosting, nesting and feeding (Canterbury et al. 1999; Soderstrom & Part 1999).

Interestingly, despite the large avian assemblage there was not any statistically significant difference observed between non-waterbirds and waterbirds, which implies that it might afford a suitable habitat for a large number of avian species. The presence of vegetation for roosting and nesting, open water for foraging and swimming as well as the large occurrence of food resources makes the site attractive for the birds. Taken together, the findings suggest that the study site may function as an important ecological niche for various bird species, including both waterbirds and non-waterbirds.

In contrast, the current study observed statistically significant difference in bird composition between the seasons, in agreement with the findings of Kopij & Paxton (2018). Particularly, the largest differences in bird composition were observed between winter and summer, and between winter and spring. These findings indicate that the dissimilarities in bird compositions across seasons are particularly conspicuous between the dry and monsoon seasons, as well as between the dry and pre-monsoon seasons.

Further, spring and autumn were found to have the highest avian diversity while winter and autumn had the highest species richness compared to spring and summer, respectively. This may be due to seasonal changes in food and resource availability, competition among related species, and predator avoidance strategies (Morin 2011), which may lead to birds utilizing different food sources that vary in quantity and accessibility over time. Additionally, the allocation of resources over time may aid in the coexistence of avian species by allowing for the exploitation of shared resources at different times (Kopij & Paxton 2018). Also, variations in the population and peak abundance of birds across seasons may suggest the migratory patterns of the birds and reveal the direction of migration (Nisbet 1957).

With regard to the feeding guilds, there was no statistically significant difference between the guilds. This statistically insignificant result may be due to the occurrence of a variety of shrubs, flowering trees and diverse array of diets such as fishes, amphibians, reptiles, mammals, and aquatic invertebrates resulting from a large fertility of sewerage treatment plant (Rajpar & Zakaria 2013; Mukhopadhyay & Mazumdar 2019) culminating in the attraction of different guilds. The diversity of feeding guild observed among birds in the vicinity of the study site certainly suggests that it may be an important avian habitat to support various foraging behaviors.

CONCLUSION

Overall, the present study provides a comprehensive assessment of the avian biodiversity present at the Babesa STP. The results reveal that the site harbors a great variety of bird species, including vagrant, resident and migrant birds as well as birds of various feeding guilds. These findings are particularly remarkable given the relatively small size of the study site. Additionally, the findings also underscore the ecological significance of man-made habitats in reinforcing biodiversity, since such ancillary habitats can afford crucial resources and support for a diverse array of species, and act as winter sojourn for migratory birds.

In light of the findings of this study, it is recommended that concerned authorities and policymakers take further action to safeguard the site as it is important for bird conservation. For instance, a valuable intervention measure for the area may be fencing to keep away potential predators such as stray dogs, which are quite common in the area. Additionally, certain points may be identified as photography spots to minimize human-induced disturbance to the birds. Otherwise, apart from serving as a suitable area for recreation, bird watching and scientific study, the site can also be a great source of educational opportunities for students, teachers, and the general public interested in learning about the features and importance of constructed wetlands in sustaining wildlife habitats and biodiversity (Semeraro et al. 2015). Further research is warranted, especially concerning the underlying factors that trigger large assemblages of birds at the site.

REFERENCES

Afdhal, B., F. Charfi-Cheikhrouha & A. Moali (2012). Tunisian man-made wetlands as alternative habitats for waterbirds and their role for conservation. *African Journal of Ecology* 51(1): 154–163. https://doi.org/10.1111/aje.12022

Airoldi, L., D. Balata & M.W. Beck (2008). The Gray Zone: relationships between habitat loss and marine diversity and their applications in conservation. *Journal of Experimental Marine Biology and Ecology* 366(1–2): 8–15. https://doi.org/10.1016/j.jembe.2008.07.034

Akinnifesi, F.K., G.W. Sileshi, O.C. Ajayi, A.I. Akinnifesi, E.G. de Moura, J.F. Linhares & I. Rodrigues (2010). Biodiversity of the urban homegardens of São Luís city, Northeastern Brazil. *Urban Ecosystems* 13(1): 129–146. https://doi.org/10.1007/s11252-009-0108-9

Alerstam, T., A. Hedenström & S. Åkesson (2003). Long-distance migration: evolution and determinants. *Oikos* 103(2): 247–60. https://doi.org/10.1034/j.1600-0706.2003.12559.x

Ali, S., B. Biswa & S.D. Ripley (1996). *Birds of Bhutan, Records of Zoological Survey India. Occasional Paper No.* 136, 207 pp.

Ali, S. & S.D. Ripley (1987). *Compact handbook of the birds of India and Pakistan together with those of Nepal, Sikkim, Bhutan, Bangladesh and Srilanka, 2nd edition.* Oxford University Press, Delhi, 737 pp.

Arbizu, M. (2020). pairwiseAdonis: Pairwise multilevel comparison using Adonis. R package version 0.4. https://github.com/pmartinezarbizu/pairwiseAdonis

Attuquayefio, D.K. & F. Gbogbo (2001). Prospects of conserving wetlands along the Mukwe Lagoon at Nungua in the Greater Accra Region of Ghana. *West African Journal of Applied Ecology* 2(1): 65–75.

Augustin, J.C., J.W. Grubaugh & M.R. Marshal (1999). Validating macroinvertebrate assumptions of the shorebird management model for the lower Mississippi Valley. *Wildlife Society Bulletin* 27: 552–558.

Benoit, L.K. & R.A. Askins (1999). Impact of the spread of Phragmites on the distribution of birds in Connecticut tidal marshes. *Wetlands* 19: 194–208. https://doi.org/10.1007/BF03161749

Bray, J.R. & J.T. Curtis (1957). An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs* 27: 325–349.

Breed, W.G., J.H. Hatch, C. Rogers, W. Brooker, A.C. Breed, M.H. Marklund, H. Roberts & M.F. Breed (2020). Bolivar Wastewater Treatment Plant provides an important habitat for South Australian ducks and waders. *Australian Field Ornithology* 37: 190–9. https://dx.doi.org/10.20938/afo37190199

Bull, J. (1974). *Birds of New York State*. Published by Doubleday/ Natural History Press. Edited by Emanuel Levine (1985). Cornell University Press, 622 pp.

Canterbury, G.E., T.E. Martin, D.R. Petit, L.J. Petot & D.F. Branford (1999). Bird communities and habitat as ecological indicators of forest condition in regional monitoring. *Conservation Biology* 14: 544–558. https://doi.org/10.1046/j.1523-1739.2000.98235.x

Catry, T., J.P. Granadeiro, J.S. Gutiérrez & E. Correia (2022). Stopover use of a large estuarine wetland by dunlins during spring and autumn migrations: Linking local refuelling conditions to migratory strategies. *Plos One* 17(1): e0263031. https://doi.org/10.1371/journal.pone.0263031

Chatterjee, A., S. Adhikari, S. Pal & S.K. Mukhopadhyay (2020). Foraging guild structure and niche characteristics of waterbirds wintering in selected sub-Himalayan wetlands of India. *Ecological Indicator* 108: 105693. https://doi.org/10.1016/j.ecolind.2019.105693

Clarke, K.R. & R.M. Warwick (2001). *Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition.* Primer-e Ltd, Plymouth Marine Laboratory, Plymouth, UK, 68 pp.

Chiarucci, A., G. Bacaro, D. Rocchini & L. Fattorini (2008). Discovering and rediscovering the sample-based rarefaction formula in the ecological literature. *Community Ecology* 9(1): 121–123. https://doi.org/10.1556/ComEc.9.2008.1.14

Dendup, P., L. Wangdi, Y. Jamtsho, P. Kuenzang, D. Gyeltshen, T. Tashi, U. Rigzin, Y. Jamtsho, R. Dorji, R. Dorji, Y. Jamtsho, C. Lham & B. Tshering (2021). Bird diversity and conservation threats in Jigme Dorji National Park, Bhutan. *Global Ecology and Conservation* 30: e01771. https://doi.org/10.1016/j.gecco.2021.e01771

Donahue, M.W. (2006). Bird records from south western Virginia Roanoke sewage treatment plant. *Banisteria* 28: 26–36.

Duchardt, C.J., L.M. Porensky, D.J. Augustine & J.L. Beck (2018). Disturbance shapes avian communities on a grassland–sagebrush ecotone. *Ecosphere* 9(10): e02483. https://doi.org/10.1002/ecs2.2483

Engle, V.D. (2011). Estimating the provision of ecosystem services by Gulf of Mexico coastal wetlands. *Wetlands* 31: 179–193. https://doi.org/10.1007/s13157-010-0132-9

Fontana, S., T. Sattler, F. Bontadina & M. Moretti (2011). How to manage the urban green to improve bird diversity and community structure. *Landscape and Urban Planning* 101(3): 278–285. https://doi.org/10.1016/j.landurbplan.2011.02.033

Feijen, C. & H.R. Feijen (2008). A review of the breeding birds of Bhutan. *Forktail* 24: 1–24.

Forcey, G.M., W.E. Thogmartin, G.M. Linz, W.J. Bleier & P.C. McKann (2011). Land use and climate influences on waterbirds in the Prairie Potholes. *Journal of Biogeography* 38(9): 1694–707. https://doi.org/10.1111/j.1365-2699.2011.02510.x

Gbogbo, F. (2007). The importance of unmanaged coastal wetlands to waterbirds at coastal Ghana. *African Journal of Ecology* 45(4): 599–606. https://doi.org/10.1111/j.1365-2028.2007.00778.x

Giosa, E., C. Mammides & S. Zotos (2018). The importance of artificial wetlands for birds: A case study from Cyprus. *PLoS One* 13(5): e0197286. https://doi.org/10.1371/journal. pone.0197286

Grimmett, R., C. Inskipp, T. Inskipp & Sherub (2019). *Birds of Bhutan and the Eastern Himalayas.* Bloomsbury publishing, London, 416 pp.

Gyeltshen, P., C. Norbu & K. Rinchen (2020). Avifauna found in the State Reserved Forest Land of Trongsa district, Bhutan. *Bhutan Journal of Natural Resources and Development* 7(1): 18–18.

Hamilton, A.J., W. Robinson, I.R. Taylor & B.P. Wilson (2005). The ecology of sewage treatment gradients in relation to their use by waterbirds. *Hydrobiologia* 534: 91–108. https://doi.org/10.1007/s10750-004-1415-z

Hansson, L.A., C. Bronmark, P. Anders Nilsson & K. Abjornsson (2005). Conflicting demands on wetland ecosystem services: nutrient retention, biodiversity, or both? *Freshwater Biology* 50(4): 705–714. https://doi.org/10.1111/j.1365-2427.2005.01352.x

Harebottle, D.M., A.J. Williams, Y. Weiss & G.B. Tong (2008). Waterbirds at Paarl waste water treatment works, South Africa, 1994–2004: seasonality, trends and conservation importance. *Ostrich* 79(2): 147–63. https://doi.org/10.2989/OSTRICH.2008.79.2.4.578

Holbech, L.H. & C.C. Cobbinah (2021). Pollution or protection - what early survey data shows on rapid waterbird utilisation of a newly established sewage treatment plant in Urban Ghana, West Africa. *Wetlands* 41(8): 110. https://doi.org/10.1007/s13157-021-01510-w

Hsu, C.B., H.L. Hsieh, L. Yang, S.H. Wu, J.S. Chang, S.C. Hsiao, H.C. Su, C.H. Yeh, Y.S. Ho & H.J. Lin (2011). Biodiversity of constructed wetlands for wastewater treatment. *Ecological Engineering* 37(10): 1533–45. https://doi.org/10.1016/j.ecoleng.2011.06.002

Hutto, R.L., S.M. Pletschet & P. Hendricks (1986). A fixed-radius point count method for nonbreeding and breeding season use. *The Auk* 103(3): 593–602. https://doi.org/10.1093/auk/103.3.593

Ibrahim, I. & N.A. Aziz (2012). The roles of international NGOs in the conservation of bio-diversity of wetlands. *Procedia—Social and Behavioral Sciences* 42: 242–247. https://doi.org/10.1016/j.sbspro.2012.04.187

IUCN (2022). The IUCN Red List of Threatened Species. Version 2022-2. Downloaded from http://www.iucnredlist.org. Accessed on 25 March 2022.

Kalejta-Summers, B., M. McCarthy & L.G. Underhill (2001). Long-term trends, seasonal abundance and energy consumption of waterbirds at Strandfontein, Western Cape, South Africa, 1953–1993. *Ostrich* 72(1–2): 80–95. https://doi.org/10.2989/00306520109485290

Kedleck, R.H. & S.D. Wallace (2008). *Treatment Wetlands, 2nd edition.* CRC Press, Boca Raton, FL, 965 pp.

Kennedy, G. & T. Mayer (2002). Natural and constructed wetlands in Canada: An overview. *Water Quality Research Journal* 37(2): 295–325. https://doi.org/10.2166/wqrj.2002.020

King, R.S. & D.A. Wrubleski (1998). Spatial and diet availability of flying insects as potential duckling food in prairie wetlands. *Wetlands* 18: 100–114. https://doi.org/10.1007/BF03161448

Kloskowski, J., A.J. Green, M. Polak, J. Bustamante & J. Krogulec (2009). Complementary use of natural and artificial wetlands by waterbirds wintering in Doñana, south-west Spain. *Aquatic Conservation: Marine and Freshwater Ecosystems* 19(7): 815–26. https://doi.org/10.1002/aqc.1027

Kopij, G. & M. Paxton (2018). Seasonal changes in the diversity and numbers of waterbirds in a tropical river in Southern Africa. *Polish Journal of Ecology* 66(3): 257–269. https://doi.org/10.3161/15052249PJE2018.66.3.006

Kumar, P., D. Rai & S.K. Gupta (2016). Wetland bird assemblage in rural ponds of Kurukshetra, India. *Waterbirds* 39 (1): 86–98. https://doi.org/10.1675/063.039.0111

Kumar, P. & A. Sharma (2018). Diversity and status of avifauna in man-made sacred ponds of Kurukshetra, India. *Journal of*

Threatened Taxa 10(9): 12173–12193. https://doi.org/10.11609/jot.3729.10.9.12173-12193

La Torre-Cuadros, M.D., S. Herrando-Perez & K.R. Young (2007). Diversity and structural patterns for tropical montane and premontane forests of central Peru, with an assessment of the use of higher-taxon surrogacy. *Biodiversity and Conservation* 16: 2965–2988. https://doi.org/10.1007/s10531-007-9155-9

Lawler, S.P. (2001). Rice fields as temporary wetlands: a review. *Israel Journal of Zoology* 47(4): 513–528. https://doi.org/10.1560/X7K3-9JG8-MH2J-XGX1

Li, D., S. Chen, H.U. Lloyd, S. Zhu, K.A. Shan & Z. Zhang (2013). The importance of artificial habitats to migratory waterbirds within a natural/artificial wetland mosaic, Yellow River Delta, China. *Bird Conservation International* 23(2): 184–98. https://doi.org/10.1017/S0959270913000099

Liu, L., X. Liu, C. Du, H. Fang, J. Zhang, W. Li, L. Cao & L. Gao (2022). Spring diet and energy intake of Whooper Swans (*Cygnus cygnus*) at the Yellow River National Wetland in Baotou, China. *Plos one* 17(2):e0264528. https://doi.org/10.1371/journal.pone.0264528

Luo, K., Z. Wu, H. Bai & Z. Wang (2019). Bird diversity and waterbird habitat preferences in relation to wetland restoration at Dianchi Lake, south-west China. *Avian Research* 10(1): 1–12. https://doi.org/10.1186/s40657-019-0162-9

Ma, Z., Y. Wang, X. Gan, B. Li, Y. Cai & J. Chen (2009). Waterbird population changes in the wetlands at Chongming Dongtan in the Yangtze River estuary, China. *Environmental Management* 43: 1187–200. https://doi.org/10.1007/s00267-008-9247-7

Margalef, R. (1968). *Perspectives in ecological theory.* University of Chicago Press, Chicago. 107pp.

Mazumdar, S., K. Mookherjee & G.K. Saha (2007). Migratory waterbirds of wetlands of southern West Bengal, India. *Indian Birds* 3(2): 42–55.

Mitsch, W.J. & J.G. Gosselink (2015). *Wetlands, 5th edition.* John Wiley and Sons, New York, 721 pp.

Molur, S., K.G. Smith, B.A. Daniel & W.R.T. Darwall (2011). The Status and Distribution of Freshwater Biodiversity in the Western Ghats, India*.* Cambridge, UK, IUCN, Gland, Switzerland & Zoo Outreach Organization, Coimbatore, India, 116 pp.

Morin, P.J. (2011). *Habitat selection. Community ecology. 2nd edition.* Wiley, Chichester, 250 pp.

Moskowitz, N.A., B. Dorritie, T. Fay, O.C. Nieves, C. Vidoudez, C.R. 2017 Biology Class, M. 2017 Biotechnology Class, E.K. Fischer, S.A. Trauger, L.A. Coloma & D.A. Donoso (2020). Land use impacts poison frog chemical defenses through changes in leaf litter ant communities. *Neotropical Biodiversity* 6(1): 75–87. https://doi.org/10.1080/23766808.2020.1744957

Muhammad, S.I., R. Ramli & A.Y. Then (2018). Seasonality, habitat type and locality influenced bird assemblage structure in Nigeria. *Ostrich* 89(3): 221–31. https://doi.org/10.2989/00306525.2018.1425927

Mukhopadhyay, S. & S. Mazumdar (2019). Habitat-wise composition and foraging guilds of avian community in a suburban landscape of lower Gangetic plains, West Bengal, India. *Biologia* 74(8): 1001–10. https://doi.org/10.2478/s11756-019-00226-x

Murray, C.G. & A.J. Hamilton (2010). Perspectives on wastewater treatment wetlands and waterbird conservation. *Journal of Applied Ecology* 47(5): 976–985. https://doi.org/10.1111/j.1365-2664.2010.01853.x

Murray, C.G., S. Kasel, E. Szantyr, R. Barratt & A.J. Hamilton (2014). Waterbird use of different treatment stages in waste-stabilization pond systems. *Emu* 114(1): 30–40. https://doi.org/10.1071/MU12121

NCHM (2013). The National Center for Weather, Climate and Water Resources. Royal Government of Bhutan. Accessed on Date 25 November 2022. http://www.hydromet.gov.bt/?q=13

Nima & U. Dorji (2022). Waterbird assemblage along Punatsangchhu River, Punakha and Wangdue Phodrang, Bhutan. *Journal of Threatened Taxa* 14(6): 21179–21189. https://doi.org/10.11609/jott.7681.14.6.21179-21189

Nisbet, I.C.T. (1957). Wader migration at Cambridge sewage farm. *Bird Study* 4(3): 131–148. https://doi.org/10.1080/00063655709475882

Norbu, L., P. Thinley, T. Wangchuck, U. Dechen, L. Dorji, T. Choephel & P. Dorji (2021). On the high bird diversity in the non-protected regions of Trashiyangtse District in Bhutan. *Journal of Threatened Taxa* 13(9): 19274–19292. https://doi.org/10.11609/jott.6843.13.9.19274-19292

Oksanen, J., F. Guillaume, R.K. Blanchet, P. Legendre, P.R. Minchin, R.B. O'Hara, G.L. Simpson, P.M. Solymos, H. Henry & H.W. Stevens (2019). Package 'vegan.' R package version 3.4.0.

Oksanen, J., F.G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P.R. Minchin, R.B.O'Hara, G.L.Simpson, P.Solymos, M.H.H. Stevens, E. Szöcs & H.H. Wagner (2020). Vegan: community ecology package (R package version 2.5-7). https://cran. r-project.org/web/packages/vegan/index.html

Orlowski, G. (2013). Factors affecting the use of waste-stabilization ponds by birds: A case study of conservation implications of a sewage farm in Europe. *Ecological engineering* 61: 436–45. https://doi.org/10.1016/j.ecoleng.2013.09.061

Passang (2018). Diversity of Waterbirds Along Bindu River of Tashi Chhoeling (Samtse), Bhutan. *Journal of the Bhutan Ecological Society* 3: 45–55.

Phuntsho, S., H.K. Shon, S. Vigneswaran, H.H. Ngo, J. Kandasamy & P. Dorji (2016). Performance of Waste Stabilization Ponds: Experience from cold climatic conditions of Bhutan. *Journal of Water Sustainability* 6(1): 1. https://doi.org/10.11912/jws.2016.6.1.1-16

Pielou, E.C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology* 13: 131-144. https://doi.org/10.1016/0022-5193(66)90013-0

R Development Core Team (2021). R: a language and environment for statistical computing. R Foundation for Statistical Computing version 4.0.2, Vienna, Austria. https://www.R-project.org/

Rajpar, M.N. (2010). Avifauna composition and its habitat in freshwater wetland ecosystem Malaysia. Ph.D. Thesis, Faculty of Forestry, Universiti Putra Malaysia, Serdang, Selangor, Malaysia.

Rajpar, M.N. & M. Zakaria (2013). Assessing an artificial wetland in Putrajaya, Malaysia, as an alternate habitat for waterbirds. *Waterbirds* 36(4): 482–493. https://doi.org/10.1675/063.036.0405

Rendon, M.A., A.J. Green, E. Aguilera & P. Almaraz (2008). Status, distribution and long-term changes in the waterbird community wintering in Doñana, south–west Spain. *Biological Conservation.* 141(5): 1371–88. https://doi.org/10.1016/j.biocon.2008.03.006

Salewski, V., F. Bairlein & B. Leisler (2003). Niche partitioning of two Palearctic passerine migrants with Afrotropical residents in their West African winter quarters. *Behavioral Ecology* 14(4): 493–502. https://doi.org/10.1093/beheco/arg021

Sebastián-González, E., J.A. Sańchez-Zapata & F. Botella (2010). Agricultural ponds as alternative habitat for waterbirds: spatial and temporal patterns of abundance and management strategies. *European Journal of Wildlife Research* 56: 11–20. https://doi.org/10.1007/s10344-009-0288-x

Semeraro, T., C. Giannuzzi, L. Beccarisi, R. Aretano, A. De Marco, M.R. Pasimeni, G. Zurlini & I. Petrosillo (2015). A constructed treatment wetland as an opportunity to enhance biodiversity and ecosystem services. *Ecological Engineering* 82: 517–26. https://doi.org/10.1016/j.ecoleng.2015.05.042

Shannon, C.E. & W. Weaver (1949). *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, Illinois, 125 pp.

Singh, J., S. Antil, V. Goyal & V. Malik (2020). Avifaunal diversity of Tilyar Lake, Rohtak, Haryana, India. *Journal of Threatened Taxa* 12(8): 15909–15915. https://doi.org/10.11609/jott.4700.12.8.15909-15915

Soderquist, P., L. Dessborn, H. Djerf, J. Elmberg, G. Gunnarsson & S. Holopainen (2021). Effects of released farmed mallards on species richness of breeding waterbirds and amphibians in natural, restored and constructed wetlands. *Wildlife Biology* 2021(3): wlb-00846. https://doi.org/10.2981/wlb.00846

Soderstrom, B.O. & T. Part (1999). Influence of landscape scale on farmland birds breeding in semi-natural pastures. *Conservation*

Biology 14(2): 522–533. https://doi.org/10.1046/j.1523-1739.2000.98564.x

Tak, P.C., J.P. Sati & A.N. Rizvi (2010). Status of waterbirds at Hathnikund Barrage wetland, Yamunanagar District, Haryana, India. *Journal of Threatened Taxa* 2(4): 841–844. https://doi.org/10.11609/JoTT.o2200.841-4

Tiéga, A. (2011). Ramsar Convention on Wetlands: 40 Years of Biodiversity Conservation and Wise Use. *Journal of International Wildlife Law & Policy* 14(3–4): 173–175. https://doi.org/10.1080/13880292.2011.626686

Tojo, H. (2015). Seasonality of the bird community in the Ogawa Forest Reserve, an old-growth deciduous forest in central Japan. *Ornithological Science* 14(2): 79–88. https://doi.org/10.2326/osj.14.79

van Biervliet, O., R.J. McInnes, J. Lewis-Phillips & J. Tosney (2020). Can an integrated constructed wetland in Norfolk reduce nutrient concentrations and promote in situ bird species richness? *Wetlands* 40(5): 967–981. https://doi.org/10.1007/s13157-019-01247-7

Vymazal, J. (2010). Constructed wetlands for wastewater treatments. *Water* 2(3): 530–549. https://doi.org/10.3390/w2030530

Wang, X., F. Kuang, K. Tan & Z. Ma (2018). Population trends, threats, and conservation recommendations for waterbirds in China. *Avian Research* 9: 1–3. https://doi.org/10.1186/s40657-018-0106-9

Webb, E.B., L.M. Smith, M.P. Vrtiska & T.G. Lagrange (2010). Effects of local and landscape variables on wetland bird habitat use during migration through the Rainwater Basin. *The Journal of Wildlife Management* 74(1): 109–19. https://doi.org/10.2193/2008-577

Zar, J.H. (2010). *Biostatistical analysis, 5th edn.* Pearson Prentice Hall, Upper Sadle River, 931 pp.

Zedler, J.B. & S. Kercher (2005). Wetland resources: status, trends, ecosystem services, and restorability. *Annual Review of Environment and Resources* 30: 39–74. https://doi.org/10.1146/annurev.energy.30.050504.144248

Journal of Threatened Taxa is indexed/abstracted in Bibliography of Systematic Mycology, Biological Abstracts, BIOSIS Previews, CAB Abstracts, EBSCO, Google Scholar, Index Copernicus, Index Fungorum, JournalSeek, National Academy of Agricultural Sciences, NewJour, OCLC WorldCat, SCOPUS, Stanford University Libraries, Virtual Library of Biology, Zoological Records.

NAAS rating (India) 5.64

Print copies of the Journal are available at cost. Write to:
The Managing Editor, JoTT,
c/o Wildlife Information Liaison Development Society,
43/2 Varadarajulu Nagar, 5th Street West, Ganapathy, Coimbatore,
Tamil Nadu 641006, India
ravi@threatenedtaxa.org

OPEN ACCESS

www.threatenedtaxa.org

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

July 2023 | Vol. 15 | No. 7 | Pages: 23463–23630
Date of Publication: 26 July 2023 (Online & Print)
DOI: 10.11609/jott.2023.15.7.23463-23630

Articles

Communications

Short Communications

Notes

Publisher & Host

WILD
ZOOREACH
Threatened Taxa