ECOLOGICAL STUDIES ON MIGRATORY WATERBIRD COMMUNITY WINTERING IN SELECTED WETLANDS WITH SPECIAL REFERENCE TO ECOSYSTEM SERVICES.

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By

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CERTIFICATE FROM THE SUPERVISORS

This is to certify that the thesis entitled "Ecological Studies on Migratory Waterbird Community Wintering in Selected Wetlands with Special Reference to Ecosystem Services" **submitted by Sri** ARKAJYOTI MUKHERJEE **who got his name registered on 26.08.2019 for the award of Ph. D. (Science) degree of Jadavpur University, is absolutely based upon his own work under the supervision of Dr. Papita Das and Dr. Subhra Kumar Mukhopadhyay and that neither this thesis nor any part of it has been submitted for either any degree / diploma or any other academic award anywhere before.**

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Declaration

This is to declare that the work is entirely my own and not of any other people, unless explicitly acknowledged (including citation of published and unpublished sources) for a specified portion. The work has not been previously submitted in any form to the Jadavpur University or to any other institution/college for assessment for any reason.

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The present PhD dissertation is dedicated to

My family,

Dr. Subhra Kumar Mukhopadhyay,

Dr. Utpal Singha Roy

&

Dr. Sudin Pal

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Preface

Waterbirds unveil noticeable and evocative rejoinders to the changing environment around them. Species diversity attributes are tell-tale of habitat changes and have been used as an important bio-indicator. Therefore, regular monitoring of waterbird populations is essential to make conservation decisions and strategies. Presently, waterbirds in developing countries are facing two-prong challenges: unrestrained urbanization and climate perturbation throughout the globe. In India, we sadly notice that many endangered waterbird species richness or abundance or both are declining alarmingly on spatial and temporal scales. The shapes, depth and sizes of the water-spread area at the habitat level are significant to waterbird diversity; the intensity of urbanization and landscape changes are important factors that require regular monitoring as the urban waters can support healthy waterbird communities if managed correctly. With the turn of the next two decades, some of the species that suffer from changing climatic features and habitat alterations may go extinct if their populations are not sincerely monitored, and accordingly, their habitats are not conserved.

Artificial wetlands could very well be an alternative solution to compensate natural habitat crunch; ironically, we hardly have species-wise comprehensive data on the waterbird habitat uses, species-species and species-environment interactions to make the artificial wetland habitats a successful wintering ground for migratory species or year-long profitable patch for resident waterbirds and water-dependent birds. Waterbirds are not only sensitive to environmental changes they are, as mentioned earlier, important ecological indications of the available profitable microhabitats and foraging resources and, thereby, good indicators of ecosystem health. A variety of functional roles are performed by these waterbirds; understanding the long-term patterns of richness and abundance would be *important in the context of conservation management. The shapes, depth and sizes of the water-spread area at the habitat level are significant to waterbird diversity; the intensity of urbanization and landscape changes are important factors that require regular monitoring as the urban waters can support healthy waterbird communities if managed correctly.*

Several wetlands of the West Bengal, that occupy both Central Asian and East Asian-Australian Flyways, shelter waterbirds in hundred thousand; waterbirds are known to be vectors and alien species are often dispersed by the visiting winged guests in a variety of mechanisms. They have a vital role in spreading aliens around once they get there. Regular monitoring of the resident and migrant waterbird species should gain greater focus in future research because of the role of waterbird vectors if the management of invasions is to be effective.

It may be highlighted that only recently bird watching, especially in the context of digital bird photography, has got new momentum; at least these photographs are providing us with indirect information regarding local populations, gainful wintering grounds, changes in migration time, and population sizes. However, only a few serious pieces of research are on record that focus on the biology and ecology of waterbirds to be important to formulate conservation strategies in India. It is high time to encourage local young scientists to come forward to prepare themselves with specialized technical knowledge and expertise on international-standard field-study techniques; the data set of present research outcome and the publications would surely provide important information to future workers. This work would also provide an important launching dais for proper planning to conserve the important wintering wetland habitats of West Bengal. The work also highlights the importance of sustained attention of the government and local authorities to make the conservation effort a success.

LIST OF ABBREVIATIONS

Abbreviation	Full form
CAF	Central Asian Flyway
EAAF	East Asian-Australasian Flyway
H/	Shannon–Wiener diversity index
DSIPM	Simpson's dominance index
J/	Pielou's evenness index
DMARG	Margalef's richness index
AAS	Atomic Absorption Spectrometer
I_{df}	Daily food consumption rate
I_w	Daily water consumption rate
BW	Body weight
I_S	Food-associated sediment consumption rate
E_j	Oral exposure dose
TDI	Total daily intake
HQ	Hazard quotient
HI	Hazard index
BAF	Bioaccumulation factor
WT	Water temperature
TDS	Total dissolved solid
EC	Electrical conductance
NL	Nutrient loading
GL	Guano loading
DFP	Daily faecal-matter production rate
DWFV	Deep water with floating vegetation
DWCS	Deep water with a clear surface
SWFV	Shallow water with floating vegetation
SWCS	Shallow water with a clear surface
SLHV	Shoreline with hydrophytic vegetation
DI	Diving
UP	Upending
BD	Beak-dip
HD	Head-dip
ND	Neck-dip
FI	Filtering
PI	Picking
GR	Grazing
B	Foraging Niche Breadth
CCA	Canonical correspondence analysis

RCPO	Red-crested pochard
NOPI	Northern pintail
GADW	Gadwall
TUDU	Tufted duck
GCGR	Great-crested grebe
COPO	Common pochard
EUWI	Eurasian wigeon
FEDU	Ferruginous duck
EUCO	Eurasian coot
LIGR	Little grebe
CPGO	Cotton pygmy-goose
LWDU	Lesser whistling-duck

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Chapter 1
Introduction

1. INTRODUCTION

Wetlands are defined as 'lands transitional between terrestrial and aquatic ecosystems' where the water level is usually at or near the surface or the land is covered by shallow water (Mitsch & Gosselink, 2015). According to Ramsar Convention wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters. Wetland ecosystems are most fragile in nature. Its number has decreased from 19% in early nineties to 5% currently (MEA, 2011). Wetlands can decrease flooding, remove pollutants from water, recharge groundwater, store heavy metal, protect shorelines, provide habitat for wildlife, and serve important recreational and cultural functions. More over wetland serve as 'kidney' of environment (Prasad et al., 2002).

Wetlands in India account for 4.7% of geographical area. Wetlands in India, are facing tremendous anthropogenic pressures (Prasad et al., 2002; Mukherjee et al., 2021). Predominant reasons for wetland loss are land-use and land-cover changes, infrastructure development, pollution from industrial effluent and agricultural runoff, climate change and variability (Bassi et al., 2014). These can adversely influence the abundance of aquatic animals (Sievers et al., 2018). Bird communities depending on wetlands are no exception in this regard (Reginald et al., 2007, Mao et al., 2019). The effects of urbanization can be immense and it has much deteriorated wetlands. Although urbanization increases avian biomass it typically results in declination of richness (Coetzee and Chown, 2016; Allen et al., 2019). As a result, many wetland-dependent species including 21% of bird species; 37% of mammal species; and 20% of freshwater fish species are either extinct or globally threatened (MEA, 2005).

Birds which are ecologically dependent on wetlands are broadly defined as waterbirds (Kumar et al., 2003). These include groups such as waterfowls, seabirds and waders. There are several other birds such as kingfishers, raptors, and some passerines which are also dependent on wetlands. These are called wetland dependent birds (Kumar et al., 2005). Waterbirds and wetland dependent birds are often collectively referred to as Wetland birds (Kumar et al., 2005). Waterbirds provides four kinds of ecosystem services, namely, supporting services, regulating services, provisioning services and cultural services (Green and Elmberg, 2013) Water birds form vital links in the food webs and nutrient cycles, making them important components of most wetland ecosystems (Dessborn et al., 2016, Boros, 2021). Besides that, waterbirds can sustain the diversity of other organisms by guanotrophication, be vital ecosystem engineers, control pests, be potential bioindicators of wetland ecosystem, and act as sentinels of potential disease outbreaks and they also play significant roles in the lives of humans culturally, socially, scientifically and as a food resource (Green and Elmberg, 2013). Out of 310 Indian wetland species 130 (i.e., 42%) are migrant and rest 173 are resident, however the status is unknown for seven species (Prasad et al., 2002). Of the migrants, 107 are winter migrants, six have some passage populations, 13 are summer migrants, and the remaining four are purely passage migrants. Of the 173 resident species, 53 are completely resident, 38 are partly resident and partly winter migrant, and 50 undertake local movements chiefly depending on weather conditions. In terms of abundance, Indian wetland birds can be categorized as Very Common (four species), Common (26), Locally Common (115), Uncommon (45), Rare (67), Very Rare (five), Vagrant (47) and Probably Extinct (one) (Kumar et al., 2005).

A number of wetlands with various physical attributes, distributed in different geographical region of West Bengal, support migratory waterbird populations during winter (Nandi et al., 2007; Chatterjee et al., 2020, Mukherjee et al., 2021). However, these water bodies are not studied in details in respect to their biotic and abiotic resources. Most of these wetlands are inadequately known and often face alteration predominantly due to anthropogenic activities. Therefore, it is thought that these wetlands would surely extend the opportunity to study waterfowl community attributes, guanotrophy and guild interactions in contrasting ambiences in reference to different physical habitat attributes and anthropogenic interference.

1.1 Biogeographical importance of the habitats

West Bengal is the only state of India have a coastline, a plateau, riverine plains as well as the Himalayas and it lies within 21°20´N - 27°32´N and 85°50´E - 89°52´E. Shivalik Himalaya is in Northern side of this state and this area is under "Indo-Burma biodiversity hotspot" of the Central Himalayas Biogeographical Zone contiguous to two important EBA’s (EBA 130: Eastern Himalayan; EBA 131: Assam Plains). BirdLife International (2003) has recognized twenty key wetland regions (W01 – W20) for threatened birds in Asia, out of which Assam and Silhet Plains (W14) hold 16 species. Three sites in the present study locations are within Assam and Silhet Plains wetlands. One site is an IBA (important bird area). Broadly, West Bengal has nine major physiographic units: (i) the Himalayas, (ii) the sub-Himalayan alluvial fans, (iii) the Barind uplands, (iv) the degenerated eastern fringes of the Chotanagpur plateau, (v) the plateau-fringe palaeo-deltas resembling subdued fans at present, (vi) the primarily non-tidal upper Ganga delta, (vii) the tidal and reclaimed lower Ganga delta, (viii) the tidally inundated lower Ganga delta occupied by the Sundarban mangroves and (ix) the Medinipur coastal plains primarily contributed by the Subarnarekha river (Alam et al., 2003; Bandyopadhyay et al., 2014). Diverse location of these habitats in different physiographic regions make these wetlands globally important from conservation point of view as waterfowl conservation at eco-regions is a global priority now-a-day. Specify your study area in a few sentences.

1.2 Migration pattern of the wintering waterbirds

In India, mainstream of the migratory waterbirds migrates from the north places like Asia Minor, Central and North East Asia, East Asia and Europe following typically two flyways, East Asian-Australian Flyways (EAAF) and Central Asian Flyways (CAF), either the western flyway along the Indus valley or north eastern flyway along the course of Brahmaputra respectively (Kumar et al., 2005; Dhanjal-Adams et.al., 2017; CAF National Action Plan- India, 2018). Kirby (2010) reported, the highest proportion (19%) of threatened migratory waterbirds use the EAAF while CAF is used by 14% threatened and near threatened waterbird species. Population trends of waterbirds in Asia are really concerning as 62% of waterbird populations with known trends were decreasing or have become extinct (Delany and Scott, 2006). Li et al. (2009) did a painstaking work on the long term (1987-2007) population trend of the waterbirds in Asia and they found that four (Mallard, Northern pintail, Common teal and Spot-billed Duck) of the eight most prevalent dabbling duck species in East Asia are declining.

In Indian subcontinent, migratory waterbirds are predominantly winter migrants. Migratory waterbirds roosting in different wetlands of West Bengal also follow both EAAF and CAF. The study of wintering waterbird richness and abundance is an essential ecological tool to evaluate wetland habitats both qualitatively and quantitatively (Ma et al., 2010; Kleijn et al., 2014, Chatterjee et al., 2020). Heterogeneity in physical characteristics of the habitat can occur within a small scale; to be precise it can also occur within a wetland; contributing to higher species richness and abundance in that habitat (Willby et al., 2018). However, the gradual losses of wetlands and degradation of habitat quality decline many waterbirds species around the world (Davidson, 2008). The objective of this study is to investigate whether any change of latitudinal migration pattern of waterbirds in West Bengal. And this study also provides a good platform to comment on whether physical attributes of a particular wetland affect the community structure of the waterbirds. Another aspect of the study is to investigate the impact of differential anthropogenic interferences in habitats.

1.3 Metal risk exposure in waterbirds

Globally peri-urban wetlands are facing various threats mainly by concentrating various noxious pollutants generated by anthropogenic activities and India is no exception in this regard (Prasad et al., 2002). In recent times, wetlands are increasingly affected by the accumulation of heavy metals from both natural and anthropogenic sources including natural erosion, hydrological processes, industrial and agricultural activities and so on (Liang et al., 2016). The toxic and non-biodegradable properties of heavy metals make these a potent source of adverse effects on biota. Waterfowl take up different elements including heavy metals mainly through food and, to a lesser extent, water consumption (Levengood and Skowron, 2007). As birds are excellent indicators of wetland health and pollution status, many studies have been conducted on the severity of heavy metal contamination on wetland-associated birds (Lavoie et al., 2015; Burger and Elbin, 2015; Sinka-Karimi et al., 2015, Xia et al., 2021). The present study was aimed to assess the heavy metal risk exposure in herbivorous waterfowls and to assess the order of the potent threats from highest to lowest among the selected heavy metals (Cu, Zn, Cr, and Pb).

1.4 Limnological features and guanotrophication

Physiochemical condition of a wetland affects the bird congregation. However, bird community roosting or breeding in a waterbody can also alter the limnological features of that wetland. Nutrients (mainly nitrate and phosphate) in the guano of the aquatic birds may alter the water quality in freshwater wetlands and, thus, waterbirds can play a considerable role in nutrient loadings in these wetlands (Adhurya et al., 2022). Fascinating studies on the effects of bird aggregation on the physicochemical conditions of wetland and vice versa have been published (Manny et al., 1994; Hanson, 2003; Unckless and Makarewicz, 2007; Singha Roy et al., 2011; Duda et al., 2021). The objectives of this study are to record the changes in the physico-chemical conditions during the wintering period, and to determine the monthly variations in the species-specific guano and nutrient loading by different waterbirds wintering in the waterbodies.

1.5 Diurnal time activity budget of waterbirds

The distribution of time in different activities in day time, including foraging, varies among waterbird species and individuals (Draidi et al., 2019). Time allocations for different daily activities surely have important implications for meeting energy requirements of the concerned species. The physical habitat, social organization and environmental conditions of the individual species can be accessed from the extensive time-activity budget study (Paulus, 1988; Datta, 2014; Mukherjee et al., 2020). From present study we will be able to comprehensively comment on wintering strategies, feeding techniques, habitat use pattern, niche sharing and resource partitioning as populations consist of individuals that differ consistently in their food choice and foraging technique.

1.6 Waterbird feeding guilds and niche structure

The presence of food resources is a crucial factor in maintaining waterbirds diversity and abundance as wetlands are critical foraging grounds for waterbirds (Hafner et al., 1986). However, limited food resources are partitioned among waterbirds in several dimensions like foraging habitat use, time of foraging, food preferences and feeding techniques (Chatterjee et al., 2020). This information is critical for management of habitats as well. Group of waterbird species, that exploit food resources in a similar way, are clustered in a feeding guild. In present study, waterbirds, both non-breeding migratory waterbirds and resident birds, are clustered in different foraging guilds to extract information about interspecific resource partitioning and optimal resource utilization.

1.7 Genetic distance and divergence of foraging behavior in Anatidae

Knowledge about adaptive radiation within a rapidly multiplying lineage can be used to detect behavioral patterns and can also be useful to identify the underlying factors for the emergence of ecological divergence within a lineage. Moreover, according to Optimal Foraging Technique (OFT) by Pyke et al. (1977), diet selection, habitat choice, time allocation and movement patterns are the four major aspects for optimal foraging. Therefore, resource utilization from different areas of the same aquatic habitat is the key to stable co-existence among waterbirds. For this to be successful, specialized foraging technique and major time investment behind that particular technique compared to others are of prime importance

(Eadie et al., 1979; Guillemain et al., 2002). Such behavior will enable a waterfowl species to obtain optimum food resources from a particular part of the habitat. This behavioral specialization could be a resultant of evolutionary force to a direction (Barnagaud et al., 2014). Present work records the foraging habitats and techniques of five waterfowl species of the family Anatidae to focus on the divergence based on the foraging behavior as a consequence of evolution.

1.8 Objectives: Questions that are addressed

Present study has addressed the following questions to elaborate waterfowl community attributes with special reference to ecosystem services in selected wetlands of West Bengal:

- How the impact of anthropogenic interferences, habitat alterations and climate perturbations influence the migratory waterbird aggregations in wetlands!
- Whether selected wetlands and waterbirds were particularly important for myriad ecological functions!
- Whether any drawdowns in migratory waterbird populations could be emphasized from a long-term study at selected wetlands!
- Whether any latitudinal variation in waterbird community structure could be observed in selected wetlands in different physiographic regions of West Bengal!
- Whether nutrients added by waterfowl to the wetlands (guanotrophy) generate nutrient load-response in trophic state of the wetlands in spatio-temporal scales!
- Whether the foraging habitats and feeding techniques used by the waterbirds during the wintering period would help in quantifying species' niche breadth and overlap!
- Whether any temporal resource partitioning between migratory and resident waterbirds could be observed!
- Whether phylogenetic distance influence the selection of foraging habitat and foraging techniques in waterfowls!

Study of the avifaunal (both non-breeding migratory and residential) community have been considered aiming at the following objectives:

- To study ecosystem services rendered by the wetlands under study.
- To study the physico-chemical conditions of selected wetland habitats used as wintering sites by migratory waterbirds.

- To study the physico-chemical changes in wetland habitat quality due to anthropogenic interferences.
- To study the quantification, distribution and spatio-temporal variations of migratory waterbirds in study sites.
- To study the foraging guild and niche characteristics of migratory waterbirds.
- To study the diurnal time activity budget of waterbirds.

Chapter 2
Review of literature

2. REVIEW OF LITERATURE

Waterbirds are excellent indicator of wetland heath. Thus, scientific works regarding diversity and ecology of waterbirds have gained much importance all over the globe. However, such works from India are at rudimentary stage presently. India is one of the seventeen mega-biodiversity countries with 2.4% of total world's terrestrial landmass. However, India harbours 13.6% of world's avifauna with roughly 1263 recorded species (Praveen et al., 2016). India ranked 9th in world in terms of number of bird's species (Lepage, 2016). Our State, West Bengal, with 88,752 sq. km. area shares only 2.7% of India's total land zone. This is the only state of India with Himalayan hill region in the north propinquity and Bay of Bengal in the south. Despite of small size, this state shelter approximately 70% of India's bird diversity (Khan, 2002) mainly because of ecosystem diversity, varied landscape features and diverse climatic conditions of this state. Moreover, rivers, various natural and artificial waterbodies provide excellent feeding and roosting grounds for waterbirds and wetland-associated birds. West Bengal has two Ramsar Sites (No. 1208; East Calcutta Wetlands and No. 2370; Sundarban Wetland) out of 27 Ramsar sites of India. West Bengal also has 10 Important Bird Areas (IBA) while 555 IBAs are present in India. Birds are critical to uphold balance of ecosystem by providing various ecological services and this is one of the major reasons behind the extensive study on this group (Tanalgo et al., 2015). Present work is designed towards ecological studies on waterbirds and wetland-dependent birds with special reference to habitat quality. Present work was carried out in wetlands distributed throughout West Bengal, but the study on habitat quality and behavioral ecology was done on the wetlands in the western West Bengal's Bankura and Purulia districts. Therefore, literature survey, clubbed in eight specific arenas, will concentrate on the important available works globally and nationally mainly to supplement hypothesis building, testing and to reach the objectives of the present work.

2.1 Habitat quality and avian richness

Jerdon's Bird of India (1863, 1864) was the first serious attempt to illustrate the birds of India. Later on, Hume, who was considered as the 'Father of Indian Ornithology,' published two important works on birds of Indian subcontinent in 1879 and 1888. The first systematic checklist of the birds of the Indian Subcontinent in post-independent India was by Ripley

(1961, 1982) with meticulous remarks on distribution, status, and movements of each taxon at the subspecies level. Ali and Ripley's works Handbook of the birds of India and Pakistan also provided an important platform in ornithology (Ali and Ripley, 1968–1974, 1978–1983a, 1986, 1996–1999) and widely regarded as an 'Epic' in Indian ornithological literature. Later, we got a variety of excellent inclusive publications on the birds of our subcontinent and these were by Inskipp et al. (1996), Kazmierczak and van Perlo (2006), Grimmett et al. (2011) and Rasmussen and Anderton (2012a, b). Bhusan et al. (1993) and Kumar et al. (2005) documented the diversity of wetland birds and water-dependent birds of India in their works. Various studies in wetland avifaunal diversity and throughout West Bengal were done in past. Chatterjee et al. (2013, 2017) studied diverse wetlands at the eastern Himalayan foothills and recorded variations in avifaunal composition among habitat types. Roy and Debnath (2016) recorded avifaunal diversity of selected wetlands of Terai and Dooars with comments on future forecasts. Das and Das (2016) made studies on birds of open-water, mudflats, and banks of Torsa River for a couple of years. Some other notable work on the avian diversity associated various wetlands of north West Bengal were done by Singha Roy et al. (2012), Das et al. (2012, 2013 a, b) and Ganguly (2015). Chowdhury and Nandi (2014) worked in selected wetlands of Malda district of upper Gangetic Plains. In that study, diversity of waterbirds of that region was recorded for consecutive four years. Mistry and Mukherjee (2015) and Bhattacharya et al. (2018) published the status and threats of waterbirds of Ahiran lake of Murshidabad at northern West Bengal, which is facing enormous anthropogenic pressure due to its location beside National Highway. In 1999 Prakiti Samsad, Calcutta, published a long-term census report on mid-winter waterfowls of south Bengal. In 2006, Mazumdar et al. did a long-term census on diversity of migratory waterbirds in selected wetlands of southern West Bengal. Chakroborty et al. (2021) reported the winter avifaunal diversity Purbasthali, a prominent waterbird wintering ground of West Bengal. Khan et al. (2016). did a sixteen-year study on population trends of migratory waterbirds in three wetlands of southern West Bengal. Nandi et al. (2004) did a painstaking survey on the winter avifauna of Bankura and Purulia districts of West Bengal. In 2007, Nandi et al. conducted another survey on wetland fauna, including avifauna, in Bankura and Purulia districts. Chowdhury (2019, 2020) conducted a study dealing with the migratory avian population declination in wetlands of Purulia. Long-term research works on status of the habitats and aspects of richness and abundance of migratory waterbirds and wetland dependent birds of West Bengal, especially at the western part of the state (Bankura and Purulia districts), are flimsy. However, the preceding publications sufficiently points out the significance of these wetlands as roosting and foraging grounds of waterbirds and imperative need for framing effective conservation strategies sharply.

In recent times, a foremost focus of avian ecology has been the investigation of habitat selection and habitat quality, because it strongly influences avian distribution, abundance, and its community structure. However, individuals use specific habitat cues that may befall in different vegetation community types (Wilson et al., 1998). Liordos and Kontsiotis (2020) designated wetlands as important critical breeding, foraging, and wintering grounds for various avian species. It has been assessed those freshwater wetlands harbor more than 40% of bird species of the entire world and 12% of all animal species (Zakaria et al., 2009). Das and Saikia (2011) and Ramírez-Albores et al. (2014) analyzed that the diversity of wintering waterbirds in a community is closely related to the structure of the vegetation, physical attributes of a habitat, foraging resources, and resting conditions. However, mainly due to changed land use pattern globally wetlands are decreasing. McAllister et al. (2001) reported 5000 km^2 wetland area lost annually to agriculture, dam construction and other purposes. India and West Bengal are no exceptions in this regard. According to a survey steered by Wildlife Institute of India, 70-80% of freshwater waterbodies in the upper and lower Gangetic flood plains were lost during the last 50 years. Prins and Namgail (2017) reported current annual rate of wetland shrinkage is about 2-3 %. Prasad et al. (2002) made a review to deal with the status and distribution of Indian wetlands and causes and consequences of wetland losses. Rahmani and Islam (2008), Praveen et al. (2014), SANDRP (2022) made inclusive reports on the pan-India distribution of waterbirds of inland waters and possible reasons of degradation of their roosting grounds. Das et al. (2000) and State of Environment Report-II, WBPCB (2021) analyzed the degradation of waterbodies and wetlands in West Bengal mainly owed to economic developments.

2.2 Hydrophytic vegetation and food resources

Availability of foraging resources are critical to maintain the waterbird community. Andrikovics et al. (2006) and Horvath et al. (2012) reported a detailed study of foraging resources of waterbirds. Main food resources were aquatic macrophytes, fish, frogs, snakes, snails, aquatic insects, crustaceans, nektonic macroinvertebrates (Coleoptera, Odonata, Heteroptera) and benthic invertebrates (Ali and Ripley, 1987). Ntiamoa-Baidu et al. (1998) also excellently analyzed the feeding preferences of waterbirds.

Warsel and Madsen (2012) reviewed the global status of aquatic plants. Cook in 1996 gave detailed illustrations of aquatic and wetlands plants of India. Das et al. (2009) reported the diversity of aquatic plants from West Bengal. In 2013, Palit and Mukherjee recorded the hydrophyte diversity in 12 wetlands of Bankura district of West Bengal. Sao (2016) meticulously worked on the aquatic plant diversity of Purulia Saheb bandh. In 2017, Mandal and Mukherjee made an excellent documentation of macrophytes associated with wetlands from 38 wetlands of Purulia district.

Mogalekar et al. (2017) did a detailed study on the freshwater fish diversity of West Bengal. Mishra et al. (2003), Mondal and Patra (2015), Bhattacharya et al. (2020) recorded ichthyofaunal diversity of Bankura and Purulia districts of West Bengal. In a noteworthy study Nandi et al. (2007) assessed the wetland faunal resources of Bankura and Purulia District. Besides avian diversity this study was aimed to record the diversity of reptiles, amphibians, fishes, macro-crustaceans, insects, molluscs associated with the wetlands.

This present work focuses on the variation of avian community structure throughout the winter months with special reference to the habitat quality of four wetlands located in the Bankura and Purulia districts of West Bengal with special focus on available foraging resources.

2.3 Habitat heterogeneity and wetlands in different physiographic regions of West Bengal to shelter migratory waterbirds

Habitat heterogeneity is one of the major factors behind the variation of species abundance (Tews et al., 2004; Bonilla et al., 2012). Species distribution pattern within a habitat depends primarily on habitat heterogeneity and environmental adaptability of a species. Present conservation strategies of migratory waterbirds rely mainly on the understanding of changing patterns of migratory wintering waterbird species diversity and sustainable maintenance mechanisms of wetland ecosystems (Bassi et al., 2014). Willby et al. (2018) analyzed that habitat heterogeneity in physical characteristics of the habitat can occur within a small scale (within a wetland) which can contribute to higher species richness and abundance in that habitat. Both habitat characteristics and physiographic location of a wetland determines the waterbird distribution and richness (Rajpar and Zakaria, 2011). Physical attributes of a wetland like area, depth, shore length and water-level fluctuation etc. contributes to the habitat heterogeneity and are the most important variables that influence species richness of avifauna (González-Gajardo et al., 2009; Almeida et al., 2018). Birds migrating towards the Indian peninsula primarily follow the Central Asian flyway and East Asia-Australasian flyway (Dhanjal-Adams et al., 2017). By species presence / absence data in different wetlands, located in a same flyway (EAAF), species turnover rate (Beta diversity) and latitudinal species variation within a region can be determined (Baselga, 2010). Globally some recent and mention-worthy works had been done on species turn over within habitats of birds by Ramirez-Albores et al. (2014), Baselga et al. (2015), Castilheiro et al. (2016), Zellweger et al. (2017), Hu et al. (2018), Li et al. (2019), Pöysä et al. (2019), Roos et al. (2020), Jones et al. (2021). In India and West Bengal no such noteworthy work has been done yet. However, works by Das et al. (2013) and Chatterjee et al. (2020) mentioned different wetland sites that usually harbor wintering waterbird communities including both migratory and resident bird species.

The present study is designed to analyze the distribution pattern of migratory and resident birds in the wetlands distributed north to south of West Bengal. Besides that, this study also analyses the effects of different physical habitat attributes on the richness and abundance of waterbirds.

2.4 Heavy metal exposure in waterbirds

Heavy metals contamination is a great concern at global, regional, and local level [Qadir et al. 2009] and heavy metal pollution in wetlands deteriorates the water quality, which has negative influence on the flora and fauna thriving there and makes a decline in the range of several waterbird species (Zhang and Ma, 2011). In waterbirds, the possible consequences of exposure to sub-lethal concentrations of heavy metals for individuals were (1) reproductive dysfunction; (2) increased susceptibility to disease; and (3) behavioral changes (Scheuhammer, 1987). As the most common waterfowl in the wetland, ducks (family Anatidae) have been recognized as bio monitors for assessing ecological contamination (Liang et al., 2016; Plessl et al., 2017; Wang et al., 2017) and thus study of heavy metal toxicity in Anatidae are imperative. Several noteworthy studies were conducted using various parts of waterbirds as monitoring units of heavy metal toxicity in waterbirds. Parslow et al. (1982), Mateo and Guitart (2003), Goodale et al. (2008), Cid et al. (2009), and Biswas et al. (2020) used internal tissues and blood as monitoring units of heavy metal toxicity. Takekawa et al. (2002), Bize et al. (2002), Dauwe et al. (2004) and Pereira et al. (2009) used eggs of waterbirds as monitoring units. Burger and Gochfeld (2000), Guo et al. (2001), and Malik and Zeb (2009) used feathers of waterbirds as monitoring units in their studies. Varagiya et al. (2022) in a review work reported that Cr, Pb, Cu and Zn predominantly accumulated in waterbird feathers in Asian countries, including India. Some studies (Wemel et al., 1996; Takekawa et al., 2002 and Dauwe et al., 2004) also used nestlings as monitoring units for heavy metal toxicity. Some recent studies (Fort et al., 2014; Salamat et al., 2014; Lavoie et al., 2015; Burger and Elbin, 2015; Sinka-Karimi et al., 2015; Pandiyan et al., 2020) were also conducted based on the direct handling of the birds for the heavy metal exposure assessment. Liu et al. (2015), Liang et al. (2016), Liu et al. (2019) and Xia et al. (2021) conducted studies on heavy metal contamination based on improved exposure risk assessment model which avoids direct handling of the birds. Studies by Siddiqi and Chandrasekhar (2010) and Dutta et al. (2019) revealed that various heavy metals might had entered wetlands of western West Bengal. But these studies did not quantify the risk exposure of heavy metals in waterbirds foraging and roosting on these wetlands.

The present study was conducted to quantify the heavy metals in water, soil and vegetation of the wetlands and to estimate heavy metal (Cr, Pb, Zn and Cu) exposure risk to herbivorous waterfowls in the wetlands with improved model. Other objectives of present study were to order the potent threats from highest to lowest among the selected heavy metals and to compare the degree of heavy metal exposure in study sites as these sites located in different location.

2.5 Limnological variables of habitats and guanotrophy

Bird congregation primarily depends on the open water area of a wetland (Patterson, 1976), while migratory waterbirds also significantly change the limno-chemical parameters of water by the addition of guano (Andrikovics et al., 2003). Nutrients in the guano (mainly nitrate and phosphate) of the waterbirds alter the water quality in waterbodies and thus birds play a considerable role in nutrient cycling in the wetlands (Manny et al., 1994). Moreover, Scherer et al. (1995) reported when bird abundance is large relative to the size of the wetland, a significant fraction of the nutrient pool may cycle through birds via guanotrophy. Pettigrew et al. (1998), Hanson (2003), Longcore et al. (2006), and Singha Roy et al. (2011) also did note-worthy studies on the effects of waterbird congregation on the limno-chemical conditions of waterbodies and vice versa. Additionally, Paracuellos (2006) reported wetland that harbor waterbirds had high nutritional value. Kear (1963), Manny et al. (1975), Dessborn et al. (2016), Martin-Velez et al. (2019), Adhurya et al. (2022) measured the nutrient content of guano in different bird species. Increased nutrient content was rapidly utilized and both GPP and secondary productivity of the habitat increased (Manny et al., 1994; Unckless and Makarewicz, 2007). Higher rates of both primary and secondary productivity influenced the speedy uptake of basic nutrients like phosphate, nitrate, and silicate as reflected in the negative correlation with higher avian density (Singha Roy et al., 2011). Moreover, bird droppings also flourish the growth of phytoplankton community, micro and macroinvertebrates, benthic organisms, and fish (Scherer et al., 1995; Longcore et al., 2006; Hanson, 2008). However, Bassi et al. (2014) recorded excessive nutrient enrichment could lead to high algal growth, which ultimately leads to eutrophication and this in turn can negatively affect the waterbird population foraging and roosting there.

The objectives of this study would be to study the change in waterbird assemblages sites for consecutive two wintering seasons, to record the changes in the physico-chemical conditions during the wintering period, and to determine the monthly variations in the species-specific guano and nutrient loading by different waterbirds wintering in the study sites.

2.6 Diurnal time activity budget of waterbirds

Many ducks and pochard species widely distributed in Palearctic and migrate within the EAAF and CAF are frequent winter visitors on the Indian subcontinent (MOEFCC, 2018; SoIB, 2020) and migratory birds share the foraging and roosting grounds with resident species. Study of time-activity budget have been used widely to provide valuable information on birds' habitat use pattern and wintering strategies like feeding, resting (Paulus, 1988; Aissaoui et al., 2011). Significant interspecific variation can be observed in time activity budget study and these studies can help us to understand their life history and ecological adaptations (Hamilton et al., 2002). Time allocations for different daily activities surely have important implications for meeting energy requirements of the concerned species. Paulus (1988) did a notable work on the time activity budget of nonbreeding Anatidae. Later, Hamilton (2002) worked extensively on the time activity budget of Anatidae family. Time activity budget has been previously studied on Common Pochard (Green, 1998; Ali et al., 2016), Ferruginous Duck (Muzaffar, 2004, Aissaoui et al., 2011, Draidi et al., 2019), Eurasian wigeon (Houhamdi and Samraoui, 2003, Saker et al., 2016), Tufted duck (Hill and Ellish, 1984), Green-winged teal or Common teal (Rave and Baldassarre, 1989), Common shelduck (Mouloud et al., 2006; Liordos, 2010; Bensizerara and Chenchouni, 2019), Marbled teal (Aberkane er al., 2014), White-headed duck (Amine et al., 2021) and Mallard (Green, 1998; Liordos, 2010). Time activity budget on several other wetland ducks (Green et al., 1998; Ali et al., 2016), shorebirds (Morrier and McNeil, 1991; Marteinson et al., 2015) and captive ducks (Rose et al., 2022) were also studied. An excellent study on behavior of a hybrid Red-crested Pochard and Ferruginous duck (*Netta rufina* x *Aythya nyroca*) was conducted by Randler (2003). Ali et al. (2016) did a meticulous work on the time activity budget of both migratory and resident birds. This study also showed the harmonious use of resources by migratory and resident birds in a Mediterranean wetland, However, studies on time activity budget of waterbirds are very insufficient. Das et al. (2011) did a study on diurnal time activity budget of Fulvous whistling duck. From West Bengal, Dutta (2014) did a comprehensive work on time activity budget of Ferruginous duck.

From this study, wintering strategies, feeding techniques, habitat use pattern can be broadly studied. Time activity budget studies are helpful in assessing the conditions of the physical habitat, social organization, feeding strategies, temporal resource partitioning of individual species. This present study can provide a platform to study the simultaneous resource utilization and resource portioning among resident and migratory birds wintering in a specific wetland.

2. 7 Waterbird community structures and feeding guilds

Waterbird communities usually have a complex structure driven by a substantial number of variables that influence both intra and inter-species interactions in a wetland (Winemiller and Pianka, 1990; Weller, 1999; Liordos, 2010;). Previous studies (Wiens, 1977; Pianka, 1980; Perez-Crespo et al., 2013) recognized that patterns of resource partitioning played decisive roles in organizing waterbird communities within a habitat and species with similar patterns of resource utilization (i.e., species of the same guild) are vulnerable to competitive interactions that could alter the community structure. Models of resource utilization, for both food and habitat resources, are usually considered in the context of niche theory. Members of the same guild similarly exploit similar resources and thus species of the same guild are susceptible to competitive interactions over shared resources (Root, 1967; Albrecht and Gotelli, 2001; Palmer et al., 2003). For coexistence of species belonged to a particular guild, reduction of competitive interaction is essential (Simberloff and Dayan, 1991). In 1959, Hutchinson developed spatial models of niches and defined niche breadth as the distance through a niche along some line in the niche space. Colwell and Futuyma in 1971 established the concept of niche overlap which refers to the shared use of resources by two or more species. Both niche breadth and niche overlap provide indirect aspects to explore ecological processes such as competition over shared resources (MacNally, 1983). Schoener in 1974 suggested three possible niche dimensions, namely, habitat, time of habitat occupancy and food type. He also predicted that by these dimensions' species can segregate and thus niche overlap can be reduced. Studies of waterbird communities by Pöysä (1983), Paszkowski and Tonn (2006), Gatto et al. (2008) and López de Casenave et al. (2008), Lara et al. (2013) have largely focused on two niche dimensions, namely habitat use and food type and accepted that dimensions influenced the distribution, abundance, resource partitioning and species richness in wetlands (Weller, 1999). Gray et al. (2007) did a notable study on the variation in community structure based on habitat variation and avian guilds. Liordos in Mediterranean coastal wetlands in 2010 and Perez-Crespo et al. in Mexico in 2013 did significant work on the foraging guild and niche breadth of waterbirds. Rajpar et al. (2022) recently compared the of foraging guild structures of waterbird species between natural and artificial wetlands. Unfortunately, not much work has been done in this field in India. One work, namely Feeding guild of avifauna of Garana wetland-reserve, Jammu, India; was done in 2014 by Pandotra and Sahi. Three published works from southern West Bengal on foraging guilds by Datta (2016), Khan et al. (2016), and Ghosh et al. (2021) without much detailed approach about foraging guilds. Chatterjee et al. (2020) published a first detailed and fascinating work on the foraging guilds of the wintering and resident birds of northern West Bengal.

The present study is aimed to study the foraging guilds based on the two dimensions namely foraging habitats and foraging techniques. Another important aspect of this study to examine the sharing of resources between resident and migratory waterbirds.

2.8 Phylogenetic distance and foraging techniques of Anatidae family

Studies by Guillemain et al. (2002), Schneider et al. (2014) and Osborn et al. (2017) pointed out that species compositions in waterfowl community could be attributed to differential macrohabitat utilization and foraging behavior by the way of differential use of resources. Studies by Brandl et al. (1994) and Katrin and Reik (1999) emphasized a correlation between phylogenetic contrasts and foraging preferences and Clay et al. (2019) reported that, the genetic difference might be a silent driving force behind the niche separation by means of foraging techniques among waterfowls. Sibley and Ahlquist (1990) did a detailed work on phylogeny and classification of birds. Livezey in 1986 and 1996 did a phylogenetic analysis of modern pochards (Aythyini) and modern geese and swans (Anseriformes: Anserinae) using various characters of skeleton, trachea, natal plumage, and definitive integuments. Livezey in 1995 also investigated phylogenetic relationships of modern sea-ducks (Mergini) using a cladistic analysis of 137 morphological characters. Donne-Gousse et al. (2002) studied the phylogenetic relationships among Anseriformes, based on the sequences for the complete mitochondrial control region (CR) of 45 waterfowl representing 24 genera and they recognized five clades among Anatidae. Afterwards Gonzalez et al. (2009) produced DNA sequence data from two mitochondrial genes (cytochrome b and the NADH dehydrogenase subunit 2) to reconstruct the phylogenetic relationships among 121 species of the Anseriformes (waterfowls including ducks, geese, swans, the magpie goose, and screamers). Huang et al. (2014) used mitochondrial cytochrome c oxidase subunit I (COI) in phylogenetic studies of 79 species from 26 genera belonging to the Anatidae family. They identified *Dendrocygna* and *Nomonyx* + *Oxyura* as early offshoots of the Anatidae. All the remaining taxa fell into two clades that correspond to the two subfamilies Anserinae and Anatiane. Moreover, a recent study by Sun et al. in 2017 aims to revise the classification, determine the phylogenetic relationships and diversification patterns in Anseriformes by exploring the Cyt *b*, ND2, COI genes and the complete mitochondrial genomes (mito-genomes). Different previous studies (Pöysä, 1983; Gatto et al., 2008; Liordos, 2010; Perez-Crespo et al., 2013; Chatterjee et al., 2020) also described foraging behavior of waterfowls in details.

This study has been carried out to determine the foraging habitats and foraging techniques of five wintering Anatidae waterfowl, to construct phylogenetic tree of the birds based on mitochondrial genomic DNA and to determine the genetic distances between these five waterfowl species to highlight the similarity and dissimilarity in foraging behavior of these nonbreeding waterfowl.

Chapter 3
Materials and Methods

3. MATERIALS AND METHODS

3.1 Study Area

The present study sites at West Bengal, India are situated within the Central Asian Flyway (CAF) and East Asian-Australasian Flyway (EAAF) that extends from Arctic Russia and North America to the southern limits of Australia and New Zealand. These flyways encompass large parts of East Asia, all of Southeast Asia and includes eastern India and the Andaman and Nicobar Islands (BirdLife International, 2011).

West Bengal is situated in the Eastern region of India and lies between 21°20´N to 27°32´N and 85°50´E to 89°52´E East, stretching from the Himalayas in the North to the Bay of Bengal in the South. It is the only Indian state to have a coastline as well as the Himalayas. The state has a total area of 88,752 sq. km (2.7% of India) and north to south stretch of this state is 623 km (Bandyopadhyay et al. 2014). Broadly, West Bengal has nine major physiographic units: (i) the Himalayas, (ii) the sub-Himalayan alluvial fans, (iii) the Barind uplands, (iv) the degenerated eastern fringes of the Chotanagpur plateau, (v) the plateau-fringe paleo-deltas resembling subdued fans at present, (vi) the primarily non-tidal upper Ganga delta, (vii) the tidal and reclaimed lower Ganga delta, (viii) the tidally inundated lower Ganga delta occupied by the Sundarban mangroves and (ix) the Medinipur coastal plains primarily contributed by the Subarnarekha river (Alam et al., 2003; Bandyopadhyay et al., 2014). Each of these regions is represented by different sets of geological characteristics, hydrology and surface water attributes. We carried out our study on species turnover in 13 wetlands of national and international importance fall under five different physiographic units of West Bengal and have different conservation status that is depicted in a tabular form (Table 3.1); locations of these wetlands are shown in Fig. 3.1. Classification of the wetlands mentioned (Table 3.1) followed the Ramsar Wetland classification and categorization (CBD, 2003). In the present study, the northernmost wetland (Gajoldoba) was 581 km apart from the southernmost wetland (Santragachi jheel). Study sites were selected from different geographic land forms viz. terai and dooars region, north Bengal plains, rarh region, western plateau and high lands and gangetic delta region. West Bengal had been divided in two meteorological subdivisions, sub-Himalayan West Bengal and gangetic West Bengal (NCCO, 2008). Five (Rasik Beel, Nararthali, Gajoldoba, Barasagardighi, Nayabandh) of our thirteen study sites belonged to the sub-Himalayan West Bengal and rest were in Gangetic West Bengal.

For the studies on habitat quality, guanotrophication, monthly variation of avian richness, diurnal time activity budget and foraging guild of waterbirds; four wetlands of western West Bengal, namely Adra Sahebbandh and Purulia Sahebbandh in Purulia district; Kadamdeuli dam and Gangdoa dam in Bankura district were selected. However, for heavy metal exposure study on waterbirds two sites of Purulia district were compared. List of prevalent aquatic vascular macrophytes, insects, mollusks, fish collected using standard methods for collection, preservation and identification following the detailed works of Sao (2016), Mandal and Mukherjee (2017), Nandi et al. (2007), Roy et al. (2013), Mondal and Patra (2015) and Ganguly et al. (2018) from these four wetlands under study (Table 3.2) were also added.

3.2 Macroclimatic conditions

For meteorological purposes West Bengal has been divided into two sub-divisions, Gangetic West Bengal and Sub-Himalayan West Bengal (NCCO, 2008). January was the coldest month in the state when the mean minimum temperature for the Gangetic West Bengal and the sub-Himalayan West Bengal are 13.3°C and 10.5°C respectively. Jalpaiguri, a district in the north Bengal, received the maximum amount of rainfall (371 cm) in a year whereas Bankura, a district in the southwest, recorded the minimum amount (116 cm) in the state.

Study sites of Bankura and Purulia districts were located in the fringes of Chhotanagpur plateau and Rarh region. As the distance between the sampling sites varied from 46.6 km to 90.9 km, spatial changes in macroclimatic conditions were ruled out. Climate of this region is sub-tropical in nature and is characterised by low precipitation and low humidity. Winter season starts from last of October and continues till end of February. Summer season begin from early March and endures till mid- June. Monsoon months commences from June and lasts till September. Average rainfall of this region varies from 1200 to 1400 mm. Average climatic conditions were reported to be extremely hot summer (mean daily maximum temperature in the hottest month: 37.1 °C) and cold winter (mean daily minimum temperature in the coldest month: 9.4℃). Mean monthly average conditions of prevailing macroclimate such as maximum and minimum air temperature, differences between maximum and minimum temperature, sunrise, sunset, day-length, solar irradiance, cloud cover, rainfall days, amount of rainfall and relative humidity were collected from authentic weather record websites (https://www.timeanddate.com › sun › India › Bankura; https://www.worldweatheronline.com › lang › en-in › Bankura › West Bengal).

3.3 Measurement of physical habitat attributes of the wetlands

Three physical habitat attributes of wetlands were considered during the present study, namely, area, shore length and depth. Measurement of area and shore length of the study sites was done by using GPS (etrex 10, Garmin) and Google Earth Pro software. The depth of the wetlands was measured (using measuring ropes) at the junction points of imaginary gridlines (spacing 25m, 50m, 100m, 150m and 200m apart, according to the size of the wetlands) over the water-spread area.

3.4 Sampling period and frequency

Present study was conducted twice in a month (preferably in second and last week) during winter months (from October through March) to record the waterbird richness and abundance in four selected wetlands (Adra Sahebbandh, Purulia Sahebbandh, Kadamdeuli Dam, Gangdoa Dam) for two consecutive seasons (2018-2019 to 2019-2020). The studies on the guanotrophication were also conducted in the same time period. Study on diurnal time activity budget and foraging guild structure of both migratory and resident birds were conducted mainly in four winter months (from November to February) of continuous two years as selected four winter months had sufficiently large (each species density ≥ 30) waterbird populations (including winter migrants) for behaviour study. However, the study on the heavy metal risk exposure was conducted in the month of January for three consecutive years (2019-2021). On contrary, the study on the waterbirds species turnover in the thirteen selected wetlands along the EAAF and CAF, mid-wintering season of Eastern India (December 15 to January 31) was selected. This study was done in 2018-2019. Numerous season specific studies on waterbirds were on record (Pöysä, 1983; Salewski et al., 2003; Mazumdar et al., 2007; Chatterjee et al., 2020) and results showed that October through March was the best period to study the assemblage of wintering as well as resident waterbirds in West Bengal.

3.5 Sampling and categorization of avian population

The counts were made along an imaginary line surrounding the wetlands. All sides of each wetland with smaller width (< 100m), where approachable, were surveyed during each sampling session, by walking along one to five (depending on the length of the wetland) such lines of the length of 1 km each. Observations were made from 6 points on each line; each point was 200m apart from the previous/next point on the line, independently by three trained observers at three specific time intervals (06:00-07:00, 12:00-13:00 and 17:00-18:00 hrs) during each of the survey day. For the larger wetlands (width >100m), manual country boat was used to sail along the length of the wetland following imaginary grid lines, 100 m apart from each other. On each line, birds of either side of the line within 50 m were counted from the points at 200m apart from each other (Hutto et al., 1986; Bibby et al., 1992; Buckland et al., 1993). We counted all birds seen on land or water within 50 m of the survey points (Ralph et al., 1995), using a TruePlus 360 Laser range finder. Distant counts would undoubtedly remain a standard method for sampling migratory waterbird species because of convenience (Paton et al., 2009). Time and weather conditions at the start of each sampling session were also recorded. Birds seen flying were recorded separately (Bibby et al., 2000). A Nikon Fieldscope (25–75 x 82 ED), Bushnell Equinox Z (4.5 X 40) Night Vision and Nikon Action (10 X 50) binoculars were used for spotting the character details of the birds in sight. The raw count data were averaged site-wise to obtain representative data and were used as indices of abundance (Gibbons and Gregory, 2006). Ali and Ripley (1987), Kazmierczak and van Perlo (2000) and Grimmett et al. (2011) were followed for avifauna identification and nomenclature.

In this study, waterbird species were clubbed in four categories, namely, dabblers, divers, waders and wetland-associated species, for convenience in analyses according to Sibley et al. (2001). Waterbirds were classified primarily based on the foraging techniques. Divers largely used diving as their feeding techniques. Dabblers showed a wide variety of feeding techniques like head-dip, neck-dip, beak-dip, filtering and upending. Waders used picking and striking as foraging techniques. Bird species belonging to the families like Accipitridae, Alcedinidae, Hirundinidae, Alaudidae, and Motacillidae were designated as wetland-associated birds and the rest were waterbirds (Kumar et al., 2005). Wetland-associated birds directly or indirectly depend on the wetlands.

3.6 Calculation of sex ratio

The sex ratio was expressed as the proportion of males within the sample (Brides et al., 2017; Frew et al., 2018). The sex ratio was calculated as: sex ratio = nm/ (nm + nf), where nm and nf refer to the total number of males and total number of females, respectively (Brides et al., 2017).

3.7 Diversity Calculations

We studied the α-diversity to examine the diversity of a community by recording the number of species within a single habitat, and the β-diversity to emphasize the changes in species composition along with a series of habitats following Whittaker (1972). Alpha-diversity (α) for each census was calculated using the Shannon–Wiener diversity index (H/). This was the index most used to calculate alpha-diversity (Pielou, 1969). Other diversity indices like Simpson's dominance index (DSIPM), Pielou's evenness index (J/), and Margalef's richness index (DMARG) were also calculated. Data were processed for calculating indices using PAST version 3.07. H/ and DSIPM both were based on the proportional species abundance in the studied area. However, H/ was more sensitive to rare species, whereas DSIPM gave more importance to common species. J/ reflects homogeneity among the species. DMARG considered both abundance and species richness. Species accumulation function (Chao1), an asymptotic model, was used to fit the species accumulations (Chao et al., 2009). Spatially Constrained Rarefaction (SCR) was used to estimate species richness that was directly comparable for areas that differed in spatial extent. Individual-based rarefaction was also applied to comment on the diversity, especially species abundance, of study sites. Beta-diversity (β) between sites was calculated for each pairwise sites for presence/absence data comparison using Whittaker's index (βw) and for abundance data comparison using Sorensen index (βs), to determine the degree of differentiation of diversity among sites (Koleff et al., 2003; Magurran, 2004; Baselga, 2010). Indices are expressed in the scale of 0 (complete similarity) to 1 (maximum β diversity). Chao et al. (2006) emphasized that each index for measuring β-diversity was derived from different theoretical justifications and each measured different aspects of assemblages. The presence/absence or incidence-based indices (βw was one of such) were useful for simply comparing species lists and had a chance of being influenced by dominant species. However, our study required more information than presence/absence only. The abundance-based indices (βs was one of such) were formulated by pooling shared abundances and were, thus, less likely to be dominated by particular species. The use of a variety of diversity indices (although might appear as related and redundant) was useful to interpret the structure of large sets of communities with varied attributes. The most appropriate value(s) of these indices was important to analyse the community as that might gather insights to interpret the structures (Daly et al., 2018; Bello et al., 2021).

3.8 Estimation of heavy metal toxicity

3.8.1 Sample collection

The surface water (0 – 15 cm) samples were collected from nine random accessible spots at each of the wetlands on the next day after the bird counting days for the entire study tenure of 2019-2021 (n=54 at each study site). The bottom sediment sampling locations were at the foraging areas of the wetlands on the day of water sample collection. Bottom sediment samples from the plant root zone, with the thickness of 10–15 cm from the surface, were collected using an Ekman dredge and stored in acid-washed plastic containers. Predominant aquatic vascular plants like *Hydrilla verticillata* (submerged/submersed) and *Vallisneria spiralis* (submerged) were observed to be the choicest waterfowl food plants in both wetlands. These plant species were also collected alongside the collection of water and bottom sediments. 108 plant samples (9 samples of each plant species from each study site on a particular sampling day) were collected from previously selected nine spots (one sample each of two plant species from one spot) at each study site throughout the study tenure. However, plant species were not digested separately but taken together to consider as NOPI food plant at each sampling spot on each sampling day (n=54 at each study site).

3.8.2 Sample preparation

Water samples were collected in acid-washed 500 ml polyethene bottles. We did not filter water samples to record the maximum possible metal intake through drinking the ambient water. 1mL of concentrated Nitric acid (HNO_3) was added to the water samples and stored in the refrigerator at 5ºC and were analysed following Eaton et al. (1995). Plant samples were washed thoroughly to remove external surface contamination to record the metal concentrations in the food plants only. Plant samples were collected in plastic bags and stored at –20º C before preparation and analysis. The plant samples were washed thoroughly with Millipore water (18 M water from a Millipore water purification unit). The whole plants were surface dried in blotting paper and 25 g wet weight (WW) of each species then cut into small pieces and mixed together; mixed plant samples were dried in an air oven slowly at a temperature of 90◦C. For plant digestion and preparation of extracts and bottom sediment sample preparation, we followed the works of Eaton et al. (1995) and Chatterjee et al. (2010). After collection, the bottom sediment samples were air-dried and sieved using a 2-mm plastic sieve to remove plant parts and pieces of detritus. For sample preparation and acid digestion, we followed Kulbat and Sokołowska (2019) and Adhikari et al. (2020). An outline of the digestion methods for extraction of four heavy metals from different sample media is given in Table 1.

3.8.3 Analytical methods

The water samples, plant extracts and digested bottom sediment thus prepared were stored inside a refrigerator for Atomic Absorption Spectrophotometric determination of Cu, Zn, Cr, and Pb. Detection limits for Cu, Zn, Cr and Pb were 1.5, 1.5, 3 and 15 µg L^{-1} respectively. All detection limits are based on 98% confidence level (Atomic Spectroscopy: www.perkinelmer.com/atomicspectroscopy). The concentrations of metals from prepared samples were measured in Atomic Absorption Spectrometer (AAS) (AAnalyst 100, Perkin Elmer) using element-specific hollow cathode lamps in default condition, by flame absorption mode and followed the methods elaborated by Eaton et al. (1995). Standards recommended by Perkin Elmer were used for the calibration of the instrument (Atomic Spectroscopy: www.perkinelmer.com/atomicspectroscopy). Each time the concentration was determined using non-linear calibration with three replicates each and 3.0s integration time. The mean concentration, standard deviation (SD), and relative standard deviation were determined. The analytical precision was conducted with a repetitive rate of 10 %.

3.8.4 Heavy metal exposure risk assessment model

3.8.4.1 Exposure assessment

The exposure model was designed to quantify the risk of exposure to chemicals in the surrounding environment. In the present study, we considered oral ingestion as the only potent accumulation pathway due to contaminant exposure (Suter, 2011). Three major paths of oral ingestion exposure in birds via food, water and food associated sediment were taken into consideration. Quantification of heavy metal exposure risk were calculated by using the below-mentioned formulae. Daily food consumption rate $[I_{df}]$ (dry weight) (g d^{-1}) can be calculated using the following equation (Liu et al., 2015):

$$I_{df} = 0.648 \times (BW^{0.651}) \quad (1)$$

where, BW was the body-weight of the selected waterbird (g). Food consumption rate (56.2 g d^{-1} dry weight) was estimated from allometric regression models proposed by Nagy (1987). The average body weight of NOPI was 950 g (www.allaboutbirds.org).

Daily water consumption rate [I_w] (mL d^{-1}) was also assessed (57 mL d^{-1}) from the allometric regression model proposed by Calder and Braun (1983):

$$I_w = 59 \times (BW^{0.67}) \quad (2)$$

where BW was the body weight of the elected waterbird (kg).

The rooted aquatic plants were uprooted and used as food by herbivorous waterbirds. Sediments associated with the uprooted aquatic macrophytes could be a potential auxiliary metal exposure pathway (Beyer et al., 1994; Liang et al., 2016; Xia et al., 2021). Food associated sediment consumption rate [I_s] (g d^{-1}) was calculated as 1.9 g d^{-1} using the following equation:

$$I_S = P \times I_{df} \quad (3)$$

where, P is the proportion of bottom sediment attached to the food plants. In the present study, P (3.3%) of Mallard (*Anas platyrhynchos*) was selected for NOPI (Beyer et al., 1994).

The oral exposure dose [E_j] of heavy metals (j) (mg kg^{-1} d^{-1}) were calculated using the below mentioned formula followed by Suter (2011).

$$E_j = \frac{\sum_{i=1}^{m}(I_i \times C_{ij})}{BW} \quad (4)$$

where, m is the number of absorbing mediums. In this study, m is three; food, water and bottom sediment. I_i is the consumption rate of the medium (i) (g d^{-1} or mL d^{-1}). C_{ij} denotes the concentration of metal (j) in the medium (i) (mg kg^{-1} or mg L^{-1}).

3.8.4.2. Risk assessment

Tolerable Daily Intake (TDI) is the quantification of a contaminant, which can be ingested daily without posing a significant health risk (Gupta, 2018). So, TDI doesn't cause any adverse health effects in any species. TDI can be estimated by the following equation (CCME, 1998):

$$TDI_j = \frac{(LOAEL_j \times NOAEL_j)^{0.5}}{UF} \quad (5)$$

TDI_j is the tolerable daily intake of heavy metal (j) (mg kg^{-1} d^{-1}). $LOAEL_j$ and $NOAEL_j$ respectively denote the lowest and no observed adverse effect of heavy metal (j) and their units are the same (mg kg^{-1} d^{-1}). Data of $LOAEL$ and $NOAEL$ for avian toxicity tests on heavy metals were taken from toxicological benchmarks for wildlife (Sample et al., 1996). UF is the uncertainty factor. UF was used to account for the uncertainty of the risk model and variances in sensitivity among various species (according to Protocol for the Derivation of Canadian Tissue Residue Guidelines for the Protection of Wildlife). The total UF applied or TDI assessment may not be less than 10 (CCME, 1998). The UF selected may be higher than 10 depending on some factors like substance, amount and data availability. In this study, 10 is selected as the value of UF. Morrissey et al. (2005) and Liang et al. (2016) in their respective studies on risk assessment selected the value of UF as 10.

The Hazard quotient (HQ_j) has been calculated to estimate particular heavy metal (j) exposure risk to birds. This calculation was done following the human health risk assessment model (USEPA, 2001).

$$HQ_j = \frac{E_j}{TDI_j} \quad (6)$$

Where, E_j is the oral exposure dose of heavy metal (j) and TDI_j is the tolerable daily intake of heavy metal (j). If $HQ < 1$, the population is unlikely to experience adverse effects of heavy metals, whereas if $HQ > 1$, a negative effect s the population may occur (Liu et al., 2015). In this present study, HQ was classified into three categories: no risk ($HQ < 1$), low risk ($1 < HQ < 2$), and high risk ($HQ > 2$). This classification was done following the work by Liang et al. (2016).

Hazard index (HI) was used to investigate the combined risk of selected heavy metals to the waterfowl at a particular habitat.

$$HI_n = \sum HQ_j \quad (7)$$

Where, HI_n is the hazard index of sampling site (n). HI represents the sum of HQ and can be used to estimate the risk of several potentially hazardous heavy metals within a wetland.

3.9 Determination of bioaccumulation factor (BAF)

Bioaccumulation factors for rooted food plants for the four metals is the ratio of concentration of heavy metals in plants and in soils and it specifies the capacity of the plants to accumulate metals (Aladesanmi et al., 2019):

$$BAF_i = \frac{P_i}{S_i} \qquad (8)$$

Where, P_i is the concentration of heavy metals in plant (mg kg^{-1}) and S_i is the concentration of heavy metals in bottom sediment (mg kg^{-1})

3.10 Estimation of physio-chemical parameters of water

Water samples collected from 5 to 10 sampling spots, depending on the size of the wetland, in clean stopper glass bottles (1 L) by dipping those completely into the water (about 6-8 cm below the water surface to evade floating debris). Factors of water samples like subsurface water temperature (WT), pH, salinity, total dissolved solids (TDS), and electrical conductivity (EC) were measured on the spot by Eutech PCSTester 35 Multi-Parameter. Dissolved oxygen (DO), phosphate (PO_4^{3-}), nitrate (NO_3^-) and silicate (SiO_2) were analysed on the spot titrimetrically using Aquamerck Field-testing kits of Merck (Germany).

3.11 Species-specific nutrient and guano loading

The direct estimation of ornithogenic nutrient loading (NL) and guano loading are nearly an impossible task (Manny et al., 1994). So, this is indirectly extrapolated from the bird count data. Different approaches of ornithogenic NL estimation is reviewed in detail in previous literature (Adhurya et al., 2020; Dessborn et al., 2016). All of these approaches relied on allometric relationship of faecal matter production to calculate species-specific NL, because digestive performance of different waterbird species are reported to be similar (Hahn et al., 2008, 2007; Manny et al., 1994; Nagy et al., 1999).

3.11.1 Guano loading (GL)

Monthly guano input (kg $month^{-1}$) by individual waterbird species was calculated by multiplying daily faecal matter production rate (DFP) into number of days in the month and equivalent monthly average bird count of that species. Total monthly guano input (kg month-

^{1}) in a particular wetland was obtained by summing up guano input data for all individual species.

3.11.2 Species-specific and total nutrient (N and P) loading

The number of waterbirds belonging to different species are converted to equivalent number of a particular reference species (preferably which is available in the studied system and for which nutrient loading (NL) estimation parameters are available in literature) depending upon their body mass (Adhurya et al., 2022). Biomass of different species used for this purpose are obtained from relevant literature (Dunning, 2008; Lepage et al., 2014). Then, the DFP rate is multiplied with the obtained equivalent waterbird number to calculate the total daily faecal matter produced by a particular waterbird species.

The estimation of DFP is a difficult task due to unavailability of data. To ease this problem, Boros (2021) classified different waterbird species into several groups and provided daily faecal nutrient (C, N and P) load per individual. This generalised estimation method is useful if different classes of waterbirds have species with similar biomass. But for the groups having species with highly variable biomass (e.g., dabbling ducks, diving ducks, cormorants, herons etc.), this method seems unrealistic. To overcome this problem, the DFP can be estimated with two approaches. In the first and most conventional approach, the DFP is estimated from dropping mass (DrM) and dropping rate (DrR) of different waterbird species (Equation 1). These two parameters are allometrically related as follows: $\mathrm{DrM} = 10^{-3.065} \times \mathrm{M}^{0.8901}$ and $\mathrm{DrR} = 10^{2.1299} \times \mathrm{M}^{-0.3065}$ (Hahn et al., 2008), where M is biomass of the species.

$$DFP = DrR \times DrM \tag{9}$$

This conventional method is followed in the most of the published researches (Gremillion and Malone, 1986; Hahn et al., 2008; Mallin et al., 2016; Manny et al., 1975; Scherer et al., 1995). Another approach to estimate the DFP is from the food intake. The food intake is in turn calculated with bioenergetic approach (Hahn et al., 2008, 2007; Post et al., 1998). In this approach, the food intake is calculated from daily energy requirement (DER), energy content in food (E) and apparently metabolizable energy in food (AM). DER follows an allometric relationship and can be calculated using following formula $\mathrm{DER} = 10^{1.0195} \times \mathrm{M}^{0.6808}$ (Nagy et al., 1999). DFP can be estimated with the formula given below (Hahn et al., 2007):

$$DFP = \frac{\alpha \times DER}{E \times AM} \qquad (10)$$

Here, α is the ratio between daily faecal production and daily food intake. All of these approaches give nearly similar results and can be used depending upon data availability of other parameters needed to estimate nutrient loading.

Now, the proportion of daily faecal production entered the lake depends on the fraction of day (f_d) the waterbird species spends inside the lake. An account of residence time of different waterbird species can be found in previous literature (Boros, 2021; Adhurya et al., 2022). In this study, f_d is taken as 1 (24h/24h) for the species reside almost whole day in the lake, *e.g.*, jacanas, coots, moorhens, many diving ducks etc. For the species which usually stay only the day-time in the lake (*e.g.*, most herons, cormorants, dabbling ducks and geese etc.), f_d is considered as $day\ length\ in\ hour/24$. While, for the species which mostly spend night in the lake (*e.g.*, bitterns, night-herons etc.), f_d is considered as $night\ length\ in\ hour/24$. In case of Woolly-necked Stork, f_d is taken as 0.167 as per personal observations on 10 individuals at different sites. Kittur and Gopi Sundar (2020) similarly reported Woolly-necked storks had higher preference for agriculture fields (64%) as foraging ground than wetlands (9%). Data on day-length was collected from web resources for the nearby city Bankura ("Sunrise and sunset times in Bankura," 2022). Before calculating the equivalent species number, the number of individuals of each species is multiplied with f_d to obtain effective number of that species. Then daily NL can be estimated with the equation given below:

$$NL = \sum_{1}^{S} DFP \times f_d \times N_b \times \frac{a}{b} \times X_{drop} \qquad (11)$$

Here, a and b is the biomass of the concerned species (for which the NL will be estimated) and reference species (for which the data regarding X_{drop} is available) respectively. X_{drop} is the elemental concentration (it can be N, P or C) of faecal matter and S is number of species. In this study, fortnightly census data are averaged to obtained monthly bird count, which is used for daily NL estimation for that month. Daily NL is further multiplied with number of days of that month to obtain monthly NL.

X_{drop} varies with the feeding habit of the species. Dropping of carnivorous waterbirds are more phosphatic than the herbivorous waterbirds (Adhurya et al., 2020). So, it is essential to group all species depending on their feeding habit prior to calculate the nutrient loading. All waterbirds are broadly categorised into three main groups: (i) herbivorous waterbirds, (ii) carnivorous waterbirds and (iii) omnivorous waterbirds. Feeding habit of the birds are understood from del Hoyo et al. (2017). For the herbivorous waterbirds, Greylag Goose (*Anser anser*) is used as reference species as per availability of X_{drop} data (Kear, 1963) and equation 2 is used for DFP estimation. The carnivorous waterbirds are further divided into seven groups due to their highly heterogeneous feeding habit. Great Cormorant (*Phalacrocorax carbo*) is used as reference species for NL estimation of cormorants and darters (piscivorous birds). Grey heron (*Ardea cinerea)* is used as reference species for the NL estimation of the species relies on arthropods and small fish diet (e.g., herons, egrets, bitterns, grebes, waterhens etc.). X_{drop} data of the aforementioned species is taken from Marion et al. (1994). Storks, ibises and Tufted duck relies mostly on molluscan diet. For this reason, White Ibis (*Eudocinus albus*) are considered as reference species for NL estimation of this group as per its data availability of X_{drop} (Bildstein et al., 1992). Equation 3 is used for DFP estimation of these three carnivorous waterbird groups. Rest of the carnivorous waterbirds are classified and NL is estimated following Boros (2021). Such as, all sandpipers belonging to genus *Actitis* and stints are classified as Small Sandpipers; all sandpipers of genus *Tringa* along with snipes classified as Large Sandpipers; and Lapwings and Plovers formed another two groups. Proportion of carnivorous and herbivorous diet varied greatly in case of Common Moorhen and Northern Shoveler, depending upon food availability. In this case, we assumed 50% carnivorous and herbivorous diet. NL for these species is estimated by considering Greylag Goose and Grey Heron as reference species. Parameter values used in NL estimation are given in Table 3.4 and Table 3.5. In addition to that, species specific feeding habit, residence time in wetlands and reference species are mentioned in Table 3.6.

3.11.3 Exclusion of certain species from NL and guano loading estimation

Raptors, lapwings (except Grey-headed Lapwing), kingfishers, wagtails, swallows, tern, gull and Red-naped Ibis were not considered in NL estimation as they spend very less time (residence time) in the waterbody to contribute significantly in the guanotrophication. Out of three lapwings recorded during the present study, Grey-headed Lapwings showed their habitat preferences in marshy laces - the edge of wetlands, wet grazing grounds within the wetlands. Ali and Ripley (1987) also recorded similar habitat preferences for Grey-headed Lapwing. However, other two Lapwings preferred drier biotopes than Grey-headed Lapwing (Ali and Ripley, 1987). Red-naped Ibis also preferred open dry land and agricultural lands

(Anjali and Rana, 2021), thus excluded from NL analysis. On contrary, other two ibises (Black-headed Ibis and Glossy Ibis) predominantly preferred wetlands as roosting and feeding ground (Taylor and Taylor, 2015; Anjali and Rana, 2021).

3.11.4 Uncertainty in NL estimation

All model estimations are prone to error due to underlying model assumptions, measurement error and paucity of data. Likewise, NL estimation of this study made several assumptions, that will contribute to uncertainty of correct predictions. Firstly, the parameter values of DER, DrR, DrM, E and AM are taken from previously published literature performed mainly on temperate zone. Since, temperature positively influence the DER of waterbirds, it will leads to underestimation of the NL (Kendeigh et al., 1977; Post et al., 1998). Additionally, our estimation not considered flight cost of birds. The foraging ground of the externally feeding ducks and geese is not known. Moreover, only a single visit to foraging ground is considered in our study. But externally feeding ducks and geese may perform double foraging trip depending upon environmental temperature and wind speed (Post et al., 1998). The additional flight cost will enhance the DER, that will ultimately enhance NL. Similarly, study needed on dropping mass and dropping rate of different waterbirds of this area to check the validity of the model of Hahn et al. (2008) for the tropical region like India. Additionally, E expected to be less in the agricultural food produced using conventional agricultural practices as compared to the E values estimated in developed temperate nation. AM depends on the diet of concerned avian species and need proper detailed study. So, generalised use of this parameter may lead to underestimation of DFP as well as NL. Furthermore, this study also not considered variances of X_{drop} due to pre-migratory weight gain and post-migratory weight loss (Post et al., 1998).

3.12 Field observations on time activity

For recording diurnal time activity of waterbirds a total period of 64 days (two days per wetland per month from November through February during the wintering period of migratory waterbirds (October through March) for consecutive two years 2018 – 2019 and 2019 – 2020) were invested at 4 study sites. Selected four winter months had sufficiently large (each species density ≥ 30) waterbird populations (including winter migrants) for behaviour study. According to Morrison (1984), thirty was the minimum sample size required for analysing waterbird behaviour. Later, in 2010, Liordos also suggested that this sample size was mandatory. For ad libitum binocular observations and video recordings, three random durations of 30 min within four 2hr 45min time durations between 6.00 AM and 5.00 PM on each sampling day were devoted to scanning the detailed behaviour of the species in the wetlands. Therefore, altogether 64 observations on time activity, spending 192 hr, were made and the mean values in percentages were represented.

Behavioural categories were recorded following Green, Fox, Hughes, and Hilton (1999) and these were: feeding (diving and interval between two dives); resting (included sleeping behaviour without head-on-back and with head-on-back and also eyes open or closed, loafing); preening (included comfort, bathe, wing-flap, head-shake, wing-shake, stretch); swimming (included searching/scanning, and flying); others (included alert, intra- and interspecific interactions social interaction).

Only the first/initial observation on each individual of waterbird was considered (following the initial observation method described by Liordos, 2010). Time-activity was quantified by the scan-sample approach (Martin and Bateson, 1983; Losito et al., 1989). Hepworth and Hamilton (2001), Gilby et al. (2010), and Ali et al. (2016) also suggested using instantaneous or scan sampling for studying the behaviour of individuals in groups. Behaviour of every individual in a group was documented at fixed time intervals (30 sec) during the scan sampling following Altman (1974) during the selected diurnal hours. Observations were made from two favoured (because of their accessibility and unimpeded yet secretive view) vantage points at each site, using Nikon Fieldscope (25–75 × 82 ED), Olympus (8 × 40 DPS I) binoculars, and Sony RX10 IV camera.

3.13 Foraging guilds of waterbirds

Twelve prevalent waterbird species were studied; out of these twelve, eight were Palearctic migrants, and rest four were residents to the eastern part of the Indian subcontinent. Previous studies by Nandi et al. (2004), Nandi et al. (2007) and Mukherjee et al. (2021) also recorded sizeable populations of these birds to winter in the sites under the present investigation. Four-letter alpha codes for the birds' names were used following Pyle and DeSante, 2003. The name of these waterbirds, their alpha codes, and conservation status are given in Table 3.7.

3.13.1 Water depth and foraging habitat

Foraging habitats of these waterbirds (mainly divers) were characterized and categorized conferring to water depth and types of associated vegetation. Portions of water bodies with <1.5 m water depth characterized as shallow water regions, whereas, deep water regions represented by water level >1.5 m.

Works of Liordos (2010) and Peŕez-Crespo et al. (2013) were followed for the categorization of the foraging habitats based on the water depth and type of associated vegetation. Five major foraging habitats for both resident and migratory waterbirds were identified in four study sites.

1. Deep water with floating vegetation (DWFV): This was the habitat that had deep water (i.e. >1.5 m depth) covered by floating vegetation.
2. Deep water with a clear surface (DWCS): This was the area of wetland having deep water (i.e.> 1.5 m depth) without any emergent or floating vegetation. This area consisted of the deepest portion of the water bodies.
3. Shallow water with floating vegetation (SWFV): The depth of this habitat was < 1.5 m, it had copious floating vegetation predominantly consisted of water hyacinth.
4. Shallow water with a clear surface (SWCS): The depth of this habitat is < 1.5 m. This area was devoid of any emergent and floating vegetation.
5. Shoreline with hydrophytic vegetation (SLHV): This habitat consisted of predominantly mudflats at the shoreline with vegetation.

3.13.2 Foraging techniques employed by the waterbirds

Feeding behaviours were categorized by the foraging techniques employed by these waterbirds following the works by Liordos (2010) and Peŕez-Crespo et al. (2013). Eight major foraging behaviours were identified:

1. Diving (DI): The bird temporarily vanishes underwater to forage
2. Upending or Tipping (UP): It is a feeding technique where the bird moderately dips in a vertical position while feeding, however, its tail and legs remain above the water surface.
3. Beak-dip (BD): In this technique birds mainly feed by dipping its beak in to the water. Dipping of beak can be either partly or in full.
4. Head-dip (HD): This technique involves dipping the head including the beak in water for foraging. In this case, the eyes too are submerged while foraging.
5. Neck-dip (ND): This foraging technique uses dipping up to the neck under water level, fully or partially at the foraging site.

6. Filtering or Gleaning (FI): In this technique the bird held its beak in plane of water surface, while submerging only the mandible for straining the food particles from the water surface.

7. Picking (PI): This foraging technique is characterized by picking the food substances mainly from the top of the muddy shorelines.

8. Grazing (GR): when birds eat floating or marginal macrophytes.

3.13.3 Niche dimension and guild structure

Two separate days, for two predetermined time durations (one from 7 am to 10 am, and other from 2 pm to 5 pm) were invested to specially record the foraging behaviour of the species from the selected vantage points at the study sites covering each habitat type. However, during the study on diurnal time activities, the foraging behaviour of waterbirds was also carefully and critically recorded. Foraging habitats and foraging techniques were recorded for a specific waterbird in consultation with the work of Ali and Ripley (1968). Not less than 30 foraging observations for each of the 12 waterbird species were used for the present study. Data were arranged into three matrices (i) Feeding habitat (12 species X 5 habitat variable), (ii) Feeding technique (12 species X 8 feeding technique), and (iii) Combined foraging habitat and foraging technique (12 species X 40 possible combinations for both the dimensions). Out of 40 possible combinations, 25 combinations were feasible rejecting combinations that were not practical (like Shoreline with hydrophytic vegetation and diving). Both niche breadth and niche overlap were tabulated following these matrices and these matrices also used for assigning foraging guilds (Gatto, Quintana, & Yorio 2008; Liordos, 2010; Chatterjee et al., 2020).

3.13.4 Niche breadth and niche overlap calculations

The one-dimensional matrices of both niche dimensions were used for calculating the foraging niche breadth and niche overlap. The foraging niche breadth of a species was calculated using the formula derived by Levins (1968):

$$Foraging\ Niche\ Breadth\ (B)\ = \sum_{i=0}^{n} \frac{1}{P_i^2} \qquad (12)$$

Where P_i was the proportion of observation in individual category (**i**) within a specific niche dimension (i.e., habitat and technique), i.e., P_i is the proportion of exploitation of a particular resource by the species under study in a specific niche dimension.

Foraging niche overlap (O) between every pair of waterbird species & within each niche dimension was calculated by means of the index of Pianka (1974):

$$O_{jk} = \frac{\sum P_{ij} \times P_{ik}}{\sqrt{\sum P_{ij}^2 \times P_{ik}^2}} \quad (13)$$

Where P_{ij} was the proportional values of exploitation of resource i by species j and k, respectively (i.e., j^{th} and k^{th} species). This index was ranged from values between 0 to 1. The value of 1 signified complete niche overlap between the species pair under contemplation and 0 denoted complete isolation.

3.13.5 Assigning guild for the waterbirds in the community

For assigning a guild to 12 waterbirds selected for the study cluster analysis was used in the present study, considering three original matrices (for foraging habitats, foraging techniques, and bi-dimensional). These matrices were subjected to arcsine transformation, as recommended by Fowler and Cohen (1990), where $y = arcsine\ X0.5$ which was used to represent proportion and to decrease Kurtosis of the distribution of a variable (Peŕez-Crespo et al., 2013).

3.14 Calculation of genetic distances and construction of phylogenetic tree

3.14.1 Pairwise Multiple Sequence Alignment

This bioinformatical analysis has been performed with Clustalw webserver (https://www.genome.jp/ tools-bin/clustalw). FASTA sequences of mitochondrial genomes have been retrieved from the NCBI database (http://www.ncbi.nlm.nih.gov/pubmed/) with respective GenBank accession numbers tabulated in Table 3.8.

3.14.2 Construction of Phylogenetic Tree

Phylogenetic tree has been reconstructed with the mitochondrial genomes of the target species of birds using the MEGA X software (https://www. megasoftware.net/). Red junglefowl *Gallus gallus* (GenBank acc. no: KX987152.1) has been taken as an outgroup. Sequence alignment has been carried out in the software itself and has been further used for finding the best suitable model for the tree construction following the instructions given in the software. The Generalised Time Reversible (GTR) has been obtained to be the best suitable model for phylogenetic tree construction. Rapid bootstrapping with 1000 replications has generated satisfactory results which have corroborated the previous report.

3.13.3 Estimation of Genetic Distance

Pairwise genetic distances between the species have been calculated based on nucleotide substitution in the mt-genomic DNA in the MEGA X software using Kaimura 2-Parameter model. Bootstrapping with 1000 replications has been performed while estimating the distances.

3.15 Statistical analyses

Basic statistical analyses like correlation, ANOVA, Post-hoc (Tukey HSD) and multivariate exploratory statistical analyses like cluster analysis, CCA (Table 3.9) were done for this present study. conducted using SPSS 16 (SPSS for Windows Release 10, 2018) and Statistica for windows 10.0 (StatSoft Inc., 13.5: 2018) software. The avian community indices were calculated by PAST (version 3.4, 2019) software. The CCA ordination analyses were done by using the Canoco for Windows (version 4.02., 1999). Graphs were made using Origin Pro (version 9.6, 2019). The selection of methods for statistical analyses was done following Quinn and Keough (2002). Multivariate statistical analyses were conducted on these data.

Table 3.1 Description of the study sites. Classification of the wetlands mentioned following Ramsar Wetland Classification (IW: Inland Wetland, HMW: Human-made Wetland, O: Permanent freshwater lakes with area >8ha, includes large oxbow lakes; Tp: Permanent freshwater pools/ponds; 1: Aquaculture ponds; 6: Water storage areas; 7: Excavations)

No.	Sites	Location	Description
1	Gajoldoba	26°45'23.13"N, 88°35'13.17"E	Shore length (SL): 13.8km (bridge length 1180m), Area (A): 700ha, Altitude: 110msl, Mean Depth: 8.4m. Located in Jalpaiguri district. It is a reservoir on Teesta river. Physiographic zone: Sub-Himalayan alluvial fans. Recently it has been declared as Pakhibitan Wildlife Sanctuary. Tourism is one of the major problems of this site. Type of wetland: HMW-6.
2	Nararthali	26°31'1.27"N, 89°44'4.63"E	SL: 1.59km, A: 6.5ha, Altitude: 57msl, Mean Depth: 2.5 m. Located in Alipurduar. This is also an ox-bow lake formed by meandering of Raidak River. Physiographic zone: Sub-Himalayan alluvial fans. Wetland is situated within the Buxa Tiger Reserve hence it is protected from anthropogenic interventions and also it is an Important Bird Areas (IBA: IN317). Timely water hyacinth removal

			is done by West Bengal Forest Department. Type of wetland: IW-Tp
3	Rasikbeel	26°25'17.44"N, 89°43'17.05"E	SL: 8.69km, A: 78.9ha, Altitude: 35.5msl, Mean Depth: 2.9m. Located in Coochbehar district. It is an ox-bow lake and formed by Raidak and Ghoramara River. Physiographic zone: Sub-Himalayan alluvial fans. This wetland complex comprises of Raichenmari, Atiamochor, Bochamari, Sakobhanga and Naldubi wetlands. Habitat quality of this wetland is abating due to water hyacinth bloom, wastewater input, fishing activity, tourism and poor management. Type of wetland: IW-O
4	Barasagardighi	24°58'1.30"N, 88° 6'0.96"E	SL: 3.05km, A: 52.1ha, Altitude: 22msl, Mean Depth: 1.9m. Located in Ganga and Mahananda river basin of Malda district. Physiographic zone: Barind upland. This wetland is under West Bengal Fishery Department, thus fairly protected from anthropogenic activities. However, unscientific water hyacinth management is a major problem in this area. Type of wetland: HMW-1
5	Nayabandh	24°56'37.32"N, 88°17'56.24"E	SL: 1.74km, A: 15.8ha, Altitude: 24msl, Mean Depth: 1.6m. Located in Punarbhaba and Tangon river basin at Malda district and near Indo-Bangladesh border. Physiographic zone: Barind upland. It is a designated Important Bird Area (IBA: IN324) of West Bengal and due to scientific conservation measures and local awareness, habitat quality of this wetland is decent. Type of wetland: IW-O
6	Ahiran	24°31'0.33"N, 88° 1'36.21"E	SL: 0.88km, A: 4.75ha, Altitude: 26msl, Mean Depth: 1.7m. Located in Hooghly and Falgu river basin at Murshidabad district and beside national highway. Physiographic zone: Upper Gangetic delta. Timely water hyacinth management and community initiatives make this wetland a suitable roosting site for waterbirds. Type of wetland: IW-Tp
7	Nilnirjon	23°49'16.25"N, 87°24'25.12"E	SL: 27.09km (bridge length 1.18km), A: 684ha, Altitude: 71msl, Mean Depth: 7.6m. Located in Birbhum district. Physiographic zone: Plateau-fringe fans. It is also known as Bakreswar dam and protected by Irrigation Department of West Bengal, which curtail the anthropogenic pressure in this area. Type of wetland: HMW-6
8	Adra Sahebbandh	23°29'0.69"N, 86°42'22.11"E	SL: 7.98km, A: 76ha, Altitude: 166msl, Mean Depth: 3.5m. It is a man-made wetland at Purulia district and surrounded by “Kang” forest. Physiographic zone:

			Degraded plateau. Timely water hyacinth management and proper protection by Indian Railway Department make this habitat suitable for winter avian fauna. Type of wetland: HMW-7
9	Purbasthali	23°27'30.15"N, 88°20'19.66"E	SL: 22.92km, A: 219ha, Altitude: 7msl, Mean Depth: 2.5m. Located in East Burdwan district and locally known as Chupi Char. It is an oxbow lake made by Hoogly river. Physiographic zone: Upper Gangetic delta. Wastewater input, runoff from adjacent agricultural fields, use of loud sound system for picnic purpose at winter, fishing activity create immense disturbance in this area. Type of wetland: IW-O
10	Gangdoa Dam	23°24'10.13"N, 87° 4'57.52"E	SL: 9.24km, A: 92.7ha, Altitude: 108msl, Mean Depth: 7.5 m. It is a reservoir of Shali river located in Bankura district. Physiographic zone: Plateau-fringe fans. This area is mostly surrounded by agricultural land, but fishing and illegal hunting creates pressure on this wetland. Type of wetland: HMW-6
11	Purulia Sahebbandh	23°20'23.10"N, 86°21'37.90"E	SL: 2.87km, A: 31.3ha, Altitude: 250msl, Mean Depth: 2.5m. It is a man- made lake governed by Purulia Municipality. Physiographic zone: Degraded plateau. Wastewater input, plastic and thermocol load, different anthropogenic activities, tourism and land use change (urbanization) in the surrounding area are major reasons for habitat degradation in this site. Type of wetland: HMW-7
12	Kadamdeuli Dam	23° 6'5.56"N, 86°51'49.87"E	SL: 5.26km, A: 38ha, Altitude: 116msl, Mean Depth: 4.5 m. Located in Bankura District and it is a dam area of Shilabati river where a canal from Mukutmanipur-Kangsabati dam meets. Physiographic zone: Plateau-fringe fans. The area is mainly surrounded by bushes, patch forest, however barren lateritic land also present. Type of wetland: HMW-6
13	Santragachi Jheel	22°34'39.60"N, 88°17'39.60'E	SL: 1.97km, A: 13.9ha, Altitude: 8msl, Mean Depth: 1.5m. Located in Hooghly river basin at Howrah district. Physiographic zone: Upper Gangetic delta. Unscientific management of water hyacinth, input of household wastewater from surroundings, garbage dumping-mainly plastics and thermocol from nearby hotels are major problems of this site. Type of wetland: IW-O

Table 3.2 List of prevalent aquatic vascular macrophytes, insects, mollusks, fish from four study sites of Purulia and Bankura District

Study sites	Major aquatic vegetation	Major macroinvertebrates	Major fish species
Adra Sahebbandh	*Eichhornia crassipes, Nymphaea pubescens, Nymphoides hydrophylla, Hydrilla verticillata, Myriophyllum spicatum, Alternanthera philoxeroides*	*Macrobrachium sp, Gerris sp, Anisops sp, Limnogonus sp, Ranatra filiformis, Bellamya dissimilis, Corbicula sp, Gyraulus labiatus*	*Labeo rohita, Cirrhinus cirrhosus,Cyprinus carpio carpio, Labeo fimbriatus, Labeo gonius, Barilius barna, Puntius terio, Puntius ticto, Aplocheilus panchax, Garra lamta.*
Purulia Sahebbandh	*Eichhornia crassipes, Wolffia globosa, Nelumbo nucifera, Hydrilla verticillata, Ceratophyllum demersum, Mersilea minuta*	*Macrobrachium sp, Gerris sp, Anisops sp, Diplonychus sp, Micronecta sp, Bithynia pulchella, Bellamya bengalensis, Gyraulus convexiusculus*	*Catla catla, Cirrhinus cirrhosus, Ctenopharyngodon idella, Cyprinus carpio carpio, Labeo bata, Puntius sophore, Puntius ticto, Oreochromis mossambicus, Notopterus notopterus, Wallago attu.*
Kadamdeuli dam	*Pistia stratiotes, Utricularia gibba, Ipomea aquatica, Nymphoides hydrophylla, Hydrilla verticillata, Typha angustifolia*	*Macrobrachium sp, Palemon sp, Gerris sp, Limnogonus sp, Canthydrus sp, Indoplanorbis exutus, Gyraulus convexiusculus, Lymnaea acuminata*	*Labeo rohita, Catla catla, Hypophthalmicthys molitrix, Ctenopharyngodon idella, Labeo boga, Labeo pangusia, Barilius vagra, Amblyopharyngodon mola, Glossogobius giuris, Mastacembelus armatus.*
Gangdoa dam	*Eichhornia crassipes, Ipomea aquatica, Nymphoides indica, Hydrilla verticillata, Myriophyllum spicatum, Typha angustifolia, Polygonum barbatum*	*Macrobrachium sp, Gerris sp, Anisops sp, Lethocerus indicus, Corixa sp, Bellamya bengalensis, Pila globosa, Lymnaea acuminata*	*Labeo rohita, Catla catla, Cyprinus carpio carpio, Labeo calbasu, Labeo boga, Glossogobius giuris, Puntius sophore, Puntius sarana, Brachygobius nunus, Oreochromis mossambicus.*

Table 3.3 Digestion techniques followed for determination of metals by AAS

Medium	Sample size	Extractant composition
Water	50mL	HNO_3 conc. + $HClO_4$ conc.
Soil	1g	HCl conc.+ HNO_3 conc. + $HClO_4$ conc.

Plant	1g	HNO_3 conc. + $HClO_4$ conc.

Table 3.4 Parameters used in NL estimation from waterbirds

Parameter	Species	Value	Unit	Reference
Concentration of N in faecal matter	White Ibis	45	g kg DW^{-1}	(Bildstein et al., 1992)
	Grey Heron	42.1	g kg DW^{-1}	(Marion et al., 1994)
	Greylag Goose	23.63	g kg DW^{-1}	(Kear, 1963)
	Great Cormorant	32.8	g kg DW^{-1}	(Marion et al., 1994)
Concentration of P in faecal matter	White Ibis	19	g kg DW^{-1}	(Bildstein et al., 1992)
	Grey Heron	114.7	g kg DW^{-1}	(Marion et al., 1994)
	Greylag Goose	3.93	g kg DW^{-1}	(Kear, 1963)
	Great Cormorant	143.2	g kg DW^{-1}	(Marion et al., 1994)
DrR	Greylag Goose	270.05	day^{-1}	(Hahn et al., 2008)
DrM	Greylag Goose	1.169	g	(Hahn et al., 2008)
A	Carnivorous waterbirds	0.395		(Hahn et al., 2007)
DER	White Ibis	1073.367	kJ d^{-1}	(Nagy et al., 1999)
	Grey Heron	1480.228	kJ d^{-1}	(Nagy et al., 1999)
	Great Cormorant	2005.354	kJ d^{-1}	(Nagy et al., 1999)
E	Carnivorous waterbirds	23900	kJ kg^{-1}	(Karasov, 1990)
AM	Carnivorous waterbirds	0.76		(Karasov, 1990)

Table 3.5. Daily faecal nutrient production (= $DFP \times X_{drop}$) of different reference waterbird species

Common Name	Scientific Name	Daily faecal nutrient production per individual bird (g d^{-1})		Reference
		Nitrogen (N)	**Phosphorous (P)**	
White Ibis	*Eudocinus albus*	1.05	0.44	Estimated
Grey Heron	*Ardea cinerea*	1.35	3.69	Estimated
Greylag Goose	*Anser anser*	7.46	1.24	Estimated
Large Sandpipers/Snipes	*Tringa spp., Gallinago spp.*	1.08	0.2	(Boros, 2021)
Small Sandpipers	*Actitis, Calidris*	0.93	0.11	(Boros, 2021)
Great Cormorant	*Phalacrocorax carbo*	1.43	6.24	Estimated
Lapwings	*Vanellus spp.*	0.65	0.12	(Boros, 2021)
Plovers	*Charadrius spp.*	0.93	0.11	(Boros, 2021)

Table 3.6. Feeding habit, residence period in the waterbodies of the waterbirds and reference waterbirds species used to calculate the GL and NL. (Reference species: 1. White Ibis (Eudocinus albus), 2. Grey Heron (Ardea cinerea), 3. Greylag Goose (Anser anser), 4. Large Sandpipers/Snipes (Tringa spp./ Gallinago spp.), 5. Small Sandpipers (Actitis spp., Calidris spp.), 6. Great Cormorant (Phalacrocorax carbo), 7. Lapwings (Vanellus spp.), 8. Plovers (Charadrius spp.))

No	Birds name	Feeding Habit	Residence period	Reference species
1	Lesser Whistling-duck	Herbivorous	Day length	3
2	Fulvous Whistling-duck	Herbivorous	Day length	3
3	Greylag Goose	Herbivorous	Day length	3
4	Cotton Pygmy-goose	Herbivorous	Whole day	3
5	Gadwall	Herbivorous	Day length	3
6	Eurasian Wigeon	Herbivorous	Day length	3
7	Indian Spot-billed Duck	Herbivorous	Day length	3
8	Northern Shoveler	Omnivorous	Day length	2,3

9	Northern Pintail	Herbivorous	Day length	3
10	Garganey	Herbivorous	Day length	3
11	Common Teal	Herbivorous	Whole day	3
12	Red-crested Pochard	Herbivorous	Whole day	3
13	Baer's Pochard	Herbivorous	Day length	3
14	Common Pochard	Herbivorous	Whole day	3
15	Tufted Duck	Carnivorous	Whole day	1
16	Ferruginous Duck	Herbivorous	Whole day	3
17	Little Grebe	Carnivorous	Whole day	2
18	Great-crested Grebe	Carnivorous	Whole day	2
19	Asian Openbill	Carnivorous	Day length	1
20	Woolly-necked Stork	Carnivorous	4 hours	1
21	Lesser Adjutant	Carnivorous	Day length	1
22	Glossy Ibis	Carnivorous	Day length	1
23	Black-headed Ibis	Carnivorous	Day length	1
24	Yellow Bittern	Carnivorous	Night length	2
25	Cinnamon Bittern	Carnivorous	Night length	2
26	Black Bittern	Carnivorous	Night length	2
27	Black-crowned Night Heron	Carnivorous	Night length	2
28	Indian Pond Heron	Carnivorous	Day length	2
29	Grey Heron	Carnivorous	Day length	2
30	Purple Heron	Carnivorous	Day length	2
31	Cattle Egret	Carnivorous	Day length	2
32	Little Egret	Carnivorous	Day length	2
33	Intermediate Egret	Carnivorous	Day length	2
34	Great Egret	Carnivorous	Day length	2

35	Little Cormorant	Carnivorous	Day length	6
36	Indian Cormorant	Carnivorous	Day length	6
37	Great Cormorant	Carnivorous	Day length	6
38	Baillon's Crake	Carnivorous	Whole day	2
39	White-breasted Waterhen	Carnivorous	Whole day	2
40	Purple Swamphen	Herbivorous	Whole day	3
41	Common Moorhen	Omnivorous	Whole day	2,3
42	Eurasian Coot	Herbivorous	Whole day	3
43	Bronze-winged Jacana	Herbivorous	Whole day	3
44	Pheasant-tailed Jacana	Carnivorous	Whole day	2
45	Grey-headed Lapwing	Carnivorous	Whole day	7
46	Little ringed Plover	Carnivorous	Whole day	8
47	Kentish Plover	Carnivorous	Whole day	8
48	Greater Painted-snipe	Omnivorous	Whole day	4
49	Pin-tailed Snipe	Carnivorous	Whole day	4
50	Common Snipe	Carnivorous	Whole day	4
51	Common Redshank	Carnivorous	Whole day	4
52	Common Greenshank	Carnivorous	Whole day	4
53	Common Sandpiper	Carnivorous	Whole day	5
54	Wood Sandpiper	Carnivorous	Whole day	4
55	Temminck's Stint	Carnivorous	Whole day	5

Table 3.7 Common name, four-letter alpha codes, scientific name, migration status and IUCN status of the selected waterbird species. Migration status: Winter migrant (WM) or Resident (R). IUCN status: Least Concern (LC), Vulnerable (VU). Source: www.iucnredlist.org

No	Common name	Alpha code	Scientific name	Migration status	IUCN status

1	Red-crested Pochard	RCPO	*Netta rufina*	WM	LC
2	Gadwall	GADW	*Mareca strepera*	WM	LC
3	Tufted Duck	TUDU	*Aythya fuligula*	WM	LC
4	Great-crested Grebe	GCGR	*Podiceps cistatus*	WM	LC
5	Common Pochard	COPO	*Aythya ferina*	WM	VU
6	Eurasian Wigeon	EUWI	*Mareca penelope*	WM	LC
7	Ferruginous Duck	FEDU	*Aythya nycora*	WM	LC
8	Northern Pintail	NOPI	*Anas acuta*	WM	LC
9	Eurasian Coot	EUCO	*Fulica atra*	R	LC
10	Little Grebe	LIGR	*Tachybaptus ruficollis*	R	LC
11	Cotton Pygmy-goose	CPGO	*Nettapus coromandelianus*	R	LC
12	Lesser Whistling-duck	LWDU	*Dendrocygna javanica*	R	LC

Table 3.8 Waterbirds considered for this study. The GenBank accession nos. and length of the mt-DNA are provided with the common name, alpha code and scientific names of the respective birds.

Common name & Alpha Code	**Scientific name**	**GenBank Accession no.**	**Length (bp)**
Lesser Whistling-duck (LWDU)	*Dendrocygna javanica*	NC_012844.1	16753
Northern Pintail (NOPI)	*Anas acuta*	KF312717.1	16599
Red-crested Pochard (RCPO)	*Netta rufina*	NC_024922.1	16625
Tufted Duck (TUDU)	*Aythya fuligula*	KJ722069.1	16616
Common Pochard (COPO)	*Aythya ferina*	KJ710708.1	16616

Table 3.9 Statistical analyses

Statistical Analysis Employed	**Applications**

Pearson Correlation	To determine correlations between physicochemical factors, guano-nutrient loading, habitat quality with avian assemblages, heavy metal concentration in the medium and exposure doses in the study sites.
T-test	T-test (two-tailed, unpaired, unequal variance) was performed to determine the significant difference (* marked) between concentrations of metals in different absorption medium (bottom sediment, water, food) from different study sites.
Regression Analysis	To determine how physicochemical factors, influence the abundance and diversity of waterbirds
Analysis of Variance (ANOVA) and Post hoc	ANOVA was carried out to test the differences among the means of the populations by examining the amount of variation within each of these samples, relative to the amount of variation between the samples. ANOVA was performed with a significance level of $P \leq 0.05$, to determine whether foraging techniques differed between habitats. Post hoc HSD Tukey tests were conducted to determine the mean values that differed significantly. Differences between different sampling sites for representative species-wise abundance data analyzing post hoc with Tukey's honestly significant difference (Tukey HSD) test (level of significance at $p < 0.05$) to highlight the significant differences between the study sites observed (Winer, 1971). The post-hoc analysis with Tukey HSD test also highlighted the significant differences between the intra-guild niche breadth of waterbirds based on foraging habitats and foraging techniques.
Principal Component Analysis (PCA)	PCA aimed at data reduction and interpretation by normally explaining variance–covariance structure through a few linear combinations of the original variables. PCA with Kaiser Normalization and Varimax rotation was performed on the dataset for macroclimatic factors. The factor loadings (FL) given by PCA for the first principal component were considered. Whether the loading was positive or negative, factors with loading magnitudes of more than 0.8 were “loaded” on the latent component and considered to be key influences on the avian population.
Canonical Correspondence Analysis (CCA)	Canonical correspondence analysis (CCA) is a multivariate method that is applied to unravel the relationships between biological assemblages and their environments (ter Braak, 1994; ter Braak and Verdonschot, 1995).

	CCA was applied to unravel the relationships between site-wise avian assemblages and gross physical features of the sites, such as depth, shore length and area. In the present study, CCA was employed to relate the crowding of migratory waterbird species to the physical features at thirteen different wetland wintering sites. This method was designed to extract synthetic environmental gradients from ecological datasets. In CCA, since species were assumed to present unimodal responses to linear combinations of physical variables of the sites, species were logically represented by points corresponding to their approximate optima in two-dimensional environmental subspace, and physical variables of the habitats by arrows indicating their directions and rates of change throughout the subspace. Species abundances could change across environmental gradients, so a unimodal response model should be a reasonable choice for analyzing quantitative abundance data spanning a narrow range of environmental parameter variations (ter Braak and Prentice, 1988). CCA was employed to analyze the compositional data, despite the fact that rare species can be problematic when using this analysis. CCA was also employed to relate the site-wise abundance of avian species to the macroclimatic factors.
Cluster Analysis	Cluster analysis was conducted to determine the linkage between the sites or months or habitat types on the basis of physicochemical factors or avian species richness and abundance using the Euclidean distance. Determination of number of guilds by cluster analysis based on two niche dimensions, namely foraging habitats and foraging techniques (i.e., bi-dimensional niche space) was also done.
Sorenson's Index (SSD)	SSD was calculated to analyze the similarities and dissimilarities in avian species composition between two study sites by using (2a/2a+b+c) formula. Where, a-number of species in both sites, b-number of species in second site only, c-number of species in first site only (Magurran, 2004).

Fig. 3.1 Study sites (1- Gajoldoba, 2- Nararthali, 3- Rasikbeel, 4- Barasagardighi, 5- Nayabandh, 6- Ahiran, 7- Nilnirjon, 8- Adra Sahebbandh, 9- Purbasthali, 10- Gangdoa, 11- Purulia Sahebbandh, 12- Kadamdeuli, 13-Santragachi jheel) location in West Bengal, India (India and West Bengal maps are not in scale).

Chapter 4
Diversity of waterbirds

4. DIVERSITY OF WATERBIRDS

Wetlands are one of the most productive and diversified ecosystems on the earth (Ghermandi et al., 2008). The copiousness of dissolved and particulate nutrients in the wetlands allows diverse planktonic and benthic communities to survive. Moreover, the abundance of dissolved nutrients in water bodies permits the growth of macrophytes, which in turn provide food, shelter, breeding and wintering grounds for many waterbird species (Adhurya et al., 2020). However, due to the reclamation of wetlands for agriculture, increased urbanization and unrestrained anthropogenic activities wetlands are disappeared in an alarming rate and since the early twentieth century half of the world's wetlands have been lost (Mckinney, 2002). Degradation of wetlands is one of the major underlying factors behind the declination of migratory waterbirds worldwide (Zakaria et al., 2013), as water avifauna use the wetlands as feeding, resting, nesting, breeding and roosting grounds (Stewart, 2001). Inversely wetland birds afford array of support to wetland ecosystem by maintaining biotic connections and ecosystem balance through seed dispersal, invertebrate and rodent population control, provide food (guano) for fish or other animals predating on them. For such reasons waterbirds are the first-rate bioindicator of wetland health (Chatterjee et al., 2020b) and therefore, studies on their diversity and abundance can aid to conservation of wetland ecosystem (Weller, 1988). Moreover, structure and composition of bird community in relation with physico-chemical factors give valuable information about environmental alteration due to anthropogenic impact. Thereby, the current conservation strategies rely mainly on the understanding of changing patterns of migratory wintering waterbird species diversity in India and sustainable maintenance mechanisms of wetland ecosystems (Randin et al., 2006; Bassi et al., 2014). Furthermore, Ma et al. (2010) pointed out that waterbird diversity is a critical ecological tool for evaluating wetland habitats both qualitatively and quantitatively. During the winter months, various migratory and resident birds inhabit different wintering sites on the East Asian-Australasian Flyway (EAAF) and Central Asian Flyway (CAF) throughout the state of West Bengal (Mazumdar et al., 2007, Nandi et al., 2007, Chatterjee et al., 2013 and Chowdhury and Nandi, 2014). The bird assemblages can be affected by various factors like the availability of foraging resources, the physical attributes of the wetlands and the abiotic changes in the wetlands and waterbird assemblages can also change the physico-chemical parameters of the wetlands (Paracuellos, 2006; Sigha Roy et al., 2011; Ramírez-Albores et al., 2014; Mukherjee et al., 2022).

Present work has been carried out at four wetlands of Purulia and Bankura districts of West Bengal, Adra Sahebbandh (ASB), Purulia Sahebbandh (PSB), Kadamdeuli Dam (KDM), Gangdoa Dam (GAD). These wetlands harbour a diverse array of waterbirds, both resident and winter migratory, during the winter months (Nandi et al. 2007, Mukherjee et al., 2021, 2022). The present study has been conducted to meet the objective to study the monthly change in waterbird assemblages at four study sites for consecutive two wintering seasons in West Bengal, i.e., October through March (2018-2019 and 2019-2020).

4.1 Results

4.1.1 Diversity of waterbirds in the study sites

A total 44 waterbird species belonging to 14 families were recorded from ASB (Table 4.1a). Family Anatidae was represented by highest number of species (14) followed by family Ardeidae (6). However, family Ciconiidae, Pandionidae, Anhingidae and Laridae was represented by a single species. Out of 44 species two species belonged to IUCN red list *Threatened* category. Common Pochard was in Vulnerable (VU) category and Baer's pochard was in Critically Endangered (CR) category. Rest 42 species were in Least Concern (LC) category. 24 species were winter migrants and rest were residents to this part of Indian subcontinent. Lesser Whistling-duck was the most predominant (mean 271.4±212.406) waterbird throughout the study tenure, followed by Red-crested Pochard (mean 124.2±147.060) and Cotton Pygmy-goose (mean 82.3±36.687). In ASB, number of individuals, number of species and estimated species (Chao1) were highest in the month of January (Fig. 4.1a). H' was highest in the month of November (2.687), followed by December (2.626) and January (2.550). Whereas D_{SIPM} were highest in the month of March (0.337), followed by February (0.223) and was lowest in December (0.096). J' was highest in the month of October (0.478) followed by November (0.420). D_{MARG} was highest in the month of November (5.485), followed by January (5.192) and December (5.042). However, three indices H', J' and D_{MARG} were lowest in the month of March (1.754, 0.263 and 3.060 respectively).

Total 37 waterbird species belonging to 10 families were recorded from PSB (Table 4.1b). Family Anatidae was represented by highest number of species (13) followed by family Ardeidae (7). Threskiornithidae, Acrocephalidae and Motacillidae families were represented by a single species. Only one species, namely Common Pochard, belonged to the Vulnerable (VU) category of the IUCN red list Threatened categories. Black-headed Ibis was in the Near Threatened (NT) category and rest 35 species were in Least Concern (LC) category. 18 species were winter migrants and rest were residents to this part of Indian subcontinent. Lesser Whistling-duck showed highest abundance (mean 369.2±698.071), followed by Common Moorhen (mean 32.5±34.321) and Red-crested Pochard (mean 25.9±31.039). An enormous decrease (~ 95% decrease from 2018-2019 to 2019-2020) in total abundance of birds were recorded from this wetland. In PSB, highest number of species were recorded in the month of January (33) and Chao1 was also highest for this month (33), however, highest number of waterbirds were recorded in March (Fig. 4.1b). H/ was highest in the month of January (2.349) and lowest in March (0.900). D_{SIPM} was highest in the month of March (0.690), and in contrast, *J/* was lowest for that specific month (0.117). However, D_{SIPM} was lowest in November (0.181) and *J/* was highest in October (0.416). D_{MARG} was highest in the December (5.038) and lowest in March (2.739).

Sixty-one waterbird species belonging to 15 families were recorded from KDM (Table 4.1c). Number of species recorded from KDM was highest among all the sites. Family Anatidae was represented by highest number of species (14) followed by family Ardeidae (10). However, three families, namely Podicipedidae, Rostratulidae and Laridae were represented by a single species. Three species, Common Pochard, Woolly-necked Stork and Lesser Adjutant; belonged to Vulnerable (VU) category and Black-headed Ibis belonged to the Near Threatened (NT) category. Rest 57 species were in Least Concern (LC) category. 29 species of waterbirds were winter migrants to this study site. Cotton Pygmy-goose was the most dominant species (mean 156.2±81.427), followed by Pheasant-tailed Jacana (mean 56.1±27.576) and Gadwall (mean 49.3±54.845). In KDM, highest number of species and estimated species (Chao1) were recorded from this study site in February (48 and 53 respectively) (Fig. 4.1c). However, highest number of waterbirds were recorded in the month of December. Both *H/* and *J/* were highest in the month of November (2.852 and 0.433 consecutively) and D_{SIPM} was lowest in this month (0.085). However, *H/* was lowest in March (2.352) and *J/* was lowest in February (0.219). On contrary, D_{SIPM} was highest in the month of February (0.210), followed by March (0.185). D_{MARG} was also highest in the month of

February (7.219) and lowest in March (4.464). However, A minor decrease in species number as well as individuals of waterfowls was recorded in the month of January. But higher number of waders were recorded in late January onwards (Table 4.1c).

A total 52 waterbird species belonging to 15 families were recorded from GAD (Table 4.1d). Family Ardeidae was represented by highest number of species (10) followed by family Anatidae (8). However, only two families, namely Accipitridae and Laridae; were denoted by a single species. Two species (Common Pochard and Lesser Adjutant) belonged to the IUCN red list Vulnerable (VU) category. Black-headed Ibis was positioned in the Near Threatened (NT) category. Rest 49 species belonged to the Lest Concern (LC) category. 28 species were winter migrants to this part of subcontinent. Barn Swallow was the most predominant (mean 54.1±49.968) waterbird throughout the study tenure, followed by Lesser Whistling-duck (mean 47.3±32.464) and Red-crested Pochard (mean 39.3±43.934). In GAD, number of waterbirds and number of species and estimated species (Chao1) were highest in the month of January (Fig. 4.1d). H' was highest in the month of December (3.004) and lowest in March (2.774). However, J' was highest in October month (0.626) and lowest in January (0.368). D_{MARG} was highest in the month of January (7.297) and lowest in March (4.580). D_{SIPM} was also highest in the month of January (0.083) but lowest in November (0.067). Overwhelming dominance (> 50% of total waterbird population) of any single species was not recorded from this study site during the wintering months.

4.1.2 Similarities in species composition between sites

Sorensen's Index (S_{SD}) was tabulated in Table 4.2. ASB and PSB, both were in Purulia district, showed maximum similarity (81%) in species composition of wintering avifauna; followed by KDM and GAD (75%). Both KDM and GAD were in Bankura district. Lowest similarity was observed in case of ASB and GAD (67%).

4.2. Discussion

All these four wetlands were in the *rarh* region of Bankura and Purulia districts of West Bengal, i.e., the connecting zone between the Chottanagpur plateau fringe and the lower Gangetic plain. All these sites harbour wintering waterfowl besides residents and are important birding sites of West Bengal (ebird.org/region/IN-WB-PU; accessed on 09/06/2022) on overlapping Central Asian Flyway (CAF) and East Asia-Australasia flyway (EAAF) (Dhanjal-Adams et.al., 2017; CAF National Action Plan- India, 2018; Mukherjee et al., 2021). Nandi et al. (2004, 2007) also recorded high diversity of wintering waterbirds from this physiographic region. Wetlands in similar geographic regions show similarities in wintering waterbird species composition (Ma et al., 2010). As the distance between the study sites varied from 46.6 km to 90.9 km, the species composition of waterbirds was quite similar (ranging from 67% to 81%).

Population trends of waterbirds in Asia are concerning as 62% of waterbird populations with known trends were decreasing or have become extinct (Delany and Scott, 2006). Li et al. (2009) did painstaking work on the long-term (1987-2007) population trend of the waterbirds in Asia, and they found that four (Mallard, Northern Pintail, Common Teal and Spot-billed Duck) of the eight most prevalent dabbling duck species in East Asia are declining. In the present study, Northern Pintail was recorded from all the sites and Common Teal was recorded only from ASB and KDM. Several other Palaearctic-Asian migrant species were also recorded during the present study. A small population of wintering critically endangered (CR) Baer's Pochard was also recorded from ASB during the present study. Hearn et al. (2013) reported that habitat loss, degradation of breeding areas, hunting, and other anthropogenic factors were the major reasons behind the rapid population decline in Asia. Moreover, this species has been facing the risk of extinction in the wild (Hearn et al., 2013). All four wetlands harboured a sizeable population of a vulnerable (VU) species, the Common Pochard. This pochard, widely distributed in the Palaearctic and breeding within western Europe to north-western China, is a common winter visitor on the Indian subcontinent (BirdLife International, 2016a, b). However, its population has declined by 35% in the last decade (Folliot et al., 2018). Two other vulnerable (VU) species, Lesser Adjutant and Woolly-necked Stork; and one near-threatened (NT), Black-headed Ibis; were also recorded during the present study. Thus, from a conservation point of view all these wetlands are extremely important (Mahato et al., 2021; Mukherjee et al., 2021b; Mukherjee et al., 2022a).

Lesser Whistling-duck, a local migrant, was the most dominant waterbird in both PSB and ASB and the second most dominant in GAD. Previous studies by Nandi et al. (2007), and Mukherjee et al. (2021) also attested dominance of Lesser Whistling-ducks throughout West Bengal during the winter season. However, Cotton Pygmy-goose was the most predominant bird in KDM. The study by Mukherjee et al. (2021) similarly found a high abundance of these local migrants in this study site. Both wetlands of the Bankura district showed a trivial increase in the total abundance of waterbirds from 2018-2019 to 2019-2020 (~ 0.5% in GAD and ~ 4% in KDM). On the other hand, a minor decrease (~ 3%) in the total abundance of waterbirds from 2018-2019 to 2019-2020 was recorded from ASB. However, in PSB waterbird population decreased by nearly 95% from 2018-2019 to 2019-2020. This could be due to increased anthropogenic pressure in form of 'Sikra'-boating, and total clearance of floating hydrophytic vegetation (Pal, 2020). Begam et al. (2021) similarly reported that unscientific management of aquatic macrophytes, especially the floating blanket of water hyacinth, could negatively influence the migratory waterbird density.

In ASB, abundance of Lesser Whistling-duck was very high in March, (nearly 56% of total waterbird population). That contributed to the highest D_{SIPM}, and lowest J' for that month. Highest D_{MARG} and comparatively higher J' endorsed to the highest H' in the month of November. A similar pattern of was also observed in PSB. In March, local migratory bird Lesser-whistling Duck also started congregating in huge numbers in this study site. Owing to overwhelming abundance of Lesser-whistling Duck (nearly 83% of total waterbird population) D_{SIMP} was highest in the month of March and thus, J' was lowest. However, highest H' was observed in January as comparatively higher D_{MARG} and J' and highest Chao1 was also recorded in January. In KDM, high abundance of Cotton Pygmy-goose (nearly 43% of total waterbird population) and Pheasant-tailed Jacana (nearly 14% of total waterbird population) in February contributed to the highest D_{SIPM} in the month of February. Estimated species number (Chao1) was also highest in the month of February owed to high number of singletons. However, H' were highest in the month of November owing to highest J' and a moderately higher $D_{MARG.}$ In January, decreased water level in this site negatively affected the abundance of the divers. Ma et al. (2010) also stated similar observations on diver's abundance variation by water level fluctuation of a habitat. Mukherjee et al. (2020) recorded significant decrease in Red-crested Pochard (diving duck) population in January month in this study site. However, higher number of waders were recorded from late-January onwards. Low water level might have created new foraging opportunities and that might augment wader's richness in that time in this site. Especially higher number of waders like Asian Openbill, Lesser Adjutant, Red-naped Ibis, Black-headed Ibis were recorded during low water-level situations. Ntiamoa-Baidu et al. (1998) and Gordon et al. (1998) also recorded higher number of waders in wetlands with water-level fluctuations, especially in low water-level conditions. In GAD, due to relatively higher J' and D_{MARG} for the month of December, H' was highest in this month. High abundance of

Barn Swallow (nearly 17% of total waterbird population) and Lesser Whistling-duck (nearly 13% of total waterbird population) endorsed the highest D_{SIPM} in the month of January.

4.3 Conclusion

Birds are excellent indicator of wetland health so their abundance and diversity study can enlighten the future conservation strategies on a pan-West Bengal scale. These sites are in East Asian-Australasian and Central Asian Flyways and attracted sizeable number of residents, local and winter migrants. However, all these wetlands are facing differential levels of anthropogenic interferences. It is noteworthy that, sharp decrease in abundance of waterbirds from 2018-2019 to 2019-2020, was prominent in PSB. This wetland needs immediate management policies to endure as a safe adobe for waterbirds.

Table 4.1 (a-d). Monthly and mean abundance of waterbirds recorded during the present study. NR: Not Recorded. (a: ASB, b: PSB c: KDM, d: GAD) Migration status: Winter migrant (WM) or Resident (R). IUCN status: Least Concerned (LC), Near Threatened (NT), Vulnerable (VU), Critically Endangered (CR). Source: www.iucnredlist.org.

a	Common Name	MS	IUCN Status	Oct18	Oct19	Nov18	Nov19	Dec18	Dec19	Jan19	Jan20	Feb19	Feb20	Mar19	Mar20	Mean
	ANATIDAE															
1	Lesser Whistling-duck	R	LC	30.5±2.121	39.5±12.346	64.5±10.607	61.0±2.828	136.5±6.364	134.0±15.556	333.0±12.728	404.5±9.192	504.0±67.882	471.5±6.364	568.0±16.971	509.0±19.092	271.4±212.406
2	Fulvous Whistling-duck	WM	LC	NR	NR	2.0±0.000	NR	2.0±0.000	1.5±0.707	NR	0.5±0.707	NR	NR	NR	NR	0.6±0.821
3	Cotton Pygmy-goose	R	LC	15.0±4.243	28.5±2.121	79.0±4.243	65.5±6.364	139.5±7.778	121.0±12.728	92.5±7.778	92.0±11.314	70.0±6.828	69.5±4.950	123.0±2.828	93.0±8.485	82.3±36.687
4	Gadwall	WM	LC	NR	NR	105.5±12.346	93.5±9.877	106.5±6.364	102.5±6.364	128.0±5.657	119.5±10.607	47.5±3.536	54.5±3.536	40.5±3.536	38.5±2.121	69.7±45.149
5	Eurasian Wigeon	WM	LC	NR	NR	13.5±3.536	11.5±3.536	70.5±4.121	78.5±2.121	80.0±9.899	80.5±8.121	13.5±2.121	19.0±2.828	NR	NR	30.6±35.222
6	Northern Shoveler	WM	LC	NR	NR	NR	NR	1.5±0.707	1.5±0.707	11.5±4.950	11.0±1.414	NR	NR	NR	NR	2.1±4.302
7	Northern Pintail	WM	LC	NR	NR	NR	NR	36.5±7.778	24.5±7.778	60.0±4.243	40.5±6.537	NR	NR	NR	NR	13.5±21.318
8	Garganey	WM	LC	NR	NR	2.0±1.414	1.0±0.00	3.0±0.707	4.5±0.707	6.0±1.414	3.5±2.828	NR	NR	NR	NR	1.7±2.114

							0									
9	Common Teal	WM	LC	NR	NR	NR	NR	2.5±0.707	3.0±0.000	4.0±1.414	3.5±0.707	2.0±0.000	NR	NR	NR	1.3±1.588
10	Red-crested Pochard	WM	LC	NR	NR	53.5±3.536	56.5±4.950	174.5±13.435	183.0±8.485	421.0±12.728	394.0±15.556	101.0±4.243	91.0±8.485	5.5±0.707	NR	124.2±147.060
11	Common Pochard	WM	VU	NR	NR	20.0±5.657	19.5±3.536	11.5±2.828	16.0±2.828	41.0±2.828	34.5±3.536	NR	NR	NR	NR	11.9±14.609
12	Baer's Pochard	WM	CR	NR	NR	3.0±0.000	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.3±0.866
13	Ferruginous Duck	WM	LC	NR	NR	13.0±2.828	17.5±2.828	6.5±0.707	2.5±0.707	72.5±7.778	75.5±7.778	20.0±4.243	31.0±4.950	11.0±2.828	9.5±2.121	20.8±25.877
14	Tufted Duck	WM	LC	NR	NR	6.0±2.828	6.5±0.707	5.5±2.121	9.0±4.243	134.0±15.556	109.5±2.212	8.5±3.536	12.0±4.243	NR	NR	24.3±46.019
	PODICIPEDIDAE															
15	Little Grebe	R	LC	54.5±4.950	64.0±8.998	21.5±0.707	26.0±1.414	51.5±6.364	50.5±2.121	38.5±9.192	28.0±1.414	116.0±41.012	111.5±17.678	62.0±4.243	64.5±4.950	57.4±30.246
16	Great-crested Grebe	WM	LC	NR	NR	1.0±0.000	1.0±0.000	2.5±2.121	1.0±0.000	11.5±0.707	16.0±2.212	NR	NR	NR	NR	2.8±5.281
	CICONIIDAE															
17	Asian Openbill	R	LC	2.0±1.414	3.5±2.121	1.5±0.707	0.5±0.707	3.0±1.414	2.5±0.707	3.5±2.121	4.5±2.828	8.0±1.414	9.5±2.121	12.5±2.121	20.0±1.414	5.9±5.696
	ARDEIDAE															
18	Black Bittern	WM	LC	NR	NR	NR	NR	NR	NR	1.5±0.707	NR	NR	NR	NR	NR	0.1±0.44

19	Black-crowned Night Heron	R	LC	4.0±4.243	2.5±0.707	NR	1.0±1.414	1.5±2.121	NR	NR	NR	NR	NR	NR	NR	0.8±1.306
20	Indian Pond Heron	R	LC	3.5±2.121	5.0±2.828	4.5±0.707	2.5±0.707	5.0±1.414	2.5±1.414	6.5±2.121	2.0±1.414	4.0±1.414	6.0±0.000	11.5±0.707	9.0±1.414	5.2±2.799
21	Purple Heron	R	LC	NR	NR	0.5±0.707	2.0±1.414	1.0±0.000	0.5±0.707	0.5±0.707	1.5±0.707	NR	0.5±0.707	NR	NR	0.5±674
22	Cattle Egret	R	LC	NR	NR	NR	NR	NR	NR	NR	NR	2.5±0.707	1.5±0.707	13.5±2.121	12.5±2.121	2.5±4.973
23	Little Egret	R	LC	11.5±2.121	9.5±2.121	13.5±2.828	14.0±4.243	12.5±2.121	19.5±6.546	9.0±1.414	4.5±2.121	8.0±1.414	11.0±1.414	11.0±2.828	13.0±4.243	11.4±3.686
	ANHINGIDAE															
24	Darter	WM	LC	NR	NR	1.0±0.000	0.5±0.707	NR	NR	2.0±0.000	2.0±1.414	NR	NR	NR	NR	0.5±0.674
	PHALACROCORACIDAE															
25	Little Cormorant	R	LC	22.5±5.624	14.0±4.564	14.5±3.536	17.5±2.121	23.0±4.536	25.0±5.657	28.5±4.950	26.5±3.538	14.5±2.121	16.0±7.071	29.0±4.243	27.0±2.828	21.7±6.047
26	Indian Cormorant	WM	LC	5.5±2.212	9.5±2.121	4.5±0.707	4.0±2.828	5.5±2.121	5.0±2.828	9.5±2.121	11.0±2.828	6.0±1.414	6.0±4.243	2.5±0.707	1.0±0.000	5.8±2.926
27	Great Cormorant	WM	LC	NR	NR	2.5±1.414	1.0±0.000	NR	2.0±2.828	14.5±0.707	12.5±4.647	4.0±1.414	4.5±3.536	NR	3.0±1.414	3.7±4.990
	PANDIONIDAE															
2	Osprey	W	L	0.5±	1.0±	1.0±	0.5±	1.0±	1.0±	1.5±	1.0±	NR	NR	NR	NR	0.6±0

8		M	C	0.707	0.000	0.000	0.707	0.000	0.000	0.707	0.000					.528
	ACCIPITRIDAE															
29	Booted Eagle	WM	LC	NR	NR	NR	NR	2.0±1.414	1.0±0.000	2.0±1.414	NR	NR	NR	NR	NR	0.4±0.793
30	Eastern Marsh Harrier	WM	LC	NR	NR	NR	NR	NR	NR	1.0±0.000	0.5±0.707	NR	0.5±0.707	NR	NR	0.2±0.326
	RALLIDAE															
31	White-breasted Waterhen	R	LC	4.0±1.414	9.5±2.121	4.0±1.414	6.5±0.707	3.5±0.707	3.0±1.414	2.5±0.707	6.0±1.414	8.5±0.707	12.5±2.121	8.5±3.536	11.0±2.828	6.6±3.345
32	Purple Swamphen	R	LC	1.5±0.707	2.0±2.121	1.5±0.707	NR	2.5±0.707	1.0±0.000	3.0±1.414	4.5±0.707	22.0±1.414	18.5±2.121	16.0±1.414	21.0±14.142	7.8±8.737
33	Common Moorhen	R	LC	4.5±2.828	1.5±0.707	13.0±2.828	15.0±4.243	50.5±6.364	47.5±7.778	52.0±4.243	45.5±2.121	54.0±18.385	28.5±7.778	65.0±2.828	51.0±3.534	35.7±21.922
34	Eurasian Coot	R	LC	NR	NR	23.5±6.764	24.0±5.657	123.0±15.556	98.5±12.212	212.0±8.243	211.5±16.263	59.5±6.364	65.0±8.485	4.0±1.414	4.0±2.828	68.8±77.878
	JACANIDAE															
35	Bronze-winged Jacana	R	LC	5.5±2.121	13.5±4.564	11.5±4.564	16.5±3.536	34.0±2.828	26.5±2.121	39.5±3.536	41.5±3.536	22.5±0.707	31.0±2.828	3.5±0.707	2.0±0.000	20.6±13.937
36	Pheasant-tailed Jacana	R	LC	2.5±0.707	2.5±2.121	27.0±5.657	24.5±3.536	43.5±3.536	49.0±2.828	25.5±4.950	27.5±4.950	25.0±2.828	19.0±2.828	15.0±5.657	19.0±7.778	23.3±13.752

	CHARADRIIDAE															
37	Grey-headed Lapwing	WM	LC	NR	NR	2.0±0.000	1.0±0.707	2.5±0.707	4.5±0.707	6.0±1.414	7.5±2.121	NR	NR	NR	NR	2.0±2.658
38	Red-wattled Lapwing	R	LC	0.5±0.707	NR	3.5±0.707	2.0±1.414	NR	NR	1.0±0.000	NR	2.5±0.707	3.0±0.000	3.0±1.414	NR	1.5±1.356
	LARIDAE															
39	Whiskered Tern	WM	LC	2.5±0.707	4.5±0.707	2.5±0.707	NR	1.0±0.000	1.5±0.707	NR	NR	NR	NR	NR	NR	1.1±1.499
	ALCEDINIDAE															
40	Stork-billed Kingfisher	R	LC	NR	NR	NR	NR	NR	1.5±0.707	1.5±0.707	NR	1.5±0.707	2.0±1.414	NR	NR	0.4±0.764
41	White-breasted Kingfisher	R	LC	1.5±0.707	0.5±0.707	1.5±1.414	NR	2.5±0.707	1.0±-0.000	1.5±0.707	1.5±2.121	1.5±1.414	2.0±0.707	2.5±0.707	1.0±0.00	1.5±0.722
42	Common Kingfisher	R	LC	1.0±1.414	NR	1.0±0.000	0.5±0.707	1.0±0.000	1.0±0.707	NR	2.0±0.000	2.5±0.707	1.5±0.707	2.0±1.414	2.0±1.414	1.2±0.811
	MOTACILLIDAE															
43	White Wagtail	WM	LC	1.5±0.707	2.0±0.000	2.0±0.707	1.0±0.000	2.5±0.707	1.0±1.414	1.5±0.707	1.0±1.414	NR	NR	NR	NR	1.0±0.891

44	Grey Wagtail	WM	LC	3.5±0.707	3.5±3.536	NR	NR	NR	NR	1.0±0.000	5.0±5.657	NR	NR	3.5±0.707	3.0±2.828	1.6±1.908

b	**Common Name**	**MS**	**IUCN Status**	**Oct18**	**Oct19**	**Nov18**	**Nov19**	**Dec18**	**Dec19**	**Jan19**	**Jan20**	**Feb19**	**Feb20**	**Mar19**	**Mar20**	**Mean**
	ANATIDAE															
1	Lesser Whistling-duck	R	LC	209.0±15.556	NR	213.5±12.021	NR	428.0±31.113	NR	482.0±21.213	NR	628.5±30.406	NR	2469.0±128.693	NR	369.2±698.071
2	Greylag Goose	WM	LC	NR	NR	NR	NR	NR	NR	2.0±1.414	NR	NR	NR	NR	NR	0.2±0.577
3	Cotton Pygmy-goose	R	LC	NR	NR	9.5±2.121	NR	15.5±2.121	NR	25.5±6.364	NR	10.5±2.121	NR	114.5±9.192	NR	14.6±32.522
4	Gadwall	WM	LC	NR	NR	44.5±6.563	4.5±0.707	80.5±12.324	13.5±2.121	59.5±10.607	26.5±7.778	28.0±5.657	5.0±1.414	13.0±1.414	3.5±4.950	23.2±25.993
5	Eurasian Wigeon	WM	LC	NR	NR	2.0±0.000	NR	3.5±2.828	NR	8.0±4.243	NR	1.5±0.707	NR	NR	NR	1.3±2.407
6	Northern Shoveler	WM	LC	NR	NR	2.5±0.707	NR	4.5±1.414	NR	4.0±1.414	NR	0.5±0.707	NR	NR	NR	1.0±1.698
7	Northern Pintail	WM	LC	NR	NR	NR	NR	17.0±2.828	NR	25.0±2.828	NR	2.5±0.707	NR	NR	NR	3.7±8.286
8	Garganey	WM	LC	NR	NR	NR	NR	1.0±1.414	NR	3.0±1.414	NR	NR	NR	NR	NR	0.3±0.888
9	Common Teal	WM	LC	NR	NR	3.0±1.414	NR	5.5±0.707	NR	7.5±2.121	NR	NR	NR	NR	NR	1.3±2.597
10	Red-crested Pochard	WM	LC	NR	NR	19.5±2.828	NR	61.5±3.536	25.0±2.828	99.0±14.142	30.0±5.768	54.5±8.675	10.0±2.828	8.0±1.414	3.0±1.414	25.9±31.039
1	Commo	W	V	NR	NR	NR	NR	2.5±0	NR	5.5±2	NR	NR	NR	NR	NR	0.7±1.

1	n Pochard	M	U					.707		.121						683
12	Ferruginous Duck	WM	LC	NR	NR	NR	NR	4.5±0.707	NR	18.5±3.536	NR	5.5±1.414	NR	NR	NR	2.4±5.436
13	Tufted Duck	WM	LC	NR	NR	NR	NR	NR	NR	2.5±0.707	NR	2.0±0.000	NR	NR	NR	0.4±0.882
	PODICIPEDIDAE															
14	Little Grebe	R	LC	4.0±2.828	4.5±0.707	40.5±7.324	3.5±2.121	31.5±4.950	NR	28.0±5.675	1.5±0.707	41.0±8.786	3.5±2.212	15.5±4.345	2.5±0.707	14.7±16.027
15	Great-crested Grebe	WM	LC	NR	NR	NR	NR	1.5±0.707	NR	5.5±2.121	NR	NR	NR	NR	NR	0.6±1.607
	THRESKIORNITHIDAE															
16	Black-headed Ibis	WM	NT	32.5±4.950	3.5±0.707	10.0±4.243	1.5±1.414	7.5±2.121	1.5±2.121	13.5±2.121	3.5±2.828	20.0±4.243	3.5±2.121	27.5±4.950	6.0±1.414	10.9±10.484
	ARDEIDAE															
17	Yellow Bittern	R	LC	1.5±0.707	0.5±0.707	NR	NR	NR	NR	0.5±0.707	NR	NR	NR	NR	NR	0.2±0.450
18	Black Bittern	WM	LC	NR	NR	NR	NR	2.5±0.707	NR	NR	NR	0.5±0.707	NR	NR	NR	0.3±0.723
19	Black-crowned Night Heron	R	LC	10.5±2.121	NR	14.0±2.828	NR	5.5±1.677	NR	15.5±4.950	NR	24.0±4.567	NR	34.5±6.785	NR	8.7±11.448
20	Indian Pond Heron	R	LC	5.5±1.414	3.5±0.707	6.5±0.707	1.0±0.000	6.5±3.536	2.5±0.707	8.0±1.414	1.5±0.707	4.0±1.414	NR	20.5±4.950	5.0±2.828	5.5±5.268
21	Purple Heron	R	LC	NR	NR	1.5±2.121	NR	1.5±0.707	NR	1.0±1.141	NR	NR	NR	NR	NR	0.3±0.615
2	Cattle	R	L	3.5±1	2.0±	NR	3.0	10.5±	5.0±	16.5±	4.0±	NR	NR	15.5±	7.0±	5.6±5.

2	Egret		C	.414	0.707		±1.414	2.121	1.414	3.536	1.141			2.121	2.828	752
23	Little Egret	R	LC	10.0±2.828	18.0±4.967	15.5±2.121	7.0±1.414	12.0±1.414	7.0±2.828	8.0±1.414	4.0±2.121	7.0±5.657	3.0±1.414	10.0±2.828	11.0±2.828	9.4±4.321
	PHALACROCORACIDAE															
24	Little Cormorant	R	LC	19.5±4.712	2.5±0.707	38.5±8.245	1.5±0.707	31.0±2.828	6.0±1.414	32.0±7.282	12.5±1.414	32.0±2.828	8.0±4.243	14.5±3.536	15.5±7.778	17.8±12.750
25	Indian Cormorant	WM	LC	4.5±1.235	1.0±0.000	5.5±2.121	3.5±0.707	32.5±16.263	5.0±1.414	8.5±3.456	4.0±1.414	2.5±0.707	4.5±2.121	4.5±2.121	8.0±1.414	7.0±8.290
26	Great Cormorant	WM	LC	NR	NR	2.5±0.707	1.0±1.000	3.5±2.121	0.5±0.707	NR	NR	2.5±3.536	NR	NR	NR	0.8±1.267
	RALLIDAE															
27	White-breasted Waterhen	R	LC	2.5±0.707	NR	3.5±1.414	NR	4.5±2.121	NR	9.5±2.121	2.5±3.536	7.5±2.121	NR	5.0±1.414	1.0±0.000	3.0±3.155
28	Purple Swamphen	R	LC	16.5±3.536	2.5±1.414	14.5±9.192	1.0±1.414	7.0±1.414	NR	5.5±2.121	NR	19.5±3.536	NR	14.0±3.536	NR	6.7±7.418
29	Common Moorhen	R	LC	47.0±4.243	3.0±0.707	46.0±9.899	0.5±0.707	50.5±4.950	1.0±1.141	90.0±14.453	4.0±2.828	72.0±14.243	1.5±2.121	74.0±8.768	1.0±0.707	32.5±34.321
30	Eurasian Coot	R	LC	NR	NR	9.5±2.121	NR	34.5±3.536	1.0±0.000	59.0±9.878	5.5±2.121	11.5±0.707	2.0±0.000	44.5±4.950	NR	14.0±20.385
	JACANIDAE															
31	Bronze-winged Jacana	R	LC	13.5±3.536	NR	15.5±4.950	NR	15.5±2.121	NR	19.5±3.536	NR	4.0±1.414	NR	16.0±2.828	NR	7.0±8.130
32	Pheasant-tailed	R	LC	41.0±8.548	NR	7.0±2.828	NR	15.0±2.828	NR	19.5±5.674	NR	7.5±2.828	NR	8.0±1.414	NR	8.2±12.267

	Jacana															
	ALCEDINIDAE															
33	Stork-billed Kingfisher	R	LC	NR	1.0±0.000	NR	NR	NR	NR	NR	1.5±0.707	NR	NR	1.5±0.707	0.5±0.707	0.4±0.608
34	White-breasted Kingfisher	R	LC	1.5±0.707	2.0±1.414	1.5±0.707	0.5 ±0.707	1.5±0.707	1.0±0.000	2.0±0.000	1.5±0.707	2.0±0.000	1.5±0.707	2.0±1.414	1.0±1.414	1.5±0.477
35	Common Kingfisher	R	LC	1.0±0.000	0.5±0.707	NR	1.0 ±1.141	2.0±1.414	1.0±0.707	1.5±2.121	1.5±0.707	1.0±0.707	1.0±1.414	1.5±0.707	1.0±0.000	1.0±0.603
	ACROCEPHALIDAE															
36	Blyth's Reed Warbler	WM	LC	NR	NR	NR	NR	1.0±0.000	0.5±0.707	NR	NR	1.5±0.707	1.0±0.000	NR	NR	0.3±0.537
	MOTACILLIDAE															
37	White Wagtail	WM	LC	NR	NR	1.0±1.141	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.1±0.289

c	Common Name	MS	IUCN Status	Oct 18	Oct 19	Nov18	Nov 19	Dec18	Dec19	Jan19	Jan20	Feb19	Feb20	Mar 19	Mar 20	Mean
	ANATIDAE															
1	Lesser Whistling-duck	R	LC	25.0 ±2.828	41.0 ±2.828	49.5 ±9.192	83.5 ±7.778	100.5 ±16.263	105.5 ±26.163	40.5 ±2.121	33.0 ±4.243	16.5 ±6.364	20.5 ±4.950	2.5±0.707	4.5±3.536	43.5 ±35.235

2	Fulvous Whistling-duck	WM	LC	NR	NR	NR	NR	1.5±0.707	0.5±0.707	1.0±1.141	0.5±0.707	NR	NR	NR	NR	0.3±0.498
3	Cotton Pygmy-goose	R	LC	51.0±7.071	76.0±15.556	92.5±7.778	103.5±12.021	117.5±9.192	97.5±4.950	171.5±21.920	157.0±11.314	298.5±19.092	287.0±18.835	210.0±12.828	212.5±14.849	156.2±81.427
4	Gadwall	WM	LC	11.0±2.828	NR	28.5±3.536	22.5±9.192	138.5±9.192	132.5±34.648	67.0±15.556	137.0±7.071	19.5±2.121	18.0±1.414	9.0±2.828	8.5±0.707	49.3±54.845
5	Eurasian Wigeon	WM	LC	NR	NR	NR	1.5±0.707	2.5±0.707	3.0±1.414	4.5±0.707	6.5±0.707	NR	NR	NR	NR	1.5±2.195
6	Indian Spot-billed Duck	R	LC	1.0±0.000	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.1±0.289
7	Northern Shoveler	WM	LC	NR	NR	NR	NR	6.0±1.414	4.5±0.707	2.5±0.707	4.5±0.707	NR	2.0±0.000	NR	NR	1.6±2.237
8	Northern Pintail	WM	LC	NR	NR	NR	0.5±0.707	13.5±2.121	17.5±2.121	13.0±5.665	32.5±2.121	NR	1.0±1.141	NR	NR	6.5±10.479
9	Garganey	WM	LC	NR	NR	NR	NR	1.5±0.707	2.5±0.707	2.5±0.707	4.5±2.121	1.0±1.414	2.0±0.000	NR	NR	1.2±1.467
10	Common Teal	WM	LC	NR	NR	NR	1.0±0.000	2.5±0.707	3.0±1.414	2.5±0.707	2.5±2.828	NR	NR	NR	NR	1.0±1.270
11	Red-crested Pochard	WM	LC	NR	NR	37.5±3.536	26.0±4.243	60.5±4.950	75.5±9.192	31.5±2.828	49.0±9.899	20.0±2.828	18.5±2.212	2.0±0.000	1.5±2.121	26.8±25.125
12	Common Pochard	WM	VU	NR	NR	NR	NR	NR	NR	2.5±0.707	3.5±2.121	NR	NR	NR	NR	0.5±1.187
13	Ferruginous	WM	LC	NR	NR	NR	NR	2.0±0.000	2.0±1.414	3.5±1.414	6.5±0.707	NR	NR	NR	NR	1.2±2.049

	Duck															
14	Tufted Duck	WM	LC	NR	NR	10.5±2.121	10.5±4.950	13.5±2.828	17.0±5.434	19.5±2.121	15.0±1.414	2.5±0.707	4.5±0.707	NR	NR	7.8±7.402
	PODICIPEDIDAE															
15	Little Grebe	R	LC	8.0±1.414	11.5±0.707	21.0±2.828	29.5±3.536	22.5±2.121	21.5±4.950	40.5±7.877	34.5±4.950	33.5±2.121	39.5±7.778	9.5±3.536	13.0±2.828	23.7±11.690
	CICONIIDAE															
16	Asian Openbill	R	LC	7.5±2.121	15.5±4.534	2.5±0.707	17.0±1.414	3.5±0.707	1.5±0.707	1.5±0.707	2.5±0.707	26.0±4.243	24.0±4.243	67.5±6.364	73.0±5.567	20.2±24.994
17	Woolly-necked Stork	R	VU	NR	NR	NR	NR	NR	NR	NR	NR	1.0±0.000	2.0±1.414	NR	NR	0.3±0.622
18	Lesser Adjutant	WM	VU	1.5±0.707	1.0±0.000	1.0±0.000	2.5±0.707	1.0±0.000	1.5±0.707	1.5±0.707	3.0±0.000	1.0±0.707	NR	1.5±0.707	2.0±0.000	1.5±0.782
	THRESKIORNITHIDAE															
19	Black-headed Ibis	WM	NT	NR	2.0±1.414	NR	NR	NR	NR	1.0±0.000	1.0±0.707	2.5±0.707	1.5±0.707	3.0±0.000	3.0±1.414	1.2±1.212
20	Red-naped Ibis	WM	LC	3.0±1.414	NR	2.0±0.707	2.0±1.414	2.5±0.707	3.0±2.121	1.0±1.414	NR	2.0±0.000	1.5±0.707	4.5±0.707	5.5±0.707	2.3±1.631
	ARDEIDAE															
21	Yellow Bittern	R	LC	NR	NR	NR	NR	0.5±0.707	NR	NR	NR	1.5±0.707	NR	NR	NR	0.2±0.498
22	Cinnamon Bittern	R	LC	NR	NR	NR	NR	NR	NR	NR	NR	0.5±0.707	0.5±0.707	NR	NR	0.1±0.195
23	Black-crowne	R	LC	5.0±2.82	4.5±0.70	NR	1.0±0.000	NR	NR	1.0±1.414	1.5±2.121	5.5±2.828	3.0±1.414	1.5±0.707	1.0±1.414	2.0±2.000

	d Night Heron			8	7											
24	Indian Pond Heron	R	LC	6.5±2.121	10.0±1.414	15.5±2.121	14.0±2.828	10.5±5.647	12.5±2.828	9.0±2.121	11.0±2.828	11.5±7.788	12.5±2.121	NR	2.0±2.828	9.6±5.112
25	Grey Heron	R	LC	NR	0.5±0.707	NR	NR	2.0±1.414	1.0±0.000	NR	NR	1.0±1.141	NR	1.0±0.000	0.5±0.707	0.5±0.640
26	Purple Heron	R	LC	0.5±0.707	2.0±0.000	2.5±0.707	2.5±.707	NR	3.0±1.414	0.5±0.707	1.0±1.414	1.5±0.707	2.0±0.000	2.0±0.000	1.5±0.707	1.6±0.925
27	Cattle Egret	R	LC	NR	NR	2.5±1.414	2.5±2.121	3.0±1.414	2.5±2.121	2.5±0.707	1.0±0.000	12.5±4.243	13.0±5.657	21.0±2.828	25.5±2.121	7.2±8.713
28	Little Egret	R	LC	16.5±2.121	13.0±1.414	16.5±2.828	22.0±1.414	10.0±1.414	7.5±0.707	11.5±3.536	12.5±6.364	17.0±1.414	17.0±5.657	19.5±2.121	18.5±2.121	15.1±4.238
29	Intermediate Egret	R	LC	1.5±0.707	4.0±2.121	1.5±0.707	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.6±1.222
30	Great Egret	R		NR	NR	NR	NR	1.0±0.000	1.0±1.414	NR	NR	NR	NR	NR	NR	0.2±0.389
	PHALACROCORACIDAE															
31	Little Cormorant	R	LC	1.5±0.707	3.5±0.707	16.0±3.534	21.5±2.121	12.0±4.564	8.5±2.828	7.5±2.121	5.0±2.828	24.0±7.788	23.0±5.657	23.5±2.121	25.0±5.657	14.3±8.923
32	Indian Cormorant	WM	LC	5.5±1.414	3.0±1.414	1.5±0.707	2.5±0.707	5.0±1.414	2.5±0.707	7.0±2.828	12.0±1.414	3.5±0.707	5.0±1.414	3.0±1.414	4.0±2.828	4.5±2.808
33	Great Cormorant	WM	LC	NR	NR	1.0±1.414	2.0±0.000	2.0±1.414	3.0±1.414	5.5±2.121	5.0±4.243	NR	NR	NR	NR	1.5±2.017
	ACCIPITRIDAE															
34	Short-toed	WM	LC	NR	2.0±0.00	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.2±0.389

	Snake Eagle				0											
35	Pied Harrier	WM	LC	NR	0.5±0.707	NR	NR	NR	NR	NR	NR	1.5±1.414	NR	NR	NR	0.2±0.326
	RALLIDAE															
36	Baillon's Crake	WM	LC	NR	NR	NR	NR	NR	NR	NR	NR	0.5±0.707	0.5±0.707	NR	NR	0.1±0.195
37	White-breasted Waterhen	R	LC	3.0±1.414	6.0±1.414	5.5±0.707	3.5±1.414	3.5±2.121	3.5±0.707	4.0±2.121	2.0±2.121	3.5±0.707	3.5±2.121	11.5±0.707	8.5±0.707	4.8±2.776
38	Purple Swamphen	R	LC	1.5±0.707	2.5±1.414	3.5±0.707	2.5±0.707	5.5±3.453	4.0±1.414	3.5±2.121	3.5±0.707	5.5±2.828	5.0±1.141	33.0±11.414	33.0±2.828	8.6±11.469
39	Common Moorhen	R	LC	NR	NR	NR	NR	2.5±0.707	0.5±0.707	2.5±0.707	2.5±2.121	2.5±0.707	2.5±2.121	11.5±3.536	14.5±5.564	3.3±4.741
40	Eurasian Coot	R	LC	NR	NR	29.0±4.243	18.5±3.534	25.5±3.536	21.5±5.675	40.0±7.778	45.5±3.536	10.5±2.121	12.0±141	NR	1.0±1.414	17.0±15.869
	JACANIDAE															
41	Bronze-winged Jacana	R	LC	74.0±4.243	58.5±2.121	40.5±2.121	38.5±7.778	37.0±7.071	37.0±2.828	34.0±15.556	23.5±3.536	38.9±9.192	60.0±9.899	20.0±2.121	24.5±1.414	40.5±16.143
42	Pheasant-tailed Jacana	R	LC	29.5±3.536	33.5±7.778	52.5±4.950	49.5±3.536	96.5±6.364	82.0±7.788	63.0±5.657	55.5±6.364	90.5±7.788	83.5±7.778	16.0±3.536	21.5±0.707	56.1±27.576
	CHARADRIIDAE															
43	Grey-headed Lapwin	WM	LC	30.5±2.121	25.5±3.536	24.5±3.536	23.0±4.592	16.5±2.121	10.5±2.121	10.5±2.121	11.5±4.950	2.5±0.707	2.5±2.121	33.5±12.121	20.0±1.414	17.6±10.267

	g															
44	Red-wattled Lapwing	R	LC	9.5±3.536	6.5±4.950	10.5±2.121	12.0±2.828	2.5±0.707	3.0±1.414	4.5±0.707	4.0±2.828	3.0±0.707	2.0±0.000	4.5±0.707	2.5±0.707	5.4±3.452
45	Yellow-wattled Lapwing	R	LC	2.5±0.707	3.0±0.000	5.5±0.707	3.0±1.414	5.5±2.828	7.0±2.828	2.0±1.414	1.0±0.000	4.0±1.414	4.5±3.536	13.5±2.121	10.0±1.414	5.1±3.594
46	Little Ringed Plover	R	LC	NR	1.5±0.707	NR	NR	NR	NR	2.0±0.000	2.0±1.141	2.0±2.212	NR	NR	NR	0.6±0.856
	ROSTRATULIDAE															
47	Greater Painted-snipe	R	LC	0.5±0.707	NR	NR	NR	NR	NR	NR	NR	2.0±1.414	NR	NR	NR	0.2±0.396
	SCOLOPACIDAE															
48	Pin-tailed Snipe	WM	LC	NR	0.5±0.707	NR	NR	1.5±0.0.707	NR	NR	NR	NR	2.0±0.000	NR	NR	0.4±0.711
49	Common Snipe	WM	LC	NR	NR	NR	0.5±0.707	NR	1.0±1.414	NR	NR	NR	NR	NR	NR	0.1±0.311
50	Common Redshank	WM	LC	NR	NR	NR	1.0±1.414	NR	NR	NR	NR	1.0±1.414	1.0±1.414	1.0±1.414	NR	0.3±0.492
51	Common Greenshank	WM	LC	NR	NR	NR	NR	NR	NR	NR	NR	1.0±0.000	1.0±1.414	NR	NR	0.2±0.389
52	Common Sandpiper	WM	LC	NR	NR	1.0±1.414	2.0±1.414	0.5±0.707	NR	1.5±0.707	NR	2.5±0.707	0.5±0.707	NR	NR	0.7±0.888

53	Temminck's Stint	WM	LC	NR	NR	NR	NR	NR	NR	NR	NR	NR	2.0±0.000	NR	NR	0.3±0.622
	LARIDAE															
54	Whiskered Tern	WM	LC	NR	NR	1.0±1.414	2.0±0.000	3.5±0.707	3.5±2.121	NR	NR	NR	NR	NR	NR	0.8±1.387
	ALCEDINIDAE															
55	Stork-billed Kingfisher	R	LC	NR	0.5±0.707	1.0±1.414	0.5±0.707	NR	0.5±0.707	NR	NR	1.5±0.707	NR	NR	NR	0.3±0.498
56	White-breasted Kingfisher	R	LC	4.0±1.414	2.5±0.707	3.5±0.707	4.5±0.707	3.5±1.414	2.0±0.000	3.5±0.707	1.0±1.414	2.5±0.707	3.0±1.414	4.0±1.414	5.5±4.950	3.4±1.125
57	Common Kingfisher	R	LC	1.5±0.707	2.0±0.000	2.5±0.707	3.0±2.828	4.5±0.707	2.5±0.707	3.5±0.707	3.0±2.828	2.0±0.000	1.5±0.707	4.0±0.000	4.0±1.414	2.8±1.008
58	Pied Kingfisher	R	LC	2.0±0.000	2.5±1.414	3.0±0.000	2.5±0.707	2.0±0.000	2.0±1.414	2.0±1.414	2.5±0.707	NR	NR	NR	NR	1.5±1.177
	MOTACILLIDAE															
59	White Wagtail	WM	LC	4.5±3.536	NR	3.5±2.121	3.0±2.828	1.5±0.707	2.5±0.707	3.0±1.414	2.5±2.121	2.5±0.707	1.5±0.707	NR	NR	2.0±1.469
60	Grey Wagtail	WM	LC	8.5±0.707	12.0±2.828	1.5±0.707	2.5±0.707	3.0±1.414	2.5±0.707	NR	NR	3.0±1.414	4.0±1.414	NR	NR	3.1±3.704
61	White-browed Wagtail	R	LC	4.5±0.707	2.5±0.707	6.5±2.828	4.5±0.707	3.5±1.414	2.5±0.707	2.5±0.707	2.0±0.000	2.0±1.414	1.0±0.000	2.5±0.707	3.0±1.414	3.1±1.475

d	Common Name	MS	IUCN Status	Oct 18	Oct 19	Nov 18	Nov 19	Dec 18	Dec 19	Jan19	Jan20	Feb19	Feb20	Mar 19	Mar 20	Mean
	ANATIDAE															
1	Lesser Whistling-duck	R	LC	15.5±0.707	16.5±3.536	23.0±1.414	23.0±5.657	40.0±4.243	44.0±5.657	110.5±12.121	105.0±16.263	36.5±6.364	43.0±5.657	52.5±4.950	55.5±7.778	47.3±32.464
2	Cotton Pygmy-goose	R	LC	2.5±0.707	3.0±1.414	6.0±1.414	7.0±1.414	15.5±2.121	11.0±2.828	9.0±282	8.5±1.237	3.5±2.121	4.0±4.234	5.0±1.414	4.5±3.536	6.6±3.832
3	Gadwall	WM	LC	3.0±0.000	NR	38.5±9.192	35.5±3.536	58.5±4.950	55.0±6.657	81.0±8.485	85.0±5.657	37.5±2.121	32.0±1.414	11.0±2.828	9.0±1.414	37.2±28.668
4	Northern Pintail	WM	LC	NR	NR	NR	NR	1.0±1.414	1.5±0.707	3.5±0.707	NR	NR	NR	NR	NR	0.5±1.066
5	Garganey	WM	LC	NR	NR	NR	6.5±0.707	NR	NR	2.0±0.000	4.0±1.414	2.0±0.000	3.5±0.707	NR	NR	1.5±2.164
6	Red-crested Pochard	WM	LC	NR	NR	2.0±0.000	3.5±0.707	41.5±4.950	40.5±2.707	96.5±20.506	98.0±11.314	100.5±13.546	86.0±11.423	1.5±0-.707	2.0±1.414	39.3±43.934
7	Common Pochard	WM	VU	NR	NR	2.0±0.000	1.0±0.000	6.0±1.414	2.5±0.707	4.5±0.707	5.0±4.243	NR	NR	NR	NR	1.8±2.251
8	Tufted Duck	WM	LC	NR	NR	12.0±1.414	18.0±1.414	12.5±3.536	15.0±7.423	21.5±707	21.5±4.950	5.5±0.707	6.5±3.536	NR	NR	9.4±8.483
	PODICIPEDIDAE															

9	Little Grebe	R	LC	2.5±0.707	3.5±2.121	3.0±1.414	2.0±1.414	5.0±1.414	5.0±2.828	7.5±2.607	8.5±3.536	6.0±4.243	12.0±1.414	10.5±2.121	16.0±1.414	6.8±4.293
10	Great-crested Grebe	WM	LC	NR	NR	1.0±0.000	1.0±0.00	2.5±0.707	4.0±2.828	4.5±1.414	1.0±0.000	NR	NR	NR	NR	1.2±1.628
	CICONIIDAE															
11	Asian Openbill	R	LC	10.5±2.121	14.0±4.243	15.0±5.657	22.0±3.414	37.5±7.778	34.0±5.657	30.0±2.828	33.0±5.657	53.5±12.021	38.5±8.763	37.5±4.950	30.5±11.389	29.7±12.381
12	Lesser Adjutant	WM	VU	NR	NR	1.5±0707	0.5±0.707	NR	NR	0.5±707	1.0±0.000	5.5±2.121	7.0±1.414	1.0±0.000	1.0±0.707	1.5±2.296
	THRESKIORNITHIDAE															
13	Black-headed Ibis	WM	NT	9.5±3.536	11.0±4.243	NR	NR	3.5±0.707	3.0±2.828	3.5±2.121	3.5±0.707	1.0±0.000	NR	1.0±1.414	NR	3.0±3.705
14	Red-naped Ibis	WM	LC	4.5±0.707	2.0±0.000	5.5±0.707	3.5±0.707	NR	NR	2.0±0.000	1.5±1.414	1.0±1.414	NR	3.5±0.707	3.5±2.121	2.3±1.853
15	Glossy Ibis	WM	LC	2.0±0.000	NR	NR	NR	NR	NR	NR	0.5±0.707	NR	NR	1.0±1.414	2.5±0.707	0.5±0.879
	ARDEIDAE															
16	Yellow Bittern	R	LC	NR	NR	NR	NR	0.5±0.707	1.0±1.414	NR	NR	1.0±0.000	0.5±0.707	NR	NR	0.3±0.399
17	Cinnamon Bittern	R	LC	NR	0.5±0.707	NR	NR	NR	NR	0.5±0.707	1.0±0.707	NR	NR	NR	NR	0.2±0.326
18	Black Bittern	WM	LC	NR	NR	1.0±0.000	NR	NR	NR	1.5±0.707	NR	1.5±0.707	NR	NR	NR	0.3±0.615
19	Black-crowne	R	LC	1.0±0.00	0.5±0.70	2.5±0.70	3.5±2.12	2.0±0.00	2.0±1.41	4.5±2.707	2.5±1.245	13.0±1.414	9.5±2.12	4.5±2.12	4.5±4.95	4.2±3.63

	d Night Heron			0	7	7	1	0	4				1	1	0	9
20	Indian Pond Heron	R	LC	6.0±1.414	4.0±2.828	10.0±1.414	7.5±0.707	13.0±1.414	12.5±3.536	13.5±4.950	16.5±7.124	25.5±6.745	18.5±4.121	10.0±4.356	12.0±3.564	12.4±5.834
21	Grey Heron	R	LC	NR	NR	0.5±0.707	0.5±0.707	1.0±1.414	1.0±0.000	2.0±1.414	0.5±0.707	3.0±1.414	2.0±1.414	NR	NR	0.9±0.980
22	Purple Heron	R	LC	1.0±0.000	1.0±0.000	NR	NR	2.5±0.707	1.0±0.000	2.0±0.000	2.5±1.216	1.0±0.000	1.5±0.707	NR	NR	1.0±0.940
23	Cattle Egret	R	LC	13.0±4.243	19.0±2.828	22.5±0.707	22.5±4.950	21.0±2.828	23.0±7.071	26.5±3.535	31.0±1.414	20.0±4.243	21.5±3.536	15.5±4.950	23.0±2.828	21.5±4.659
24	Little Egret	R	LC	27.5±4.950	27.0±2.828	31.0±2.828	32.0±15.556	10.5±2.121	23.0±4.243	26.5±4.950	29.5±12.345	36.0±11.412	40.5±9.763	16.0±9.899	13.5±3.536	26.1±9.007
25	Great Egret	R		NR	NR	0.5±0.707	NR	1.5±0.707	1.5±0.707	2.5±0.707	1.5±0.707	NR	NR	NR	NR	0.6±0.882
	PHALACROCORACIDAE															
26	Little Cormorant	R	LC	12.0±2.828	15.0±5.657	21.5±0.707	16.5±0.707	43.5±3.536	40.5±2.121	52.5±14.950	40.0±11.314	25.5±2.121	31.0±6.828	20.5±3.536	23.0±2.828	28.5±12.913
27	Indian Cormorant	WM	LC	5.0±1.414	6.0±4.243	10.5±3.536	15.5±2.212	10.0±1.414	12.0±4.828	20.0±2.141	23.0±4.243	8.0±1.414	12.5±2.121	4.5±0.707	5.5±3.536	11.0±5.971
28	Great Cormorant	WM	LC	1.5±0.707	NR	2.0±0.000	2.5±0.707	3.5±0.707	5.5±4.950	3.5±0.707	5.5±0.707	NR	0.5±707	NR	NR	2.0±2.083
	ACCIPITRIDAE															
29	Eastern Marsh Harrier	WM	LC	NR	NR	NR	NR	1.0±0.000	1.0±0.707	2.0±0.000	1.0±0.000	NR	NR	NR	NR	0.4±0.669
	RALLI															

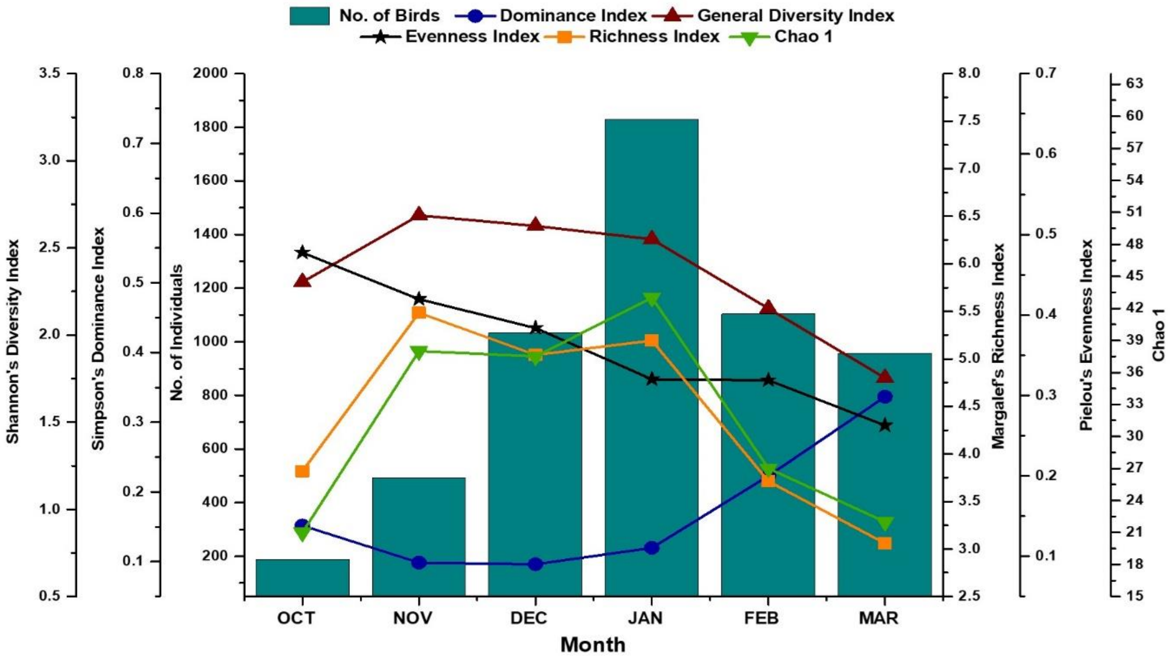
	DAE															
30	White-breasted Waterhen	R	LC	9.5±3.536	10.0±1.414	6.0±1.414	4.5±2.121	7.0±2.414	8.5±2.121	4.5±1.234	7.5±6.364	5.5±2.121	4.5±2.121	3.5±2.121	7.0±1.414	6.4±2.043
31	Purple Swamphen	R	LC	2.5±0.707	1.0±0.000	3.5±2.121	1.5±0.707	4.5±0.707	5.0±2.828	9.5±2.121	11.5±3.536	20.0±4.234	20.5±6.546	25.5±9.192	30.5±4.950	11.3±10.270
32	Eurasian Coot	R	LC	NR	NR	NR	5.0±1.414	33.0±2.828	42.5±13.536	52.0±2.828	53.0±8.485	10.5±4.563	13.5±4.950	6.5±0.707	2.5±0.707	18.2±20.880
	JACANIDAE															
33	Bronze-winged Jacana	R	LC	5.0±2.828	6.5±2.121	3.5±0.707	12.5±2.121	8.0±5.657	5.5±0.707	15.5±3.707	14.0±5.567	9.5±3.536	7.5±2.121	18.0±4.243	15.5±6.364	10.2±4.914
34	Pheasant-tailed Jacana	R	LC	15.5±3.536	13.0±2.828	21.5±4.243	15.0±1.414	15.0±2.828	16.5±2.121	17.5±2.121	16.5±7.778	15.0±8.485	22.0±7.071	25.0±1.414	19.5±6.785	17.7±3.582
	CHARADRIIDAE															
35	Grey-headed Lapwing	WM	LC	NR	NR	2.5±3.536	3.0±1.414	24.5±3.536	22.0±4.828	37.0±7.071	42.5±4.950	3.5±0.707	1.5±0.707	NR	NR	11.3±15.595
36	Little Ringed Plover	R	LC	NR	NR	NR	NR	NR	0.5±0.707	1.5±0.707	1.0±1.414	NR	NR	NR	NR	0.2±0.498
37	Kentish Plover	WM	LC	NR	NR	NR	NR	0.5±0.707	1.0±0.000	2.5±0.707	3.0±1.212	NR	NR	NR	2.0±0.000	0.8±1.118
	SCOLOPACIDAE															
38	Common	WM	LC	NR	NR	NR	NR	NR	NR	1.0±0.000	2.0±0.000	1.5±0.707	2.0±1.41	NR	NR	0.5±0.83

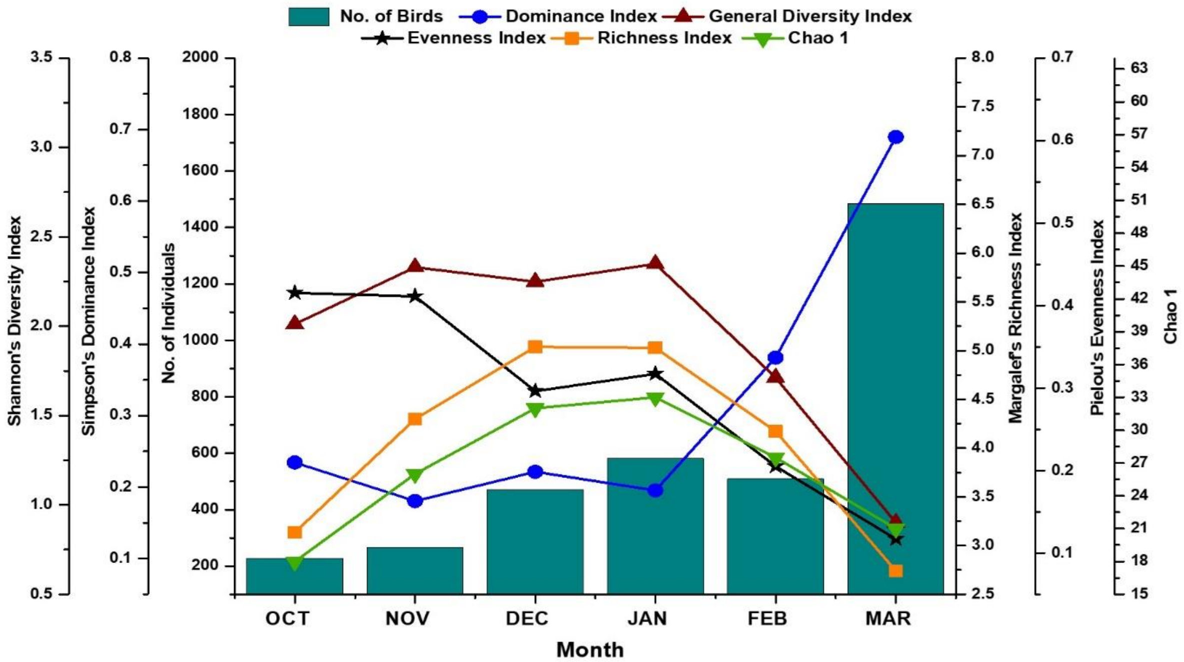
	Snipe												4			8
39	Common Redshank	WM	LC	NR	NR	NR	0.5±0.707	NR	NR	2.0±1.414	2.0±1.212	NR	NR	NR	NR	0.4±0.772
40	Common Greenshank	WM	LC	NR	NR	NR	NR	1.0±0.000	NR	2.0±0.000	2.5±0.707	1.5±1.414	1.0±0.707	NR	NR	0.7±913
41	Wood Sandpiper	WM	LC	NR	NR	NR	NR	NR	NR	1.0±0.707	0.5±0.707	2.0±0.000	1.0±0.000	NR	NR	0.4±0.644
42	Common Sandpiper	WM	LC	1.5±0.707	1.0±1.414	NR	1.0±1.414	1.5±0.707	NR	2.5±0.707	2.0±2.828	3.5±1.212	2.0±1.212	1.0±1.414	2.0±1.414	1.5±1.000
	LARIDAE															
43	Brown-headed Gull	WM	LC	NR	NR	NR	NR	3.5±0.707	2.5±0.707	4.5±1.457	NR	3.0±1.212	3.5±2.121	NR	NR	1.7±1.801
	ALCEDINIDAE															
44	Stork-billed Kingfisher	R	LC	NR	NR	1.5±0.707	NR	2.0±0.000	1.5±0.707	1.5±0.707	4.0±1.212	NR	NR	1.5±0.707	NR	0.8±0.812
45	White-breasted Kingfisher	R	LC	3.5±0.707	5.0±4.243	3.5±2.121	5.5±2.121	5.0±1.414	2.5±1.414	3.5±2.121	3.5±1.235	3.0±1.414	4.5±3.536	3.5±1.212	1.5±0.707	3.7±1.137
46	Common Kingfisher	R	LC	3.0±1.414	2.5±0.707	2.0±1.414	1.5±0.707	3.5±0.707	2.0±0.000	3.5±0.707	2.0±1.414	2.5±0.707	3.5±2.121	2.5±0.707	1.0±0.000	2.5±0.811
	HIRUNDINIDAE															

47	Barn Swallow	WM	LC	5.5±4.950	2.0±1.414	13.5±2.121	14.0±243	76.0±15.556	86.0±8.485	147.0±32.728	130.0±14.243	68.5±13.435	72.0±9.899	17.5±0.707	17.0±8.485	54.1±49.968
48	Wire-Tailed Swallow	WM	LC	NR	NR	NR	NR	1.0±1.414	2.5±0.707	3.5±0.707	1.5±0.707	NR	NR	NR	NR	0.7±1.196
	MOTACILLIDAE															
49	Citrine Wagtail	WM	LC	NR	NR	NR	NR	1.0±1.414	1.0±0.000	2.5±1.414	1.5±0.707	NR	NR	NR	NR	0.4±0.772
50	White Wagtail	WM	LC	NR	NR	NR	1.0±1.414	2.0±0.000	3.5±0.707	1.5±0.707	NR	1.5±0.707	2.0±1.414	NR	NR	1.1±1.125
51	Grey Wagtail	WM	LC	NR	NR	4.5±0.707	1.5±0.707	4.0±1.414	1.0±0.707	NR	1.5±2.212	NR	NR	NR	NR	0.9±1.635
52	White-Browed Wagtail	R	LC	1.0±0.000	0.5±0.707	NR	1.0±1.414	1.5±0.707	2.5±1.414	1.0±0.000	NR	1.0±0.000	1.5±0.707	NR	NR	0.9±0.733

Table 4.2: ***S_{SD} (in %) between the four study sites.***

	PSB	KDM	GAD
ASB	81	71	67
PSB	-	68	70
KDM	-	-	75


No. of Birds
Dominance Index
General Diversity Index
Evenness Index
Richness Index
Chao 1
Shannon's Diversity Index
Simpson's Dominance Index
No. of Individuals
Margalef's Richness Index
Pielou's Evenness Index
Chao 1
OCT
NOV
DEC
JAN
FEB
MAR
Month


No. of Birds
Dominance Index
General Diversity Index
Evenness Index
Richness Index
Chao 1
Shannon's Diversity Index
Simpson's Dominance Index
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Margalef's Richness Index
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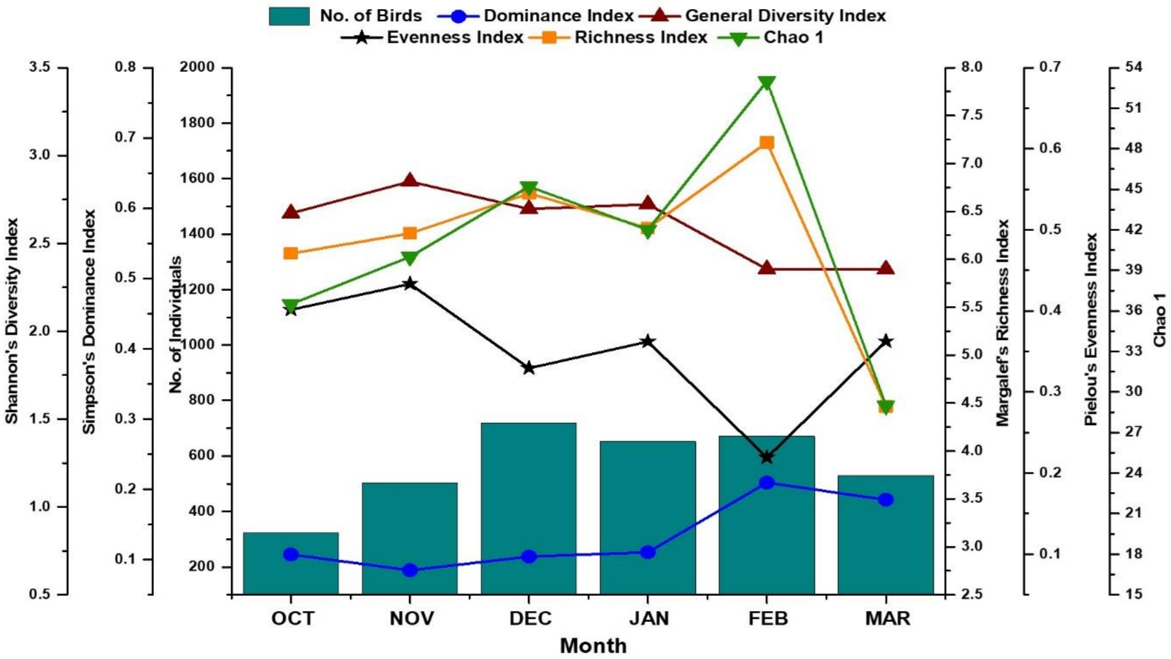

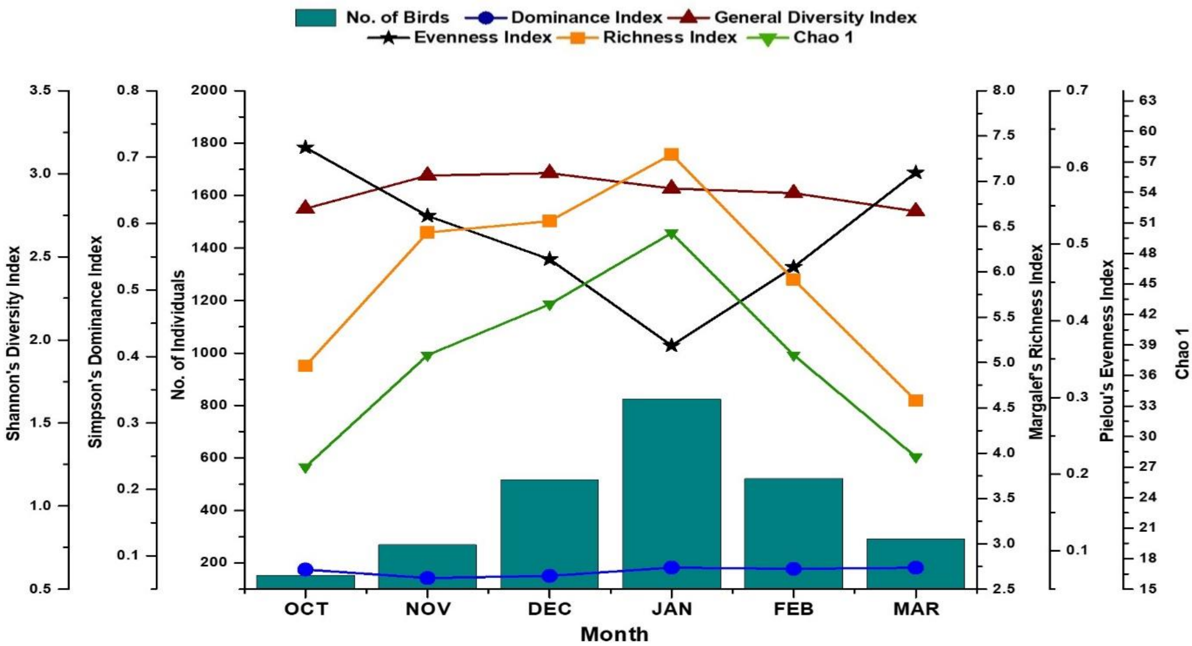

Fig. 4.1 Waterbirds community attributes (No of birds recorded, Chao 1, Shannon's diversity index, Simpson's dominance index, Margalef's richness index and Pielou's evenness index) in study sites (a: ASB, b: PSB c: KDM, d: GAD)

Chapter 5
Physical habitats and population turnover

5. PHYSICAL HABITATS AND POPULATION TURNOVER

Agreements for designating a habitat or a species as protected by International bodies are proved to be a key contrivance to curb the deterioration of habitats and drawdown in species richness and abundance (Glowka et al., 1994). In the context of migratory waterbirds, we need ample information about the potential wetland habitats that regularly shelter the wintering waterbirds for protection against evil effects of ever-increasing human population pressures (Ogden et al., 2014). Many published works record the close relation of vegetation structure, foraging resources and resting conditions with the diversity of wintering waterbirds in a community (Roth, 1976; Short, 1979; Sarkar, 2006; Zakaria and Rajpur, 2010; Ramírez-Albores et al., 2014). Varied geographical features can also influence species assemblages and abundance of wintering waterfowl (Mendez et al., 2012; Almeida et al., 2017). The paucity of foraging and resting resources limit habitat conditions and in the sequel, the waterbird richness and abundance are influenced (González-Gajardo et al., 2009; Almeida et al., 2018).

One of the major determining factors behind the variation of species abundance from local to biogeographical scale is habitat heterogeneity and environmental adaptability (Tews et al., 2004; Bonilla et al., 2012). Thereby, the present conservation strategies rely mainly on the understanding of changing patterns of migratory wintering waterbird species diversity in India and sustainable maintenance mechanisms of wetland ecosystems (Randin et al., 2006; Bassi et al., 2014). However, Ma et al. (2010) pointed out that the waterbird diversity is a critical ecological tool to evaluate wetland habitats both qualitatively and quantitatively. Heterogeneity in physical characteristics of the habitat has gained comparatively little attention in local, regional and global scales; such physical heterogeneity of wetland habitats occurs within a small scale, to be precise it can also occur within a wetland, contributing to higher species richness and abundance in that habitat (Tamme et al., 2010; Sebastian-Gonzalez and Green, 2014; Willby et al., 2018).

Migratory waterbirds of Asia were protected by Asia-Pacific Migratory Waterbird Conservation Strategy (2006) and Partnership for East Asian-Australasia flyway (EAAFP, 2006). First one is working on Asia-pacific region while the geographical scope of the EAAFP is the entire East Asian-Australasia flyway (CMS Technical Series, 2014). However, about 20% of waterbirds of EAAF are in Threatened and Near-threatened category which is much higher than Americas (10%), Africa-Eurasia (15%) and Central Asia (14%). Population trends of waterbirds in Asia are really concerning as 62% of waterbird populations with known trends were decreasing or have become extinct (Delany and Scott, 2006). Li et al. (2009) did a painstaking work on the long term (1987-2007) population trend of the waterbirds in Asia and they found that four (Mallard, Northern pintail, Common teal and Spot-billed Duck) of the eight most prevalent dabbling duck species in East Asia are declining. At the 10th Meeting of the Partners of EAAFP (MoP10) all parties emphasised on the identification and protection of waterbodies harbouring decent population of migratory waterbirds (EAAFP, 2018).

Different wetland sites of West Bengal (Das et al., 2013; Chatterjee et al., 2020) that usually home to wintering waterbird communities were studied to quantify the differences among communities. West Bengal is one of the eastern states of India and has remarkably varied physiographic features (Rudra, 2012). It is the only Indian state to have a coastline as well as the Himalayas. Along the north-south axis, there is northern mountain ranges of Shivalik Himalaya, located within the ecologically sensitive "Indo-Burma biodiversity hotspot" of the Central Himalayas Biogeographical Zone adjacent to two important Endemic Bird Areas, namely Eastern Himalayan and Assam Plains EBAs (EBAs 130 and 131 respectively) and southern delta region made by two major rivers, namely, Ganga and Brahmaputra and their tributaries like Matla, Jamira, Gosaba, etc. forms an extremely low lying area covered by mangrove forest known as Sunderban (Ramsar site No. 2370). While along the west-east axis we find the western plateau (Chhottanagpur Plateau) and the fringing uplands gradually merge in Rarh plain and Gangetic plain. This is our attempt to test the prediction that the features of physical habitats (viz., area, mean depth and shore length) are important determinants of migratory waterbird richness and abundance.

The physical features of wetlands were all important to sustain breeding, migratory, or wintering bird populations (Riffell et al., 2001; Chettri et al., 2005). Wetland area and water surface area had profound effects on various factors like species richness, abundance and guild structure (Babbitt, 2000). Anthropogenic alteration of wetland habitats along the flyways of migratory waterbirds negatively affected the ability of these wetland areas to sustain bird populations (González-Gajardo et al., 2009; Constantin et al., 2019). Each species of wetland-dependent bird had a distinctive and intricate set of needs for wetland habitats that made it difficult to generalize about how loss or degradation of wetlands affected bird populations. Norazlimi and Ramli (2015) and Sohil and Sharma (2020) pointed out that both physical and biological heterogeneity of the habitats favoured avifaunal persistence by providing favourable foraging, roosting, and nesting opportunities to birds. In the present study the selected wetlands were important staging and wintering areas for waterbirds migrating along the Central Asian Flyway (CAF) and East Asian-Australasian Flyway (EAAF), located on varied physiographic features and climatic heterogeneity along the north-south and east-west axes of the state of West Bengal, India (Dhanjal-Adams et al., 2017; CAF National Action Plan- India, 2018). Present information would help to employ suitable strategies to conserve waterbird habitats and to understand their population turnover in India.

5.1 Results

5.1.1 Avifaunal diversity

A total of 117 species of birds belonging to 21 families were recorded from thirteen study sites (Table 5.1). Out of these 117 species, seven species belonged to IUCN red list Threatened category (four species in Vulnerable category and three species in Endangered category). Ten species were in Near Threatened category. While rest hundred species were under Least Concern category (Table 5.1). Family Anatidae was represented by highest number of species (27 species) followed by the family Scolopacidae (14 species). A single species under the families Burhinidae, Rostratulidae, Glareolidae while a couple of species under Jacanidae, Hirundinidae, Alaudidae were recorded. Altogether 76 species of waterbirds out of 117 wetland associated bird species were winter migrants in eastern India.

5.1.2 Physical habitat and community attributes

Site-wise physical attributes (area, shore length and depth) and community attributes (total birds, species number, H/, DSIPM, J/, DMARG and Chao1) were depicted in Table 5.2. Pearson correlation coefficients (*marked correlations significant at $p < 0.05$) were depicted in Table 5.3 to highlight the influence of physical habitat attributes on waterbird community attributes. The positive correlations with both area and shore length of the wetlands were significant between total density of the birds (r= 0.670 and r= 0.600 respectively; $p<0.05$), species richness (r= 0.570 and r= 0.468 respectively; $p<0.05$) and species accumulation function (r= 0.488 and r= 0.362 respectively; $p<0.05$) in this study. The depth of the wetland was also positively significantly correlated with total number of birds (r=0.333; $p<0.05$) and number of species (r=0.322; $p<0.05$). Usually, the higher the wetland area, higher was the bird density, with a few exceptions. Largest area was recorded for Gajoldoba followed by Nilnirjon. The highest bird density was observed at Nilnirjon while highest number of species observed at Gajoldoba (Table 5.2). Gajoldoba also showed highest Chao1 value (91.20). Gajoldoba and Nilnirjon with fairly large areas sheltered different dabblers in fairly large numbers. A total of 14 and 12 dabbler species out of 20 were recorded from Gajoldoba and Nilnirjon respectively. Santragachi and Barasagardighi wetlands had much smaller in area but comparatively higher shore length and harbored unusually high bird densities. At Santragachi the number of species and Chao1 were minimum (24.00 and 27.33 respectively) and single species dominance by Lesser-whistling duck *Dendrocygna javanica* was observed. Barasagardighi, a protected area with minimum human interference, sheltered considerably higher number of species besides the total density. A number of sites at southern West Bengal where the length of shore line was much higher comparative to their area, a higher number of species were recorded, although the total bird density was much lower in these wetlands. Species richness indices were also showed a similar trend in correlations (Table 5.3).

Ahiran and Nararthali wetlands had comparatively higher shore length while much lower surface area (Table 5.1 and 5.2). Interestingly, in these wetlands we observed comparatively higher number of species. Ahiran wetland, having the smallest area (4.75 ha) showed comparably higher Chao1 (71.0) and higher species richness index value (8.578). Ahiran supported 19 singleton species out of total 59 species. Highest dominance index at Santragachi jheel (0.918) could be accounted for the presence of highest percentage of Lesser-whistling duck *Dendrocygna javanica* to the total number of water birds (nearly 95%) and such was the case for Nilnirjon. Nilnirjon with much larger area and highest shore length showed higher dominance index (0.545) next to Santragachi jheel and showed much lower species richness and evenness indices; this could also be accounted for the exceedingly higher numbers of Lesser-whistling duck *Dendrocygna javanica* (nearly 73%) at this site. For such single species dominance, these two sites were significantly different from other sites in post hoc analyses (Table 5.4).

The positive significant correlations were noted between H/ and number of species (r=0.610; *p*<0.05), J/ (r=0.762; *p*<0.05), DMARG (r=0.713; *p*<0.05) and Chao1 (r=0.617; *p*<0.05), while a significant negative correlation with DSIPM (r= –0.956; *p*<0.05). However, besides H/, DSIMP showed significant negative correlations with J/ (r= –0.833; *p*<0.05), DMARG (r= –0.509; *p*<0.05), Chao1 (r= –0.401; *p*<0.05), and the number of species (r= –0.385; *p*<0.05). Significant positive correlations, on the other hand, were observed between DMARG, Chao1, and the number of species (r= 0.973 and r= 0.986 respectively; *p*<0.05). Individual-based rarefaction curves for the site-wise waterbird species richness (with abundance on x-axis and number of species on the y-axis) were shown in Fig. 5.1. The rarefaction curves for present study sites showed that the cumulative species richness (alpha diversity) was highest in case of Gajoldoba, followed by Purbasthali, Ahiran and Barasagardighi.

5.1.3 Cluster analysis based on abundance of waterbirds

Four prominent clusters were formed where the primary cluster composed of nine study sites having comparable linkage distance while, the secondary cluster was formed by three sites with much larger and yet much varied linkage distances. Gajoldoba appeared as an intermediate out-group (Fig. 5.2). Varied density of species occurred in the wetlands was reflected in the dendrogram as principal clusters with larger cluster distances or smaller sub-cluster with smaller cluster distances. Nine study sites in the primary cluster of dendrogram showed comparable waterbird diversity. However, Barasagardighi, Santragachi jheel and Nilnirjon harboured high abundance of waterbirds during the study period and dominance of single or couple of species were also recorded in these sites. Thus, in the dendrogram these three sites formed a separate secondary cluster. Sub-clusters were formed due to comparable abundance of several species recorded in these study sites.

5.1.4 Species turnover: northern and southern habitats

The species-wise post hoc analysis based on the abundance of each species between site pairs for 13 selected wetlands highlighted not only the significant (p<0.05) differences between the site pairs, but also especially indicated the significant differences between the wetlands located at northern (Gajoldoba, Nararthali, Rasikbeel, Barasagardighi, Nayabandh) and southern (Ahiran, Nilnirjon, Adra Sahebbandh, Purbasthali, Gangdoa, Purulia Sahebbandh, Kadamdeuli, Santragachi) parts of the state of West Bengal (position of the Ganges near Malda district of West Bengal, India, demarcates between northern and southern West Bengal; Ghosh, 2016). A contrasting picture for the species abundance between the northern and the southern regions was obtained in ANOVA and a significant difference ($F = 538.52$; partial $\eta 2 = 0.997$; $n = 39$; level of significance $p<0.05$) was recorded. However, when the comparisons were made between the wetlands of northern regions, or between the wetlands of southern regions in respect to βw and βs, the ANOVA results did not show any significant differences; the ANOVA results at level of significance $p<0.05$ were $F = 0.75$ (partial $\eta 2 = 0.176$) and $F = 1.07$ (partial $\eta 2 = 0.137$) for northern and southern wetlands respectively. Present study revealed Whittaker's index of beta-diversity on presence/absence data (βw) was the highest (0.59) between Gajoldoba and Rasik beel and also between Gajoldoba and Santragachi jheel (Table 5.5). The βw was also comparable between Gajoldoba and Nararthali (0.56). Other sites, such as between Rasik beel and Purbasthali, Gajoldoba and Purulia Sahebbandh, Rasik beel and Santragachi, Ahiran and Santragachi, Gajoldoba and Adra Sahebbandh had βw values ≥ 0.5 (Table 5.5). Gajoldoba, with highest number species (Chao1 91.2), made it different from other sites, such as Rasik beel (Chao1 27.0), Santragachi jheel (Chao1 27.3), Nararthali (Chao1 29.3), Adra Sahebbandh (Chao1 33.3) and Purulia Sahebbandh (Chao1 36.0). The lowest βw between site pairs, namely, Kadamdeuli–Gangdoa and Adra Sahebbandh–Purulia Sahebbandh (0.24) and almost a similar value of 0.25 between Nayabandh and Adra Sahebbandh were noted indicating almost comparable number of observed species (Table 5.5). Sorensen index of beta-diversity on abundance data (βs) was highest (0.97) between Nayabandh and Santragachi jheel due to exceedingly high abundance of Lesser-whistling duck *Dendrocygna javanica* at Santragachi and, on the contrary, this species was absent in Nayabandh. The lowest βs (0.31) was noted between Nilnirjon and Santragachi jheel as these wetlands had Lesser-whistling duck *Dendrocygna javanica* dominance.

5.1.5 Habitat preference highlighted in CCA

The CCA plot (Fig. 5.3) depicted influences of physical features of the habitats on the species-wise abundance of four broad groups of waterbird species, namely dabblers, divers, waders and water-associated birds, at different study locations. The CCA, displayed in an ordination diagram, the species were represented by points, and environmental variables were represented by arrows. In the CCA plot, the length of an arrow was equal to the rate of change in the weighted average and was a measure of how much the species distributions differed along a particular variable of the physical habitat. Thereby, abundance of waders, dabblers and divers were under the influence of shore length (66% of waders), area (70% of dabblers) and depth (38% of divers) respectively while the water-associated birds were under the influence of these three factors (Fig. 5.3).

5.2 Discussion

Wetlands are fast degraded in the past century due to the aggressive human activities and already over half of the world's wetland wealth has been lost (Ma et al., 2010; Quesnelle et al., 2013). Steps to reverse wetland habitat degradations are increasingly becoming important to restore ecosystem services. Most critical issue in waterbird conservation is to gather ample regional information on wetland area, perimeter, habitat heterogeneity and community structure (Sebasti´an-Gonz´alez and Green, 2014; Andrade et al., 2018). The diversity of wintering waterbird community was examined in the present study by recording the number of species within a single habitat (alpha-diversity) and the turnover, i.e., the changes in species composition along a series of wetland habitats (beta-diversity). Waterbird species richness and abundance vary according to area of the wetland, mean depth, shoreline length (perimeter), and origin/position of the wetlands (like wetlands of riverine floodplains, catchment areas of barrage/dam and lacustrine wetlands) (Ma et al., 2010). This work attempted to compare the relationship between the variations in physical habitat and parameters of species diversity and turnover, especially for the migratory waterbirds along the gradient from foothills of the Himalayas to lower flood plains of the Gangetic West Bengal, India.

Lake area, depth, and shore length were the most important variables explaining species richness (González-Gajardo et al., 2009; Almeida et al., 2018). The species-area relationship depicted a positive relationship between area and richness (Rosenzweig, 1995), and likewise, a positive relationship between the waterbird species richness and lake area was on record (Bidwell et al., 2014; Dronova et al., 2016). We recorded significant positive correlation coefficients between area of wetlands and the number of species and total birds. All the wetlands under the present study with a larger area (> 100 ha) sheltered large populations. Larger lakes could shelter more individuals and thereby might have a higher chance of sheltering individuals of diverse species. The total number of species, Chao1, and species richness index were not only higher in the sites with larger surface area, but also for the cases of wetlands with higher shore length or depth. Larger habitable shoreline and depth could also contribute to higher habitat heterogeneity (Gawlik, 2002; Dauda et al., 2017), that in turn could increase the richness and abundance. Present study also recorded significant positive correlation coefficients with total birds and number of species when compared with shore length and depth respectively. Longer the shore length more wader species were accommodated (Mandal and Siddique, 2018); on the hand, deeper the wetland more diver species were sheltered (Ma et al., 2010). The present study corroborated with their works.

Different diversity indices were considered as important tool to analyse the community structure and waterbird community dynamics was depicted in the works of Gonzalez-Gajardo et al. (2009), Villamagna et al. (2012) and Rao et al. (2014). In the present study, as the total number of birds increased, the Shannon diversity index and evenness index decreased showing significant negative correlations (r= –0.468 and r= –0.741 respectively; $p<0.05$). This decrease in these two indices was due to the disproportionate increase, in most cases, of a single species, the Lesser-whistling duck *Dendrocygna javanica* (Table 5.1). For such single species dominance, the dominance index showed significant positive correlation with total birds (r=0.575; $p<0.05$). Shannon diversity index and the richness index were positively influenced by the increase in number of species and, hence, significant positive correlations were noted (r= 0.610 and r= 0.973 respectively; $p<0.05$); as the number of species increased, a decrease in dominance was evident in significant negative correlation between number of species and dominance index (r= –0.385; $p<0.05$). Likewise, increase in Shannon diversity index values positively influenced the evenness and the richness and thereby, strong positive correlations were noted. (r= 0.762 and r= 0.713 respectively; $p<0.05$). On the contrary, a decrease in dominance index was reflected in strong negative correlation value (r= –0.956; $p<0.05$).

Individual-based rarefaction curves were used to estimate alpha diversity of the wetlands. Species richness was a fundamental dimension of community diversity and it triggered many ecological models and conservation strategies (Gotelli and Colwell, 2001). Individual-based rarefaction curves suggested an intuitive way to compare the richness that did differ in the number of individuals collected (Gotelli and Colwell, 2011). Gajoldoba and Purbasthali both had comparable species richness and these sites were barrage catchment and riverine oxbow wetland respectively. Likewise, most contrasting richness was also evident between Gajoldoba and Santragachi. For the wetlands under study, either comparable or contrasting physical features of the habitats were important to influence the richness and abundance of wintering migratory avian species. Further, in cases of Kadamdeuli and Gangdoa, both were the catchment areas of river dams, had almost similar species composition, and were located in the same physiographic zone, i.e., Plateau-fringe fans in the western part of West Bengal. Ma et al. (2010) also reported that wetlands in similar geographic region show a similarity in wintering waterbird species composition. It was revealed from the rarefaction curves (Fig. 5.1) that many of the curves did not approach asymptotes. Generally, lower samplings were often related to such depiction (Akite et al., 2015). Homogenising data sets by area or sampling effort could produce very different results compared to standardizing by number of individuals sampled, and it was not always clear which measure of diversity was more appropriate (Karl et al., 2003; Gotelli and Colwell, 2001). In the present study, different wetlands that had many singleton species or species with a few individuals together with lower number of total birds did not reach asymptote. The rarefaction curve for the wetlands, on the other hand, with large number of total birds reached asymptote. Chao et al. (2009) pointed out that in the tropics, where species diversity was high and most species were rare, reaching an asymptote was also prohibitive.

Cluster analysis for physical habitat wise (González-Gajardo et al., 2009; Joshi et al., 2018) or foraging resources wise (Mishra et al., 2020; Chatterjee et al., 2020) changes in avian species composition were on record. In this study, the primary cluster of nine study sites in the dendrogram (Fig. 5.2) had comparable total waterbird density (ranged 682–2646). The secondary cluster formed by, Barasagardighi, Santragachi jheel and Nilnirjon harboured much higher number of waterbirds (ranged 4049 –7584) mostly due to dominating presence of a single or a few species during the study period. However, Gajoldoba, the intermediate out-group, had also higher density (3336) but no single species dominance was observed. Rajashekara and Venkatesha (2010) in a study reported segregation of clusters for significant contrasting characteristics. Species-wise density and the higher dominance of a single or a couple of species also influenced the two sub-clusters under the principal cluster of the nine sites.

Beta diversity, or the amount of change in species composition among sites in a region, had particular relevance for explaining ecological patterns in regional biodiversity (Si et al., 2015; Żmihorski et al., 2016). Lorenzón et al. (2019) reported that variations in water level may generate species turnover between years, increasing temporal-beta diversity. The higher βw values highlighted the larger turnovers between sites due to contrasting species presence/absence data. In the present study, the sites with larger differences in the characters of the physical habitats, such as in cases of Gajoldoba−Rasik beel and Gajoldoba−Santragachi jheel, showed higher βw values. Sites in the present study that had comparably higher βw values also showed contrasting habitat conditions and aggregations of diverse species. Kadamdeuli and Gangdoa both were catchment areas of the river dam and had similar species composition and, thereby, the lowest βw. Similar were the reasons for lower βw for site pairs, namely, Purulia sahebbandh–Adra Sahebbandh Nayabandh – Adra Sahebbandh. The βs, on the other hand, highlighted the contrasts in species abundance and the total abundance was observed to be influenced by contrasting dominance by a single or a couple of species, such as in case of Nayabandh−Santragachi. On the contrary, the lower βs values highlighted the similarities in abundance and the most similarity between Nilnirjon−Santragachi jheel could be accounted for the comparable abundance of Lesser-whistling duck *Dendrocygna javanica*. Our results suggested that an important proportion of changes in bird composition at spatial scale were related to habitat attributes. Out of nine physiographic zones of West Bengal we studied the wetlands under five of these, namely, Sub-Himalayan alluvial fans (Gajoldoba, Nararthali, Rasikbeel), Barind upland (Barasagardighi, Nayabandh), Degraded plateau (Adra sahebbandh, Purulia sahebbandh), Plateau-fringe fans (Kadamdeuli, Gangdoa, Nilnirjon), and Upper Ganga delta (Ahiran, Purbasthali, Santragachi). However, we were especially interested to compare the wetlands of northern West Bengal with the wetlands of southern region. Interestingly, the ANOVA results noted a contrasting picture in community turnover (for βw and βs) between the wetlands of northern and southern regions of West Bengal while the results were insignificant for the wetlands within the northern or within the southern wetlands.

The CCA plot constructed on the species-wise abundance of dabblers, divers, waders and wetland associated birds to the area, depth, and a shore length of the study sites respectively highlighted the importance of quality and quantity of the physical habitat in structuring the waterbird communities (Fig. 5.3). González-Gajardo et al. (2009) reported that the shoreline length was an important feature influencing total species number. A simple regression analysis, however, showed that the species area relationship occurred in wetlands too. Their study concluded that species richness and bird abundance reach higher values in larger and structurally more heterogeneous wetlands. The habitat requirements of waterbirds, including waterfowl, were related to the birds' species richness and abundance (Arzel et al., 2015). Mandal and Siddique (2018) reported high abundance of waders of the family Charadriidae, the family Ardeidae and family Scolopacidae at Purbasthali wetland. Sen and Mandal (2018) also reported high wader density from the same wetland. Cintra (2018) reported that the lake perimeter, area, and shape affected local heterogeneity in species composition of the bird community, whereas at larger scales differences among sites in water-body richness were associated with variation in waterbird richness. In the present study, Gajoldoba and Purbasthali with longer shore length accommodated a good number of wader species with fairly large population sizes. Likewise, the depth of the wetlands showed a positive relation with divers and the deep wetlands such as Gangdoa and Adra Saheb bandh. Gajoldoba with different deeper zones also harboured a good number of diver species with large population sizes. Gajoldoba and Nilnirjon with fairly large areas sheltered different dabblers in fairly large numbers. Wetland associated birds aggregated at the node of the axes in CCA plot indicating the moderate influence of all the three features of the physical habitat on richness and abundance of these birds. Chatterjee et al. (2020) reported that wetland physical features were found to have a significant effect both on bird abundance and richness. Present investigation corroborated with the studies of González-Gajardo et al. (2009), Arzel et al. (2015), Cintra (2018) and Chatterjee et al. (2020).

Birds migrating towards the Indian peninsula primarily follow the CAF and EAAF (Li et al., 2009; Dhanjal-Adams et al., 2017; CAF National Action Plan- India, 2018). The present study recorded that the patterns of species compositions and the abundance of migratory waterbirds varied species to species along the gradient from north to south in the state of West Bengal, India. The local migratory Lesser-whistling Duck *Dendrocygna javanica* was present in almost all sites. Most species under family Rallidae, such as Purple swamphen *Porphyrio porphyrio*, Common moorhen *Gallinula chloropus* and Eurasian coot *Fulica atra* were almost steadily distributed throughout the study sites. India Pond Heron *Ardeola grayii*, of Ardeidae, was also uniformly distributed throughout the study sites. Other important resident or local migratory waterbird species, such as Cotton pygmy goose *Nettapus coromandelianus* and Little grebe *Tachybaptus ruficollis*, were almost evenly distributed in the study sites. Bronze-winged jacana *Metopidius indicus* of the Jacanidae family was also found throughout the study sites with comparable abundance. However, Pheasant-tailed jacana *Hydrophasianus chirurgus*, another Jacanidae, was found in higher numbers in the southern West Bengal, especially wetlands located in the districts of Bankura and Purulia. Porte and Gupta (2017) listed the reasons for differences in local distributions of waterbirds in India. Winter migrants, such as Gadwall *Mareca strepera*, Eurasian wigeon *Mareca penelope*, Northern shoveler *Spatula clypeata*, Northern pintail *Anas acuta* and Common teal *Anas crecca* were also evenly distributed throughout the state, however, populations of Ferruginous duck *Aythya nyroca* were slightly higher in the northern part of West Bengal and populations of common teal were highest in study sites of Malda district; especially Barasagardighi. The abundance of Red-crested pochard *Netta rufina* noticeably increased southward from Murshidabad district to the further southern part of the state. In westernmost district of West Bengal, Purulia, abundance of Red-crested pochard *Netta rufina* was highest. On the contrary, the abundance of Mallard *Anas platyrhynchos*, a winter migrant, and Indian spot-billed duck *Anas poecilorhyncha*, and Fulvous-whistling duck *Dendrocygna bicolor*, both local migrants were higher in the study sites located in the northern part of the state. Abundance of Bar-headed goose *Anser indicus*, another long-distance flyer, was highest in Birbhum district. Nilnirjon dam harboured as many as five hundred Bar-headed gooses *Anser indicus*. Ruddy shelducks *Tadorna ferruginea*, in the present study, were observed to appear in higher numbers near rivers and associated wetlands such as Gajoldoba, Purbasthali. In Gajoldoba, Ruddy shelduck *Tadorna ferruginea* was the most dominant species. River associated abundance of Ruddy shelduck *Tadorna ferruginea* was also reported by Singha Roy et al. (2012). Waders, mainly belonging to family Scolopacidae, also preferred habitats along the shorelines of rivers and river-associated wetland habitats. For this reason, Gajoldoba and Purbasthali harbored most of the waders. Some rare winter-visitors, like Greater white-fronted goose *Anser albifrons*, Smew *Mergellus albellus*, Common Goldeneye *Bucephala clangula*, Falcated duck *Anas falcata*, were found at Gajoldoba (Falcated duck *Anas falcata* was also recorded from Nayabandh). Another rare winter-visitor, Baikal teal *Anas formosa*, was recorded from Rasik beel. The present study thus suggested that the variations in physical features of the habitats were crucial in supporting the richness and abundance of waterbirds, especially the migratory waterbirds.

5.3 Conclusions

Millennium Ecosystem Assessment (2005) reports the steepest decline of wetland bird populations. Widespread wetland habitat alterations and fragmentations had significant effects on waterbirds (Quesnelle et al., 2013). Conservation of suitable habitats for wintering migratory waterbirds on the CAF and EAAF needs a thorough understanding of the characteristics of physical habitats and the avian community attributes. Present information on migratory waterbird richness, evenness and abundance would be important for the future conservation strategies at major wintering sites of West Bengal. Waterbird communities are noted to be excellent indicator of wetland conditions; apart from comparable physical features of the habitats, the wetlands protected by difficulties in approaching due to remote locations or by the state laws or by the way of controlled anthropogenic interferences, such as at Nararthali, Gajoldoba, Nilnirjon, and Purbasthali, could have benefitted in harbouring diverse migratory waterbirds. The unscientific management of the aquatic macrophytes, especially the floating blanket of water hyacinth, could also have a negative impact on sheltering migratory waterbirds (Chatterjee et al., 2020; Mukherjee et al., 2021; Begam et al., 2021). Complete clearing of the water hyacinth or clearing operations at the onset of the migratory period might have impact on the richness and abundance of waterbirds (Mukherjee et al., 2021). However, most of the sites in present work, especially at the northern West Bengal, harbour moderately healthy waterbird community; a few of the wintering habitats are with early warnings of alarming conditions showing low evenness and high dominance. In the coming years more intense studies are necessary to identify the reasons for drawdown in waterbird richness and evenness. The deterioration of habitat quality and immense anthropogenic activities are primary reasons for natural wetland degradation, especially at the lower Gangetic plains (Mukherjee et al., 2020). Effective landscape planning is urgently necessary to encourage migratory waterbird diversity. Our study shows that along the length of the state of West Bengal there are a good number of natural wetland habitats important to shelter diverse waterbirds that migrate through CAF and EAAF.

Table 5.1. Total species and average abundance of birds found during present study in different study sites. Name of wetlands denoted as 1- Gajoldoba, 2- Nararthali, 3- Rasikbeel, 4- Barasagardighi, 5- Nayabandh, 6- Ahiran, 7- Nilnirjon, 8- Adra sahebbandh, 9- Purbasthali, 10- Gangdoa, 11- Purulia sahebbandh, 12- Kadamdeuli, 13-Santragachi jheel. Migration status: Winter migrant (WM) or Resident (R). IUCN status: Least Concerned (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN). Source: www.iucnredlist.org

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Common Name	MS	IUCN Status	1	2	3	4	5	6	7	8	9	10	11	12	13

	ANATIDAE															
1	Lesser Whistling-Duck	R	LC	57±7.2	652.±20.6	248±5.3	2230±87.7	-	153±9.8	5568.3±66.1	449±16.5	729.3±43.2	122.3±10.5	252±11.5	24.7±2.1	3884.3±229.6
2	Fulvous Whistling-Duck	R/WM	LC	10.3±1.5	12.3±1.5	-	60.0±4.6	-	12±1	2.0	1.0	2.0	-	-	-	1.0
3	Greylag Goose	WM	LC	13.3±1.5	-	-	12.3±1.5	-	-	5.3±2.1	-	-	-	1.7±0.6	-	-
4	Greater White-Fronted Goose	WM	LC	4.7±0.6	-	-	-	-	-	-	-	-	-	-	-	-
5	Bar-Headed Goose	WM	LC	24.7±2.1	-	-	-	-	-	481.3±23.5	-	-	-	-	-	-
6	Knob-Billed Duck	WM	LC	-	-	3.7±0.6	3.3±1.2	-	-	-	-	-	-	-	-	-
7	Common Shelduck	WM	LC	1.0	-	-	-	-	-	-	-	-	-	-	-	-
8	Ruddy Shelduck	WM	LC	924±88	-	-	-	-	-	3.7±0.6	-	52.7±2.5	-	-	-	-
9	Cotton Pygmy-Goose	R	LC	85.7±2.5	60.7±5.9	52±3	84.7±2.5	56.3±4.5	14.7±2.5	79.3±2.5	188.3±3.2	167.3±2.5	66±5.6	13.3±3.2	273.7±9	-
10	Gadwall	WM	LC	228±16.1	113.3±16.8	61.3±4	288.3±20.1	55.7±10.1	25.7±3.1	53.3±3.8	125.7±3.1	44.7±2.5	25±2	41±3.6	227±3	23±2

11	Falcated Duck	WM	NT	0.7±0.6	-	-	-	1.0	-	-	-	-	-	-	-	-
12	Eurasian Wigeon	WM	LC	12.7±1.5	2.0	-	-	6.7±1.5	-	30.3±3.1	26.7±0.6	3.7±0.6	-	2.3±0.6	-	1.0
13	Mallard	WM	LC	135.3±16.3	8.7±2.1	6±1	-	12.0±1.0	-	-	-	-	-	-	-	-
14	Spot-Billed Duck	R	LC	14±2.6	7.7±0.6	-	-	-	-	-	-	-	-	-	1.0	-
15	Northern Shoveler	WM	LC	13.7±0.6	2.3±0.6	1.0	-	13.3±2.1	1.0	17.0±1.0	19.0±1.0	11.0±1.0	-	1.0±0.0	8.0±1.0	-
16	Northern Pintail	WM	LC	138±23.5	-	-	82.3±5.7	253.7±21.7	3.7±0.6	46.0±4.4	62.7±4.5	61.7±4.5	1.0±0.0	11.7±0.6	16.7±3.5	10.0±1.0
17	Garganey	WM	LC	26.7±4.7	-	1.7±0.6	89±10.5	24.7±1.5	15.0±1.0	17.3±2.1	-	11.3±1.2	-	-	-	-
18	Common Teal	WM	LC	25.3±3.5	3.7±0.6	13.0±1.7	742.3±46	70.7±5.1	12.7±1.5	56.7±3.5	3.7±0.6	56.3±1.5	-	1.7±0.6	2.3±0.6	-
19	Baikal Teal	WM	LC	-	-	2.0	-	-	-	-	-	-	-	-	-	-
20	Red-crested Pochard	WM	LC	41±3.6	2.0	6.0±2.6	3.3±1.2	2.7±0.6	312.3±8	84.3±5.9	432.7±33.1	128.0±5.6	82.7±7.5	50±1.7	83.7±3.5	-
21	Common Pochard	WM	VU	49.7±9.5	-	-	103.3±4.7	2.0±1.0	1.0	22.7±2.5	56±5	20.7±0.6	-	-	-	-
22	Ferruginous	WM	LC	147.3±22	84.7±9.1	150.3±6	111.0±8.	117.3±4.	1.7±0.	67±2	80.3±2.1	23±1	-	17±1	3±1	1.7±0.6

	Duck			.4			9	7	6							
23	Tufted Duck	WM	LC	89.0±9.8	-	-	-	-	-	82.3±2.5	118.3±4.7	34.3±3.5	-	-	11.7±2.5	-
24	Greater Scaup	WM	VU	-	-	4.0	-	-	-	-	-	-	-	-	-	-
25	Common Goldeneye	WM	LC	4.0	-	-	-	-	-	-	-	-	-	-	-	-
26	Smew	WM	LC	2.0	-	-	-	-	-	-	-	-	-	-	-	-
27	Goosander	WM	LC	26.3±1.5	-	-	-	-	-	-	-	-	-	-	-	-
	PODICIPEDIDAE															
28	Little Grebe	R	LC	45.3±6.7	11±2	-	53.3±4	24.7±2.1	13.7±1.5	79.3±1.5	59.7±3.1	123.7±3.5	11.3±0.6	17.3±2.5	40.0±2.6	6.7±1.5
29	Great Crested Grebe	WM	LC	37.3±4.5	-	1.7±0.6	-	0.7±0.6	1.7±0.6	152±27.2	14.7±1.5	11.3±2.1	2.3±0.6	-	-	-
30	Red-Necked Grebe	WM	LC	-	-	-	-	-	1.0	-	-	-	-	-	-	-
	CICONIIDAE															
31	Asian Openbill	R	LC	17.7±5.5	-	-	-	23.3±2.5	4.0±1	1.7±0.6	-	10.3±0.6	36±1	-	25.3±5.0	2.0
32	Woolly-Necked Stork	R	VU	-	-	-	-	-	1.7±0.6	-	-	-	-	-	1.0±0.0	-
3	White	W	LC	1.0	-	-	-	-	-	-	-	-	-	-	-	-

3	Stork	M														
34	Black-Necked Stork	WM	NT	1.7±0.6	-	-	-	-	-	-	-	-	-	-	-	-
35	Lesser Adjutant	WM	VU	6.7±5.0	-	8.3±1.2	-	1.0	0.7±0.6	-	-	2.3±0.6	-	-	0.7±0.6	-
36	Greater Adjutant	WM	EN	0.7±0.6	-	-	-	-	-	-	-	-	-	-	-	-
	THRESKIORNITHIDAE															
37	Black-Headed Ibis	WM	NT	3.3±0.6	-	-	-	1.3±0.6	-	-	-	4.3±0.6	-	34.7±5.5	-	-
38	Red-Naped Ibis	WM	LC	-	-	-	-	-	1.0	-	-	16.0±3.6	-	-	3.7±0.6	-
39	Glossy Ibis	WM	LC	-	-	-	-	-	-	-	-	1.0	-	-	-	-
	ARDEIDAE															
40	Yellow Bittern	R	LC	-	-	-	-	-	-	-	-	1.0	-	-	-	1.0
41	Cinnamon Bittern	R	LC	1.0±1.0	-	-	-	-	1.3±0.6	1.7±0.6	-	1.0	-	1.0±0.0	1.0±0.0	1.7±0.6
42	Black Bittern	WM	LC	-	-	-	-	-	1.7±0.6	-	0.7±0.6	2.3±0.6	-	-	1.7±0.6	-
43	Striated Heron	R	LC	-	-	-	2.3±0.6	-	-	-	-	-	-	-	-	-
44	Black-Crowned Night Heron	R	LC	-	-	-	-	-	1.7±0.6	-	-	6.7±1.5	-	22.7±2.5	-	-

45	Indian Pond Heron	R	LC	12.0±1	3.3±0.6	5.3±1.5	21.7±1.2	5.7±1.5	2.0±1	13.0±3.6	6.7±1.5	5.7±0.6	7.7±0.6	11.7±0.6	2.7±2.5	7.7±1.5
46	Grey Heron	R	LC	2.7±0.6	1.0	-	5.0±1	-	1.7±1.2	-	1.0	2.3±0.6	1.0±0.0	-	1.3±0.6	-
47	Purple Heron	R	LC	1.0	-	-	6.3±1.2	1.7±0.6	3.0±1	-	2.0	3.7±0.6	2.3±0.6	1.0	1.7±0.6	2.0±1
48	Cattle Egret	R	LC	14.0±2	-	3.7±0.6	4.0±1	1.0	12.3±1.5	8.0±1.0	2.0	113.3±3.2	-	2.3±0.6	-	21.3±3.5
49	Little Egret	R	LC	128±6.6	111.0±2	13.7±1.5	50±6.6	17.0±2	4.0±1	15.3±2.1	16.3±1.2	23.7±3.1	11.7±0.6	17.7±5.0	18.3±1.5	2.3±0.6
50	Intermediate Egret	R	LC	14.3±1.2	-	-	1.7±0.6	-	1.7±0.6	-	-	17.0±2.0	1.0±0.0	-	1.0±0.0	-
51	Great Egret	R		11.7±2.5	-	-	0.7±0.6	-	2.3±0.6	-	-	2.0	-	-	-	-
	ANHINGIDAE															
52	Oriental Darter	WM	NT	-	-	-	1.7±1.5	-	4.0±1	2.0	-	-	-	-	-	-
	PHALACROCORACIDAE															
53	Little Cormorant	R	LC	155.3±11.5	11.3±3.8	11.7±0.6	19.3±1.5	25.7±1.5	5.7±1.5	41.3±6.0	4.3±0.6	154.0±8.2	13.7±2.1	15.7±0.6	14.3±2.5	40±4.4
54	Indian Cormorant	WM	LC	18.0±4.6	3.0±1		2.7±0.6	0.7±0.6	20.7±2.5	18.3±3.5	8.3±0.6	14.3±2.5	45.7±1.2	2.3±0.6	2.3±0.6	8.0±1.0
55	Great Cormorant	WM	LC	25.7±1.5	24.7±3.2	19.3±5.5	19.0±2	1.7±0.6	66.3±6.1	7.7±1.5	11.7±1.5	2.3±0.6				
	ACCIPITRIDAE															
56	Osprey	WM	LC	2.0	-	-	1.0	-	1.7±0.6	0.7±0.6	0.7±0.6	1.7±0.6	-	-	-	-

									6							
57	Booted Eagle	WM	LC	-	-	-	-	-	-	-	-	1.0	-	-	-	-
58	White-Tailed Eagle	WM	LC	1.0	-	-	-	-	-	-	-	-	-	-	-	-
59	Pallas's Fish Eagle	R	EN	-	-	-	0.7±0.6	-	-	-	-	-	-	-	-	-
60	Short-Toed Snake Eagle	WM	LC	0.7±0.6	-	-	-	-	-	-	-	-	-	-	-	-
61	Grey-Headed Fish Eagle	WM	NT	-	-	-	-	-	1.0	-	1.3±0.6	-	-	-	-	-
62	Eurasian Marsh Harrier	WM	LC	1.0	-	-	-	1.0	0.7±0.6	1.3±0.6	-	1.7±0.6	-	-	-	-
63	Pied Harrier	WM	LC	-	1.0	-	-	1.0±1.0	-	-	-	-	-	-	-	-
64	Greater Spotted Eagle	WM	VU	1.7±0.6	-	-	-	1.0	1.3±0.6	-	-	-	-	-	-	-
65	Brahminy Kite	R	LC	-	-	-	-	-	-	1.3±0.6	-	-	-	-	-	-
	RALLIDAE															
66	Baillon's Crake	WM	LC	-	0.7±0.6	-	-	-	1.0	-	-	-	-	-	-	-
6	White-	R	LC	4.0±	4.3±	-	2.7±	1.3±	2.3	12.7±	2.3±	12.0	12.0	4.7±	2.0	2.3±0.

7	Breasted Waterhen			1	1.5		0.6	0.6	±0.6	2.1	0.6	±1	±3	0.6	±0.0	6
68	Watercock	R	LC	-	-	-	-	-	-	-	-	1.0	-	-	-	-
69	Purple Swamphen	R	LC	15.3 ±2.1	-	-	18.7 ±1.5	-	51.3 ±4.5	-	4.0	14.7 ±2.5	2.0	11.3 ±1.2	4.0	-
70	Common Moorhen	R	LC	46.0 ±4.4	29.0 ±7.0	26.7 ±3.2	31.3 ±1.5	1.3±0.6	1.7 ±0.6	21.3±1.5	42.7 ±2.5	15.7 ±1.5	14.3 ±2.5	96.7 ±4.5	32.7 ±6.1	3.7±1.5
71	Eurasian Coot	R	LC	84.7 ±3.8	18.3 ±2.5	11.3 ±2.5	150.7±5.5	214.0±19.3	41.0 ±6.6	229.7 ±8.7	214.3±4	237.0±15.1	52 ±4	63±3.6	40.3 ±1.2	-
	BURHINIDAE															
72	Great Thick-knee	R	NT	25.3 ±1.5	-	-	-	-	1.7 ±0.6	-	-	-	-	-	-	-
	JACANIDAE															
73	Bronze-winged Jacana	R	LC	14.7 ±2.1	15.0 ±5.2	16.3 ±3.8	12.0 ±1.0	15.7 ±1.5	13.3 ±1.5	2.0±0.0	12.7 ±2.1	12.0 ±1	6.7±0.6	18.0 ±1.7	31.0 ±3.6	1.7±0.6
74	Pheasant-tailed Jacana	R	LC	-	-	-	1.7±0.6	10.7 ±1.5	17.0 ±1	11.3±2.1	45.7 ±5	55.7 ±5.5	9.3±0.6	11.3 ±0.6	154.7±9	-
	CHARADRIIDAE															
75	Northern Lapwing	WM	NT	132.3±23.5	-	-	-	-	-	-	-	-	-	-	-	-
76	River Lapwing	R	NT	12.0 ±1	-	-	-	-	1.0	-	-	4.0±1	-	-	-	-
7	Grey-	W	LC	28.0	49.3	30.0	-	-	4.0	-	-	11.7	2.3±	-	14.3	-

7	Headed Lapwing	M		±6.1	±3.8	±2.6			±2			±0.6	0.6		±2.5	
78	Red-Wattled Lapwing	R	LC	6.7±0.6	-	13.0±1	2.3±0.6	-	-	-	-	23.7±3.1	11.0±1	-	2.0	-
79	Yellow-Wattled Lapwing	R	LC	-	-	-	-	-	-	-	-	2.0	-	-	-	-
80	Pacific Golden Plover	WM	LC	78.0±2.6	-	-	-	-	-	-	-	5.3±2.5	-	-	-	-
81	Little Ringed Plover	R	LC	25.3±2.1	-	-	-	-	1.7±0.6	-	-	23.3±3.5	-	-	0.7±0.6	-
82	Kentish Plover	WM	LC	16.7±4.5	-	-	1.7±0.6	-	-	-	-	13.7±0.6	-	-	-	-
	ROSTRATULIDAE															
83	Greater Painted-Snipe	R	LC	-	-	-	-	-	-	-	-	1.0	-	-	-	-
	SCOLOPACIDAE															
84	Pin-Tailed Snipe	WM	LC	-	-	-	0.7±0.6	-	-	-	-	2.3±0.6	-	-	-	-
85	Common Snipe	WM	LC	-	-	-	-	-	1.3±0.6	-	-	2.0	-	-	-	-
8	Black-	W	N	-	-	-	-	-	16.0	-	-	-	-	-	-	-

6	Tailed Godwit	M	T						±4.6							
87	Common Redshank	WM	LC	15.0 ±1.7	-	-	-	-	1.3 ±0.6	-	-	52.7 ±6.0	-	-	-	-
88	Common Greenshank	WM	LC	3.3±1.2	1.3±0.6	-	1.0	-	-	-	-	31.7 ±1.2	-	-	1.0	-
89	Spotted Redshank	WM	LC	-	-	-	-	-	-	-	-	3.3±0.6	-	-	-	-
90	Green Sandpiper	WM	LC	1.7±0.6	-	-	-	-	-	-	-	12.0 ±1	-	-	-	-
91	Wood Sandpiper	WM	LC	7.0±1	-	-	-	-	-	-	-	6.3±0.6	2.3±0.6	-	-	-
92	Marsh Sandpiper	WM	LC	-	-	-	-	-	-	-	-	1.7±0.6		-	-	-
93	Common Sandpiper	WM	LC	56.0 ±6.2	-	-	-	-	1.3 ±0.6	1.7±0.6	-	11.0 ±1.0	0.7±0.6	-	1.0 ±0.0	-
94	Great Knot	WM	EN	4.0±1.0	-	-	-	-	-	-	-	-	-	-	-	-
95	Little Stint	WM	LC	14.0 ±1.0	-	-	1.7±0.6	-	-	-	-	33.0 ±3.6	-	-	-	-
96	Temminck's Stint	WM	LC	23.3 ±2.5	-	-	-	-	-	-	-	17.3 ±1.5	-	-	-	-
97	Ruff	WM	LC	-	-	-	-	-	-	-	-	1.0	-	-	-	-
	GLAREOLIDAE															
9	Small	R	-	3.7±	-	-	-	-	-	-	-	24.7	-	-	-	-

8	Pratincole			1.5								±2.1				
	LARIDAE															
99	Pallas's Gull	WM	LC	1.0	-	-	-	-	-	-	-	-	-	-	-	-
100	Brown-Headed Gull	WM	LC	26.7±1.5	-	-	-	-	-	-	-	-	-	-	-	-
101	Black-Headed Gull	WM	LC	14.7±1.5	-	-	-	-	3.7±0.6	-	-	-	1.7±1.5	-	-	-
102	River Tern	R	NT	-	-	-	-	-	1.7±0.6	-	-	3.7±0.6	-	-	-	-
103	Whiskered Tern	WM	LC	-	-	-	-	-	2.0	-	-	-	1.0	-	-	-
	ALCEDINIDAE															
104	Stork-Billed Kingfisher	R	LC	-	0.7±0.6	-	-	-	0.7±0.6	1.3±0.6	-	1.7±0.6	2.0	-	2.3±0.6	-
105	White-Throated Kingfisher	R	LC	-	3.0±1.0	2.3±1.2	1.7±0.6	1.0	1.0	1.0	2.3±0.6	5.3±3.5	2.3±0.6	0.7±0.6	0.7±0.6	2.7±0.6
106	Common Kingfisher	R	LC	3.7±0.6	1.3±0.6	2.3±0.6	4.3±1.5	1.7±0.6	4.3±0.6	2.0	1.7±0.6	1.0	1.0±0.0	2.3±0.6	0.7±0.6	1.0
107	Pied Kingfisher	R	EN	2.0	-	-	1.0	-	1.0	-	-	2.0	-	-	2.0±0.0	-
	HIRUNDINIDAE															
108	Barn Swallow	WM	LC	26.3±2.5	-	-	249.7±15.5	-	-	317.3±5.5	-	131.7±5.5	137.0±13.5	-	43.7±4.2	26.3±3.1

109	Wire-Tailed Swallow	WM	LC	16.7 ±1.5	-	-	1.7± 0.6	-	-	2.0	-	-	-	-	-	-
	ALAUDIDAE															
110	Crested Lark	WM	LC	4.0± 1.0	-	-	-	-	-	-	-	-	-	-	-	-
111	Sand Lark	R	LC	2.0	-	-	-	-	-	-	-	-	-	-	-	-
	SYLVIIDAE															
112	Blyth's Reed Warbler	WM	LC	-	-	-	-	-	-	-	-	-	-	1.0	-	-
	MOTACILLIDAE															
113	Yellow Wagtail	WM	LC	1.0± 1	-	-	1.7± 0.6	-	-	-	-	16.3 ±4.5	-	-	-	-
114	Citrine Wagtail	WM	LC	0.7± 0.6	-	-	1.0	-	-	-	-	1.7± 0.6	-	-	-	3.3±0.6
115	White Wagtail	WM	LC	61.7 ±6.8	-	2.0	14.3 ±2.5	-	4.0 ±1.0	31.0± 3.6	-	6.7± 1.5	2.0± 0.0	-	6.7 ±0.6	1.0
116	Grey Wagtail	WM	LC	1.0± 0.0	-	-	1.7± 0.6	-	-	3.7±0.6	-	-	-	2.3	-	-
117	White-Browed Wagtail	R	LC	5.7± 1.5	-	-	0.0± 1.2	-	-	-	-	1.0	0.7± 0.6	-	12.0 ±1.0	-

Table 5.2 Physical habitat attributes (area, shore length, depth) of the study sites and site-wise total number of species, average number of individuals (±SD), Shannon's general diversity index (H/), Simpson's dominance index (DSIPM), Pielou's evenness index (J/), Margalef's richness index (DMARG) and Species accumulation function (Chao 1).

	Area (in ha)	Shore length (in km)	Depth (in m)	No of Species	No of individuals (Mean±SD)	H/	DSIMP	J/	DMARG	Chao 1
Gajoldoba	700	13.8	8.4	84	3336.3±129.7	3.223	0.096	0.299	10.230	91.20
Nararthali	6.5	1.59	2.5	29	1130±45.9	1.749	0.350	0.198	3.983	29.33
Rasikbeel	78.9	8.69	2.9	27	709.7±53.2	2.247	0.183	0.350	3.961	27.00
Barasagardighi	52.1	3.05	1.9	48	4486.3±228.2	1.939	0.283	0.145	5.589	54.00
Nayabandh	15.8	1.74	1.6	34	956.3±29.4	2.347	0.148	0.308	4.809	44.50
Ahiran	4.8	0.88	1.7	59	864.7±47.8	2.537	0.170	0.214	8.578	71.00
Nilnirjon	684	27.10	7.6	43	7584.3±1133.8	1.300	0.545	0.085	4.701	43.00
Adra Sahebbandh	76	7.98	3.5	33	2005±167.3	2.439	0.128	0.347	4.209	33.33
Purbasthali	219	22.92	2.5	76	2646.7±87.9	3.055	0.102	0.279	9.517	82.00
Gangdoa	92.7	9.20	7.5	33	681.7±57.1	2.562	0.111	0.393	4.905	35.50

Purulia Sahebbandh	31.3	2.87	2.5	30	719±67.8	2.415	0.160	0.373	4.409	36.00
Kadamdeuli	38	5.30	4.5	43	1105.3±117.4	2.509	0.133	0.286	5.993	46.75
Santragachi	13.9	1.97	1.5	24	4049.3±312.7	0.279	0.918	0.055	2.769	27.33

Table 5.3 Pearson multiple correlation coefficients to highlight the influence of physical habitat attributes (area, shore length and depth) on waterbird community attributes [total birds, species number, Shannon diversity index (H/), dominance (DSIPM), evenness (J/), richness (DMARG) and species accumulation function (Chao1)]. *marked correlations are significant at p< 0.05; N=39.

	Total Birds	**Species Number**	**H/**	**DSIPM**	**J/**	**DMARG**	**Chao1**
Area	0.670*	0.570*	0.143	0.035	−0.184	0.438*	0.488*
Shore Length	0.600*	0.468*	0.162	−0.023	−0.092	0.352*	0.362*
Depth	0.333*	0.322*	0.255	−0.158	0.155	0.263	0.234
Total Birds		0.220	−0.468*	0.575*	−0.741*	0.014	0.154
Species Number			0.610*	−0.385*	0.006	0.973*	0.986*
H/				−0.956*	0.762*	0.713*	0.617*
DSIPM					−0.833*	−0.509*	−0.401*
J/						0.144	0.016
DMARG							0.980*

Table 5.4 Species-wise Post hoc Analysis (Tukey HSD) between thirteen selected sites (numbers at the horizontal heading denoted the sites as mentioned in Table 3.1. Numbers 1 – 5 were the wetlands located in northern West Bengal and the rest were in the southern part). The numbers in the columns denote the significant ($p<0.05$) differences between site pairs calculated on the basis of the particular species abundance.

	Common Name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	Lesser Whistling-Duck	2-4,7-9,13	4-7, 10-13	4,7,9,13	5-13	7-9,11, 13	7-9,13	8-13	9,10, 12,13	10-13	13	12, 13	13
2	Fulvous Whistling-Duck	3-5,7-13	3-5,7-13	4,6	5-13	6	7-13	-	-	-	-	-	-
3	Greylag Goose	2,3,5-7,13	4,7	4,7	5-7,13	7	7	8-13	-	-	-	-	-
4	Greater White-Fronted Goose	2-13	-	-	-	-	-	-	-	-	-	-	-
5	Bar-Headed Goose	2-13	7	7	7	7	7	8-13	-	-	-	-	-
6	Knob-Billed Duck	3,4	3,4	5-13	5-13	-	-	-	-	-	-	-	-
7	Common Shelduck	-	-	-	-	-	-	-	-	-	-	-	-

8	Ruddy Shelduck	2-13	-	-	-	-	-	-	-	-	-	-	-
9	Cotton Pygmy-Goose	2,3,5,6,8-13	4,6-12	4,6-13	5,6,8-13	6-12	7-10,12,13	8-13	9-13	10-13	11-13	12	13
10	Gadwall	2-11,13	3-7,9-13	4,6,10,12,13	5-13	8,12	8,12	8,12,13	9-13	12	12	12	13
11	Falcated Duck	2-4,6-13	5	5	5	6-13	-	-	-	-	-	-	-
12	Eurasian Wigeon	2-13	5,7,8	5,7-9	5,7-9	6-8,10-13	7-9	8-13	9-13	10,12	-	-	-
13	Mallard	2-13	-	-	-	-	-	-	-	-	-	-	-
14	Indian Spot-Billed Duck	2-13	3-13	-	-	-	-	-	-	-	-	-	-
15	Northern Shoveler	2-4,6-13	5,7-9,12	5,7-9,12	5,7-9,12	6-8,10-13	7-9,12	9-13	9-13	10-13	12	12	13
16	Northern Pintail	2-13	4,5,7-9	4,5,7-9	5-7,10-13	6-13	7-9	10-13	10-13	10-13	-	-	-
17	Garganey	2-4,6,8-13	4-7,9	4-7	5-13	8-13	8,10-13	8,10-13	-	10-13	-	-	-
18	Common Teal	4	4,5,7,9	4,5,7,9	5-13	6,8,10-13	7,9	8,10-13	9	10-13	-	-	-
1	Baikal	-	-	-	-	-	-	-	-	-	-	-	-

9	Teal												
20	Red-crested Pochard	2-10,12,13	6-12	6-12	6-12	6-12	7-13	8,9,11,13	9-13	10-13	11,13	12	13
21	Common Pochard	2-7,9-13	4,7-9	4,7-9	5-13	7-9	7-9	8,10-13	9-13	10-13	-	-	-
22	Ferruginous Duck	2,4-13	3-6,9-13	4-13	6-13	6-13	7,8	9-13	9-13	-	-	-	-
23	Tufted Duck	2-6,8-13	7-9,12	7-9,12	7-9,12	7-9,12	7-9,12	8-13	9-13	10-13	12	12	13
24	Greater Scaup	-	-	-	-	-	-	-	-	-	-	-	-
25	Common Goldeneye	-	-	-	-	-	-	-	-	-	-	-	-
26	Smew	-	-	-	-	-	-	-	-	-	-	-	-
27	Goosander	2-13	-	-	-	-	-	-	-	-	-	-	-
28	Little Grebe	2,3,5-11,13	3-5,7-9,12	4-12	5-7,9-13	6-10,12,13	7-9,12	8-13	9-13	10-13	12	12,13	13
29	Great Crested Grebe	2-7,9-13	7	7	7	7	7	8-13	-	-	-	-	-
30	Red-Necked Grebe	-	-	-	-	-	-	-	-	-	-	-	-

31	Asian Openbill	2-4,6-13	5,9,10,12	5,9,10,12	5,9,10,12	6-11,13	10,12	9,10,12	9,10,12	10-13	11-13	12	13
32	Woolly-Necked Stork	6,12	6,12	6,12	6,12	6,12	7-13	12	12	12	12	12	13
33	White Stork	-	-	-	-	-	-	-	-	-	-	-	-
34	Black-Necked Stork	2-13	-	-	-	-	-	-	-	-	-	-	-
35	Lesser Adjutant	2,4-8,10-13	3	4-13	-	-	-	-	-	-	-	-	-
36	Greater Adjutant	2-13	-	-	-	-	-	-	-	-	-	-	-
37	Black-Headed Ibis	11	11	11	11	11	11	11	11	11	10, 11	12, 13	-
38	Red-Naped Ibis	9,12	9,12	9,12	9,12	9,12	9,12	9,12	9,12	10-13	12	12	13
39	Glossy Ibis	-	-	-	-	-	-	-	-	-	-	-	-
40	Yellow Bittern	-	-	-	-	-	-	-	-	-	-	-	-
41	Cinnamon Bittern	-	6,7,13	6,7,13	6,7,13	7,13	10	8,10	13	-	13	-	-
42	Black Bittern	6,9,12	6,9,12	6,9,12	6,9,12	6,9,12	7,8,10,11,13	9,12	9,12	10,11,13	12	12	13

43	Striated Heron	4	4	4	5-13	-	-	-	-	-	-	-	-
44	Black-Crowned Night Heron	9,11	9,11	9,11	9,11	9,11	9,11	9,11	9,11	10-13	11	12,13	-
45	Indian Pond Heron	2-6,8,9,12	4,7,11	4,7,11	5-13	7,11	7,10,11,13	8-10,12,13	-	11	12	12,13	13
46	Grey Heron	2-7,10,11,13	4	4,6,9	5-13	9	7,11,13	9	-	11,13	-	-	-
47	Purple Heron	4,6,9	4,6,9,10,13	4,6,9,10,13	5-13	9	7,11	9	-	11,13	-	-	-
48	Cattle Egret	2-5,7-13	6,7,9,13	6,9,13	6,9,13	6,7,9,13	8-13	8-13	9,13	10-13	13	13	13
49	Little Egret	2-13	4,9	4,13	5-13	6,13	7-9,11,12	13	13	10,13	-	13	13
50	Intermediate Egret	2-13	9	9	9	9	9	9	9	10-13	-	-	-
51	Great Egret	2-13	6	6	-	-	7,10-13	-	-	-	-	-	-
52	Oriental Darter	4,6,7	4,6,7	4,6,7	6,9-13	6,7	7-13	8-13	-	-	-	-	-
53	Little Cormorant	2-8,10-13	7,9,13	7,9,13	7,9,13	6-9	7-9,13	8-12	9,13	10-13	13	13	13
5	Indian	2-	6,7,9,	6-	6,7,9,	6-	8-13	8,10,	10	10-	11	-	-

4	Cormorant	5,8,10-13	10	10,13	10	10,13		11-13		13	-13		
55	Great Cormorant	5-13	5-13	5-7,9-13	5-7,9-13	6	7-13	-	9-13	-	-	-	-
56	Osprey	2-5,7,8, 10-13	4,6,9	4,6,9	10-13	6,9	7,8,10-13	9	9	10-13	-	-	-
57	Booted Eagle	-	-	-	-	-	-	-	-	-	-	-	-
58	White-Tailed Eagle	-	-	-	-	-	-	-	-	-	-	-	-
59	Pallas's Fish Eagle	4	4	4	5-13	-	-	-	-	-	-	-	-
60	Short-Toed Snake Eagle	2-13	-	-	-	-	-	-	-	-	-	-	-
61	Grey-Headed Fish Eagle	6,8	6,8	6,8	6,8	6,8	7-13	8	9-13	-	-	-	-
62	Eurasian Marsh Harrier	2-4,8,10-12	5,7,9	5,7,9	5,7,9	10-13	9	8,10-13	9	10-13	-	-	-
63	Pied Harrier	2,5	3,4,6-13	5	5	6,7,9-13	-	-	-	-	-	-	-
64	Greater Spotted Eagle	2-4,7-13	5,6	5,6	5,6	7-13	7-13	-	-	-	-	-	
6	Brahmi	7	7	7	7	7	7	8-13	-	-	-	-	-

5	ny Kite												
66	Baillon's Crake	2,6	3-5,7-13	6	6	6	7-13	-	-	-	-	-	-
67	White-Breasted Waterhen	3,7,9,10	3,7,9,10	7,9-11	7,9,10	7,9,10	7,9,10	8,11-13	9,10	11-13	11-13	-	-
68	Watercock	-	-	-	-	-	-	-	-	-	-	-	-
69	Purple Swamphen	2,3,5-8,10,12,13	4,6,9,11	4,6,9,11	5-8,10-13	6,9,11	7-13	9,11	9,11	10,12,13	11	12,13	-
70	Common Moorhen	2-7,9-13	5,6,8-11,13	5,6,8-11,13	5,6,9-11,13	7-12	7-12	8,11-13	9-11,13	11-13	11,12	12,13	13
71	Eurasian Coot	2-10,12,13	4-12	4-10,12,13	5-13	6,10-13	7-9,13	10-13	10-13	10-13	13	13	13
72	Great Thick-knee	2-13	6	6	6	6	7-13	-	-	-	-	-	-
73	Bronze-winged Jacana	7,10,12,13	7,10,12,13	7,10,12,13	7,12,13	7,10,12,13	7,12,13	8,9,11,12	12,13	12,13	11,12	12,13	13
74	Pheasant-tailed Jacana	6-9,11,12	6-9,11,12	6-9,11,12	6,8,9,12	8,9,12	8,9,12,13	8,9,12,13	10-13	10-13	12	12,13	13
75	Northern	2-13	-	-	-	-	-	-	-	-	-	-	-

	Lapwing												
76	River Lapwing	2-13	9	9	9	9	9	9	9	10-13	-	-	-
77	Grey-Headed Lapwing	2,4-13	3-13	4-13	9,12	9,12	9,12	9,12	9,12	10,11,13	12	12	13
78	Red-Wattled Lapwing	2-13	3,9,10	4-12	9,10	9,10	9,10	9,10	9,10	10-13	11-13	-	-
79	Yellow-Wattled Lapwing	-	-	-	-	-	-	-	-	-	-	-	-
80	Pacific Golden Plover	2-13	9	9	9	9	9	9	9	10-13	-	-	-
81	Little Ringed Plover	2-8,10-13	9	9	9	9	9	9	9	10-13	-	-	-
82	Kentish Plover	2-8,10-13	9	9	9	9	9	9	9	10-13	-	-	-
83	Greater Painted-Snipe	-	-	-	-	-	-	-	-	-	-	-	-
84	Pin-Tailed	9	9	9	9	9	9	9	9	10-13	-	-	-

	Snipe												
85	Common Snipe	6,9	6,9	6,9	6,9	6,9	7-13	9	9	10-13	-	-	-
86	Black-Tailed Godwit	6	6	6	6	6	7-13	-	-	-	-	-	-
87	Common Redshank	2-13	9	9	9	9	9	9	9	10-13	-	-	-
88	Common Greenshank	2-13	9	9	9	9	9	9	9	10-13	-	-	-
89	Spotted Redshank	9	9	9	9	9	9	9	9	10-13	-	-	-
90	Green Sandpiper	2-13	9	9	9	9	9	9	9	10-13	-	-	-
91	Wood Sandpiper	2-8,10-13	9,10	9,10	9,10	9,10	9,10	9,10	9,10	10,13	11-13	-	-
92	Marsh Sandpiper	9	9	9	9	9	9	9	9	10-13	-	-	-
93	Common Sandpiper	2-13	9	9	9	9	9	9	9	10-13	-	-	-
94	Great Knot	2-13	-	-	-	-	-	-	-	-	-	-	-

95	Little Stint	2-13	9	9	9	9	9	9	9	10-13	-	-	-
96	Temminck's Stint	2-13	9	9	9	9	9	9	9	10-13	-	-	-
97	Ruff	-	-	-	-	-	-	-	-	-	-	-	-
98	Small Pratincole	2-13	9	9	9	9	9	9	9	10-13			
99	Pallas's Gull	-	-	-	-	-	-	-	-	-	-	-	-
100	Brown-Headed Gull	2-13	-	-	-	-	-	-	-	-	-	-	-
101	Black-Headed Gull	2-13	6	6	6	6	7-13	-	-	-	-	-	-
102	River Tern	6,9	6,9	6,9	6,9	6,9	7-13	9	9	10-13	-	-	-
103	Whiskered Tern	-	-	-	-	-	-	-	-	-	-	-	-
104	Stork-Billed Kingfisher	7,9,10,12	10,12	7,9,10,12	7,9,10,12	7,9,10,12	10,12	8,11,13	9,10,12	11,13	11,13	12	13
105	White-Throated Kingfisher	9	-	-	9	9	9	9	-	11,12	-	-	-

106	Common Kingfisher	2,6,8-10,12,13	4,6	4,6	5,7-13	6	7-13	-	-	-	-	-	-
107	Pied Kingfisher	-	-	-	-	-	-	-	-	-	-	-	-
108	Barn Swallow	2-13	4,7	4,7	5,7-13	7	7						
109	Wire-Tailed Swallow												
110	Crested Lark	2-13	-	-	-	-	-	-	-	-	-	-	-
111	Sand Lark	-	-	-	-	-	-	-	-	-	-	-	-
112	Blyth's Reed Warbler	-	-	-	-	-	-	-	-	-	-	-	-
113	Yellow Wagtail	9	9	9	9	9	9	9	9	10-13	-	-	-
114	Citrine Wagtail	9,13	4,9,13	4,9,13	5-8,10-13	9,13	9,13	9,13	9,13	8,10-13	13	13	13
115	White Wagtail	2-13	4,7	4,7	5-13	7	7	8-13	-	-	-	-	-
1	Grey	2-13,	4,7,11	4,7,11	5-	7,11	7,11	8-13	11	11	11	12,	-

16	Wagtail				10,12,13							13	
117	White-Browed Wagtail	2-13	4,12	4,12	5-13	12	12	12	12	12	12	12	13

Table 5.5 Beta diversity or species turnover of birds between study sites (1- Gajoldoba, 2- Nararthali, 3- Rasikbeel, 4- Barasagardighi, 5- Nayabandh, 6- Ahiran, 7- Nilnirjon, 8- Adra sahebbandh, 9- Purbasthali, 10- Gangdoa, 11- Purulia sahebbandh, 12- Kadamdeuli, 13-Santragachi jheel).

Whitaker Index	Sites	1	2	3	4	5	6	7	8	9	10	11	12	13	Sorensen Index
	1	**0.00**	0.78	0.76	0.73	0.70	0.82	0.83	0.67	0.63	0.80	0.80	0.70	0.95	
	2	0.56	**0.00**	0.37	0.63	0.72	0.71	0.78	0.48	0.53	0.67	0.53	0.71	0.72	
	3	0.59	0.36	**0.00**	0.77	0.63	0.64	0.87	0.61	0.71	0.59	0.42	0.72	0.87	
	4	0.38	0.45	0.47	**0.00**	0.76	0.86	0.48	0.64	0.58	0.81	0.80	0.79	0.45	
	5	0.47	0.33	0.34	0.44	**0.00**	0.80	0.85	0.61	0.67	0.73	0.71	0.71	0.97	
	6	0.38	0.45	0.49	0.38	0.38	**0.00**	0.89	0.55	0.70	0.53	0.54	0.71	0.91	
	7	0.40	0.39	0.43	0.32	0.30	0.33	**0.00**	0.73	0.66	0.86	0.86	0.89	0.31	
	8	0.50	0.29	0.40	0.33	0.25	0.33	0.26	**0.00**	0.42	0.68	0.58	0.57	0.83	
	9	0.28	0.52	0.55	0.34	0.45	0.27	0.38	0.41	**0.00**	0.63	0.66	0.65	0.73	
	10	0.50	0.42	0.47	0.38	0.43	0.37	0.39	0.36	0.43	**0.00**	0.51	0.56	0.90	
	11	0.54	0.36	0.44	0.38	0.28	0.44	0.32	0.24	0.49	0.40	**0.00**	0.66	0.86	
	12	0.42	0.33	0.43	0.34	0.40	0.27	0.35	0.32	0.31	0.24	0.37	**0.00**	0.95	
	13	0.59	0.43	0.53	0.44	0.41	0.52	0.37	0.37	0.52	0.40	0.33	0.43	**0.00**	

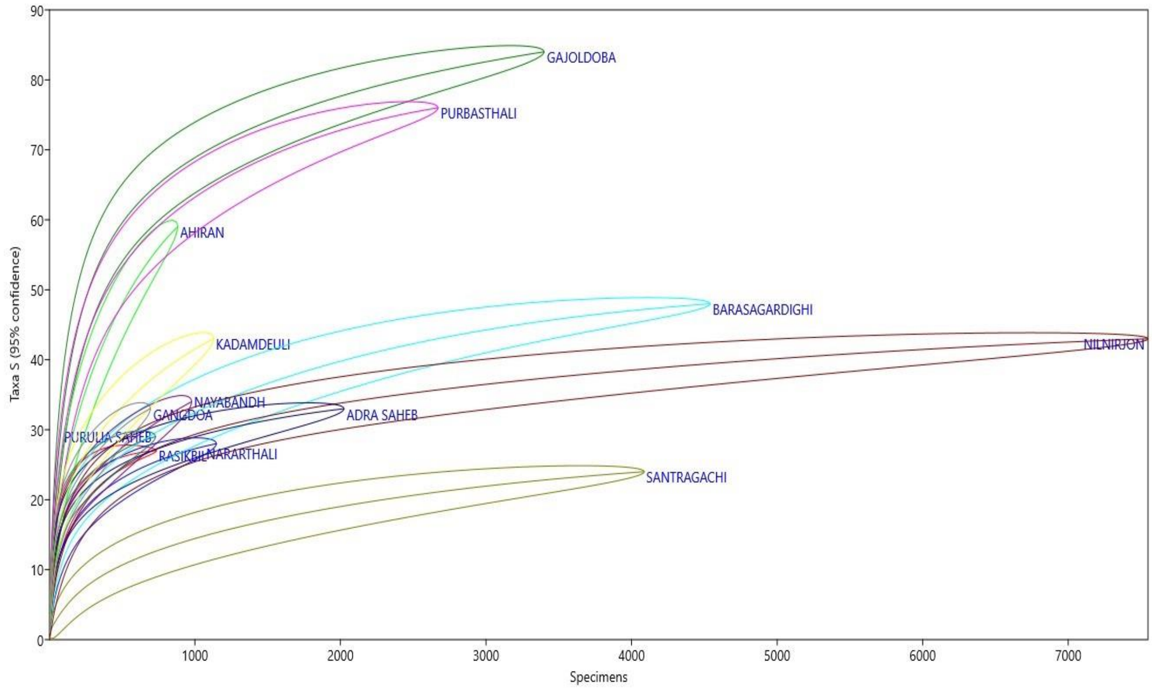


Fig. 5.1 Rarefaction curves for 13 wetlands calculated based on waterbirds number in the wintering period

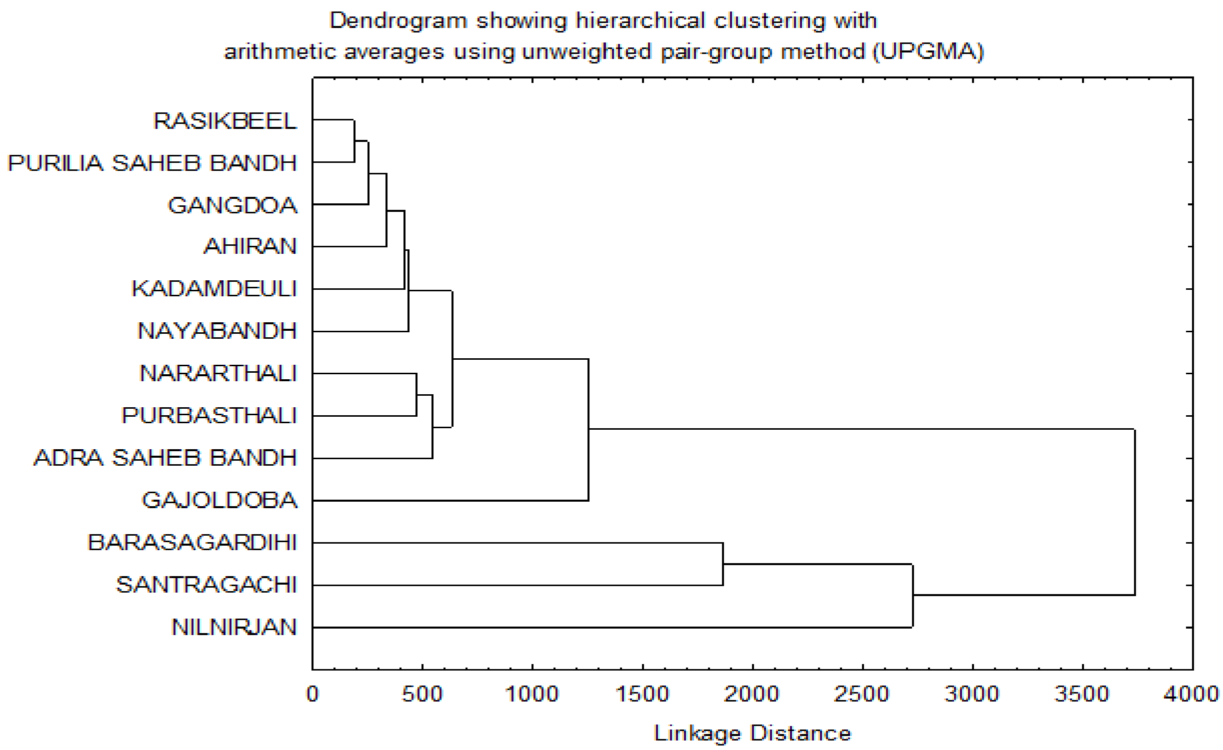


Fig. 5.2 Hierarchical cluster analysis of study sites based on species abundance and diversity using unweighted pair-group method (UPGMA).

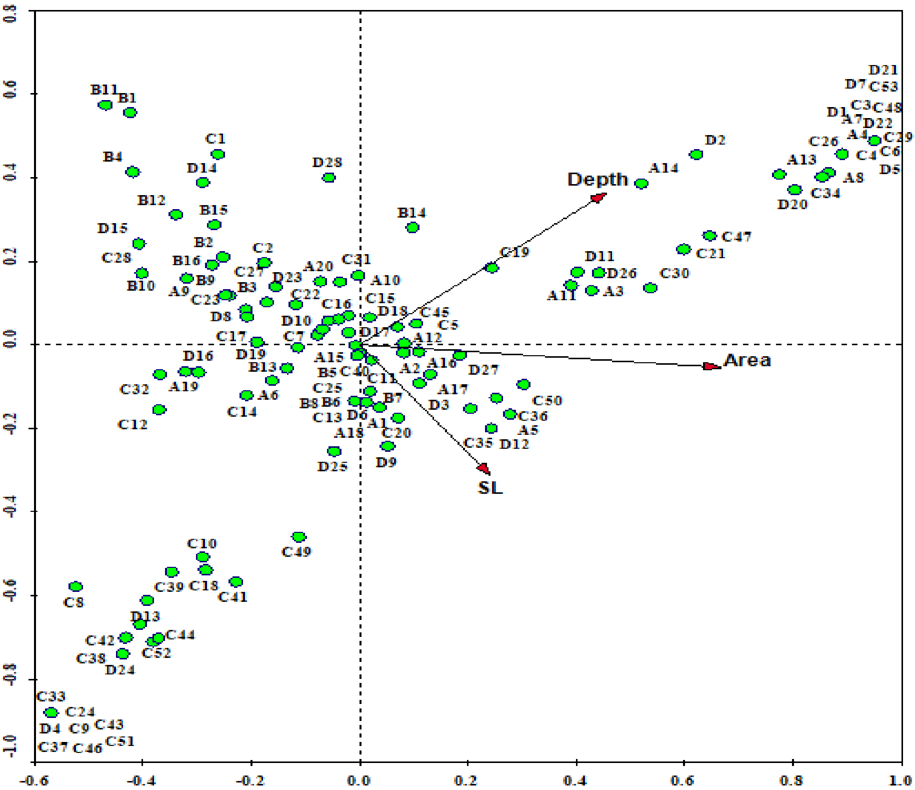


Fig. 5.3 CCA plot for analysis of relationship between physical conditions (area, shore length and depth) and wetland birds categorized as dabblers, drivers, waders and wetland associated birds. (Wetland birds categorized as dabblers, drivers, waders and wetland associated birds for CCA.

DABBLERS: A1. Lesser whistling duck, A2. Fulvous whistling duck, A3. Greylag goose, A4. Greater white-fronted goose, A5. Bar-headed goose, A6. Knob-billed duck, A7. Common shelduck, A8. Ruddy shelduck, A9. Cotton-pygmy goose, A10. Gadwall, A11. Falcated duck, A12. Eurasian wigeon, A13. Mallard, A14. Indian spot-billed duck, A15. Northern shoveler, A16. Northern pintail, A17. Garganey, A18. Common teal, A19. Baikal teal, A20. Common moorhen; DIVERS: B1. Red-crested pochard, B2. Common pochard, B3. Ferruginous duck, B4. Tufted duck, B5. Greater scaup, B6. Common goldeneye, B7. Smew, B8. Goosander, B9. Little grebe, B10. Great-crested grebe, B11. Red-necked grebe, B12. Oriental darter, B13. Little cormorant, B14. Indian cormorant, B15. Great cormorant, B16. Eurasian coot; WADERS: C1. Asian openbill, C2. Woolly-necked stork, C3. White stork, C4. Black-necked stork, C5. Lesser adjutant, C6. Greater adjutant, C7. Black-headed ibis, C8. Red-naped ibis, C9. Glossy ibis, C10. Yellow bittern, C11. Cinnamon bittern, C12. Black bittern, C13. Striated heron, C14. Black-crowned night heron, C15. Indian pond heron, C16. Grey heron, C17. Purple heron, C18. Cattle egret, C19. Little egret, C20. Intermediate egret, C21. Great egret, C22. Baillon's crake, C23. White-breasted waterhen, C24. Watercock, C25. Purple swamphen, C26. Great thick knee, C27. Bronze-winged jacana, C28. Pheasant-tailed jacana, C29. Northern lapwing, C30. River lapwing, C31. Grey-headed lapwing, C32. Red-wattled lapwing, C33. Yellow-wattled lapwing, C34. Pacific golden plover, C35. Little-ringed plover, C36. Kentish plover, C37. Greater painted snipe, C38. Pin-tailed snipe, C39. Common snipe, C40. Black-tailed godwit, C41. Common redshank, C42. Common greenshank, C43. Spotted redshank, C44. Green sandpiper, C45. Wood sandpiper, C46. Marsh sandpiper, C47. Common sandpiper, C48. Great knot, C49. Little stint, C50. Temminck's stint, C51.Ruff, C52. Small pratincole, C53. Pallas's gull; WETLAND-ASSOCIATED BIRD: D1. Brown-headed gull, D2. Black-headed gull, D3. Osprey, D4. Booted eagle, D5. White-tailed eagle, D6. Pallas's fish eagle, D7. Short-toed snake eagle, D8. Grey-headed fish eagle, D9. Eurasian marsh harrier, D10. Pied harrier, D11. Greater spotted eagle, D12. Brahminy kite, D13. River tern, D14. Whiskered tern, D15. Stork-billed kingfisher, D16. White-throated kingfisher, D17. Common kingfisher, D18. Pied kingfisher, D19. Barn swallow, D20. Wire-tailed swallow, D21. Crested lark, D22. Sand lark, D23. Blyth's reed warbler, D24.Yellow wagtail, D25. Citrine wagtail, D26. White wagtail, D27. Grey wagtail, D28. White-browed wagtail)

Chapter 6

Contaminated ambience & exposure risk

6. CONTAMINATED AMBIENCE & EXPOSURE RISK

Many plant and animal species live in peri-urban wetlands that serve as the staging or wintering sites of many migratory waterbird species. However, Das et al. (2021) pointed out that rapid urbanization has put immense pressure on the urban/peri-urban wetlands and this situation is more prominent in developing countries. The absence of proper scientific town and country planning has created fragmented and chaotic urbanization in most of the developing countries of Asia. With increasing anthropogenic activities, peri-urban wetlands face various threats in India (Prasad et al., 2002; SANDRP, 2022). Concentrations of various noxious pollutants, generated mainly by anthropogenic activities, are continuously increasing in various water bodies and those pollutants pose serious risk to the species dependent on such habitats. Wetlands located adjacent to human settlements are more prone to habitat deterioration due to a higher degree of human interference (Preisner, 2020). In recent times, wetlands are increasingly affected by the accumulation of heavy metals from both natural and anthropogenic sources, including natural erosion, hydrological processes, industrial and agricultural activities and so on (Liang et al., 2016; Kandoh et al., 2021). The toxic and non-biodegradable properties of heavy metals make these a potent source of adverse effects on biota. Moreover, the potential bioaccumulation properties of different metals, in the food chains of any ecosystem, aggravate their adverse effects and many of these metals can act as potent carcinogens to wildlife and humans (Mora, 2003; Ali et al., 2019; Celik et al., 2021). Further, trace elements can also be transported from one place to the other through the faeces of migrants (Liang et al., 2016). The Habitat Directive (92/43/EEC) and the Birds Directive (79/409/EEC and 2009/147/EU) adopted by the E.U. Member States, ensure the protection of some rare, threatened and declining bird species in affected wetlands (Kopij, 2017); unfortunately, no such efforts are on record in developing countries including India.

An exponential upsurge in urban and industrial activities in recent times has led to extensive landscape changes at the global scale (Sayadi et al., 2010). Being more prone to natural and man-induced changes, wetland ecosystems are facing threats at the global, regional and local levels. Anthropogenic sources have significantly affected the surface water quality, especially the rivers and wetlands, because of the increasing pollutant loads of diverse origins released into surface waters (Collins et al., 2018). Many studies are on record from India that elaborate on the spectra of wetland pollution due to untreated wastewater discharges to the surface waters (Chatterjee et al., 2010; Aich et al., 2017; Pal et al., 2014, 2019). Such pollution of the wetland ecosystems invariable affects the biota that thrives therein, especially through the exposure to different waste elements including heavy metals (Roy Goswami et al., 2013; Pal et al., 2018). Tang et al. (2013) reported three possible ways of heavy metals invasion into organisms, such as direct inhalation, ingestion and dermal contact absorption; however, for aquatic organisms later two paths would be relevant. Trace element pollution engrossed much attention because of various properties, namely, toxicity, persistence, wide-ranging sources, and non-biodegradable properties (Mora, 2003).

Waste elements are increasing sharply in the present time in many wetlands of developing countries where wastewaters discharge into surface waters without any pre-treatment. Such practices are, thereby, affecting the structural and functional integrity of wetland ecosystems by negatively impacting the wetland floral and faunal community structure (Zhang and Ma, 2011). Waterfowl take up different elements including heavy metals, mainly through food and, to a lesser extent, water consumption (Levengood and Skowron, 2007; Xia et al., 2021). The accumulation and concentration of metals in waterfowl follow composite processes, and several physico-chemical and biological factors that influence the entry, duration, and severity of exposure play key roles (Aloupi et al., 2017; Kanwal et al., 2020). As birds are excellent indicators of wetland health and pollution status, many studies have been conducted on the severity of heavy metal contamination on wetland-associated birds (Lavoie et al., 2015; Burger and Elbin, 2015; Sinka-Karimi et al., 2015; Pandiyan et al., 2020). Liu et al. (2019) conducted a meticulous study on the distribution of trace elements in various tissues of dead Ruddy Shelduck. These studies were based on the direct handling of the birds for the heavy metal exposure assessment. However, modelling can offer an alternative non-destructive way of quantifying for heavy metal exposure risk assessment without causing any harm to the organisms. Liu et al. (2015), Liang et al. (2016), Liu et al. (2019), and Xia et al. (2021) conducted studies on heavy metal contamination based on an integrated and improved exposure risk assessment model. In these studies, two major pathways of heavy metal exposure in birds via food, and bottom sediment; were taken into consideration.

Chowdhury (2020) studied several large and small water bodies of the lower Chota Nagpur Plateau and reported that these wetlands were important habitats for wintering migratory avian species besides the resident waterbirds. These wetlands, located on the CAF and EAAF, contributed much to the migratory avian biodiversity on regional and global scales by having diverse aquatic flora and fauna that supported waterfowl. The present study was aimed to assess the heavy metal exposure in Northern Pintail (alpha code: NOPI; Pyle and DeSante, 2003) *Anas acuta* in two important peri-urban wetlands, namely Purulia Sahebbandh and Adra Sahebbandh of Purulia district of West Bengal, India. NOPI is a Palearctic winter migrant to this region of the Indian subcontinent. In this study NOPI was chosen as the model bird mainly for three reasons: (a) abundance: large populations of NOPI were present in both the wetlands throughout the study tenure (2019-2021); (b) diet: NOPI was a predominantly herbivorous dabbling duck (almost 92% of its diet consisted of rooted submerged aquatic plants (Ballard et al., 2004; Jha, 2013); for predominant herbivory, the model minimized the error in risk exposure calculations; (c) similarity between NOPI and Mallard: foraging details needed for applying in the risk assessment model were lacking for NOPI in available literature; on the contrary, necessary information on diet was available for Mallard, another dabbling duck; both NOPI and Mallard were having comparable morphometric and foraging details (Pecsics et al., 2017). Thereby, the data of Mallard was conveniently applied in the risk assessment model for NOPI (Beyer et al., 1994; Liang et al., 2016). Purulia Sahebbandh (Site 1), located at the heart of Purulia town is more vulnerable to anthropogenic wastewaters than the distantly located Adra Sahebbandh (Site 2); therefore, the physico-chemical conditions of these two wetlands under different degrees of anthropogenic interferences provided an opportunity to compare the metal accumulations through foraging. The present work focused on the four metals, namely, Cu, Zn, Cr, and Pb, as the nature of industrial activities around the said wetlands and the outfalls received by the sites were primarily concerned about these four elements studied (Dutta et al., 2019). This study was conducted to meet the following objectives: (1) to quantify the heavy metals like Cu, Zn, Cr, and Pb in water, bottom sediment and vegetation of the wetlands (2) to calculate heavy metal exposure risk to NOPI in both the wetlands and (3) to order the potent threats from highest to lowest among the selected heavy metals.

6.1 Results

6.1.1 NOPI population

In both the study sites, a steady wintering population of NOPI was recorded in the month of January throughout the study period (i.e., 2019-2021), hence the month was chosen for the present study. Consequently, this month is also selected for the sampling of water, bottom sediment and vegetation. The population size of NOPI was much higher in Site2 (56.7±3.78 - 67.3±4.98) than in Site1 (8.3±2.3 - 48±4.98). Highest abundance was recorded in 2020. The highest abundance of NOPI in Site1 (40.3±3.76 - 48±4.98) and Site2 (67.3±4.98 - 66.7±12.34) were recorded in January, 2020 (Table 6.1). NOPI predominantly fed on aquatic plants. We observed them to feed mainly during late hours of the daytime both by dabbling and upending in shallow water for plants. In the present study, we recorded NOPIs to feed primarily on *Hydrilla verticillata* and *Vallisneria spiralis* in both the study sites. However, the categorization of the food composition of the waterbird was not done in this study. Daily migration of the bird was also not taken into account in the present study.

6.1.2 Heavy metal concentrations

The concentration of four heavy metals (Cu, Zn, Pb and Cr) in plants, bottom sediment and water samples are represented in Table 6.2 and Fig. 6.1. The range of heavy metal concentrations in bottom sediment for all four metals was much higher in the case of Site1. The concentration of Cu (mg kg^{-1}, dry weight) was highest in bottom sediment of Site1, while in the case of Site2, the concentration of Zn (mg kg^{-1}, dry weight) was highest. Heavy metal concentrations in water in both the sites were low. The concentration of Pb in water samples of both the sites was below detection level (BDL), however, the concentration of Cr in water samples of only Site 2 was below detection level. The concentration of all four heavy metals in aquatic vegetation was higher in Site 1. In Site1, concentration of heavy metals in plants decreased in following order: Zn> Cu> Pb> Cr and in Site 2 the order was Zn> Cr> Cu> Pb. WHO recommended maximum permissible limits for Cr, Pb, Cu, Zn in water (0.1 mgL^{-1}, 0.05 mgL^{-1}, 2.0 mgL^{-1}, 5.0 mgL^{-1} respectively), in plants (1.30 $mgkg^{-1}$ dw, 2.0 $mgkg^{-1}$ dw, 10.0 $mgkg^{-1}$ dw, 50.0

$mgkg^{-1}$ dw respectively), and in the tissues of edible bird (1.0 $mgkg^{-1}$ dw, 0.1 $mgkg^{-1}$ dw, 1.0 $mgkg^{-1}$ dw, 20.0 $mgkg^{-1}$ dw respectively). Metal concentrations in water, bottom sediments and plant along with the BAF are depicted in Table 6.2. Heavy metal concentrations showed significant positive correlations between bottom sediment and plants metal at both sites (Table 6.3). Similarly, these metal concentrations in the bottom sediment and plants also showed significant positive correlations with exposure doses (sediments, plants and total) for both the study sites (Table 6.3)

6.1.3 Exposure to heavy metals for NOPI

Selected toxicity parameters (NOAEL and LOAEL) and calculated TDIs are represented in Table 6.4 and site-wise heavy metal exposure doses to NOPI were calculated and results are presented in Fig. 6.2. Due to the low concentration of heavy metals in water, the water exposure pathway was not considered in this study.

In Site1, the bottom sediment exposure dose of Cr was higher than the corresponding TDI. It is also noteworthy that, in the case of Pb bottom sediment exposure dose is nearly equal to the corresponding TDI. In Site1, the total exposure dose of all four metals was higher than their conforming TDIs, However, in Site2, the total exposure dose Pb, Zn and Cu were below their corresponding TDI.

6.1.4 Heavy metal exposure risk to NOPI and hazard index of the study sites

The HQ values for Cu, Zn, Pb and Cr at the study sites are depicted in Table 6.2 and Fig. 6.3. At Site1, the risk of heavy metals decreased in the following order: Cr>Pb>Cu>Zn. However, at Site2 this order was: Cr>Zn>Pb>Cu. At Site1, Cr had the highest risk with HQ well above 2. A high risk of Cu and Pb (HQ>2) was also posed to NOPI at Site1. However, a low risk of Zn (1<HQ<2) was recorded at Site1. In Site 2, no risk (HQ<1) was found for Pb, Zn and Cu. However, a low hazard risk (1<HQ<2) for Cr was recorded at Site2. Further, the HI was very high at Site1 (9.99±4.09) than Site2 (2.75±1.99).

6.2 Discussion

The ducks (family Anatidae), as the most common waterfowl in the wetlands, have been recognized as bio-monitors for assessing habitat contamination (Liang et al., 2016; Wang et al., 2017). We selected wintering NOPI as the model for their consistent presence in both study sites and their predominant herbivory in winter as reported by Ali and Ripley (1987) and Parejo et al. (2019) and NOPI is a Palearctic migratory waterbird that migrates towards the Indian subcontinent during the winter months (Ali and Ripley, 1987). Ballard et al. (2004) did careful work on the diet and nutrient choice of NOPIs in their wintering grounds. They reported more than 92% of their diet consisted of plant materials. Perry and Deller (1996) similarly stated *Hydrilla verticillata* comprised a significant part of NOPIs' diet. Jha (2013) reported that NOPIs fed on shoot, leaves and stems of *Hydrilla verticillata* and various parts of *Vallisneria spiralis* in wintering grounds. Beyer et al. (1994) estimated the proportion of food plant associated sediment ingested along with food in Mallard was 3.3%. This value was used for NOPI in this study as Pecsics et al. (2017) reported similar cranial morphometrics and similar foraging techniques (predominantly upending) in the case of both Mallard and NOPI. Liang et al. (2016) in their work commented, "soil attached to the plant leaves and roots can be ingested by herbivores when grazing, so it is a potential exposure pathway."

The present study recorded steady populations of wintering NOPI from both sites throughout the study tenure. The lower Chota Nagpur Plateau of global attention has several large and small water bodies having diverse aquatic flora and fauna (Mandal and Mukherjee, 2017). Alongside NOPI, Chowdhury (2019) recorded Red-crested Pochard, Tufted Duck, Lesser Whistling Duck, Gadwall, Eurasian Wigeon, Common Coot etc. in large numbers during the winter season in Purulia wetlands which were in support of the present recordings from Site1 and Site2. Chowdhury (2020) reported 43 migratory bird species belonging to 12 families in wetland regions of the Purulia district. However, Das Sarkar et al. (2020) made an ecosystem vulnerability assessment vis-a-vis eutrophication of 27 Indian tropical floodplain wetlands and commented that eutrophication due to rapid urbanization had adversely impacted these wetlands. Majumdar et al. (2007) recorded the presence of eight species of trans-Himalayan migrants at Purulia Sahebbandh and reported that no dependable census data earlier to 2006 were available from the said wetland. Mukherjee et al. (2021) also recorded a variety of herbivore Anatids, other than NOPI, from these wetlands, namely, Lesser Whistling-duck, Fulvous Whistling-duck, Cotton Pygmy-goose, Gadwall, Eurasian Wigeon, Garganey, Common Teal, Red-crested Pochard, Common Pochard, and Ferruginous Duck. High abundance of Lesser Whistling-duck, Red-crested Pochard and Gadwall was also recorded from these wintering grounds. Though, all of the previous studies attested that the abundance of migrant species, especially trans-Himalayan migratory duck species, fluctuated in the wetlands of importance, however, their richness was declining steadily and could never be concluded.

Wild animals imbibed elements from environments through water, food and soil, and following prolonged exposures, elements gradually concentrated at successive trophic levels. Liu et al. (2015), Liang et al. (2016), and Xia et al. (2021) pointed out that both food ingestion and food-associated bottom sediment consumption were important for estimating the impact of exposure to heavy metals in waterfowl. They, however, in several instances eliminated the exposure risk through water intake because of negligible concentrations of metals in ambient water. Exposures through water intake were also ignored in this study as the metal concentrations were either negligible or below detection limits. Regulatory limits (mg kg^{-1} dw) of Zn, Cu, Pb, and Cr in bottom sediment were 1500, 775, 20, and 100, respectively (Wuana and Okieimen, 2011; Kfle et al., 2020). Except for Cr in Site1, concentrations of all other metals in the bottom sediments of study sites were well within the regulatory limit of this metal. Heavy metal concentrations in lakes usually decrease in the order of bottom sediment >> surface water; however, a directly proportional relationship can be found at the sediment-water interface (Luck et al., 2008). Heavy metal concentrations in surface water samples of both sites were negligible as heavy metals precipitated in bottom sediments. The heavy metals trapped in suspended solids in water could be settled in surface bottom sediment. Thereby, the metal concentrations in surface water did not reflect the actual loads of elements that could influence biota in a lake system; whereas bottom sediment was always an important reservoir of heavy metals in the aquatic environment (Harguinteguy et al., 2014). Hydrophytic rooted plants can uptake some amount of metals from water and predominantly from surface bottom sediment through active and passive absorption. Thereby, a significant positive correlation between heavy metal concentrations in bottom sediment and plants was observed at both study sites. At Site2, a significant positive correlation between heavy metal concentrations in plants and water could account for a higher Zn concentration (0.155±0.006 mg L-1) in water at the site. Bai et al. (2018) also recorded positive correlations between metal concentrations in aquatic plants and the concentrations in water and sediment. Heavy metal accumulations in rooted submerged plants seemed to be more closely related to concentrations in water and sediment.

Rooted aquatic plants growing on metal-contaminated bottom sediments can accumulate heavy metals at high concentrations, some of which have indispensable properties of metal tolerance (Chatterjee et al., 2010). These metal contaminants must be bio-available for root zone uptake by the plants. The disparity in levels of bioaccumulation was an outcome of the physical properties of the ambient environment of metal bioavailability (Racena et al., 2021), as evident from our study. Out of four elements under investigation, two elements, Cu, and Zn, were known to be essential for higher plants (Singh et al., 2016). The concentration of Cu was much higher than the concentrations of Zn in the bottom sediment at Site1. However, concentrations of Zn were highest in plants at both the study sites. We also interestingly noted that the percentages of transport of Cu from bottom sediment to the plants (BAF 0.09and 0.11at Site1 and Site2 respectively) were considerably lower than Zn in both study sites (BAF 0.25 and 0.30 at Site1 and Site2 respectively). Zn, one of the essential plant micronutrients, was crucially important for plant metabolism (Gupta et al., 2016) and the normal range for zinc in plant tissue was 15-60 mg kg^{-1}. In the present study, we recorded Zn concentration in plants was higher than the normal range at Site1. Copper, on the other hand, is a micronutrient in plants and acts in conjunction with a large number of enzymes related to respiration and photosynthesis. Plant requirement of Cu was 2–50 mg kg^{-1} and became toxic in higher accumulation (Miotto et al., 2014). Gupta et al. (2016) also reported that a higher concentration of Cu could be physiologically more toxic than Zn concentration. The organometallic Cu complexes played a key role in regulating Cu mobility than that of the other micronutrient cation Zn (Yruela, 2005). Moreover, the increased Cu availability in the bottom sediments affected the concentrations and accumulation of Cu in the plants by the way of up and down regulations of catalase activity (Miotto et al., 2014). This can be attributed to the higher Zn uptake by plants at both the study sites. Interestingly plants in Site1, growing in bottom sediment with a high concentration of Cu, also accumulated much higher Zn than Cu. However, on the contrary to these findings, Ivanova et al. (2010) reported that high Cu concentrations in bottom sediment significantly slowed down zinc uptake by the roots. In both study sites, transport of Pb (BAF 0.05 and 0.10 at Site1 and Site2 respectively) from bottom sediment to plant was more than Cr (BAF 0.02 and 0.07 at Site1 and Site2 respectively). The bottom sediment Cr was largely unavailable to plants as it (Cr^{3+}) bound to negatively charged sites, especially clay and organic matter (Banks et al., 2006). Therefore, in our study, the average concentration levels in the rooted wetland plants showed a much lower accumulation of Cr despite high concentrations in the respective bottom sediments. Pb was also toxic to plants as it mimicked the metabolic behaviour of Ca and inhibited many enzymatic reactions (Kasowska et al., 2017). Organic lead was exceptionally transportable in bottom sediment and was taken up by plants much more readily than Pb^{2+} (Schwab et al., 2005) which could be accounted for the higher rates of Pb transport in plants at the study sites. Interestingly, the BAF values for food plants were higher for the comparatively cleaner Site2 than for the polluted Site1. Mcgeer et al. (2003), and Xu et al. (2022) commented that accumulations of metal in plants did not increase linearly with the increase in concentrations in soil. Physico-chemical properties of the soil could very well influence uptake and accumulation (Lopes et al., 2012). The physiological basis for the inverse relationship of BAF to metal exposure concentration arose from metal uptake and mobility. At low soil metal levels, aquatic biota was able to sequester, while metal exposure levels were chronically elevated, and biota were able to control bioaccumulation (Mcgeer et al., 2003). The extent and distribution of metal contaminations remained unknown in Indian wetland systems occupying both EAAF and CAF that sheltered hundreds of thousands of migratory waterfowls as their wintering or staging habitats. The wetlands under the present study were under these Flyways; these wetlands had been serving as important wintering and staging grounds for the migratory waterbirds. If such wintering habitats acquire waste metals, these winter visitors would be at the risk of accumulating metal pollutants, which may affect waterbird health and, in the sequel, the breeding and roosting habitats (Martín-Vélez et al., 2021). Risk assessment with NOPI as a model bird, a regular visitor of wintering habitats on CAF and EAAF, would focus on the extent of metal accumulation in waterbird guests and also points out the possibility of contamination of the distant breeding sites with their contaminated droppings. Anthropogenic deposition of waste elements might be contributing to negative population-level effects in waterfowl, water-associated birds and other organisms that depend on dynamic wetland habitats. Lavoie et al. (2014) pointed out that the contamination of heavy metals in the wintering grounds could negatively influence waterfowl populations in their breeding habitats through altered reproductive success. Site 1 is facing immense anthropogenic pressure due to its location. On the other hand, Site 2 is protected from all-embracing anthropogenic alterations to some extent due to its far-flung location from major urban settlements and industries. This extended an ideal situation for us to compare the levels heavy metal risk exposure in waterbirds in study sites with fairly similar abundance of waterbirds.

We estimated exposure doses and hazard risks of two important wintering habitats of migratory waterfowl to prioritize threats using NOPI as the model waterfowl. In general, food ingestion pathway (via aquatic plant consumption) can be recognized as the main course of heavy metal exposure. Kertesz et al. (2006) and Sinkakarimi et al. (2018) reported that metals like Pb, Cr, Zn, and Cu in high concentrations had harmful effects on herbivore waterfowl as their food macrophytes were frequently tolerant of high concentrations of metal and bio-concentrated metals. Binkowski (2012) reported waterfowl populations accumulated too much heavy metal including Pb. Burger and Gochfeld (1996) reported neurotoxic effects of Cr and Pb in Gulls. Waterfowl exposed to high concentrations of Cr and Pb showed altered growth rates, waterfowl brain, nervous system, red blood cells, kidneys and reproductive success (Mateo et al., 1999; Burger and Gochfeld, 2000). Jayasinghe et al. (2004) did meticulous work on Pb concentrations in liver and striated muscle of NOPIs and reported severe physiological malfunctioning in high Pb concentrations. Moreover, Pain et al. (2015) estimated that in the UK 1.5-3.0% of the wintering wildfowl population perished each winter as a direct consequence of Pb poisoning. Aloupi et al. (2017) reported that concentrations of the metabolically essential metals like Cu and Zn were higher than the nonessential element like Pb or elements with minor metabolic functions like Cr in the tissues of waterfowl and followed the order Zn>Cu>Pb>Cr. Pb, a heavy metal having no known metabolic function in organisms, had a higher concentration in tissues followed by Cr, known to have a metabolic function in glucose metabolism (Goldhaber, 2003). Aendo et al. (2020) also reported that the concentrations of essential metals like Fe, Zn, and Cu were higher than the metals like Pb and Cr. The levels of Zn > Cu, while Pb > Cr in duck tissues were reported. Zn poisoning in the livers of Mallards was reported at a contain rate of 1100 mg kg^{-1} dry weight (Beyer et al. 2004). However, the calculated TDI of Zn levels at both study sites was much lower than Zn toxicity levels. In the present study, it was apparent that exposure doses were always above the TDI for both essential (Cu, Zn and Cr) and nonessential metal (Pb) in terms of total exposure and exposure through food (aquatic plants) at the Site1. As the bottom sediment Cr content was significantly higher at Site1, the exposure through bottom sediment associated with food plants, Cr was above the TDI values at Site1. On the contrary, for Site2 total exposure doses for metals were always below the TDI values except Cr. Moreover, in both the study sites, exposure through food consumption was recognised as the major heavy metal exposure route. Liu et al. (2015) also recorded a similar pattern of heavy metal exposure in herbivorous waterfowl.

Cobbina et al. (2015) reported heavy metals often exist in mixtures in the environment, and their cumulative effects had been barely investigated in the past. Therefore, investigating the HI of a study site could help to identify the priority areas for management. Waterfowl are ranked high in the wetland food chain and thus they are more inclined to the risk due to the bioaccumulation of heavy metals (Sinkakarimi et al., 2018). Thereby, habitats with high HI adversely affected the physiology of waterfowl that were using such sites as their foraging grounds. HI represented the combined HQ and this could be used to estimate risk after exposure to a mixture of several potentially hazardous elements (Goumenou and Tsatsakis, 2019). Liang et al. (2016) identified high heavy metal risk sites (with HI> 5) as priority areas for risk control and management. HI of Site1 in the present site was noted as 9.99±4.09; therefore, Site1 could be identified as a high-risk zone and should be prioritized for risk management for waste metal pollutants. Any single heavy metal with an exposure level greater than the toxicity value would cause HI to exceed unity, for multiple heavy metal exposures, HI could also exceed unity even if no single heavy metal exposure exceeded its TDI (USEPA, 1989). Thus, this approach assumed that concurrent sub-threshold exposures to various heavy metals could also result in an adverse effect. At Site1, total exposure doses for all four heavy metals exceeded the corresponding TDI values that accounted for a very high HI in that wetland. However, at Site2, only the total exposure dose of Cr surpassed the TDI value. Total exposure doses of all other metals were well below the TDI of that particular metal indicating no major threats due to metals in the ambient habitat. Further, the exposure doses (for bottom sediment, food and total) showed significant positive correlations with metal loads in food plants and bottom sediments of the study sites. Municipal and small-scale industrial wastewaters were regularly discharged at Site1 through five major inlets, which inadvertently increased the concentrations of heavy metals. Dutta et al. (2019) reported that various heavy metals entered Site 1 as a consequence of not only natural processes but also by direct and indirect activities of humans in the vicinity. Basta et al. (2005) stated that municipal sewage and sludge deposition led to the accumulation of a host of heavy metals in wetlands. Waterfowl wintering at Site2, however, were fairly protected from heavy metal exposure risk. Siddiqi and Chandrasekhar (2010) reported that the chemical raw water quality of Site 2 was clean and safe, and this could be attributed to the high waterfowl diversity at this site. Both study sites, being located on CAF and EAAF, harbour a variety of waterfowl during the winter months (from October through March). Among four metals in the present study, Pb (toxic and no metabolic function) could be considered the primary pollutant followed by Cr and Cu having proven toxicity to waterfowl in exceedingly high concentrations in the ambient environment. Curbing potential external sources of nonessential elements, rather potent toxicants like Pb, Cr and Cu in the studied wetlands would help to sustain a more viable environment for the wintering waterbird populations.

6.3 Conclusion

Major limitations in applying the risk exposure model were (1) dermal contact and inhalation exposure pathways were ignored; (2) herbivory (92% of the total diet) was emphasized ignoring carnivory (other 8%) (del Hoyo et al. 2017); (3) assumed that NOPI consumed both choicest food plants in the equal proportion; (4)ignored any daily migration of NOPI to the agricultural fields and grasslands during nocturnal foraging (Clark et al., 2020); and (5) food associated sediments ingestion (Beyer et al., 1994) might incorporate some uncertainty. Although there were some uncertainties, the method was established as an effective tool for risk exposure assessment, and the results were considered to be convenient for risk management for waterbirds in wetlands (Liu et al., 2015; Liang et al., 2016, Xia et al., 2021).

Indian wetlands on CAF and EAAF are important wintering habitats for migratory waterfowl but have been degraded by many anthropogenic activities including heavy metal contaminated wastewater loadings. In this study, a method for exposure risk assessment of migratory herbivorous waterfowl, NOPI, a widespread winter migratory species in Indian wetlands, has been employed by calculating Hazard Indices of two important wintering habitats of eastern India to identify priority pollutants/habitats. The waterfowl population wintering in Site1 is facing a high exposure risk of heavy metals. An urban location of this wetland, with a rapidly growing human population, makes it more prone to human interferences in several ways including increased discharges of untreated wastewaters. Unwanted metal sources in wastewater are to be identified and curbed for sustainable use of the wetland. Prioritize threats (HQ> 2) at Site1 are decreased in the following sequence: Cr>Pb>Cu>Zn and Cr, Pb and Cu were considered to be the priority pollutants. It is recommended that priority conservation strategies should be developed in this area. Site1, the priority area with HI> 5 can be identified for immediate risk management and development of suitable conservation strategies for this age-old wintering waterfowl habitat. The presented method can also be used for exposure risk assessment of other pollutants to other waterfowl species and risk management around important wintering waterfowl habitats of India. Assessment of possible sublethal effects of waste elements in waterfowl habitats, including different other stress factors in aquatic situations, demands further research. Species, trophic position and foraging behaviour are important factors to determine toxicity due to heavy metals in waterfowl habitats (Goumenou and Tsatsakis, 2019). We envisage in our future endeavour to consider detailed food composition of herbivore, piscivore and omnivore waterfowl and to include other toxic, yet not-so-uncommon heavy metals like Cd, As and Hg in urban wastewaters. Besides, this indirect method for assessment of quantitative risk exposure can also be used for other pollutants to other wildlife and management of wildlife habitats in and around rapidly growing urban areas.

Table 6.1 Abundance of NOPI in January 2019-2021 in two study sites. Site1: Purulia Sahebbandh, Site2: Adra Sahebbandh.

Year	**Site1**		**Site2**	
	2nd week	4th week	2nd week	4th week
2019	12.3±1.02	21.3±4.66	62.7±2.67	67.0±13.11
2020	40.3±3.76	48±4.98	66.7±12.34	67.3±4.98
2021	9.7±2.00	8.3±2.3	56.7±3.78	60.0±11.34

Table 6.2 Heavy metal concentrations (mean ± SD; n=54) in water, bottom sediment, plants, and BAF, HQ of the selected metals and HI of the study sites. (Reference values: Water: National recommended natural surface water quality criteria US EPA; www.epa.gov › wqc › national-recommended-water; accessed on 03/06/2021, Bottom sediment: Regulatory limits as per US EPA; www.epa.gov, cited by Wuana and Okieimen, 2011; Kfle et al., 2020, Plants: Standard reference materials for aquatic vascular plant Ulva lactuca as B.C.R. reference material No. 279/504; Institute for Reference Materials and Measurements, IRMM, Brussels, Belgium, cited by Bonanno et al., 2017) BDL: Below Detection Level

		Cu	**Zn**	**Pb**	**Cr**
Site 1	Water (mg L^{-1})	0.079±0.021	0.022±0.002	BDL	0.006±0.007
	Bottom sedimentl (mg kg^{-1} DW)	410.7±26.62	364.9±36.38	171.1±10.51	281.6±16.66
	Plants (mg kg^{-1} DW)	37.9±12.61	91.6±13.18	8.0±1.58	6.3±3.28
	BAF	0.09	0.25	0.05	0.02
	HQ	2.2±0.78	1.4±0.31	2.2±1.21	4.1±1.82
	HI	**9.99±4.09**			
Site 2	Water (mg L^{-1})	0.022±0.007	0.155±0.006	BDL	BDL
	Bottom sediment (mg kg^{-1} DW)	30.1±6.11	109.1±12.71	14.5±6.43	60.4±12.55
	Plants (mg kg^{-1} DW)	3.4±2.10	33.4±15.87	1.58±0.77	4.48±2.48
	BAF	0.11	0.30	0.10	0.07
	HQ	0.2±0.14	0.5±0.38	0.3±0.28	1.7±1.22
	HI	**2.75±1.99**			
Reference Values	Water (mg L^{-1})	No mention	0.12	0.065	0.57
	Bottom sediment (mg kg^{-1} DW)	775	1500	600	100
	Plants (mg kg^{-1} DW)	13.1 ± 0.37	51.3 ± 1.20	13.5 ± 0.40	10.7 ± 0.90

Table 6.3 Pearson Correlation coefficients between metal concentration in bottom sediment, plant and oral exposure doses (Es: Exposure through soil, Ef: Exposure through food plant, Et: Total exposure) at the study sites. (marked correlations are significant at $p < 0.05$; n=54)*

Site1	**Plant**	**Es**	**Ef**	**Et**
Bottom sediment	0.634*	0.999*	0.634*	0.683*
Plant		0.633*	0.999*	0.998*
Es			0.633*	0.681*
Ef				0.998*
Site 2	Plant	Es	Ef	Et
Bottom sediment	0.920*	0.999*	0.920*	0.933*
Plant		0.925*	0.999*	0.999*
Es			0.925*	0.937*
Ef				0.999*

Table 6.4 Selected toxicity parameters no observed adverse effect level of heavy metal (j) [$NOAEL_j$]; lowest observed adverse effect level of heavy metal (j) [$LOAEL_j$] and tolerable daily intake of heavy metal (j) [TDI_j] (mg kg^{-1} d^{-1})

	Cu	**Zn**	**Pb**	**Cr**
NOAEL	11.7	14.5	1.13	1
LOAEL	15.4	131	11.3	5
TDI	1.34	4.36	0.36	0.22

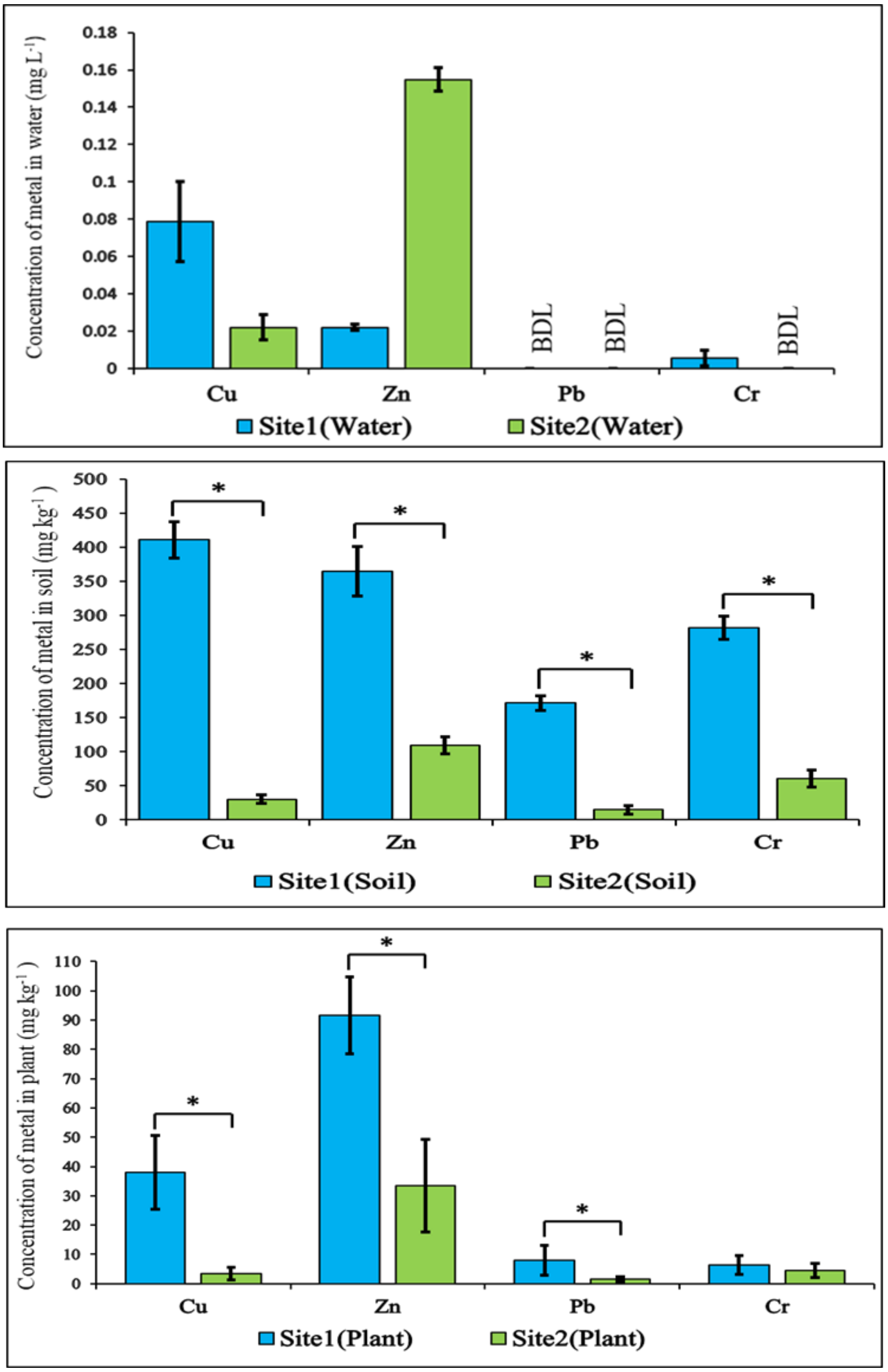


*Fig. 6.1 Average heavy metal concentrations in water, bottom sediment, and food plants at both study sites. (BDL: Below Detection Level). Significant differences (at $p<0.05$) in concentrations between the sites in t-test were denoted by * mark.*

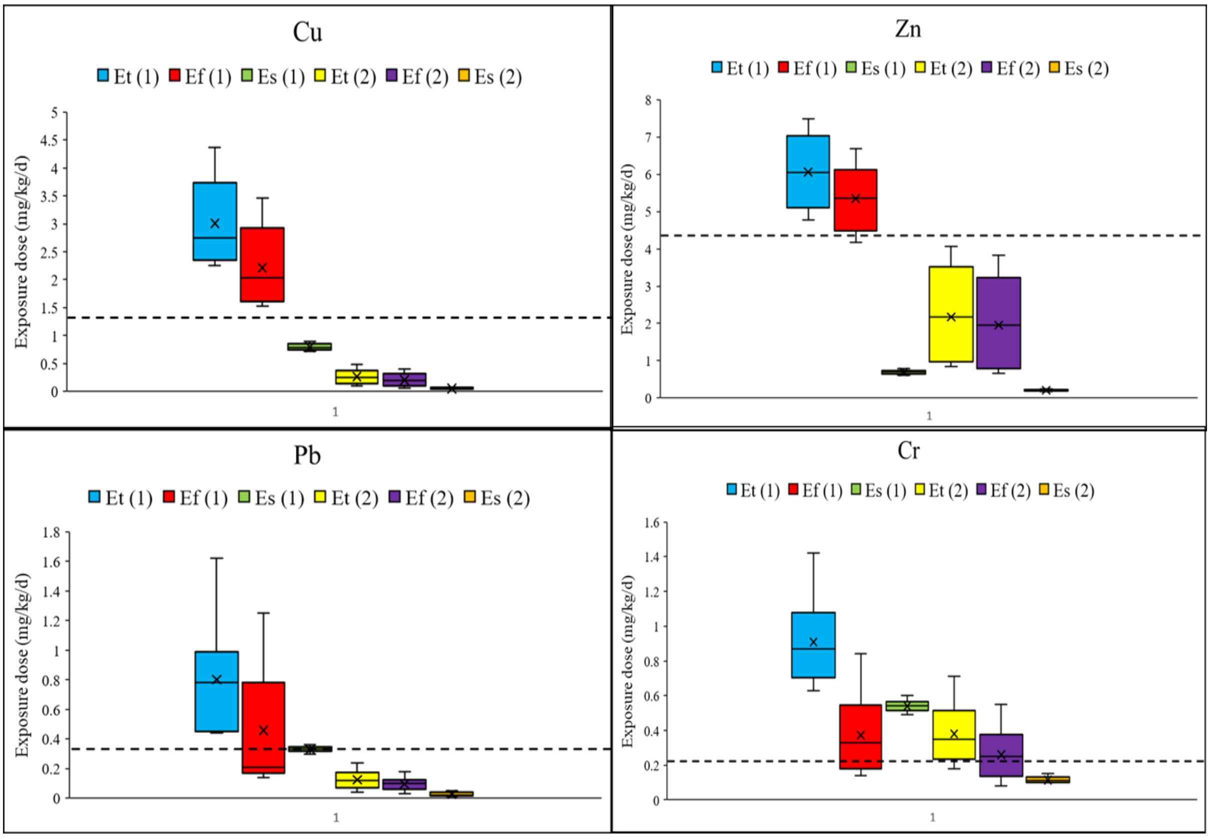


Fig. 6.2 NOPI's exposure doses for four prevalent heavy metals at study sites (denoted with 1 and 2 in parenthesis). Total exposure (E_t), exposure through Food plants (E_f), and exposure through sediments associated with food plants (E_s). The dotted line denotes the corresponding tolerable daily intake (TDI) of the metal. 'x' denotes the mean values of exposure dose.

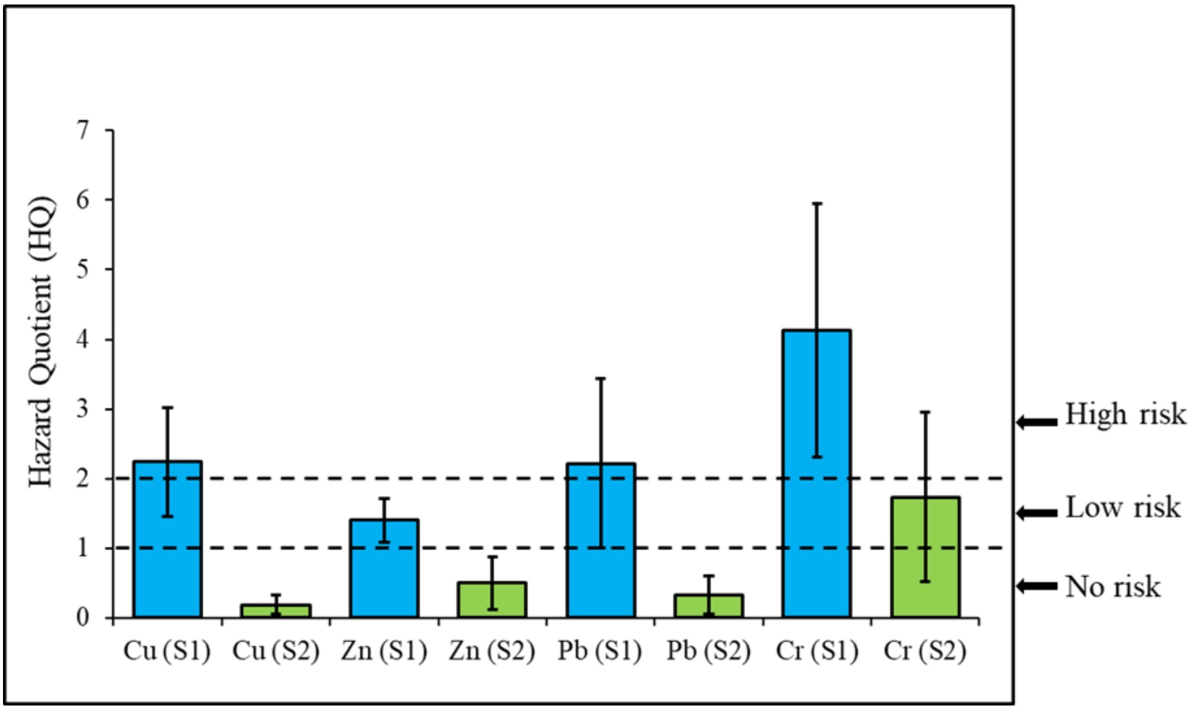


Fig. 6.3 Average hazard quotient (HQ) of four heavy metals at both study sites (denoted with S1 and S2 in parenthesis) for NOPI.

Chapter 7

Ecosystem Service by Nutrients Replenishment

7. ECOSYSTEM SERVICE BY NUTRIENTS REPLENISHMENT

Green and Elmberg (2013) defined "ecosystem services as the ecosystem processes that directly or indirectly benefit human well-being." A good number of publications have focused on different services that are rendered by the communities and species to the ecosystem. Studies on such community and/or species services at the local and regional scales are imperative steps towards the management and maintenance of these services. In this chapter, I specifically address the waterbirds, which play key functional role in wintering habitats, the replenishment of nutrients, although the role has often been overlooked. Nutrients (mainly nitrate and phosphate) in the guano of the aquatic birds alter the water quality in wetlands and thus birds play an important role in nutrient cycling in the wetlands (Manny et al., 1994; Chatterjee et al., 2017, 2020; Adhurya et al., 2020). Further, Scherer et al. (1995) reported when bird abundance is large, relative to the size of the wetland, a significant fraction of the nutrient pool may cycle through waterbirds via guanotrophy. Many noteworthy studies on the effects of waterbird congregation on the limno-chemical conditions of wetlands and vice versa have been already published (Manny et al., 1994; Pettigrew et al., 1997; Hanson, 2003; Longcore et al., 2006; Roy et al., 2011; Dessborn et al., 2016; Duda et al., 2021). However, some research works are unable to establish any correlation between the avian congregation and nutrient enrichment (Gremillion and Malone, 1986; Marion et al., 1994; Scherer et al., 1995).

The term 'Quantitative structure activity relationship (QSAR),' a computational modelling method for revealing molecular structure-activity relationships, is extrapolated for community structure and function, based on the idea that when the characters of structural components of the community is changed then also the functions of the communities will be modified (Pal et al., 2017; Rumschlag et al., 2020). In the present study quantitative models have been used to avoid direct intervention in wildlife and to predict the species-wise activities for avian populations (Watkins et al., 1999; Ruiz- Rodríguez et al., 2013). The direct estimation of ornithogenic nutrient loading (NL) is nearly an impossible task (Manny et al., 1994). Therefore, quantitative structure activity relation (QSAR) indirectly extrapolated NL from the bird count data. Different approaches of ornithogenic NL estimation are reviewed in detail in previous literature (Dessborn et al., 2016; Adhurya et al., 2020;). All of these approaches relied on allometric relationship of faecal matter production to calculate species-specific NL, because digestive performance of different waterbird species is reported to be similar (Hahn et al., 2008, 2007; Manny et al., 1994; Nagy et al., 1999). The extent of nutrient enrichment in a waterbody depends on several factors like species-specific lake use by diverse waterbirds, foraging behaviour, food preference, area of the wetland and residence time of water in the waterbody (Manny et al., 1994, Boros, 2021, Laguna et al., 2021). Boros et al. (2008) reported that most of the ducks (Anatidae family) predominantly feed on the terrestrial ecosystem but spend a considerable amount of diurnal time inside the wetland for mainly roosting and thus these ducks are responsible for net nutrient import to the lake from the terrestrial ecosystem. This nutrient enrichment could stimulate vigorous hydrophyte growth, reduces water quality, and quickens sediment deposition processes in wetlands (Manny et al., 1994, Aymerich et al., 2008, Verstijnen et al., 2021).

Several wetlands of India are facing severe anthropogenic pressure and West Bengal is no exception in this regard (Bassi et al., 2014; Mukherjee et al., 2021). Present work has been carried out at four wetlands of Bankura and Purulia districts of West Bengal, Gangdoa Dam (GAD), Kadamdeuli Dam (KDM), Purulia Sahebbandh (PSB), Adra Sahebbandh (ASB). These wetlands harbour a diverse array of waterbirds, both resident and winter migratory, during the winter months (Nandi et al., 2007, Mukherjee et al., 2021,2022). Mukherjee and Palit (2013) report on the water quality assessment in several wetlands of the Bankura district. Siddiqi and Chandrasekhar (2010) and Mandal (2017) record the physico-chemical conditions of Adra Sahebbandh, Purulia. Dutta et al. (2017) report on the water quality and trophic status of Purulia Sahebbandh. The present study has been conducted to meet the following objectives 1) to record the changes in the physico-chemical conditions for consecutive two wintering seasons in West Bengal, i.e., October through March (2018-2019 and 2019-2020) and 2) to determine the monthly variations in the species-specific guano and nutrient loading by different waterbirds wintering in the study sites.

7.1 Results

7.1.1 Physico-chemical conditions

Lowest subsurface water temperature at GAD was recorded in January (20.60±0.29 °C) and water was weakly alkaline. EC, TDS and Salinity did not show any consistent pattern of monthly variation and varied slightly between months (Table 7.1a). DO values ranged from 3.0±0.26 mg L^{-1} (in March) to 3.8±0.22 mg L^{-1} (in January).

Lowest subsurface water temperature was recorded in January (20.90±0.36 °C) and water was weakly alkaline at KDM (Table 7.1b). Both EC and TDS values, were highest in the month of December (334.3±6.90 mg L^{-1} and 234.0±3.92 mg L^{-1} consecutively) and lowest in October (259.3±3.30 mg L^{-1} and 197.3±2.36 mg L^{-1} consecutively). However, values of salinity were highest in January (161.8±5.80 mg L^{-1}) and lowest in November (130.3±1.89 mg L^{-1}). DO values were ranged from 4.6±0.22 mg L^{-1} (in March) to 6.2±0.13 mg L^{-1} (in October).

Lowest subsurface water temperature was recorded in January (21.50±0.78 °C) and water was weakly alkaline at PSB (Table 7.1c). EC, TDS and Salinity reached the highest value in the month of March (438.0±37.02 µS cm^{-1}, 307.0±35.39 ppm and 199.5±22.59 ppm respectively), and lowest in the month of October (393.0±8.83 µS cm^{-1}, 284.7±12.42 ppm and 188.25±8.3 ppm respectively). DO values ranged from 2.9±0.13 mg L^{-1} (in October) to 3.1±0.18 mg L^{-1} (in February).

Lowest subsurface water temperature was recorded in January (21.19±0.59 °C) and water was also weakly alkaline at ASB (Table 7.1d). Highest value for EC, TDS and Salinity were recorded in the month of January (188.5±6.19 µS cm^{-1}, 132.5±3.87 ppm and 89.3±2.75 ppm respectively). However, lowest values of these parameters were recorded in the month of October (163.8±4.43 µS cm^{-1}, 111.5±2.08 ppm and 79.8±1.71 ppm consecutively). DO values ranged from 4.0±0.14 mg L^{-1} (in March) to 6.2±0.33 mg L^{-1} (in January).

At KDM and ASB, water temperature showed significant negative relationship with both nitrate ($r = -0.748$ and $r = -0.748$ respectively; $p<0.05$) and phosphate ($r = -0.740$ and $r = -0.800$ respectively; $p<0.05$) concentration (Table 7.2). However, in PSB only phosphate concentration showed significant positive relationship with water temperature ($r = 0.567$; $p<0.05$). On contrary, water temperature did not show any significant relationship with both nitrate and phosphate concentration. It was interesting to note that pH, TDS and Salinity showed significant positive correlation with both nitrate and phosphate concentration in

KDM, PSB and ASB. However, in GAD, pH showed significant positive relationship with only phosphate concentration (r = 0.945; $p<0.05$) and salinity was significantly positively correlated with nitrate concentration (r = 0.709; $p<0.05$). DO showed negative correlation with nitrate and phosphate concentration at most of the instances (Table 7.2).

7.1.2 Total GL, nutrient (N and P) loading by waterbirds, and NO_3-N concentration and PO_4-P concentration in the study sites

Overall GL in the study tenure was highest in ASB followed by PSB, KDM and GAD respectively. In GAD, KDM and ASB, total GL was highest in the month of January (764.4 kg $month^{-1}$ in Jan20, 777.9 kg $month^{-1}$ in Jan20, and 2979.1 kg $month^{-1}$ in Jan20 respectively) and lowest (50.2 kg $month^{-1}$ in Oct19, 148.5 kg $month^{-1}$ in Oct18, 63.2 kg $month^{-1}$ in Oct18 respectively) in the month of October (Fig. 7.1). However, in PSB total GL was highest (2334.3 kg $month^{-1}$) in March 2020 and lowest (11.7 kg $month^{-1}$) in November 2019. An extreme decrease (~ 94% decrease from 2018-2019 to 2019-2020) in the total GL was also recorded from PSB. Similar trends were observed in case of both N and P Loading in all the study sites (Fig. 7.1). Nitrate concentration was higher than the phosphate concentration in all the study sites. Highest nitrate and phosphate concentration (40.5±6.78 and 8.0±1.45 mg L^{-1} respectively) was estimated from PSB in March 2019 (Fig. 7.1). However, lowest nitrate and phosphate concentration (5.3±2.12 and 1.5±0.18 mg L^{-1} respectively) was estimated from KDM in October 2018 and ASB in October 2018 respectively.

In all four study sites, total guano added by herbivorous waterbirds was much higher than total guano added by carnivorous waterbirds (ranged from 3.1% to 14.3%) and omnivorous waterbirds (ranged from 0% to 4.5%). However, guano loaded by carnivorous waterbirds was highest at GAD, followed by KDM, PSB and ASB respectively. A different result was recorded in total GL by omnivorous waterbirds. Total guano loaded by omnivorous waterbirds was highest at PSB, followed by ASB, KDM and GAD respectively.

7.1.3 Correlations between total GL, total nutrient (N and P) loading, NO_3-N and PO_4-P concentrations

Pearson correlation coefficients (*marked correlations significant at $p< 0.05$) were depicted in Table 7.3. to highlight the relation between total GL, N loading, P loading, NO_3-N and PO_4-P concentrations at four study sites. Total GL showed significant strong positive relation with both N and P loading at all the study sites (r= 0.999 and r= 0.997 respectively; $p<0.05$ in ASB; r= 0.999 and r= 0.969 respectively; $p<0.05$ in PSB; r= 0.997 and r= 0.952 respectively; $p<0.05$ in

KDM; r= 0.999 and r= 0.986 respectively; $p<0.05$ in GAD). Total GL also showed significant positive correlation with both nitrate and phosphate concentration at ASB and KDM (r= 0.801 and r= 0.761 respectively; $p<0.05$ in ASB; r= 0.868 and r= 0.851 respectively; $p<0.05$ in KDM). However, total GL positively correlated with only phosphate concentration at GAD (r=0.639; $p<0.05$) and with nitrate concentration at PSB (r=0.940; $p<0.05$). N loading showed significant positive correlation with nitrate concentration, P loading and phosphate concentration at all the wetlands with an exception at GAD, where N loading was not significantly correlated with nitrate concentration. Nitrate concentration was significantly correlated with P loading and phosphate concentration at three study sites except GAD. Similarly, P loading was not significantly correlated with phosphate concentration only at GAD.

7.1.4 CCA interpretation

The CCA plots depicted influences of site-wise total abundance of waterbirds on the phosphate and nitrate of the habitats (Fig. 7.2) and site-wise abundance of broad foraging groups of waterbird species, namely herbivores, carnivores and omnivores, on the phosphate and nitrate of the habitats (Fig. 7.3). In the CCA plot, the length of an arrow was equal to the rate of change in the weighted average and was a measure of how much the nutrient distributions (for N and P) differed along particular site-wise abundance variables. Site-wise seasonal pooled data showed excellent relation between the total abundance of waterbirds and phosphate and nitrates availability (Fig. 7.2). In Monte Carlo Test, the cumulative percentage variance of species-environment relation was 76.2 for the first axis (Table 7.4). However, the influences were much more pronounced in the CCA for PSB and ASB than for GAD and KDM. Site-wise abundance of herbivores (H), carnivores (C) and omnivores (O) also differently influenced the nitrate and phosphate of the study sites (Fig. 7.3). CCA plot showed that nitrate and phosphate at PSB and ASB were influenced by the abundance of H in these sites. GAD, a site with a carnivorous waterbird-dominated community, showed a strong influence on nitrate of that site; however, at GAD and KAD other relations were not much evident in the CCA plot. The cumulative percentage variance of species-environment relation for the first axis in the Monte Carlo Test was 64.4 (Fig. 7.3 and Table 7.4).

7.2 Discussion

7.2.1 Physico-chemical ambience

Surface water temperature is influenced by various factors like latitude, altitude, time of day, air circulation, cloud cover and depth of the wetland (Chapman 1996). Subsurface water temperature ranged between 20.0 °C in January and 33.0 °C in March at the study sites; as all the sites were in the same physiographic zone thus the water temperature was comparable. The lowest subsurface water temperature was recorded in January in all four study sites as this was the coldest month in both the Gangetic West Bengal and the sub-Himalayan West Bengal (NCCO 2008).

The published results showed that with increasing water temperatures, the DO concentrations decreased (Arfi 2003; Li et al. 2013). Findings from our study corroborated these findings. The degree of pollution in a wetland by organic matter and the level of natural purification of a wetland can be estimated by the measurement of DO (Slack 1971; Jane et al. 2021). In our study, the DO was highest in KDM (mean 5.4±0.61 mg L^{-1}), followed by ASB (mean 5.1±0.89 mg L^{-1}), which indicated the somewhat fair quality of water. DO level of PSB was the lowest among all other sites. Chatterjee et al. (2014) Chatterjee and Bhattacharjee (2015) and Dutta et al. (2017) reported that in recent years, the vicinity of PSB wetland was dotted with several automobile-servicing garages, nursing homes, private residences and housing complexes, bathing ghats, amusement park etc. Dutta et al. (2019) also indicated that PSB was getting polluted due to anthropogenic loads of untreated effluents and wastes from city wastewater and domestic sewage carried by five major wastewater inlets at a mean flow rate of 277 m3 h^{-1}. Besides, a mining operation was located around 450 m away from PSB (District Industrial Profile 2017-2018, Purulia). Kumar and Reddy (2008) reported that the discharge of municipal wastes declined the DO level in an urban canal. Such was the case in PSB wetland where wastes containing high organic matter, led to a decrease in DO level; higher microbial respiration (Manitcharoen et al. 2020) and algal bloom (Mitsch and Gosselink 2015) caused a higher consumption of dissolved oxygen and, thereby, negative correlations between DO and nitrate or phosphate concentrations at most of the instances were evident in the present study.

No definite seasonal fluctuation of pH was noted at the study sites and pH values were weakly alkaline range throughout the wintering period. Longcore et al. (2006) reported that a water pH in the weakly alkaline range supported higher macroinvertebrate diversity and thereby attracted more waterbirds. EC and TDS both these electro-physical collinear factors were often used for monitoring the temporal disparity of water quality (Pal et al., 2015). An increase or decrease in conductance in a water body might indicate pollution and agricultural runoff or a sewage leak might be the primary cause of the rise in conductivity due to the additional chloride, phosphate, and nitrate ions (Pal et al., 2015, Mandal et al., 2015). The highest EC, TDS and salinity were recorded at PSB, while the lowest values were recorded in ASB, which indicated relatively bad and good water qualities of these sites respectively. Siddiqui and Chandrasekhar (2010) also reported that the overall physico-chemical and biological milieu of ASB wetland and categorized it as oligotrophic and raw water quality was also clean and safe. In three sites, viz., KDM, PSB and ASB, significant positive correlation between pH, TDS, and salinity with both nitrate and phosphate concentration were noted. Akpor and Momba (2008) reported that nitrate release was optimum at pH 6. This could lead to higher nitrate concentration in higher pH levels (ranging from 7.62 to 8.55) at our study sites. It was also evident from the publication that high pH resulted in desorption of phosphate from suspended surface sediments and changed the parameters of the adsorption isotherms in a way that would result in higher phosphate in the waterbody (Jensen and Andersen 1992). High TDS concentration also occurred with high nitrate concentration at the study sites. Fadlelmawla et al. (2008) reported that both freshwater and brackish-water nitrate concentrations were correlated to TDS concentrations at all sampling depths. Kent and Landon (2013) similarly found that Nitrate concentrations were directly correlated with TDS concentrations in their study. However, they also reported that, unlike nitrate trends, TDS trends were not correlated with most of the potential explanatory factors, such as land use. Their findings suggested that the sources for TDS trends were more complex than for nitrate trends as TDS derived from a variety of both natural and human sources. In the present study, the higher salinity level was also accompanied by both higher nitrate and phosphate concentrations. The study by Baek et al. (2009) also highlighted the significant positive correlations between salinity and nitrate, and also between salinity and phosphate concentrations.

7.2.2 Guanotrophic nutrient dynamics

Waterbirds can moderate the nutrient dynamics of a waterbody by nutrient cycling and external nutrient loading (Hahn et al. 2007, 2008). Moreover, Post et al. (1998) reported that over-winter flocks of waterbirds could enrich nutrients in freshwater lakes. Manny et al. (1994) also reported that the waterbird guano added nutrients (mainly in form of nitrate and phosphate) which changed the water quality. This excess input of nutrients during a shorter period could occasionally lead to eutrophication (Gere and Andrikovics 1992). Previous studies indicate that 0.5 mg $L^{-1}$of inorganic Nitrogen and 0.01 mg L^{-1} of organic Phosphorus in wetlands can induce undesirable algal growth (Bassi et al. 2014). Therefore, the eutrophication phenomenon reduces the open water area of water bodies and this in turn can negatively affect the waterbird population foraging and roosting there. A large invasion of waterbirds in a wetland would not only alter the trophic interaction of that habitat but also degraded the habitat quality (Scherer et al. 1995). Thus, waterbird richness and density were highly correlated with two important building ingredients of protoplasm, *viz*., nitrate and phosphate of a waterbody (Murphy et al., 1984). Manny et al (1975, 1994) estimated that nearly 27% of nitrate and 70% of phosphorous entering wetlands was added through goose and duck droppings. However, the behaviour of the aquatic birds also influenced the addition of nutrients to the wetlands (Johnsgard 1965). Although Marion et al. (1994), Scherer et al. (1995) and Wambach and Mallin (2002) did not record any significant role of bird guano accumulation in nutrient enrichment of a waterbody, several published works (Andrikovics et al. 2003; Unckless and Makarewicz 2007; Hanson 2008; Singha Roy et al. 2011; Zwolicki et al. 2013) supported the model of enrichment of nutrients in wetlands due to the addition of avian droppings.

In three (GAD, KDM and ASB) of these four study sites, high waterbird abundance was recorded in January, which contributed to the high guano and nutrient loading in this month. A previous study by Mukherjee et al. (2022) also attested to a similar high abundance of waterbirds from these study sites from previous years. However, in PSB the highest abundance was recorded in March due to an almost mono-specific huge congregation of Lesser Whistling-duck, and thereby, a contrasting scenario of guano and nutrient loading was evident at the said wetland. Nitrate and phosphate concentrations were also higher in PSB than other three wetlands, even at the outset of migration season (early October). This could be owed to five major wastewater inlets that carried wastewater from small-scale industrial and municipal areas to the wetland habitat (Dutta et al. 2019). Moreover, Wetzel (2001) reported that orthophosphate (PO_4^{3-}) is the most imperative form of inorganic phosphorus and it is known for bioaccumulation in the food chain. Phosphorus was not only a limiting factor of primary productivity in freshwater wetlands, but also it is the limiting nutrient for algal growth (Wetzel, 1999). Further, artificial increases in concentrations primarily due to uncontrolled anthropogenic activities could lead to eutrophication (Fadiran et al. 2008). It appeared that PSB wetlands with higher phosphate concentrations could become hypertrophic in near future, if not managed properly.

Studies (Manny et al. 1994; Post et al. 1998) reported that waterfowl significantly contributed, particularly to phosphorus, through guano. Previous studies by Kear (1963), Gould and Fletcher (1978), Gwiazda (1996), and Purcell (1999) also recorded the presence of N and P in the guano of waterbirds of different families. Thus, it is pertinent that as total guano input increases, total N and P loading will also increase proportionately. Adhurya et al. (2020) documented that a large population of waterbirds could contribute a substantial amount of nutrients (0.4–28.7% N and 2.4–92% P of total N and P input to the lake, respectively) to a wetland. Similar findings were also recorded from the present study. Total GL was significantly positively correlated with both N and P loading at all the study sites. For the same reason, total GL also showed a significant positive correlation with both nitrate and phosphate concentrations in two study sites, *viz*, ASB and KDM. However, in PSB total GL showed a significant positive correlation with nitrate concentration and in GAD phosphate concentration. The CCA plot constructed on the site-wise total abundance of waterbirds to the phosphate and nitrate of the study sites highlighted the importance of the waterbird communities in nutrients enrichment (Fig. 7.2). Gwiazda et al. (2014) and Laguna et al. (2021) reported that the waterfowl were importers of nutrients in wetlands and especially when bird population density was high, e.g., in wintering or breeding periods. However, the guanotrophic nutrients loading by wintering waterbirds were much pronounced in the CCA plots for PSB and ASB than for GAD and KDM. Later two wetlands were the reservoirs of rivers; GAD had a huge water spread and depth while KAD had complex physiography, being a reservoir of a river dam that received an inflow of a canal from another river dam.

The grouping of waterbirds depending on their food choice it would contribute to some uncertainty in model predictions. Most herbivorous species consumed some proportions of carnivorous diet and vice versa (Zhang et al. 2018; Verstijnen et al. 2021). The ratio of taking herbivorous and carnivorous food in the diet of waterbirds varied with food availability, season and developmental condition of the bird (Bakker and Nolet 2014; Laguna et al. 2021). The most challenging part in this regard was to calculate the NL of omnivorous birds, like Common Moorhen and Northern Shoveler. Though Tufted ducks are clumped with openbills for NL estimation in our study due to their similar molluscan diet, similarity of their digestive performance should be a subject for further investigation. Marion et al. (1994)

recorded that carnivorous waterbird contributed more P than N due to P-rich guano. Hahn et al. (2008) and Zhang et al. (2018) reported that on a local scale the effects of carnivore and omnivore waterbird colony would be more dramatic concerning P or N enrichment. Zhang et al. (2018) reported that omnivores always preferred animal food over plant material. The CCA plot, when constructed on the site-wise abundance of herbivore, carnivore and omnivore waterbirds to the concerned nutrients, emphasized the waterbird food choice may also be important to influence guanotrophic nutrient enrichment. Present study recorded significant influence of carnivore abundance on nitrate enrichment at the carnivore-dominated GAD (Fig. 7.3), The percentage of total guano input by carnivorous waterbirds was higher in GAD (~14% of total guano input) than in the other three wetlands (ranging from ~3% to ~8% of total guano input). However, herbivore-dominated communities of KDM, PSB and ASB enriched both nitrate and phosphate concentration; in the CCA plot role of herbivores was more evident, followed by carnivorous and omnivorous waterbirds in said sites. In the present study, as noted in Table 3.6, the occurrence of omnivores in the wintering waterbird community was negligible (0.5%) compared to herbivores (30%) and carnivores (64.5%) and, thereby, herbivores and carnivores had a major influence in guanotrophication. The importance of guanotrophic nutrient enrichment by herbivores and carnivores was well documented by Gwiazdaet al. (2014), Laguna et al. (2021) and Verstijnen et al. (2021).

Present study also recorded the decline in wintering waterbird populations and anthropogenic interferences ushered contrasting situations (as noted for PSB) in GL and available nitrates and phosphate in ambient water. The abundance of waterbirds in PSB decreased immensely by nearly 95% from 2018-2019 to 2019-2020 (Table 4.1b). Although the decrease in the abundance of waterbirds influenced both the guano and nutrient loadings (Fig. 7.1), however, phosphate concentration was not influenced in PSB. Olson et al. (2005) also recorded that the proportion of nutrients loaded to a waterbody was sensitive to population size, allochthonous inputs, food choice and foraging behaviour. However, in all four wetlands, guano and nutrients added by herbivorous waterbirds were much higher than the carnivorous and omnivorous waterbirds due to the manifold high abundance of herbivorous waterbirds. A high abundance of anatids was recorded from all the study sites during the study period and 15 out of 17 anatids recorded were herbivorous. Thereby, the present work recorded similar higher nutrient loading by herbivorous waterbirds, followed by carnivorous waterbirds. Hahn et al. (2007) on a landscape scale and Adhurya et al. (2022)

on a local scale reported that loading by carnivorous waterbirds were of minor importance for freshwater habitats.

7.3 Conclusion

Wetlands of the Gangetic plains were facing differential levels of anthropogenic interference (Chatterjee et al. 2020). However, these sites were on East Asia-Australasia and Central Asian Flyways and attracted a sizeable number of winter migrants. These birds play important role in nutrient cycling by the way of guanotrophy. Higher nutrient levels in wetlands could influence the growth of aquatic biota, which served as a major food base for the waterbirds (Rader and Richardson 1994). Moreover, bird droppings also helped to encourage the growth of phytoplankton community, hydrophytes, micro and macroinvertebrates, benthic organisms, and fish (Scherer et al. 1995; Longcore et al. 2006; Hanson 2008). Avian guanotrophy in the waterbird wintering season conceivably sustained the nutrient prerequisite of the present study sites for the rest of the year. In these freshwater wetlands for phosphate and nitrate enrichments wintering waterbirds played an important role, mainly by the herbivore waterbirds followed by the carnivores. Therefore, the management of the wetland ecosystem, harbouring winter migratory birds, depended on the delicate balance of two factors, namely the effects of waterbirds on nutrient replenishment and the sustainability of habitats to invite the wintering waterbird guests.

Table 7.1 Monthly variation of selected physico-chemical parameters of the study sites. (a: GAD, b: KDM, c: PSB, d: ASB)

a Physico-chemical factors	**October**	**November**	**December**	**January**	**February**	**March**
Subsurface water temperature (° C)	30.68±0.39	28.18±0.56	22.10±0.14	20.60±0.29	27.08±0.66	33.15±0.21
pH	8.14±0.03	8.21±0.03	8.26±0.05	8.33±0.02	8.31±0.04	8.32±0.14
Electrical conductivity (µS cm^{-1})	216.5±5.57	223.0±5.10	229.8±2.99	232.3±4.03	225.5±2.89	216.5±4.80
Total dissolved solid (ppm)	156.5±3.11	158.5±1.29	160.8±3.50	166.0±8.29	161.3±12.84	154.5±3.70
Salinity (ppm)	108.3±2.22	106.3±2.99	111.0±7.87	108.8±2.22	113.3±4.35	104.5±3.70
Dissolved oxygen (mg L^{-1})	3.8±0.30	3.7±0.39	3.2±0.21	3.8±0.22	3.1±0.25	3.0±0.26

b Physico-chemical factors	October	November	December	January	February	March
Subsurface water temperature (°C)	30.03±0.76	28.35±0.29	22.25±0.34	20.90±0.36	26.55±0.38	33.13±0.25
pH	7.62±0.04	7.69±0.04	8.14±0.08	7.98±0.06	8.02±0.04	7.89±0.02
Electrical conductivity (µS cm^{-1})	259.3±3.30	268.3±3.20	334.3±6.90	327.5±3.42	326.3±3.30	277.3±7.80
Total dissolved solid (ppm)	197.3±2.36	212.5±3.11	234.0±3.92	223.5±5.20	224.8±1.71	211.8±2.22
Salinity (ppm)	130.8±2.50	130.3±1.89	160.3±4.99	161.8±5.80	158.3±2.99	139.5±3.87
Dissolved oxygen (mg L^{-1})	6.2±0.13	6.1±0.13	5.5±0.13	5.1±0.17	5.0±0.13	4.6±0.22

c Physico-chemical factors	October	November	December	January	February	March
Subsurface water temperature (°C)	30.13±0.17	28.13±0.59	23.03±0.39	21.50±0.78	27.10±0.36	32.50±0.39
pH	8.09±0.03	8.03±0.05	8.19±0.04	8.24±0.05	8.29±0.05	8.55±0.12
Electrical conductivity (µS cm^{-1})	393.0±8.83	397.3±5.06	405.8±5.68	415.0±7.87	414.5±4.93	438.0±37.02
Total dissolved solid (ppm)	284.8±12.42	285.8±11.32	292.8±14.08	298.0±23.58	300.3±31.85	307.0±35.39
Salinity (ppm)	188.3±8.26	189.0±9.83	192.8±12.53	196.5±14.48	193.3±13.96	199.5±22.59
Dissolved oxygen (mg L^{-1})	2.9±0.13	3.0±0.13	2.9±0.08	3.1±0.13	3.1±0.18	2.9±0.29

d Physico-chemical factors	October	November	December	January	February	March
Subsurface water temperature (°C)	29.92±0.37	27.81±0.38	22.10±0.41	21.19±0.59	26.73±0.31	32.58±0.59
pH	7.82±0.15	7.81±0.03	7.91±0.08	7.96±0.04	7.85±0.05	7.76±0.06
Electrical conductivity (µS cm^{-1})	163.7±4.43	168.8±3.30	179.8±2.50	188.5±6.19	183.0±2.16	169.5±3.87
Total dissolved solid (ppm)	111.5±2.08	114.3±2.50	126.5±2.38	132.5±3.87	124.5±2.08	119.5±2.08
Salinity (ppm)	79.8±1.71	71.8±1.71	87.3±2.75	89.3±2.75	81.0±1.83	81.8±2.22
Dissolved oxygen (mg L^{-1})	4.3±0.22	4.8±0.18	5.5±0.22	6.2±0.33	5.8±0.13	4.0±0.14

Table 7.2 Pearson's correlations (significant at p<0.05) between physico-chemical factors at four study sites (n=24)

		pH	TDS	Salinity	DO	Nitrate	Phosphate
GAD	**Water Temp.**	−0.318	−0.923*	−0.543*	−0.269	0.100	−0.386
	pH		0.432	0.132	−0.517*	−0.233	0.945*
	TDS			0.568*	0.318	−0.119	0.443
	Salinity				−0.180	0.709*	0.335
	DO					−0.429	−0.604*
	Nitrate						−0.675*
KDM	**Water Temp.**	−0.617*	−0.740*	−0.791*	0.032	−0.746*	−0.740*
	pH		0.934*	0.923*	−0.658*	0.938*	0.858*
	TDS			0.876*	−0.459	0.988*	0.979*
	Salinity				−0.571*	0.905*	0.819*
	DO					−0.437	−0.336
	Nitrate						0.977*
PSB	**Water Temp.**	0.314	0.092	−0.021	−0.457	0.481	0.567*
	pH		0.954*	0.914*	0.115	0.976*	0.879*
	TDS			0.944*	0.389	0.898*	0.734*
	Salinity				0.258	0.847*	0.779*
	DO					0.018	−0.243
	Nitrate						0.931*
ASB	**Water Temp.**	−0.926*	−0.777*	−0.622*	−0.896*	−0.748*	−0.800*
	pH		0.681*	0.695*	0.815*	0.637*	0.633*
	TDS			0.821*	0.826*	0.992*	0.959*
	Salinity				0.533*	0.804*	0.768*
	DO					0.533*	0.804*
	Nitrate						0.968*

Table 7.3 Pearson's correlations between total guano loading, total N loading, total P loading, NO_3-N and PO_4-P concentrations at four study sites.

		Guano loading	N Loading	Nitrate Conc.	P Loading
GAD	N Loading	0.999*			
	Nitrate Conc.	–0.116	–0.123		
	P Loading	0.986*	0.988*	–0.159	
	Phosphate Conc.	0.639*	0.634*	–0.277	0.556
KDM	N Loading	0.997*			
	Nitrate Conc.	0.868*	0.849*		
	P Loading	0.952*	0.965*	0.857*	
	Phosphate Conc.	0.851*	0.836*	0.971*	0.861*
PSB	N Loading	0.999*			
	Nitrate Conc.	0.940*	0.939*		
	P Loading	0.969*	0.972*	0.869*	
	Phosphate Conc.	–0.041	0.916*	0.953*	0.820*
ASB	N Loading	0.999*			
	Nitrate Conc.	0.801*	0.799*		
	P Loading	0.997*	0.997*	0.815*	
	Phosphate Conc.	0.761*	0.758*	0.675*	0.747*

***Table 7.4 Eigenvalues for four axes in Canonical Correspondence Analysis (CCA) plots for total abundance (Fig. 7.2) and abundance of herbivores, carnivores and omnivores (Fig. 7.3) to influence** phosphate and nitrate of the study sites.*

CCA Fig. 7.2					
Axes	1	2	3	4	Total inertia
Eigenvalues:	0.078	0.024	0.000	0.000	0.102
Species-environment correlations:	1.000	1.000	1.000	0.000	
Cumulative percentage variance of species data:	76.2	99.7	100.0	0.0	
Sum of all eigenvalues	0.102				
Sum of all canonical eigenvalues	0.102				
CCA Fig. 7.3					
Axes	1	2	3	4	Total inertia
Eigenvalues:	0.097	0.047	0.005	0.001	0.150
Species-environment correlations:	1.000	1.000	1.000	1.000	
Cumulative percentage variance of species data:	64.4	95.8	98.8	99.8	
Sum of all eigenvalues	0.150				
Sum of all canonical eigenvalues	0.150				

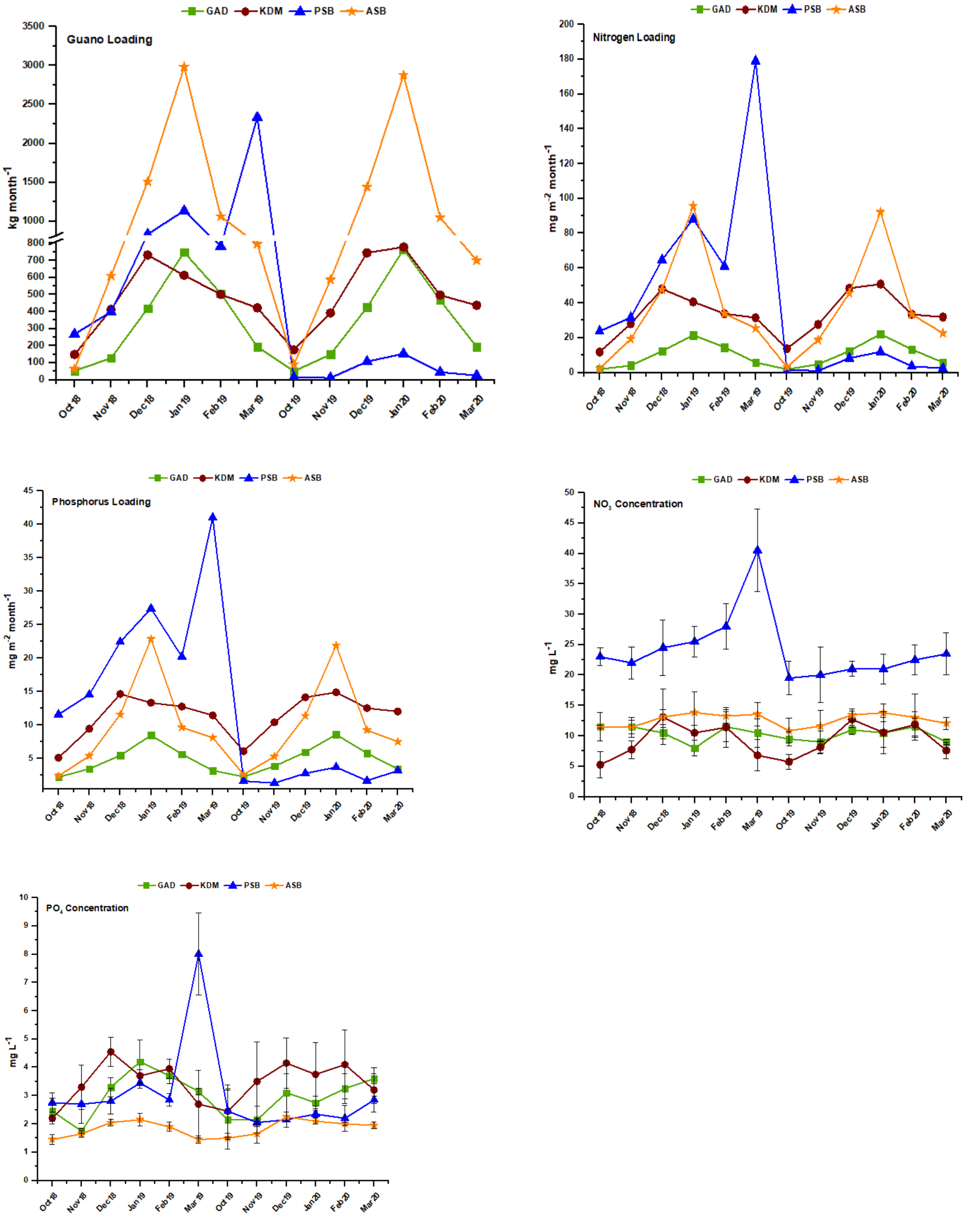


Fig. 7.1 Guano loading (kg month^{-1}), nitrogen loading (mg m^{-2} month^{-1}), phosphorus Loading (mg m^{-2} month^{-1}), nitrate concentration (mg L^{-1}) and phosphate concentration (mg L^{-1}) of the habitats. GAD, KDM, PSB, ASB are names of the study sites.

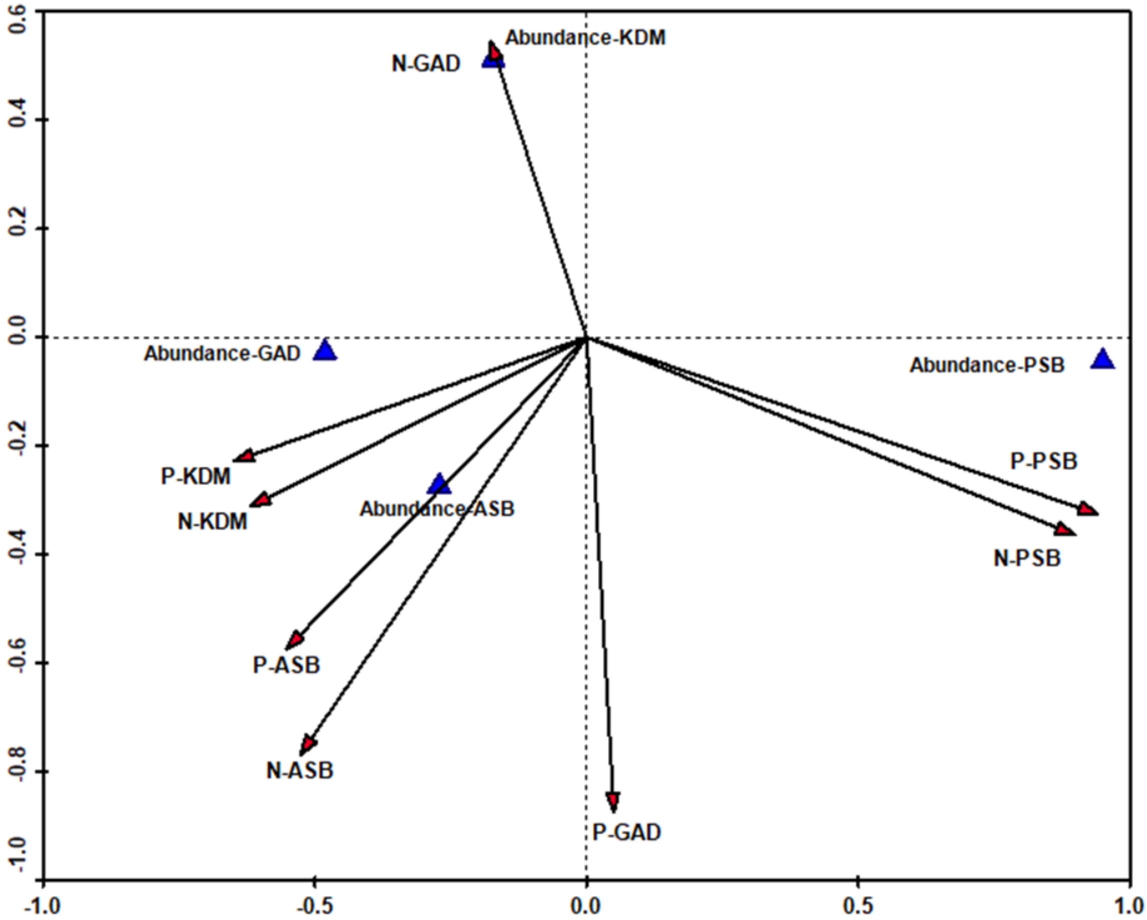


Fig. 7.2 The CCA plot depicted influences of site-wise total abundance of waterbirds on the phosphate and nitrate of the habitats. GAD, KDM, PSB, ASB are names of the study sites; N=Nitrate; P=Phosphate.

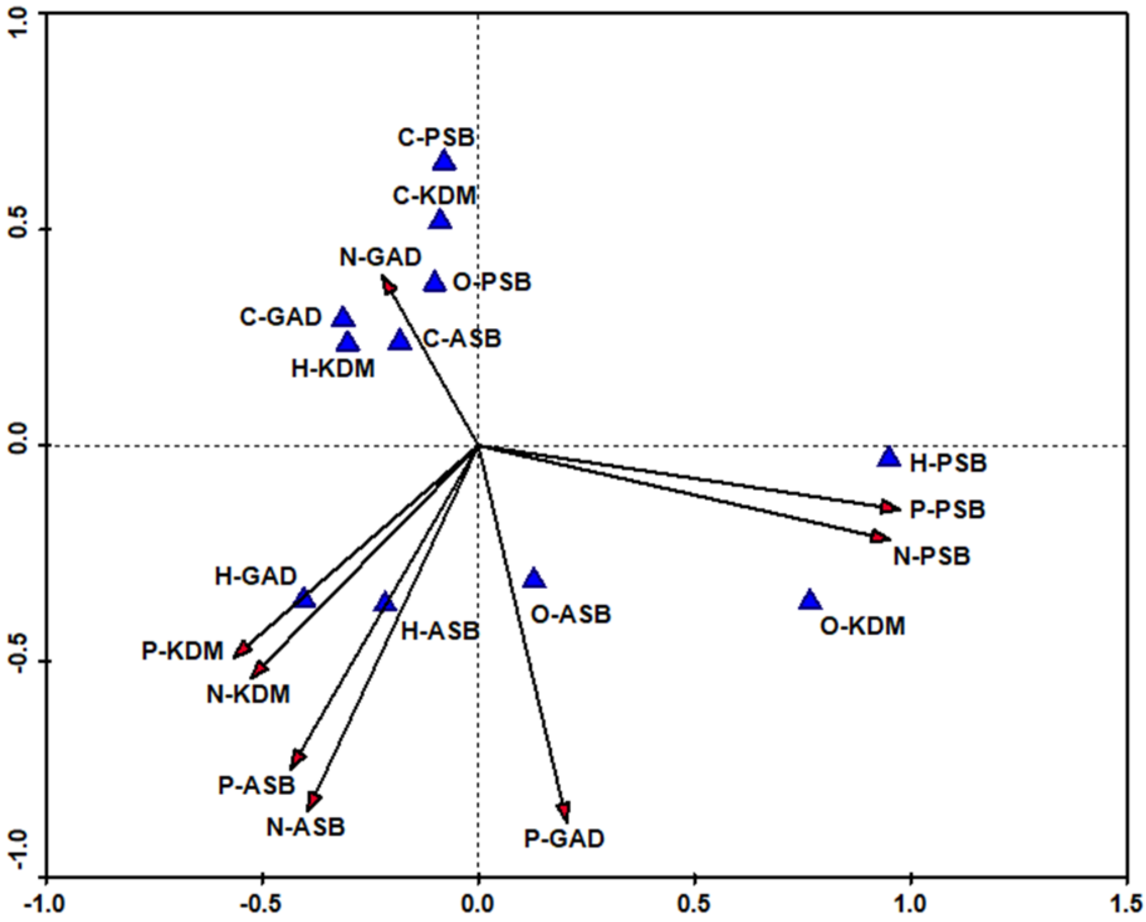


Fig. 7.3 The CCA plot depicted influences of site-wise abundance of herbivore (H), carnivore (C) and Omnivore (O)waterbirds on the phosphate and nitrate of the habitats. GAD, KDM, PSB, ASB are names of the study sites; N=Nitrate; P=Phosphate.

Chapter 8

Time-activity budget & foraging guilds

8.TIME-ACTIVITY BUDGET & FORAGING GUILDS

Habitat attributes and inter and intra-specific interactions play crucial roles in structuring communities in a habitat (Pianka, 1974). Accordingly, effective species conservation strategies mainly focus on the reflective knowledge of habitat quality and community structures (Hanski and Gilpin, 1997). However, available resources also play a pivotal role in shaping community structure (Weller, 1999). Waterbirds, using wetlands as their foraging and roosting grounds, are no exception in this regard.

Wetland birds that migrate southwards along Central Asia/South Asia Flyway (CAF/SAF) and East Asian-Australasian Flyway (EAAF) through tropical areas forage and rest at their wintering sites and accumulate sufficient fat reserves before leaving for colder regions of breeding sites at higher latitudes (Li et al., 2009; Dhanjal-Adams et.al., 2017; CAF National Action Plan–India, 2018). In the wintering months, both resident waterbirds and Palearctic migrants use the wetlands of West Bengal as their foraging or staging grounds (Chatterjee et al., 2020). Therefore, waterbird communities showed a complex structure owed to a decent number of variables that affected both intra and interspecific interactions (Pérez-Crespo et al., 2013). Based on resource utilization of the species within a habitat, the community can be divided into distinct ecological units are called 'guilds' (Root, 1967). Simberloff and Dayan (1991) defined guilds as the 'building blocks' of a specific community. These are composed of species that use similar resources (food and nutrition) within a defined physical habitat in a comparable manner. However, differences in foraging habitat use, feeding techniques, food preferences, and time of foraging plays crucial roles in resource partitioning in these birds (Polla et al., 2018).

The use of wetland habitats in a harmonizing way by waterbirds (residents and migrants) in good numbers is chiefly supported by the habitat heterogeneity (Perez-Garcia et al., 2014). The present study has been carried out on the use of Indian freshwater wetland habitats (Adra Sahebbandh (Site1), Purulia Sahebbandh (Site2), Kadamdeuli Dam (Site3), Gangdoa Dam (Site4)) by 12 waterbirds species (4 residents and 8 Palearctic migrants) populations during the wintering period (from October through March) (Table 3.7). The study analyses species-specific diurnal time-activity budgets and compared behaviour between residents and the migrants during the wintering period. The present study, therefore, comprehensively comments on the time-activity budget, feeding techniques, habitat use, niche sharing, and guild structure reflecting resource partitioning within and between residents and wintering waterbirds. This study aims to answer two important questions: 1) whether there are any temporal variations in diurnal activities within and between migratory and resident waterbirds or not and 2) whether the resident and migratory birds are sharing the same feeding guild or not.

8.1 Results

8.1.1 Diurnal time-activity budget

The diurnal time-activity budget of eight Palearctic migrants and four resident birds were analysed and five major diurnal activities: resting (included sleeping behaviour without head-on-back and with head-on-back and eyes open or closed, loafing), swimming (included searching/scanning, and flying), feeding (dabbling, diving and interval between two dives); preening (included comfort, bathe, wing-flap, wing-shake, head-shake, stretch) and others (included alert, intra- and interspecific interactions social interaction) were recorded and represented in Fig. 8.1. In diurnal hours, the maximum percentage of time was allotted to resting (ranging from 39.9% to 70.0%) by most of the migratory waterbirds except GCGR. In the case of GCGR, the highest percentage of diurnal time was allotted to swimming (44.9 ± 10.25 %), followed by feeding (26.1 ± 11.60 %). Most of the migratory species spent the morning hours (6.00 to 8.45) in resting while they were engaged in different other activities during midday and afternoon hours. In the case of resident waterbirds, the maximum percentage of diurnal time was also allotted to swimming (ranging from 39.9% to 49.0%) except LWDU. LWDU spent the maximum percentage of diurnal time in resting (58.4 ± 32.11%). The hierarchical cluster analysis using mean proportional diurnal time activities highlighted the similarity and dissimilarity in diurnal time activities (Fig. 8.2). Waterbirds, namely, RCPO, FEDU, TUDU, GADW, EUWI, and EUCO formed a cluster as they invested a higher percentage of diurnal hours both in resting and swimming. Another cluster, comprising COPO, NOPI, and LWDU showed exceedingly higher preferences for resting followed by swimming. While the third cluster of GCGR, LIGR, and CPGO showed a higher percentage for swimming followed by feeding activities throughout the daytime. From morning hours through the evening, the time-activity budget of waterbirds changed significantly (One-way ANOVA F=32.29; p<0.001; Partial η2 = 0.701); further, significant differences in diurnal activities were also noted between migrants and residents as they behaved differently during daytime (One-way ANOVA F = 67.38; P< 0.001; Partial η2 = 0.530)

8.1.2 Temporal partitioning of feeding activity

DCA plot highlighted the temporal partitioning of diurnal feeding activity in the waterbirds. Three resident birds (LIGR, CPGO, and EUCO) and one migrant (GCGR) formed a separate group as the percentages of time allotted to their feeding activities were comparatively evenly distributed throughout the day (Fig. 8.3). Other waterbirds allotted a higher percentage of time in feeding between 11.30 and 14.15 hrs. However, the resident LWDU invested more time (36.6 ± 1.23 %) in feeding during the late afternoon session (14.15 to 17.00).

8.1.3 Foraging behaviour of the waterbirds

Foraging techniques and foraging habitats used by the waterbirds were represented in Fig. 8.4 (a,b). Among eight migratory waterbirds, five birds (RCPO, TUDU, GCGR, COPO, and FEDU) most frequently used DI (on average 82.6 %) as a foraging technique mainly from DWCS (on average 58.9 %) and SWCS (on average 16.6 %). Two resident birds, namely LIGR and EUCO, also used DI as the most prevalent foraging technique (93.0 ± 1.95 % and 61.8 ± 2.49 % respectively). However, these two birds mainly used SWCS (79.6%) followed by DWCS (12.3 %). NOPI used UP most frequently (52.7 ± 3.29 %) followed by BD (13.1 ± 1.56 %). Both EUWI and CPGO used HD as primary foraging technique (59.1 ± 4.01 % and 37.3 ± 2.98 % respectively), followed by ND (17.9 ± 2.10 %) in the case of EUWI while UP (18.9 ± 1.23 %) for CPGO. These three birds, namely, NOPI, EUWI, and CPGO primarily used SWFV (on average 67.5 %) as their favoured foraging habitat. GADW and LWDU, on th3 other hand, used all the eight foraging techniques. UP (31.4 ± 2.78 %) and HD (26.9 ± 3.10 %) were the two most frequently used foraging techniques in GADW. However, LWDU primarily used HD (28.0 ± 2.69 %) followed by DI (17.2 ± 1.39 %). GADW used SWFV (39.1 ± 3.42%) primarily followed by SWCS (24.3 ± 3.21%) while LWDU used SLHV (82.5 ± 5.62%) as main foraging habitat followed by SWFV (8.9 ± 1.94%).

8.1.4 Foraging guild structure:

Foraging niche overlap was calculated basing on foraging habitats and techniques; exceedingly higher niche overlaps (0.80 – 0.99) for foraging habitats were observed in between five migrant species, namely, RCPO, TUDU, COPO, FEDU, and GCGR (Table 8.1a). Higher foraging habitat overlap was also recorded in between the remaining three migrant species, namely, GADW, EUWI, and NOPI. A resident species, CPGO, also showed high foraging habitat overlap with three migrant species, namely, GADW, EUWI, and NOPI. Overlaps in between other resident birds or with migrant species were much less (0.01 – 0.56). Niche overlaps for foraging techniques were somewhat different; higher niche overlaps (0.79 – 0.99) for foraging techniques in between five migrant species, namely, RCPO, TUDU, COPO, FEDU, and GCGR, were, however, similar as observed for foraging habitats (Table 8.1b). Similar high overlaps for foraging techniques, as for habitats, were also recorded in between GADW, EUWI, and NOPI. However, two resident species, namely EUCO and LIGR, showed exceedingly high (0.94 – 1.00) overlap values with RCPO, TUDU, GCGR, COPO, and FEDU. Another two resident species, CPGO and LWDU showed similar high overlap with EUWI. High overlaps in foraging technique in between two resident species pairs, namely, EUCO–CPGO, and LWDU–CPGO were recorded. Foraging technique overlaps in between other resident birds or with migrant species were much less (0.01 – 0.66).

Foraging niche breadth based on foraging habitats (varied from 1.26 – 3.47) showed that GADW had the highest niche breadth followed by EUWI, NOPI, FEDU, and COPO (Table 8.2). However, the lowest value of the same was recorded for CPGO followed by LIGR and EUCO. Foraging niche breadth based on foraging techniques (varied from 1.13 – 4.54) had different results; the highest breadth on foraging techniques was observed for LWDU followed by GADW, CPGO, and NOPI. Comparable higher values were recorded for EUWI, EUCO, and RCPO. The narrowest niche breadth based on foraging techniques was observed for GCGR, LIGR, TUDU, and FEDU. Considering both feeding dimensions GADW showed the widest niche breadth (8.63) followed by LWDU (8.12), whereas the narrowest niche breadth showed by GCGR (1.64) followed by LIGR (1.69).

Cluster analysis based on two niche dimensions, namely foraging habitats, and foraging techniques (i.e., bi-dimensional niche space) suggested that a mean Euclidean distance of 5.63 reliably defined four species clusters (Fig. 8.5). Thereby, the waterbirds were represented as four separate guilds: shallow water generalists (Guild1), predominantly shallow water dabblers (Guild2), predominantly divers (Guild 3), and specialist divers (Guild4). Guild 1 was represented by two waterbirds, namely, GADW and LWDU. Guild1 was characterized by a wide niche breadth considering both foraging dimensions. Guild2 contained three species (EUWI, CPGO, and NOPI) that showed the next higher bi-dimensional foraging niche breadth. Predominantly diver species, like COPO, FEDU, TUDU, RCPO, and EUCO, that occupied Guild3 had further less niche breadth while the occupants of the Guild4, namely, LIGR and GCGR, had the minimum breadth and hence were considered as specialist divers. Mean niche breadths based on foraging habitat revealed the broadest breadth for Guild 1 while the narrowest breadth for Guild 4. The post-hoc analysis with Tukey HSD test highlighted the significant differences between the intra-guild niche breadth based on foraging habitats and foraging techniques (Table 8.3). Niche breadth of Guild 1 (GADW and LWDU) was significantly different from the other three guilds; Guild 2 (EUWI, CPGO, and NOPI), Guild 3 (COPO, FEDU, TUDU, RCPO, and EUCO), and Guild 4 (LIGR and GCGR). However, niche breadth Guild 2 was significantly different from Guild 1, and Guild 4, and the niche breadth of Guild 3 was significantly different from only Guild 1.

8.2 Discussion

Time activity budgets together with habitat study were expedient in outlining suitable conservation strategies (Das et al., 2011). Different factors, such as the physical conditions of the individuals of the species, community organization, foraging resources, habitat heterogeneity, and environmental conditions were the major determinants of time-activity budgets (Paulus, 1988). Therefore, the quantum of time apportioned for different activities was critically important to understand the demands for specific resources and also to identify the challenges the waterbirds might face in wintering habitats. The remarkable worldwide decline in migratory waterbird species initiated us to study time-activity budgets of migratory ducks and their interactions with resident counterparts to determine strategies for waterbird management in the habitats in eastern India.

In the present study, the time-activity budget and the niche dimensions of waterbirds were analysed to emphasis on the resource partitioning among migratory and resident birds. A detailed account of the diurnal time activity budget was conducted to explore the temporal aspect of resource partitioning between the waterbird species. Previous studies by Liordos (2010), Peŕez-Crespo et al. (2013), and Chatterjee et al. (2020) emphasized on the utilization of resources from viable foraging habitats and the employment of different foraging techniques determined the resource partitioning. Resting, locomotion, and feeding were the dominant diurnal activities of ducks; these three activities together constituted over 93% of all activity (Green et al., 1999). Our result confirmed this report. Our study recorded that all birds spent much of their daytime in three major activities, namely resting, swimming, and feeding. Interestingly, for all the waterbird species under study, either resting or swimming dominated the diurnal activities while time invested for active foraging was never higher than those two activities.

Resting was the most dominant day time activity in nine out of twelve waterbirds studied. Our study was supported by several previous reports. Khan et al. (1998) studied the diurnal activity budget of wintering COPO in Turkey and commented that this species spent most of the time (>75 %) in resting, probably due to warmer temp. Muzaffar (2004) quantified diurnal time-activity budgets for wintering FEDU and also reported that individuals spent the most time in resting (60%), with less time spent in feeding (17%), preening (14%), and swimming (9%). Ali et al. (2016) reported sleeping as the major diurnal activity of FEDU, COPO, and TUDU. However, feeding as the dominant daytime activity of wintering EUWI (Saker et al., 2016) and also of EUCO, GADW, and EUWI (Ali et al., 2016) was also on the record; it was commented that higher foraging than other daytime activities was probably due to the availability of several foraging habitat types and abundant food items during the wintering season. Contrary to these reports, we recorded resting followed by swimming were the major daytime activities of EUCO, GADW, and EUWI. Diurnal resting and other comfort activities in Anatidae represented one of the best ways to preserve energy because of migratory preparedness for wintering populations (Green et al., 1999, Tamisier and Dehorter, 1999; Draidi et al., 2019).

We recorded that swimming was the dominant activity of GCGR, LIGR, and CPGO while for the rest nine waterbirds (namely, RCPO, FEDU, TUDU, GADW, EUWI, EUCO, COPO, NOPI, and LWDU) swimming was the second most important diurnal activity. Such differences were well depicted in the cluster analysis. On average the birds in our study spent 31% in swimming and 16% in feeding in their diurnal activities. In conformity to our findings, Abdellioui et al. (2015) also reported that for both GCGR and LIGR, swimming was the main diurnal activity in winter. Mason et al. (2013) reported that GADW invested nearly 50% of their daytime activities in swimming. However, Paulus (1984) recorded that GADW spent 64% of their daytime in feeding and spent more time in resting during the night than day. Food searching activity corresponded to one-fourth of the total diurnal time budget of the FEDU (Draidi et al., 2019). Kaminski and Prince (1981) recorded that foraging and swimming were negatively correlated in dabblers and that response might have been linked to nutrient constraints. However, no difference in diurnal time activity budget between dabblers and divers was significant. Interestingly, migrant and resident waterbird species in this study showed significant differences in diurnal time activity budget. Swimming, rather the locomotion, was an indispensable activity for waterbirds as it was associated with searching for food and suitable foraging and roosting habitats, often rewarded with small snacks. Wintering waterbirds, especially the duck species, spent long diurnal hours by loafing, sleeping, and performing basic maintenance and comfort movements (Johnson et al., 2016). By moving among a variety of loafing and roosting sites, the waterbirds can maximize their energy savings under different weather conditions and at different times of the day. Karasov (1990) claimed that birds can adaptively control the efficiency of food utilization and thereby, undergo pre-migratory fattening without increases in energy intake or decreases in energy expenditure. Waterbirds using foraging habitats regularly adjusted their activity and foraging strategies to meet energy demands while splitting foraging effort among habitat types (Daniels et al., 2019).

The migrant species, GCGR, along with two residents, namely LIGR and CPGO, had feeding activity as the second-highest daytime activity in our study. CPGO, the tropical resident species fed mostly in the first and last hours of the daylight (Upadhyay and Saikia, 2010); however, we observed a more or less similar trend and CPGO in this study were largely busy in foraging throughout the diurnal hours. Fox (1994) studied the feeding ecology of wintering LIGR and recorded that LIGR foraged throughout the daylight hours. He recorded a notable decline in daytime resting during the winter period of comparatively shorter day lengths and suggested that LIGR needed to feed for 7 – 9 hours per day throughout the winter. Our study amply supported the records of Fox (1994). In our study both LIGR and GCGR were engaged in feeding almost throughout the diurnal period. Gagliardi et al. (2006) reported that the distribution of feeding efforts of LIGR and GCGR, two predominantly specialist divers, were related to optimizing feeding success in the context of energetic costs incurred in diving for food. Interestingly, these birds form a separate cluster in the dendrogram. Further, these three birds together with EUCO formed a group in DCA as their feeding activity was dispersed almost uniformly in the diurnal hours. The other eight birds, seven migrant species and LWDU, a resident species, formed a distinct group in DCA showing their feeding preference from midday to evening times suggesting temporal partitioning of daytime feeding activity. The present study recorded that FEDU and LWDU, those were preferably nocturnal foragers (Ali and Ripley, 1987), showed higher feeding activity during the late hours of the day. The diurnal feeding maxima at the end of the day was probably the initiation of the higher night feeding activity that compensated an increase of energy needs spent in thermoregulation (Aissaoui et al., 2011; Draidi et al., 2019). Feeding was recorded as the third important diurnal activity for seven out of eight winter migrants in this study. Foraging in diving species like FEDU, TUDU, COPO, RCPO and dabbling species like EUWI, GADW, NOPI, took third place in the total budget of diurnal activities. Numerous factors like types of food, temperature, and both inter- and intraspecific competitions determine the importance of diurnal foraging (De Leeuw et al., 1999). Feeding rates in tropical areas were lower than the colder northern latitudes (Draidi et al., 2019) which could be explained by upper energy needs for colder temperature.

Time-activity budgets were used to describe dominance relationships, foraging strategies, and responses of wintering waterbirds to the environment and habitat condition (Bergan et al., 1989). However, few studies have examined behavioural strategies of wintering coexisting species of resident and migrant waterbirds. Besides, the behavioural ecology of wintering diving and dabbling ducks has received minimal attention. We extended our observations on diurnal feeding time-activity budgets of both resident and migratory waterbirds to examine potential interspecific differences in niche sharing and guild structure. The richness of foraging resources and accessibility to that wealth often greatly influenced habitat use by waterbirds (Bolduc and Afton, 2004). Intrinsic (neck length, tarsus length, and body size, etc.) and extrinsic factors (water depth, vegetation density, etc.) of food accessibility differed among waterbird species and groups, and particular species of waterbirds generally fed in particular wetlands with features that maximized the abundance and accessibility of their foods (Taft and Haig, 2003). Waterbirds were assigned into a specific guild primarily depending on several dimensions like the type of foraging habitat used by the species, techniques used for foraging, types of food item consumed, time of day allocated for maximum foraging activity, depth of water frequently used for foraging (MacNally, 1994). Resource partitioning in the guilds could depend on other niche dimensions like prey size and depth of water body (Pearse et al., 2012). Thus, the compositions of waterbird guilds differed among various study sites and were interrelated with mainly physical habitat attributes and foraging techniques in resource exploitation (Pöysã, 1983; Liordos, 2010; Peŕez-Crespo et al., 2013; Pöysä and Vaananen, 2014; Pöysä et al., 2016; Chatterjee et al., 2020). Foraging resources were commonly dispersed heterogeneously in both time and space and foraging waterbirds showed flexible responses to this heterogeneity (Guillemain and Fritz, 2002).

We recorded that diverse foraging habitats were occupied by diverse species with different feeding techniques to exploit resources differently in a particular microhabitat. Niche breadth and niche overlap of species in this study emphasized that species were rather specialists in feeding technique while more plastic so far as feeding habitat was concerned. The niche overlap in the present study was larger among species of the same guild than between other species in the community. Higher niche overlaps of the waterbirds in a guild in the present study would surely suggest the absence of any strong competition. Pérez-Crespo et al. (2013) reported that overlaps of species occupied the same guild were high, but observed habitat partitioning to avoid intense competition. Small niche overlap between species of different guilds would suggest a comparatively high degree of specialization within the waterbird groups. Liordos (2010) reported a similar pattern of niche overlap of foraging guilds of waterbirds. Processes such as morphological differences, different abundances of species, migration, resource fluctuations, and clumped resources could explain the observed patterns (Pérez-Crespo et al., 2013). Niche breadths (uni- and bi-dimensional) were calculated to assess the similarity in resource utilization among species. The bi-dimensional niche breadth (under the assumption that it reflects differences in resource exploitation; Chatterjee et al. (2020) structured the waterbird community into four feeding guilds. Pöysä (1983) commented that changes in resource availability in case of narrow niches could affect the composition of the community and the reverse was true for the wider niches. Guild 1 (GADW and LWDU) having members with exceedingly high niche breadth in both dimensions were shallow water generalists and, thereby, would be less affected in changes in resource availability. Contrarily, Guild 4 (GCGR and LIGR) was formed by two specialist divers showed the narrowest niche breadth and thereby any change in habitat, especially the water depth or food resources at the depth would adversely affect the abundance of these waterbirds. Ali et al. (2016) stated that members of the guild with a specialized single feeding technique considered specialists. Both GCGR and LIGR used more than 90% of foraging techniques in diving. We observed that the specialist guild members showed the notably lower value of bi-dimensional niche breadth (mean value 1.11) whereas the generalist guild members showed much larger values of niche breadths that ranged from 2.56 to 8.63. Guild 2 (EUWI, CPGO, and NOPI), Guild 3 (COPO, FEDU, TUDU, RCPO, and EUCO) had intermediate bi-dimensional niche breadths between breadths those defined Guild 1 and Guild 4. Therefore, Guild 2 and Guild 3 had wider niche breadths in both dimensions and would be less affected in habitat perturbations. The ability of these guild members to exploit resources using diverse techniques at several microhabitats of the wetlands allowed segregation, thus decreasing potential inter- and intraspecific competitive interactions. Similar situations prevailed in the works of Liordos (2010) and Pérez-Crespo et al. (2013). Interestingly, in our study, we find each of the four foraging guilds had one resident waterbird species along with other migratory species (Guild 1- LWDU, Guild 2- CPGO, Guild 3- EUCO, Guild 4- LIGR). Wiens (1989) reported birds with similar foraging habitats and feeding techniques utilized similar food types and formed the guilds. Therefore, both migratory and resident species effectively partitioned foraging resource and they might have depended on other niche dimensions like prey size, time of foraging, depth of waterbody, and physical advantages.

Our study suggested that uses of foraging habitats and different foraging techniques and temporal variations in foraging activities accommodated resident and winter migrant waterbirds in feeding guilds. Waterbirds preferred wetlands with higher diversity and richness of food resources like aquatic plants, insects, mollusca, fish, and amphibians that occurred in wetlands with varied water depth-classes accounted for supporting a greater diversity of waterbirds like dabbling ducks, diving ducks, and other divers besides waders (Meerhoff et al., 2003). Present findings and dataset on time-activity budget and foraging behaviour would be indicative of habitat heterogeneity and foraging resources of wintering sites in wetlands of eastern India. Therefore, such information would be crucially important for conservation and effective management strategies of these wetland habitats on EAAF and CAF/SAF that shelter residents alongside winter migratory waterbird species during the tropical wintering period at important staging and wintering sites.

8.3 Conclusion

Stopover areas during the wintering period are considered ecologically important habitats for migratory waterbirds, yet research on the importance of specific stopover areas is lacking (Beatty et al., 2013). Wetland loss or land-use changes may lead to a change in waterbird habitat selection and diet choice (Kloskowski et al., 2009; Brochet et al., 2012). Therefore, wetland management must be based on the region-specific knowledge about waterbird communities, including the species composition and foraging preferences of the birds, especially in the wetlands that are important staging and wintering sites on the EAAF and

CAF. Time activity budgets together with habitat study are useful in framing suitable conservation strategies (Das et al., 2011). Different factors, such as the physical conditions of the individuals of the species, community organization, foraging resources, and environmental conditions are the major determinants of time-activity budgets (Paulus, 1988). Therefore, the quantum of time apportioned for different activities is critically important to understand the demands for specific resources and also to identify the challenges the waterbirds may face in wintering habitats. Foraging habitat requirements and/or foraging techniques vary between waterbird species, more specifically between different foraging guilds. This work suggests resource partitioning in waterbird species could depend on differences in time activity and foraging behaviour to cope with different niche dimensions.

Table 8.1 Nice overlap based on foraging habitats (a) and foraging techniques (b).

(a)	GADW	TUDU	GCGR	COPO	EUWI	FEDU	NOPI	EUCO	LIGR	CPGO	LWDU
RCPO	0.47	0.99	0.99	0.98	0.21	0.99	0.18	0.27	0.42	0.10	0.06
GADW		0.46	0.36	0.57	0.93	0.54	0.90	0.53	0.52	0.80	0.26
TUDU			0.99	0.97	0.20	0.96	0.18	0.22	0.36	0.11	0.07
GCGR				0.96	0.11	0.97	0.07	0.23	0.38	0.02	0.01
COPO					0.29	0.98	0.24	0.41	0.56	0.15	0.02
EUWI						0.28	0.95	0.40	0.35	0.93	0.34
FEDU							0.21	0.41	0.54	0.12	0.14
NOPI								0.18	0.14	0.95	0.27
EUCO									0.97	0.06	0.18
LIGR										0.05	0.01
CPGO											0.13

(b)	GADW	TUDU	GCGR	COPO	EUWI	FEDU	NOPI	EUCO	LIGR	CPGO	LWDU
RCPO	0.15	0.96	0.95	0.97	0.10	0.96	0.12	0.95	0.94	0.29	0.51
GADW		0.11	0.05	0.10	0.72	0.10	0.86	0.17	0.05	0.92	0.66
TUDU			0.99	0.99	0.11	0.99	0.07	0.97	0.99	0.22	0.49

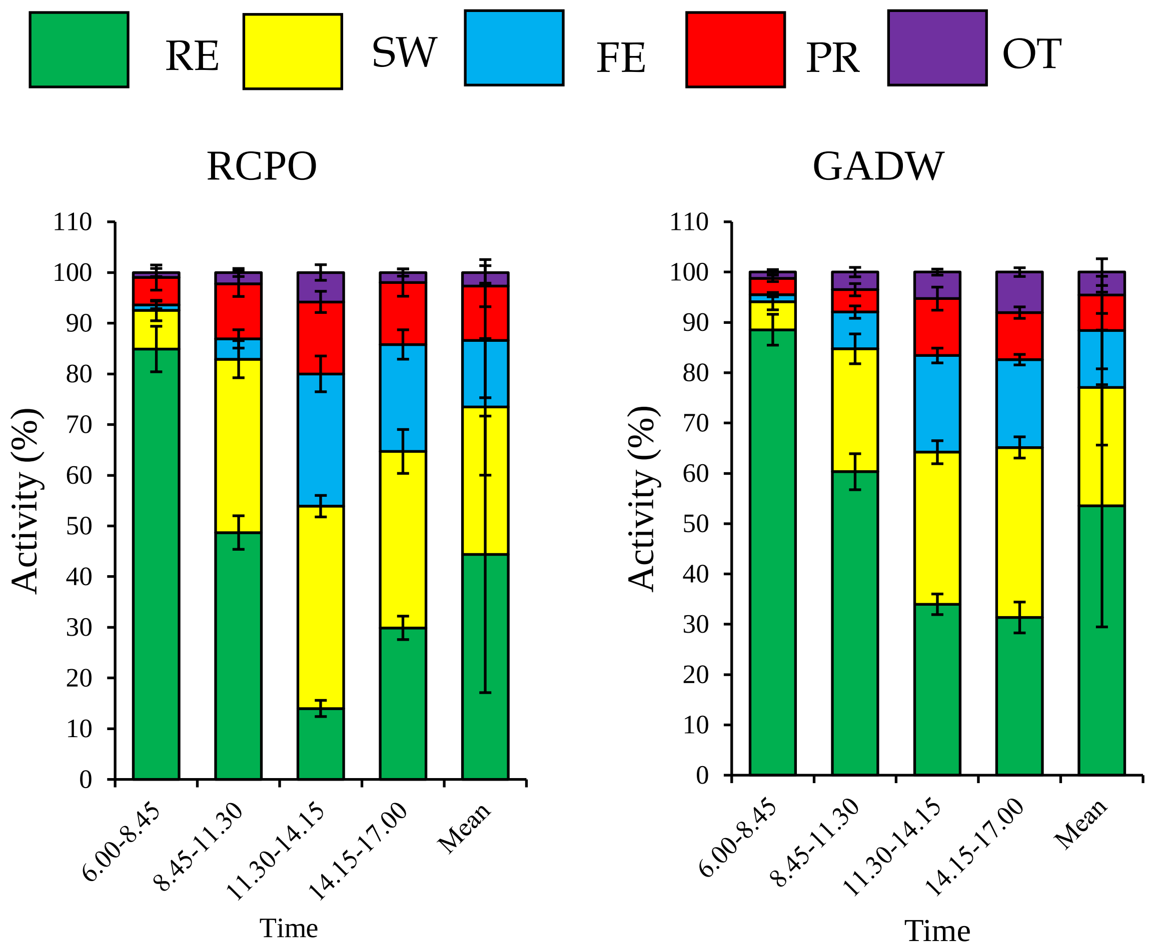
GCGR	0.98	0.04	0.99	0.01	0.95	1.00	0.16	0.44
COPO		0.06	0.99	0.08	0.97	0.99	0.21	0.48
EUWI			0.04	0.31	0.20	0.03	0.88	0.78
FEDU				0.08	0.96	0.99	0.19	0.47
NOPI					0.08	0.01	0.65	0.40
EUCO						0.95	0.30	0.63
LIGR							0.16	0.45
CPGO								0.79

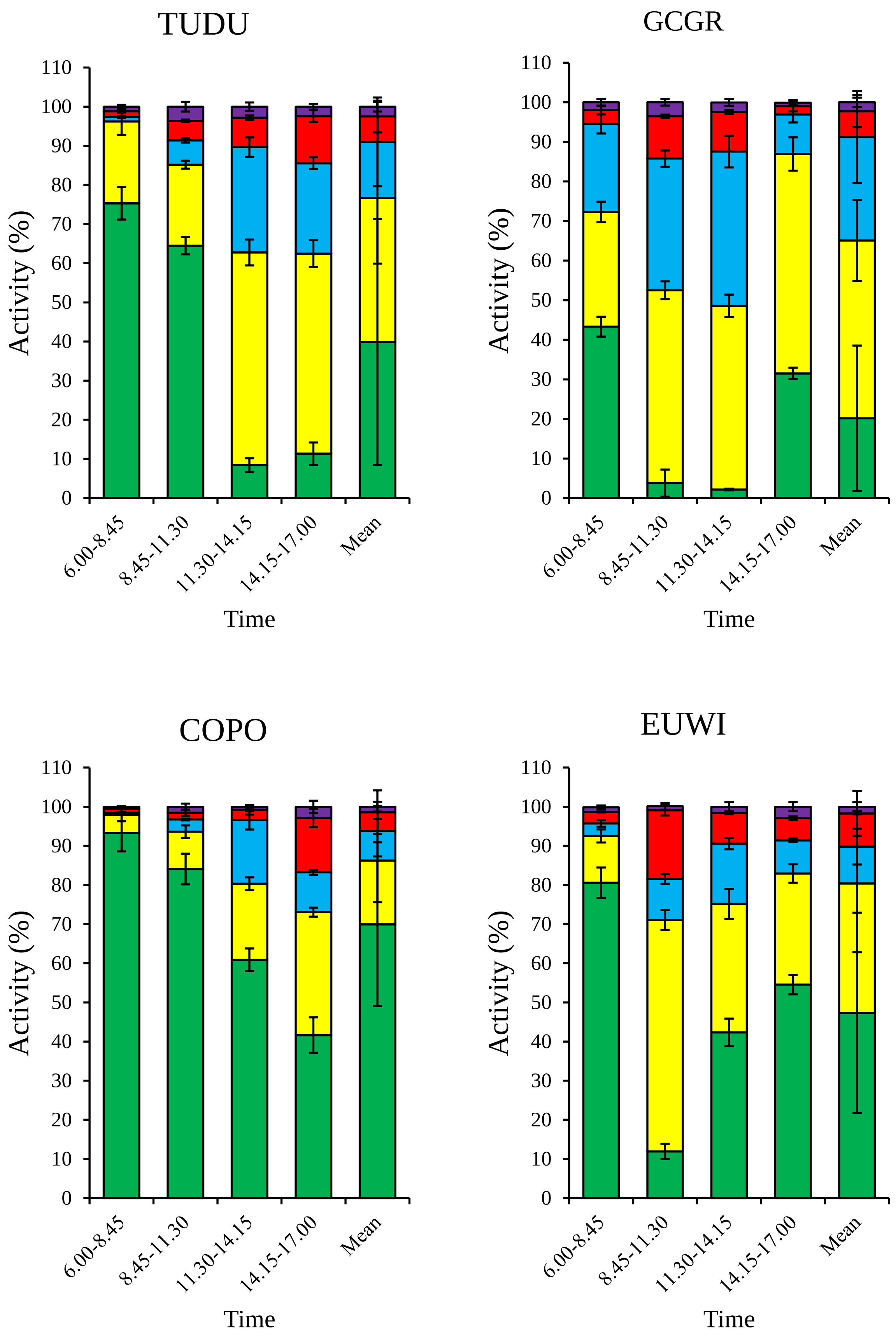
Table 8.2 Nice breadth based on foraging habitats and foraging techniques.

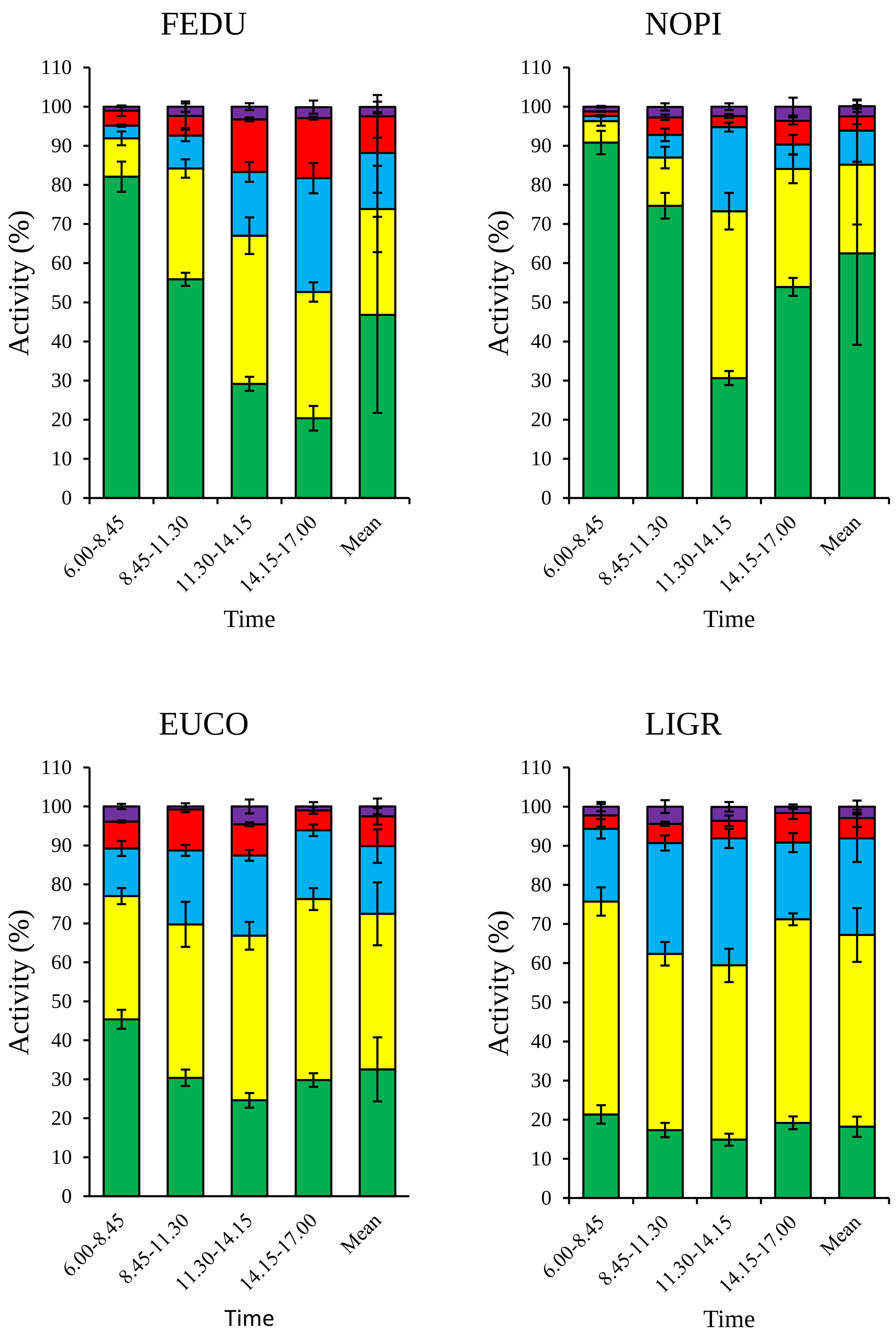
Name	Foraging habitat (n=5)	Foraging technique (n=8)	Both dimension(n=25)
RCPO	1.93	1.84	3.04
GADW	3.47	4.54	8.63
TUDU	1.84	1.40	2.73
GCGR	1.30	1.13	1.64
COPO	2.36	1.51	2.56
EUWI	2.69	2.50	3.74
FEDU	2.38	1.41	2.88
NOPI	2.50	3.05	4.93
EUCO	1.57	2.36	3.24
LIGR	1.45	1.15	1.69
CPGO	1.26	3.07	4.06
LWDU	2.26	4.97	8.12

*Table 8.3 Multiple comparisons using Post Hoc analysis with Tukey HSD test to highlight the significant differences between the intra-guild niche breadth based on foraging habitats and foraging techniques. * marks are the significant mean differences at the 0.05 level.*

Guilds (I)	Guilds (J)	Mean Difference (I-J)	Guilds (I)	Guilds (J)	Mean Difference (I-J)
1	2	2.245*	3	1	-3.128*
	3	3.128*		2	-0.883
	4	3.935*		4	0.807
2	1	-2.245*	4	1	-3.935*
	3	0.883		2	-1.690*
	4	1.690*		3	-0.807




TUDU
GCGR
COPO
EUWI
Activity (%)
110
100
90
80
70
60
50
40
30
20
10
0
6.00-8.45
8.45-11.30
11.30-14.15
14.15-17.00
Mean
Time


FEDU
NOPI
EUCO
LIGR
Activity (%)
Time
0
10
20
30
40
50
60
70
80
90
100
110
6.00-8.45
8.45-11.30
11.30-14.15
14.15-17.00
Mean

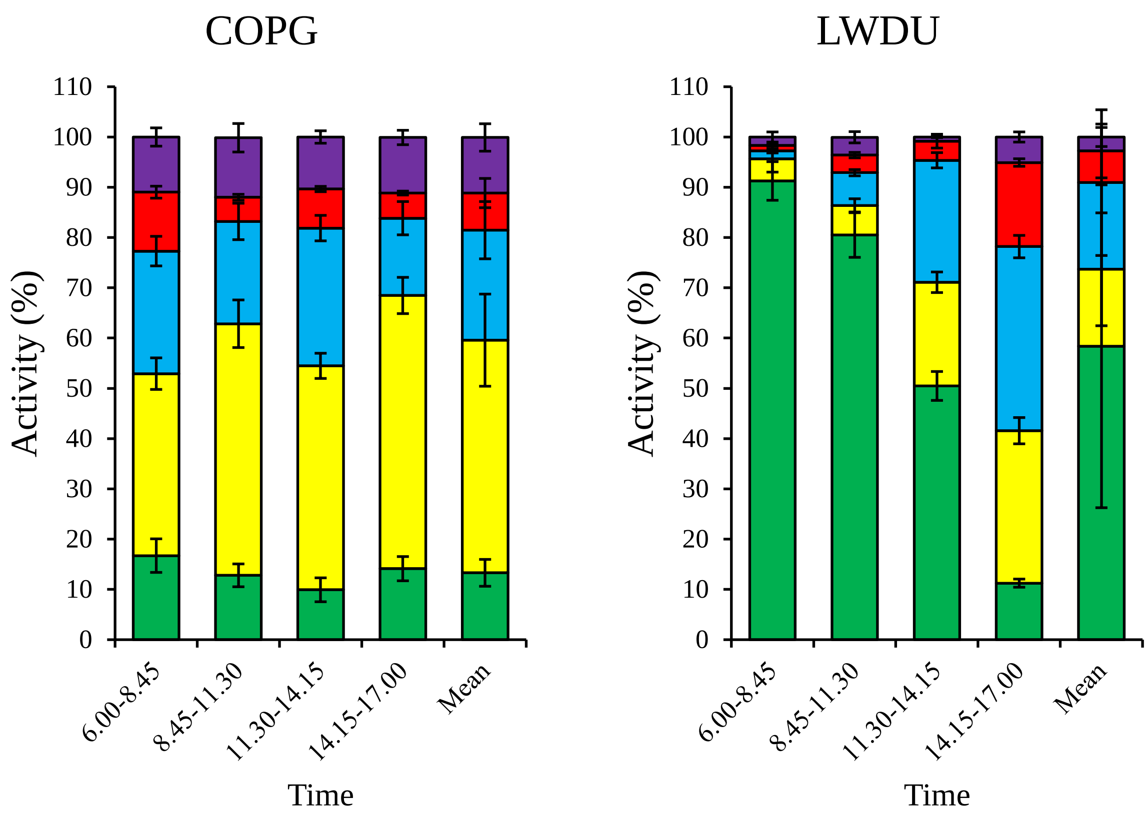


Fig. 8.1 Diurnal time-activity budget of 12 waterbirds wintering in four wetlands. Major five categories of behaviour were denoted as RE - Resting, SW- Swimming, FE- Feeding, PR- Preening and OT- Others.

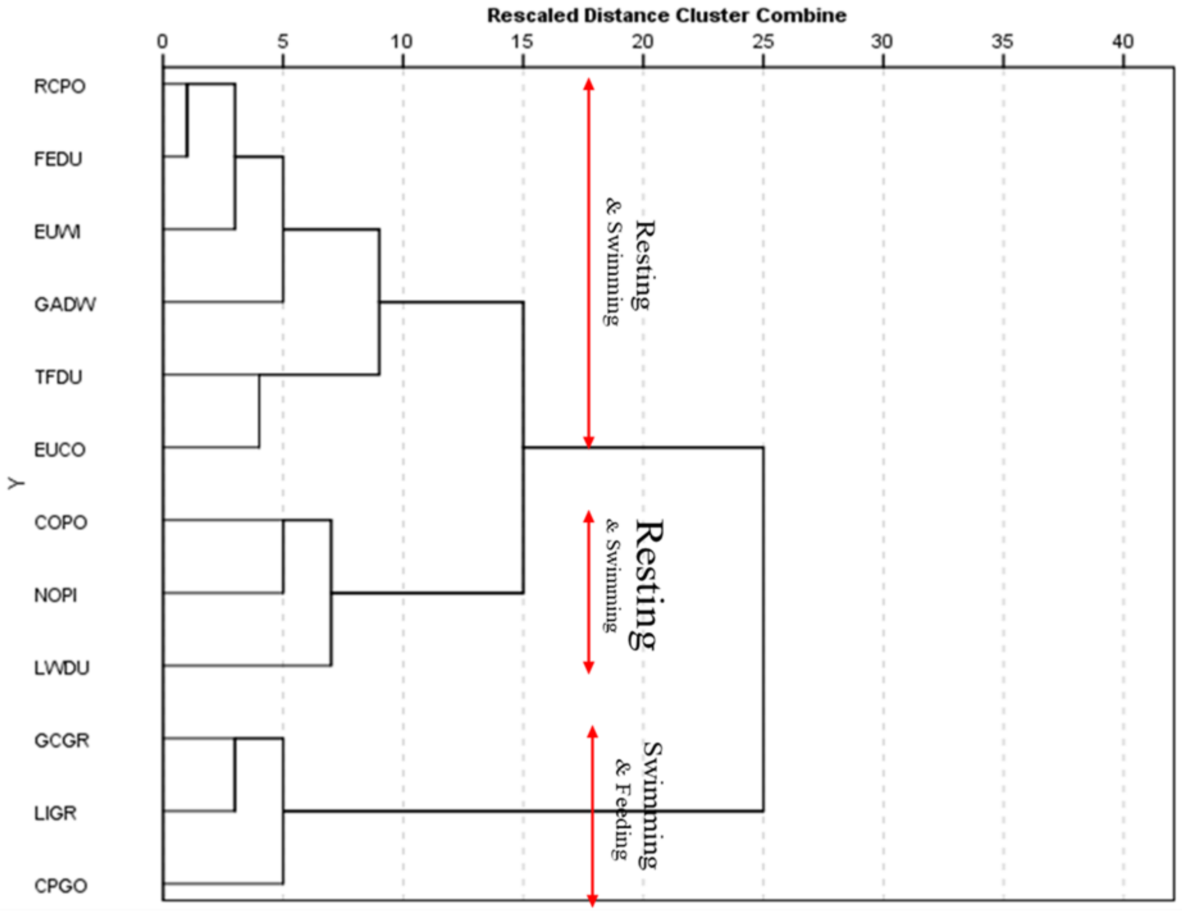


Fig. 8.2 Dendrogram showing clusters of waterbird species depending on mean proportional diurnal time activities using unweighted pair group method (UPGM).

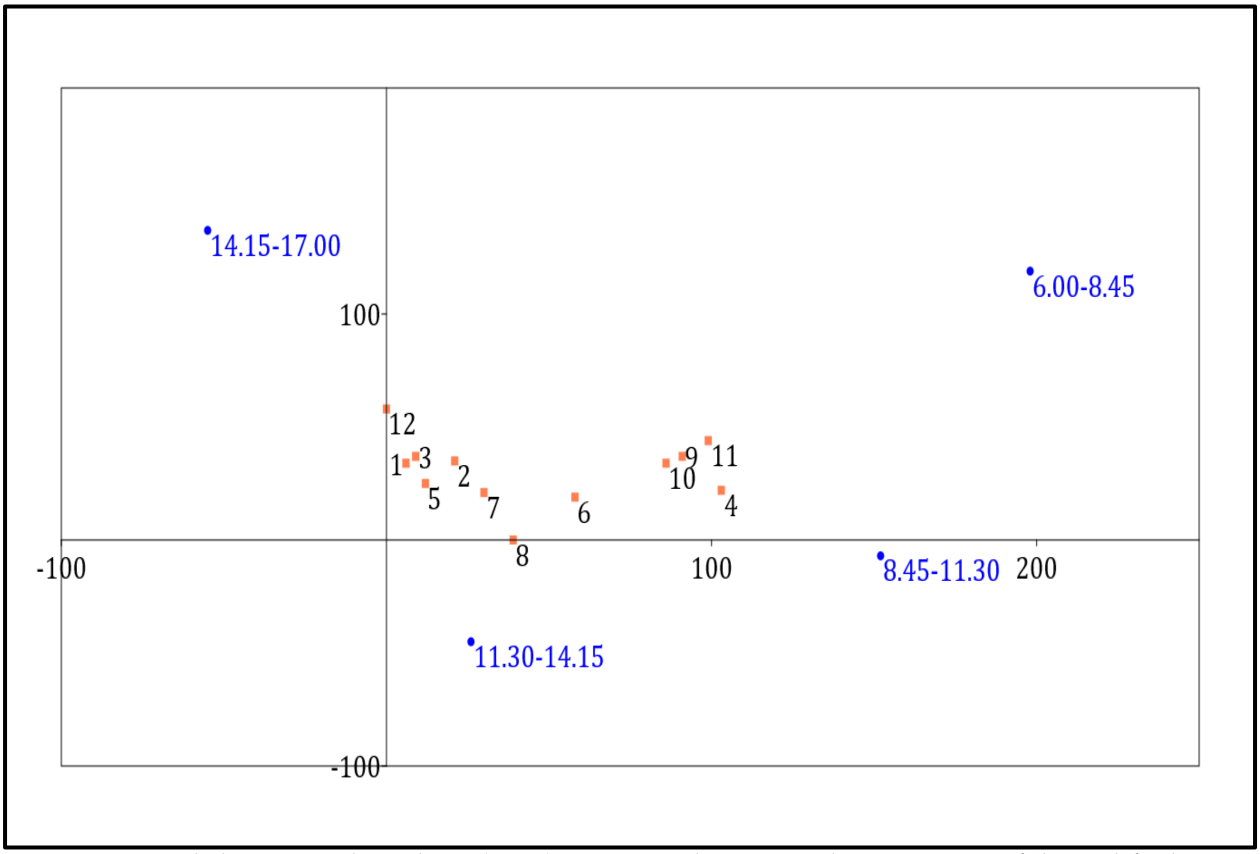
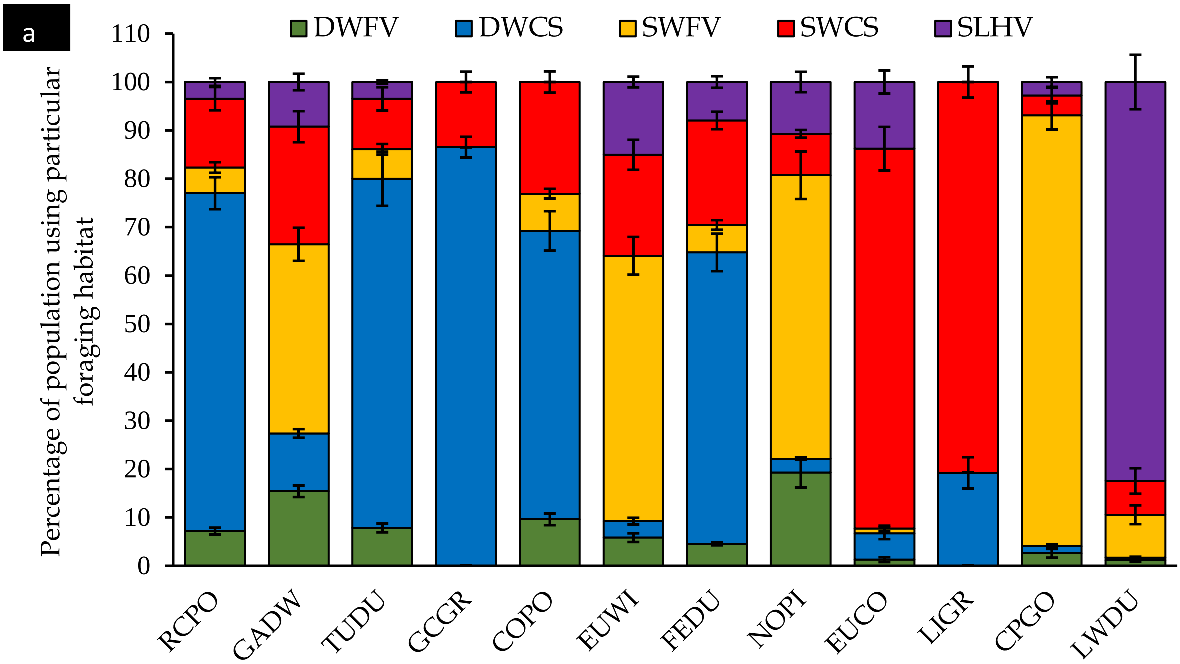


Fig. 8.3 Detrended Canonical Analysis (DCA) to assess the temporal partitioning of diurnal feeding activitiy in the waterbirds (1. RCPO, 2. GADW, 3. TUDU, 4. GCGR, 5. COPO, 6. EUWI, 7. FEDU, 8. NOPI, 9. EUCO, 10. LIGR, 11. CPGO, 12. LWDU.)



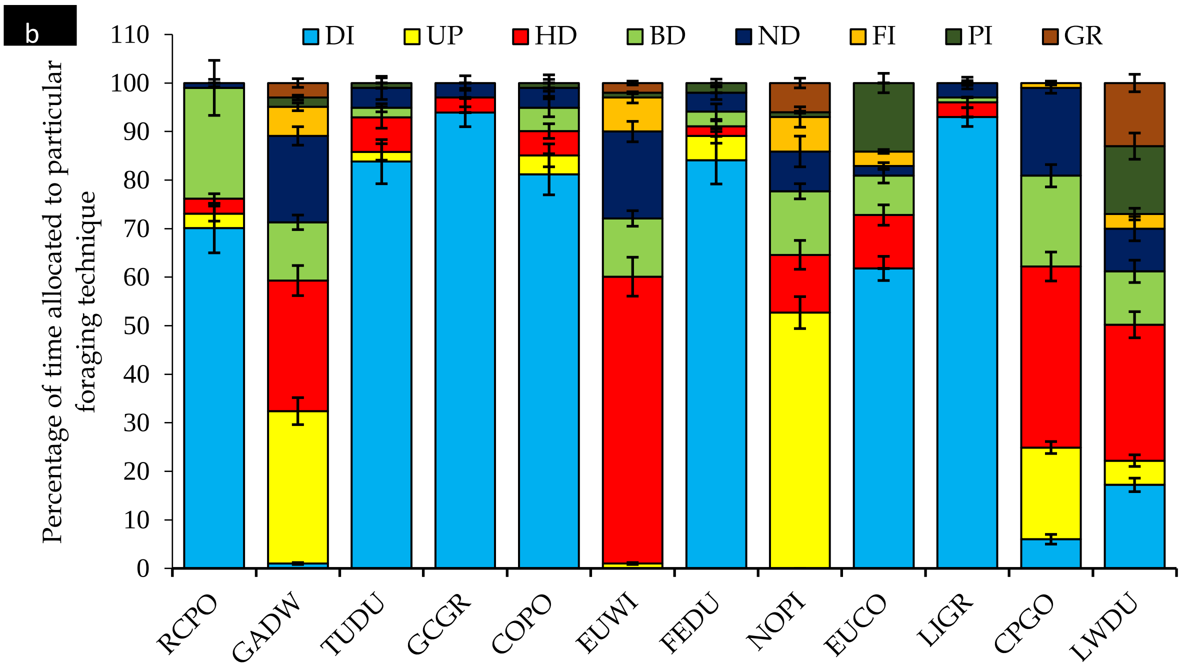


Fig. 8.4 Percentage population of waterbirds using specific foraging habitat (a) and percentage of time allocated for using different foraging techniques by waterbirds (b).

(Foraging habitats: DWFV: Deep water with floating vegetation; DWCS: Deep water with clear surface; SWFV: Shallow water with floating vegetation; SWCS: Shallow water with clear surface; SLHV: Shoreline with hydrophytic vegetation) (Foraging techniques: DI: Diving, UP: Upending, HD: Head-dip, BD: Beak-dip, ND: Neck-dip, FI: Filtering, PI: Picking, GR: Grazing)

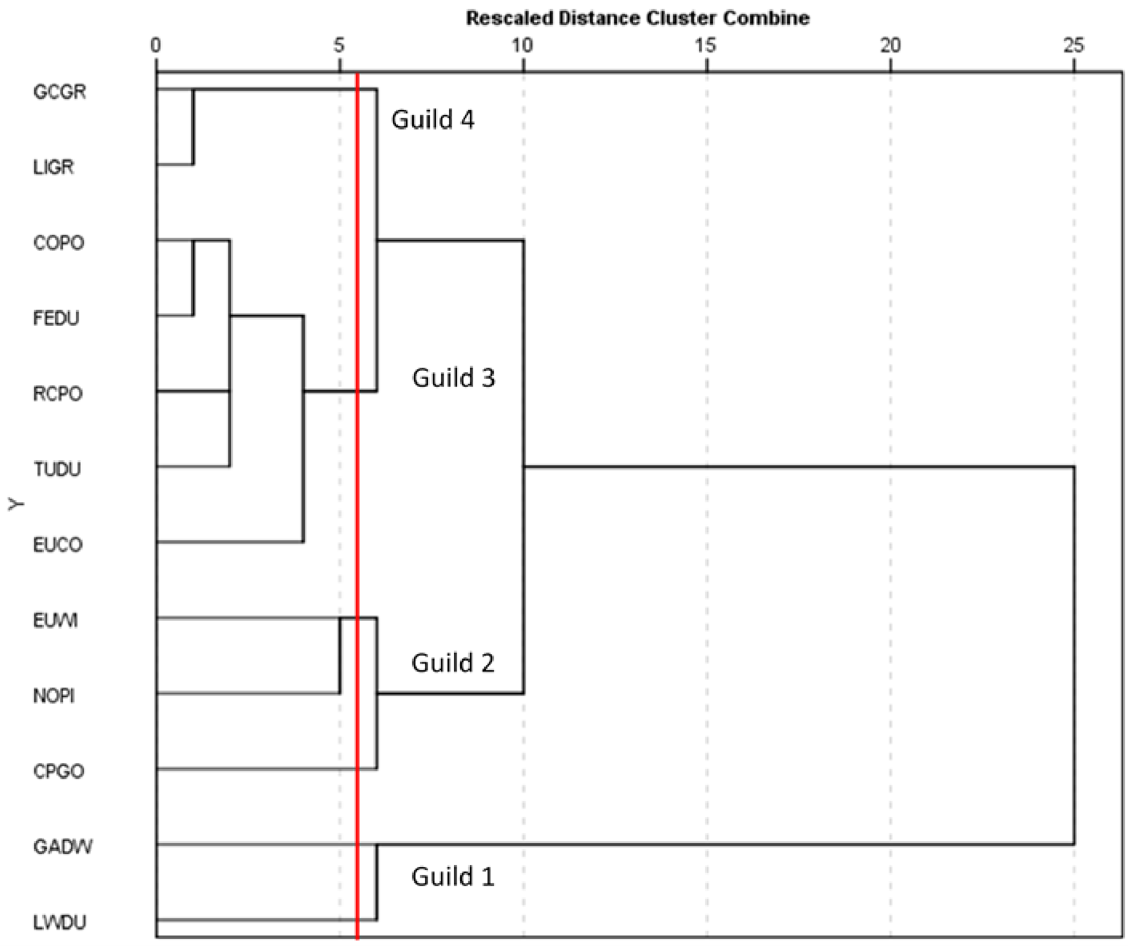


Fig. 8.5 Dendrogram showing foraging guilds based on niche breadth of 12 waterbirds consisting two niche dimensions, namely, foraging habitats and foraging techniques using unweighted pair group method. The mean Euclidean distance of 5.63 in Cluster analysis is shown in red line.

Chapter 9
Foraging behaviour of Red-crested Pochard

9 FORAGING BEHAVIOUR OF RED-CRESTED POCHARD

Wetland birds, like Red-crested Pochards (RCPO), *Netta rufina,* that migrate southwards along the East AsianAustralasian flyway (EAAF) through tropical areas continue storing fat reserves before leaving for colder regions of breeding sites at higher latitudes (Morrier and McNeil, 1991). Migrants of the EAFF must forage when 1) replenishing at a stop-over site after a long over Himalayas flight, 2) molting, and 3) accumulating fat in preparation for long migration crossing the Himalayas towards their breeding sites. The distribution of time in different activities in the day time, including foraging, varies among waterbird species and individuals (Draidi et al., 2019). Time allocations for different daily activities surely have important implications for meeting the energy requirements of the concerned species. The physical habitat, social organization, and environmental conditions of the individual species can be accessed from extensive time-activity budget studies (Paulus, 1988; Datta, 2014). Wintering strategies, feeding techniques, habitat use patterns, niche sharing, and resource partitioning can also be comprehensively commented on from such studies (Aissaoui et al., 2011; Ali et al., 2016). Populations consist of individuals that differ consistently in their food choices and foraging techniques (Van Donk et al., 2019). In the present study, focus was placed on the diurnal time-activity budget of RCPO, a Palearctic species that breeds locally across southern and central Europe to the west and central Asia. The breeding distribution of RCPO extends across Eurasia from Mongolia to Portugal between the latitudes of 35°N and 55°N. A great deal of data has been recorded on the Black Sea and eastern Mediterranean wintering group and the central European/western Mediterranean wintering groups (Delany and Scott, 2002). However, information on the south Asia wintering group is limited (Delany et al., 2006). RCPOs winter from Afghanistan to India and southern China, and are a high-flying winter visitor to the whole Indian subcontinent. This bird is categorized as least concern (LC) on the International Union for Conservation of Nature (IUCN) Red List (BirdLife International, 2019b); however, its population trend is unknown. Being a migratory species, it is protected under the Convention on the Conservation of Migratory Species of Wild Animals or Convention on

Migratory Species (Bonn Convention) under the United Nations Environment Program and Wildlife and Countryside Act, 1981. RCPOs are predominantly herbivores and have been reported as a diurnal species (Carboneras and Kirwan, 2019). Amat (2000) reported that RCPOs collect submerged macrophytes underwater and bring the plants to the surface to eat. Their vegetative diet is often supplemented for protein with aquatic insects and their larvae, crustaceans, snails, amphibians, and small fish (Amat, 2000). RCPOs usually forage employing 3 main techniques, such as diving, up-ending, or dabbling, depending on the availability of the types of aquatic macrophytes and depth of the water. However, they do favour rather deep, large lakes and lagoons of fresh or brackish waters with abundant fringing (Kear, 2005; Carboneras and Kirwan, 2019). Amat (1984) compared the habitat use of RCPOs and common pochards in winter and spring. The timeactivity budgets of common pochards (Green, 1998a; Ali et al., 2016) and ferruginous ducks (Sabir, 2004; Draidi et al., 2019) have been studied. Although the time-activity budgets of several other wetland ducks (Green et al., 1998a; Das et al., 2011; Ali et al., 2016; Saker et al., 2016) and shorebirds (Morrier and McNeil, 1991; Marteinson et al., 2015) are on record, such studies on RCPOs are altogether absent. The only report on the behaviour of a hybrid of RCPOOs (*Netta rufina* × *Aythya nyroca*) was made by Randler (2003). Extensive information on the timeactivity budget of an individual species would focus on the conditions of the physical habitat and social organization (Paulus, 1988; Datta, 2014). The time-activity budget could also comprehensively point out the strategies for the use of feeding techniques, habitat use, niche sharing, and resource partitioning (Aissaoui et al., 2011; Datta, 2014). In the present work, the time-activity budget and foraging techniques of RCPOOs in their natural wintering habitats (Adra Sahebbandh (Site1), Purulia Sahebbandh (Site2), Kadamdeuli Dam (Site3), Gangdoa Dam (Site4)) was recorded to understand their habitat use, and diurnal and seasonal changes in the time-activity during wintering period. To our knowledge, this was the first attempt to examine the diurnal time-activity of wintering RCPOs in the Indian subcontinent. The present work tested 3 main hypotheses: 1) time investment in foraging is never highest for diurnal activities; 2) there exist sex-wise differences in employing the foraging techniques, and 3) the physical habitat (here depth) can influence the time invested in a particular foraging technique.

9.1 Results

9.1.1 Abundance and sex ratio

During the present study, the first appearance of RCPOs was recorded at Site 2 in November (Table 9.1). After November, the density of RCPOs increased and was highest in January at Site 2. This site maintained a fairly similar number of individuals from December through February, which suddenly dropped to a minimum in March. However, the density of RCPOs was much higher at Site 1 when compared to the other 3 sites and the highest mean number, as high as 431.5 (SD ± 19.93) individuals, was recorded in January. RCPOs arrived in December at Sites 1, 3, and 4. The highest number of individuals was in December at Site 3, while it was in February at Site 4. At Site 3, following the fast decrease in water depth within a week, a substantial decrease in the population of RCPOs (nearly 64%) was recorded in January. However, at the other sites, the population of RCPOs markedly declined in March, the usual time of emigration (Table 9.1). The projections in the CCA plots were constructed using the data obtained on the month-wise and site-wise RCPO density together with select climatic factors obtained from the PCA results (Fig. 9.1). Like many other ducks, RCPOs are sexually dimorphic, and thus determining the sex ratio becomes easier. At the present study sites, the RCPO populations were mainly male-dominated (Table 9.2) and a similar situation prevailed throughout the wintering period. No definite changes in the sex ratio were observed at the study sites during the study period. The average adult sex ratio, considering all of the sites, was 0.655 ± 0.138.

9.1.2 Diurnal time-activity budget

Fig. 9.2 depicts the percentage of time allocated by the RCPOs for different activities during the day. Resting, including sleeping, was the major diurnal activity (ranging from 42.8% in February to 47.0% in January) of the RCPOs. Other major diurnal activities were swimming (ranging from 27.1% in February to 29.8% in December), followed by feeding (ranging from 10.9% in December to 16.6% in February) and preening (ranging from 9.0% in January to 12.1% in February). A trivial percentage (ranging from 1.6% in February to 4.2% in January) of the total diurnal time was allotted to all other minor activities, such as alert, and intra- and interspecific social interactions. Around 27% of the time allocated for swimming was allotted to searching/scanning and short stint flights throughout the study period. The time allocated for resting, swimming, and foraging varied from November through February. A considerable variation in the time allocated for foraging activity was recorded during the study period (an increase in foraging time by around 52% between December and February). The time allocated for resting was highest in the morning, i.e., 6:00–8:45 AM (ranging from 79.5% in February to 90.0% in January), while it was lowest during midday, i.e., 11:30 AM–2:15 PM (ranging from 11.5% in February to 16.0% in December). However, the allocation of time for swimming was highest midday, i.e., 11:30 AM–2:15 PM (ranging from 37.5% in February to 42% in November), while it was lowest in the morning, i.e., 6:00–8:45 AM (ranging from 5.1% in December to 10.5% in February) throughout the study period. Likewise, the allocation of time for foraging was highest midday, i.e., 11:30 AM–2:15 PM (ranging from 19.9% in December, to as high as 33.1% in February), while it was lowest in the morning, i.e., 6:00–8:45 AM (ranging from 0.9% in December to 2.0% in February). Significant ($P < 0.05$) negative correlation coefficients (Table 9.4) were noted for foraging with swimming ($r = -0.850$) and resting ($r = -0.775$). An increase in preening activity from late morning, i.e., 8:45–11:30 AM, through the afternoon, i.e., 2:15–5:00 PM, was prominent. Preening showed a significant negative correlation with resting ($r = -0.776$). Time allocations for other different activities, such as alert, and intra- and interspecific social interactions, were also highest midday, i.e., 11:30 AM–2:15 PM (ranging from 3% in February to 7.9% in January). Other activities showed significant negative correlations with preening ($r = -0.937$) and foraging ($r = -0.656$), while a significant positive correlation was found with resting ($r = 0.738$).

9.1.3 Effects of climatic factors

Climatic factors, such as the maximum and minimum air temperatures, difference between the maximum and minimum air temperatures, and day length (PCA component-I: FLs > 0.8) were influential on the diurnal time activities of the RCPOs. At the onset of winter (arrival time) and at the time approaching spring (departure time), the minimum air temperature decreased and increased, respectively, in much higher degrees than the changes in the maximum air temperature (Table 9.3). Likewise, the differences between the maximum and minimum temperatures were also greater during the arrival and departure times of the migratory waterbirds. The day length also started decreasing from the time of arrival of migrant species and again increased considerably at the end of the wintering period. Both resting activity and feeding activity were significantly ($P < 0.05$) correlated with different climatic factors (Table 9.4). Resting was negatively correlated with the minimum temperature ($r = -0.714$) and positively correlated ($r = 0.786$) with the difference between the maximum and minimum temperatures. Contrarily, significant positive correlations were noted between foraging and the maximum temperature (r = 0.517) and day length (r = 0.862); however, the difference between the maximum and minimum temperatures had no significant effect on foraging. A significant negative correlation between the RCPO population density and maximum air temperature (r = –0.609) and day length (r = –0.727) was recorded. terBraak (1994) reported that interpretation of the angles in a canonical correspondence biplot yielded the correct sign for the correlation, but not the correct magnitude, and mentioned that the canonical correspondence biplot was correctly interpreted via projection. The quality of the display could be derived from the eigenvalues that showed definite effects of the climatic factors on the RCPO densities during the months of study at the 4 study sites. The eigenvalues for the first 2 axes were 0.087 and 0.071, while the constrained eigenvalue was 0.258. The biplots for the site-wise and month-wise RCPO densities represented 55.16% and 44.84% of the variance in the climatic factors. These climatic factors, such air temperatures, difference between the maximum and minimum temperatures, and day length were important in influencing the RCPO populations at the study sites (Fig. 9.1).

9.1.4 Foraging techniques in males and females

Techniques in deep water

Deep-water conditions (mean depth always >1.5 m) prevailed throughout the study period at Sites 1, 2, and 4, and at Site 3 until the end of December. Under deep water conditions, the percentage of time allotted to diving in the case of male individuals (ranging from 78.8 ± 0.55 at Site 4 in December to 82.6 ± 0.42 at Site 2 in January) was significantly higher than that of females (ranging from 58.1 ± 2.11 at Site 4 in December to 61.2 ± 1.20 at Site 2 in December). This was noted at all of the study sites (Fig. 9.3). However, the percentage of time allotted to beak dipping by females (ranging from 32.4 ± 0.21 at Site 2 in January to 35.0 ± 1.87 at Site 4 in December) was much higher than in male individuals (ranging from 11.2 ± 0.69 at Site 1 in December to 13.2 ± 0.95 at Site 4 in December). It was observed that the RCPOs were predominantly divers in deeper water habitats (ranging from 69.2 ± 11.11 at Site 4 to 71.6 ± 11.08 at Site 2), followed by beak dipping (ranging from 21.9 ± 11.28 at Site 2 to 23.3 ± 12.57 at Site 4). During 10-min ad libitum observations, while 4–5 dives were recorded for males, 2–3 dives were recorded for females. Time spans of the dives were 10.9 ± 3.0 s for males and 8.3 ± 2.4 s for females during the peak hours of feeding, i.e., 12:00–3:00 PM, at all 4 study sites. A significant difference (ANOVA: $F = 30.88$; $P < 0.001$; partial $\eta 2 = 0.347$; $n = 60$) was noted between the males and females with regards to their preferred foraging techniques in deeper waters. Significant mean differences in the different foraging techniques used by the male and female RCPOs at Sites 1, 2, and 4 were also noted in the post hoc analysis (Table 9.5a). The RCPOs were basically divers and thereby, foraging by diving was significantly different from other foraging techniques in deeper water. This was also true for the RCPOs at Site 3 in December (Table 9.5b).

Techniques in shallow water

Site 3 provided an ideal situation to compare the changes in foraging techniques employed by the males and females in shallow water (mean depth of 0.9 ± 0.6m in January). Site 3, at the Kadamdeuli Dam, is a reservoir where a canal from the Mukutmanipur Kangsabati Dam meets the Shilabati River. Water of the reservoir was usually drained at the onset of a drier period for irrigation and processing for drinking water supply of drought-prone Bankura District of West Bengal, India. The dominant submerged hydrophyte in this study site was Water thyme (*Hydrilla verticillate),* which stood on an average of 0.8 ± 0.5 m high above the bottom. A contrasting picture in using foraging techniques was apparent (Fig. 9.3) when the techniques were compared between December (deeper water habitat) and January (shallow water habitat). A significant difference in the preferred foraging techniques (ANOVA: $F = 12.46$; $P = 0.0024$; partial $\eta 2 = 0.41$; $n = 20$) was noted between the deeper and in shallow water habitat conditions. As mentioned, both the male and female RCPOs were predominantly divers (percentage of time allotted was 70.4 ± 11.68) in deeper water habitats (in December), followed by beak dipping (23.1 ± 11.90). However, under shallow water conditions during January, foraging by beak dipping was highest (50.4 ± 1.18 for males and 60.8 ± 1.90 for females), followed by upending (30.5 ± 1.63 for males and 23.6 ± 0.99 for females). Under shallow water conditions, diving was not a preferred foraging technique for either the males or the females. No significant difference in foraging by diving was recorded between the males and females (values were 14.1 ± 0.47 for males and 10.4 ± 1.41 for females), which was contrary to the deeper water conditions at all of the sites (Tables 9.5a and 9.5b). Under shallow water conditions, the RCPOs used neck dipping, which was altogether absent under deep water conditions. Under shallow water conditions during January, both sexes preferred neck dipping (2.0 ± 0.36 for males and 3.1 ± 2.68 for females), alongside beak dipping and upending for collecting food materials. Significant mean differences between the different foraging techniques employed by different sexes and under the contrasting habitat conditions of Site 3 were evident in the post hoc analysis (Table 9.5b).

9.2 Discussion

Many ducks and pochard species, which are widely distributed in the Palaearctic and migrate within the EAAF and Central Asia Flyway, breeding in a discontinuous band from western Europe to western China and Inner Mongolia, are common winter visitors on the Indian subcontinent (BirdLife International, 2019a, 2019b). The RCPO is a widely distributed winter migratory species in India, including several parts of West Bengal (Ali, 1996; Kumar et al., 2005; Ahmed et al., 2019). As in case of other different migratory waterbirds, RCPOs appear in their wintering areas in India in late October and leave for their breeding ground in late March. Madge and Burn (1988) reported that once the post-breeding moult is complete, RCPOs depart their breeding areas for their winter quarters, to arrive there from October/November onwards. The present work recorded a similar time frame, i.e., November to March, usual entry and exit months, respectively, for RCPOs at the study sites herein. Changes in the day length are considered important environmental cues that trigger avian migration (Marra et al., 2005). In the current study, it was apparent that the higher density of RCPOs was observed in the lower day length period. However, the differences in ambient air temperatures were also observed to be an important cue for zugunruhe (Halkka et al., 2011; Chatterjee et al., 2017). In the present study, significant negative correlations between the density of RCPOs, and the maximum air temperature and day length supported the aforesaid observations. The CCA plots strongly suggested that air temperature and day length significantly influenced the RCPO densities. The projections in the CCA plot showed that the maximum and minimum temperatures and day length affected the RCPO populations in November (inward migration at the wintering sites) and March (outward migration from the wintering sites). Furthermore, at Site 3, the population size of the RCPOs decreased markedly at the end of December for a drastic decrease in water level. Ma et al. (2010) also recorded similar observations on the effects of water level variations on population sizes of diving ducks. Alexander and Taylor (1983) studied the differential sex distributions of several wintering diving ducks and recorded that the proportion of females in the populations varied from 52% to as low as 21%. Blums and Mendis (1996) reported that many diving and dabbling ducks have highly skewed adult sex ratios in favor of the males. Recently, Pöysä et al. (2019) reported that for the breeding population, the proportion of female tufted ducks decreased from 42.9% (during 1951–1970) to 36.9% (during 1996–2015), while in the case of female common pochards, these percentages were 41.8% and 39.5%, respectively. As reported by Pöysä et al. (2019), ‘These findings are worrying, considering that adult sex ratios are more heavily male-biased in populations. On average, 37% of the female RCPOs in the populations in the present study conformed to their studies. Frew et al. (2018) reported a significantly male-biased sex-ratio for pochard, pintail, tufted duck, and shoveler. They record that the sex ratio for dabbling and diving ducks varied between 0.558 and 0.734. In the present study, the mean sex ratio was recorded as 0.655 for the RCPOs, which was almost similar to those of the other dabblers and divers. Time-activity budgets are important for focusing on the ecological requirements of migratory waterbirds (Boulekhssaim et al., 2006). Information on the timeactivity budget pinpoints the functional role of wetlands and indicates how changes in the habitats may affect birds using the ecosystem (Chatterjee et al., 2020). The large variation in the pattern of time-activity exhibited by waterfowl always remains an annoying question. Many hypotheses have been put forward to account for diel feedings, such as the visual selection of food, food abundance, foraging efficiency, niche sharing, competition, metabolic need, and predation risk (Boulekhssaim et al., 2006). Incidentally, there is no record of previous studies on the diurnal time budgets of RCPOs. Khan et al. (1998) recorded that nonbreeding common pochard preferred to spend >50% of their time resting. Ali et al. (2016) reported that the proportion of time allocated for sleeping ranged between 40% and 75% in white-headed duck, ferruginous duck, Eurasian teal, common pochard, and tufted duck. Das et al. (2011) and Draidi et al. (2019) also reported similar diurnal activity patterns in fulvous whistling duck and ferruginous duck, respectively. In the present study, resting, including sleeping in the RCPOs, was the dominant activity during the entire wintering period. Diurnal resting and other comfort activities represented a way for rearrangement of energy reserves in wintering populations of Anatidae (Tamisier and Dehorter, 1999; Draidi et al., 2019). In the present study, swimming was the next prevalent activity. Swimming is an essential activity associated with foraging in many dabblers. However, for the RCPOs, a predominant diver species, a significant negative correlation between swimming and foraging was observed. The time allotted for diurnal foraging was always less than 30% of the entire activities. Fasola and Biddau (1997) reported that diurnal foraging could be much lower at tropical wintering sites (ranging from 25% to 87%) than at northern latitudes (80% to 100%). This was explained by much higher energy needs for colder temperatures than in the tropics. Diurnal variations in the feeding time were prominent during the study period. Marked diel fluctuations in the time-activity budgets were also reported for white-headed duck, shelduck, and fulvous whistling teal (Green et al., 1998b; Boulekhssaim et al., 2006; Das et al., 2011; Draidi et al., 2019). Khan et al. (1998) studied selected activities of nonbreeding common pochards at Sarp Lake, Turkey, and recorded a negative correlation between foraging and swimming, resting and swimming, and swimming and preening. The current findings were consistent with these records. A marked seasonal variation in the diurnal time-activity budget was reported by Bezzalla et al. (2019). Different environmental factors are important for influencing the diurnal time-activities of migratory waterbirds, which include temperature (Wolf and Walsberg, 1996; Khan et al.,1998), differences in the mean maximum and minimum temperature (Chatterjee et al., 2013; O'Neal et al., 2018), day length (O'Neal et al., 2018), cloud cover (Khan et al., 1998; O'Neal et al., 2018), solar irradiance (Huertas and Diaz, 2001; Visser and Sanz, 2009), precipitation (Khan et al., 1998; Draidi et al., 2019), and humidity (Philip et al., 2016; O'Neal et al., 2018). The seasonal pattern of time allocated for feeding by the RCPOs during the present study was almost consistent with that of previous studies (Paulus 1988; Tamisier et al., 1995; Brochet et al., 2012). A higher foraging time was evident in the present study at the arrival, i.e., early wintering period, and departure, i.e., late wintering period, while a decrease was observed in between these 2 periods. Tamisier et al. (1995) correspond these 3 periods to the wintering strategy of the ducks, namely the restoring, pairing, and fattening periods, during which feeding time budgets differ. Nilsson (1970) stated that in early and late migratory periods with shorter nights, diurnal feeding rates might be higher because birds need to spend part of the day feeding to meet excessive nutrient needs. In the current study, comparatively higher day lengths were observed to be the proximate reason for higher foraging activities at arrival and departure times. Morrier and McNeil (1991) also recorded increased feeding rate in 2 plovers, in months with higher day lengths. However, the ultimate reasons for the higher feeding activity at the onset of the wintering period was to make up for the energy loss during arduous in-migration, while the increased feeding time before departure in out-migration could have been attributed to migratory preparedness (Ali et al., 2016). Laich et al. (2012) and Osterrieder et al. (2014) reported that the dive duration is influenced by prey distribution, depth, and climatic conditions. Intrinsic factors, such as the duration of preceding and subsequent inter-dive intervals and body size, also influence the dive duration and interdive interval. Because of the high energy expenditures in diving, the ingestion rate should be maximized during each dive to minimize time underwater, with diving spells simply being ended upon satiation (Richman and Lovvorn, 2004). In sexually dimorphic ducks, the diving durations were higher in the case of the larger males; in musk duck, the larger sex (males) had 10% longer dives and 20% interdive intervals than the smaller females due to their greater oxygen storage capacity (Osterrieder et al., 2014).

Behney (2014) observed that the effect of feeding depth on stint duration was much stronger for blue-winged teal (small-bodied) than mallards (large-bodied). Male RCPOs that were 1.4%–8.4% larger than the females (BirdLife International, 2019a) showed a higher diving frequency (36.4% higher on average) and duration (35.4% higher on average) in the present study. Larger lung capacity and larger head: body ratio in male RCPOs make them capable of having more foraging time in energy expensive diving than the females. Wintering RCPOs must prepare for the ensuing breeding period by balancing the demands of long migratory upand-down flights and self-maintenance while functioning within phenotypic, energetic, and geographical constraints. To meet these challenges, Austin et al. (2019) reported that species must adapt their foraging behaviours in ways that ultimately optimize both survival and fitness. The diet of RCPOs consists predominantly of the roots, seeds, and vegetative parts of aquatic macrophytes, although they occasionally also consume aquatic invertebrates, amphibians, and small fish (Defos du Rau, 2002; Defos du Rau et al., 2003). The present study sites harboured varied aquatic macrophytes, associated insects, molluscs, and fish populations. Johnsgard (1965), in his detailed work, indicated that RCPOs frequently feed by upending; however, they could dive very well in the usual pochard manner of using only the feet. Amat (2000) reported that RCPOs forage either by diving, upending, or dipping their head underwater. In the present study, in addition to head dipping, the RCPOs were observed to dip their head, stretching up to the end of the neck, underwater (thus named neck dipping) in shallow water habitats. However, similar head and neck dipping feeding were reported in common eider (MacCharles, 1997), ferruginous duck (Draidi et al., 2019), common shelduck (Liordos, 2010), and mallard (Green, 1998b; Liordos, 2010). The present study interestingly also revealed striking differences in foraging technique usage in deeper water habitats and shallow water habitats. Furthermore, the techniques also differed between male and female individuals under such contrasting habitat conditions. Under deep water conditions, the predominant foraging techniques were diving, followed by beak dipping, for both male and female RCPOs. However, dabbler-like beak dipping and upending were the major foraging techniques under shallow water conditions for both the males and females. The post hoc results attested to this observation. The RCPO, a Palearctic migrant species, is considered as a link between pochards (Aythyinae) and dabbling ducks (Anatinae); hence, it is an interesting species from a phylogenetic point of view (Johnson and Sorensons, 1999). The present study on the foraging behaviour of RCPOs was also interesting to attest to their phylogenetic position between divers and dabblers.

9.3 Conclusion

Time-activity, foraging habitats, and feeding techniques of waterbirds are important to understand the resource partitioning and optimal utilization of available resources of the wetlands (Muzaffar, 2004; Chatterjee et al., 2020). The present study on the time-activity budget and foraging techniques of nonbreeding RCPOs focused on their ability to winter in Indian tropical climates, replenish food after migration, and get set before spring migration. Changes in habitat conditions influence their foraging techniques and thereby, RCPOs exploit foraging resources under different habitat conditions by using varied foraging techniques. Such generalist behaviour might be the key to the breeding success and maintenance of a large worldwide population. The RCPO has an extremely large breeding range (from the British Isles to China) and is evaluated as LC on the IUCN Red List, even though Defos du Rau (2002) identified habitat degradation as one of the threats to this species. Humans affect RCPOs in many ways, including habitat loss, hunting, and pollution (Defos du Rau, 2002; Kear, 2005). Rapid developmental activities and urbanization in developing countries, like India, habitat destruction, and anthropogenic disturbances are high (Datta, 2014). The population limits and degree of isolation for RCPOs are not well-known, along with local population sizes in popular wintering areas of India. The ecology of waterbird communities and particularly, in eastern India, remain poorly studied, while the entire region is an important wintering ground for migratory waterbirds. This study would offer an important service in managing waterfowl communities and habitats in India. Several monitoring plans should be implemented so that better information is available for this species and interactions with other waterbirds in the communities. The present study recorded the fundamental information on the functional role of wetlands, and how changes in habitats might affect waterbirds using a particular wetland.

Table 9.1 Monthly site-wise population size of RCPO (Mean ± SD) (NR: Not Recorded).

Month	**Site1**	**Site2**	**Site3**	**Site4**
Nov’18	NR	18.5±1.80	NR	NR
Dec’18	185.8±5.31	66.8±7.98	84.0±6.04	14.5±2.89
Jan’19	431.5±19.93	64.5±4.56	29.8±3.96	80.3±3.30
Febr’19	124.5±8.38	51.5±4.72	22.0±1.87	101±6.73
Mar’19	NR	7.0±0.71	2.25±0.43	1.0±0.00

Table 9.2 Site-wise monthly male (M) and female (F) density and sex ratio (SR) expressed as the proportion of males within the sample of RCPO (NR = not recorded).

Month	**Site 1**		**Site 2**		**Site 3**		**Site 4**	
	M: F	SR	M: F	SR	M: F	SR	M: F	SR
November 2018	NR	NR	11:7	0.611	NR	NR	NR	NR
December 2018	121: 65	0.651	37: 30	0.552	53: 31	0631	8: 7	0.533
January 2019	259: 173	0.599	33: 32	0.508	20: 10	0.666	50: 30	0.625
February 2019	82: 42	0.661	31: 21	0.596	15: 7	0.681	60: 41	0.594
March 2019	NR	NR	4:3	0.571	2:0	1.000	1: 0	1.000

Table 9.3 Macroclimatic factors recorded for the study period

Mean monthly climatic conditions	**Nov'18**	**Dec'18**	**Jan'19**	**Feb'19**	**Mar'19**
Max air temp. (^{0}C)	30.4	25.6	28.6	28.9	32.5
Min air temp. (^{0}C)	21.5	14.7	14.3	17.6	22.4
Temp. difference (^{0}C)	8.9	10.9	14.3	11.3	10.1
Sunrise (h: min)	5:55	6:14	6:25	6:14	5:51
Sunset (h: min)	16:57	16:55	17:16	17:37	17:50
Day length (h)	11.37	10.73	10.86	11.39	12.33
Solar irradiance (Cal. m^{-2} day^{-1})	3670.55	3403.82	3609.02	4093.02	4790.82
Rainfall (days/month)	0	3	0	9	11
Rainfall (mm)	0.0	88.5	0.0	74.2	48.4
Cloud cover (%)	10.1	15.7	7.5	22.0	19.4
Humidity (%)	48.4	43.1	38.3	39.1	36.7

Table 9.4 Pearson Correlation coefficients between selected climatic factors, time allocated in different diurnal time activities and RCPO population densities at the study sites (marked correlations are significant at P < 0.05; n = 16) (TD: Difference between maximum and minimum *temperature, DL: Day Length)*

	Max Temp.								
Min Temp	0.758*	**Min Temp.**							
TD	- 0.229	- 0.809*	**TD**						
DL	0.810*	0.847*	- 0.532*	**DL**					
Resting	- 0.310	- 0.714*	0.786*	- 0.794*	**Resting**				
Swimming	- 0.419	- 0.059	- 0.290	- 0.578*	0.332	**Swimming**			
Feeding	0.517*	0.484	- 0.256	0.862*	- 0.775*	- 0.850*	**Feeding**		
Preening	- 0.353	0.167	- 0.568*	0.257	- 0.776*	- 0.124	0.467	**Preening**	
Other activities	0.271	- 0.054	0.325	- 0.329	0.738*	0.444	- 0.656*	- 0.937*	**Other activities**
RCP Density	- 0.609*	- 0.264	- 0.155	- 0.727*	0.410	0.974*	- 0.891*	- 0.066	0.358

Table 9.5a Multiple comparisons of significant differences in using foraging techniques by male and female RCPO in December and January with deeper water habitats (at Site 1, Site 2 and Site 4) in both months using post hoc analysis with Tukey HSD (* marked mean differences are significant at the 0.05 level).

Site 1,2,4	**Foraging Techniques (I)**	**Foraging Techniques (J)**	**Mean Difference (I -J)**	**Site 1,2,4**	**Foraging Techniques (I)**	**Foraging Techniques (J)**	**Mean Difference (I - J)**
Males in December (with deeper water > 1.5 m)	Diving	Beak dip	69.02*	Males in January (with deeper water >	Diving	Beak dip	69.90*
		Head dip	79.26*			Head dip	80.00*
		Upending	75.30*			Upending	76.05*
		Neck dip	80.85*			Neck dip	81.46*

	Beak dip	Diving	-69.02*	1.5 m)	Beak dip	Diving	-69.90*
		Head dip	10.24*			Head dip	10.10*
		Upending	6.28*			Upending	6.15*
		Neck dip	11.83*			Neck dip	11.56*
	Head dip	Diving	-79.26*		Head dip	Diving	-80.00*
		Beak dip	-10.24*			Beak dip	-10.10*
		Upending	-3.96*			Upending	-3.95*
		Neck dip	1.59			Neck dip	1.46
	Upending	Diving	-75.30*		Upending	Diving	-76.05*
		Beak dip	-6.280*			Beak dip	-6.15*
		Head dip	3.96*			Head dip	3.95*
		Neck dip	5.55*			Neck dip	5.41*
	Neck dip	Diving	-80.85*		Neck dip	Diving	-81.46*
		Beak dip	-11.83*			Beak dip	-11.56*
		Head dip	-1.59			Head dip	-1.46
		Upending	-5.55*			Upending	-5.41*
Females in December (with deeper water > 1.5 m)	Diving	Beak dip	26.32*	Females in January (with deeper water > 1.5 m)	Diving	Beak dip	27.78*
		Head dip	55.25*			Head dip	55.56*
		Upending	58.12*			Upending	58.63*
		Neck dip	59.80*			Neck dip	60.43*
	Beak dip	Diving	-26.32*		Beak dip	Diving	27.78*
		Head dip	28.93*			Head dip	55.56*
		Upending	31.80*			Upending	58.63*
		Neck dip	33.47*			Neck dip	60.43*
	Head dip	Diving	-55.25*		Head dip	Diving	27.78*
		Beak dip	-28.93*			Beak dip	55.56*

		Upending	2.86*			Upending	58.63*
		Neck dip	4.54*			Neck dip	60.43*
	Upending	Diving	-58.12*		Upending	Diving	-58.63*
		Beak dip	-31.80*			Beak dip	-30.85*
		Head dip	-2.86*			Head dip	-3.06*
		Neck dip	1.67			Neck dip	1.80*
	Neck dip	Diving	-59.80*		Neck dip	Diving	-60.43*
		Beak dip	-33.47*			Beak dip	-32.65*
		Head dip	-4.54*			Head dip	-4.86*
		Upending	-1.67			Upending	-1.80*

Table 9.5b Multiple comparisons of significant differences in using foraging techniques by male and female RCPO in December with deeper water and January with shallow water habitats (at Site 3) using post hoc analysis with Tukey HSD (* marked mean differences are significant at the 0.05 level).

Site3	**Foraging Techniques (I)**	**Foraging Techniques (J)**	**Mean Difference (I - J)**	**Site3**	**Foraging Techniques (I)**	**Foraging Techniques (J)**	**Mean Difference (I - J)**
Males in December (with deeper water > 1.5 m)	Diving	Beak dip	57.48*	Males in January (with shallow water < 1.5 m)	Diving	Beak dip	-19.44
		Head dip	64.70*			Head dip	12.92
		Upending	63.20*			Upending	-3.48
		Neck dip	67.34*			Neck dip	19.30
	Beak dip	Diving	-57.48*		Beak dip	Diving	19.44
		Head dip	7.22			Head dip	32.36*
		Upending	5.72			Upending	15.96
		Neck dip	9.86			Neck dip	38.75*
	Head dip	Diving	-64.70*		Head dip	Diving	-12.92
		Beak dip	-7.22			Beak dip	-32.36*
		Upending	-1.50			Upending	-16.40

		Neck dip	2.64			Neck dip	6.39
	Upending	Diving	-63.20*		Upending	Diving	3.48
		Beak dip	-5.72			Beak dip	-15.96
		Head dip	1.50			Head dip	16.40
		Neck dip	4.14			Neck dip	22.79
	Neck dip	Diving	-67.34*		Neck dip	Diving	-19.31
		Beak dip	-9.86			Beak dip	-38.75*
		Head dip	-2.64			Head dip	-6.39
		Upending	-4.14			Upending	-22.79
Females in December (with deeper water > 1.5 m)	Diving	Beak dip	26.18*	Females in January (with shallow water < 1.5 m)	Diving	Beak dip	-29.04
		Head dip	50.46*			Head dip	13.62
		Upending	53.44*			Upending	1.00
		Neck dip	54.56*			Neck dip	16.37
	Beak dip	Diving	-26.18*		Beak dip	Diving	29.04
		Head dip	24.28*			Head dip	42.66*
		Upending	27.26*			Upending	30.04
		Neck dip	28.38*			Neck dip	45.41*
	Head dip	Diving	-50.46*		Head dip	Diving	-13.62
		Beak dip	-24.28*			Beak dip	-42.66*
		Upending	2.98			Upending	-12.62
		Neck dip	4.10			Neck dip	2.75
	Upending	Diving	-53.44*		Upending	Diving	-1.00
		Beak dip	-27.26*			Beak dip	-30.04
		Head dip	-2.98			Head dip	12.62
		Neck dip	1.12			Neck dip	15.37
	Neck dip	Diving	-54.56*		Neck dip	Diving	-16.37

	Beak dip	-28.38*	Beak dip	-45.41*
	Head dip	-4.10	Head dip	-2.75
	Upending	-1.12	Upending	-15.37

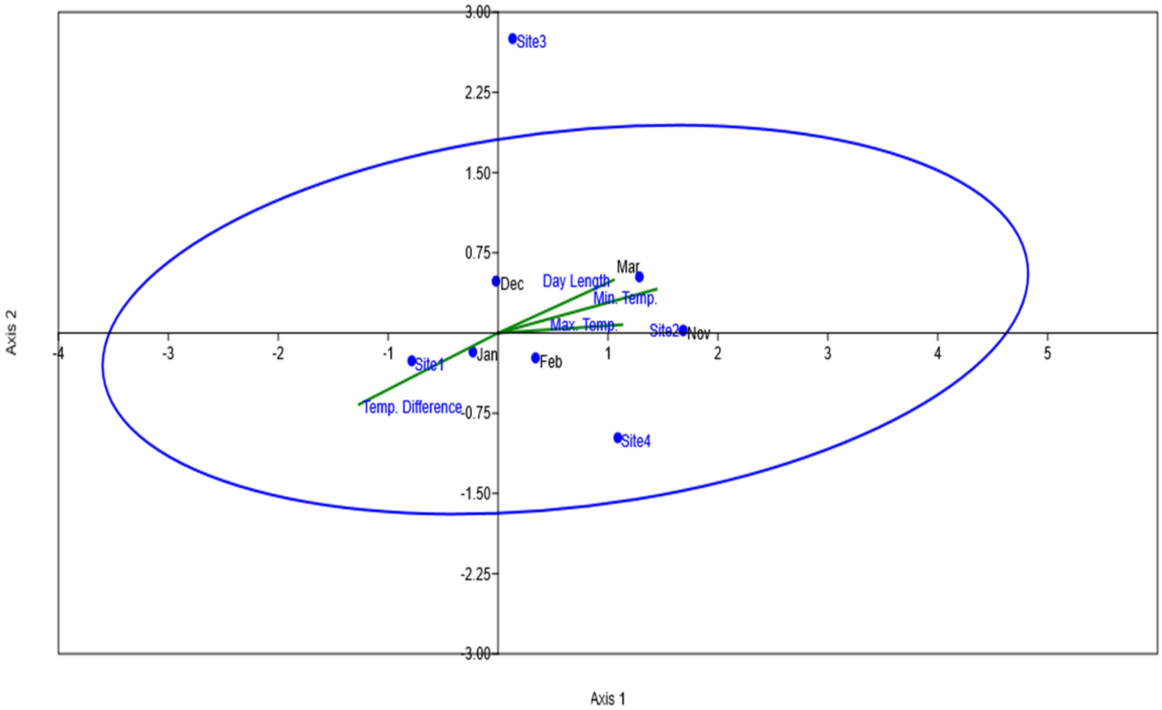


Fig. 9.1 Canonical correspondence analysis (CCA with 95% ellipses) ordination diagram showing scatter plot for month-wise and site-wise density of wintering RCPO together with selected environmental variables. Vector lines represent the relationship of significant environmental variables to the ordination axes; their length is proportional to their relative significance.

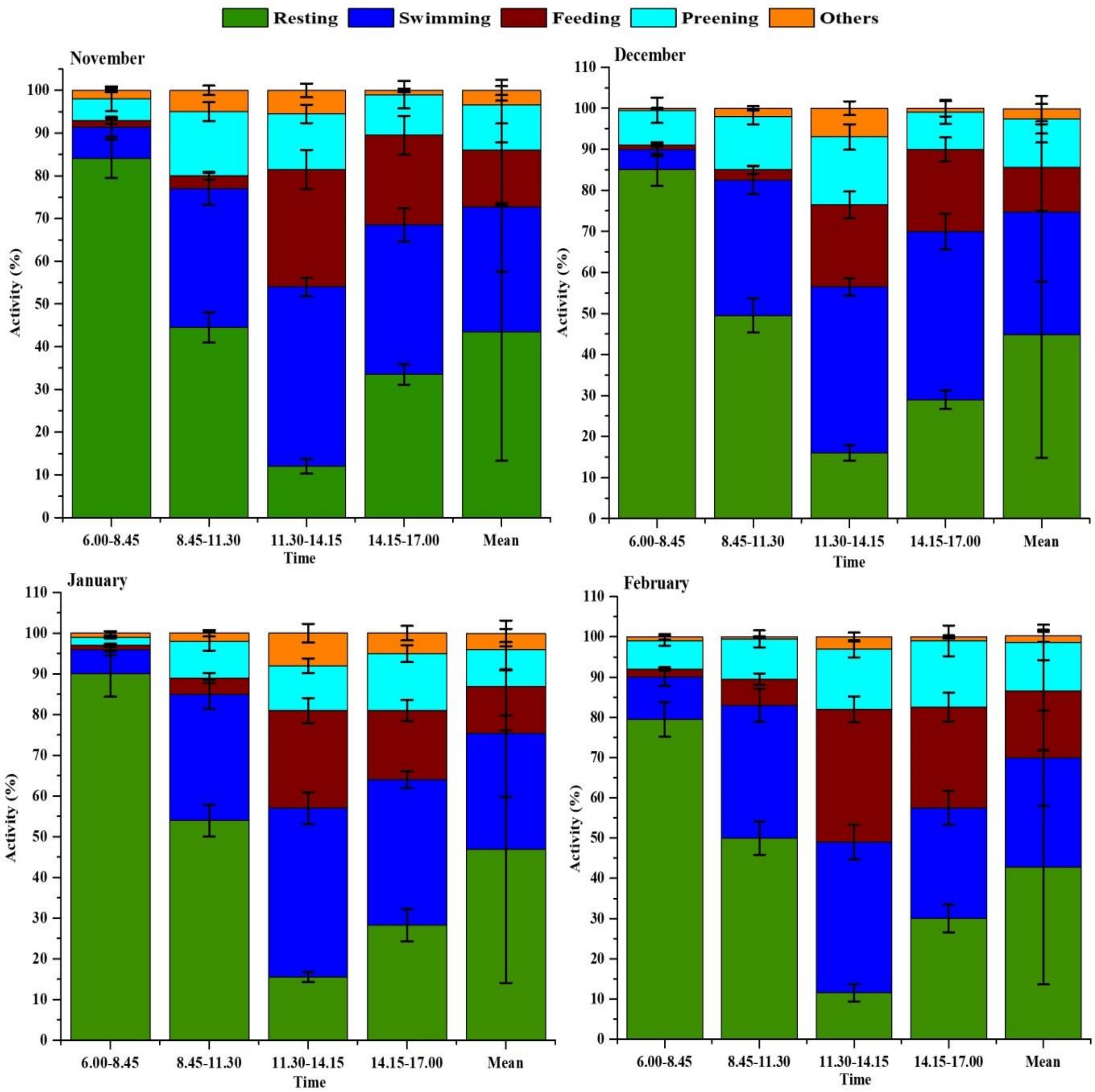


Fig. 9.2 Month-wise and time-wise proportional time budget of RCPO; values are in percentages of time spent in diurnal activities (mean value ± SD; n = 32; 96 h observation).

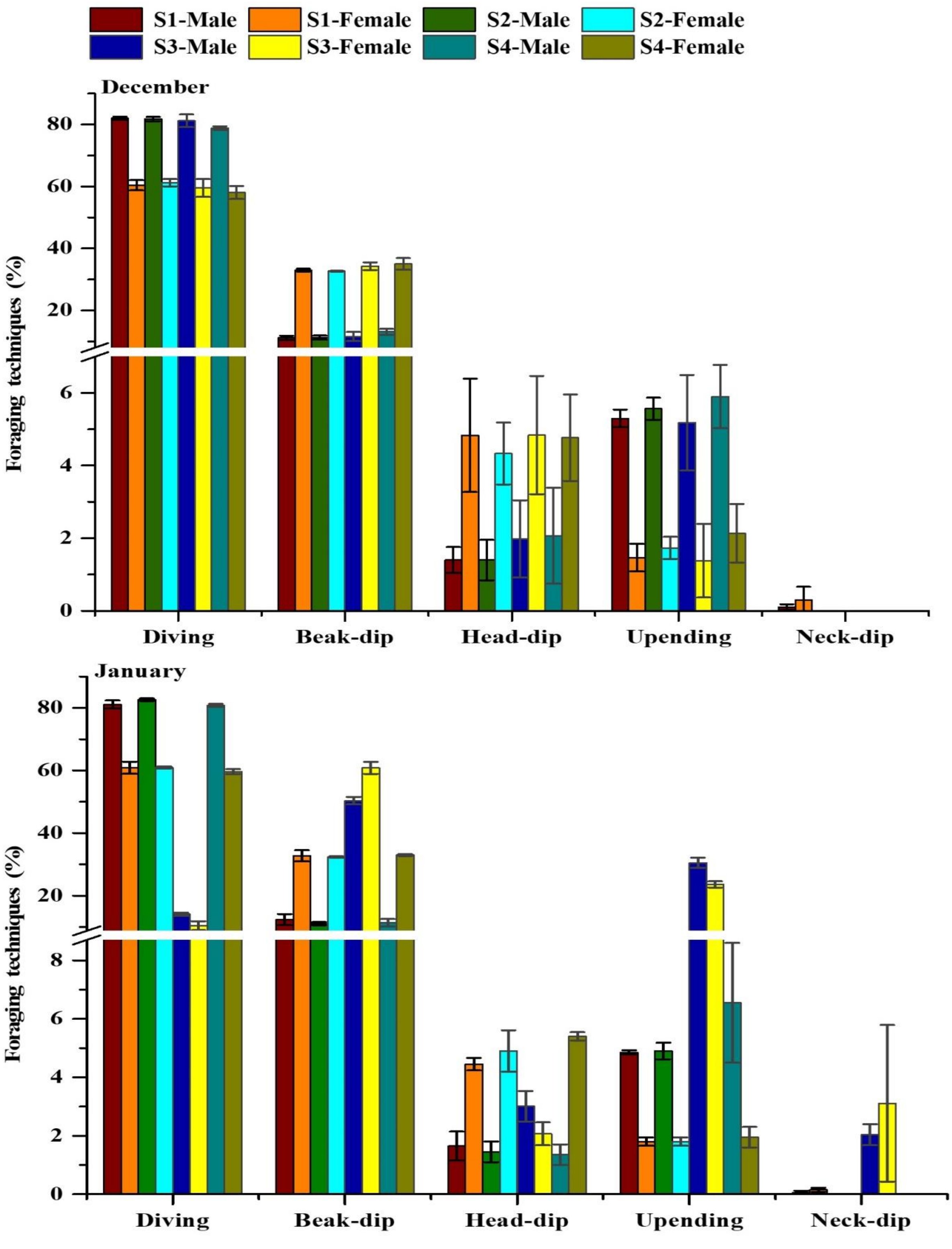


Fig. 9.3 Comparison of aggregated proportional time budget (values in percentages of time spent) in diurnal foraging activities of male and female RCPO in January and December; deep water condition prevailed in both December and January at Site 1, 2 and 4 while shallow water condition prevailed at Site 3 in January.

Chapter 10

Genetic distance & foraging behaviour

10 GENETIC DISTANCE & FORAGING BEHAVIOUR

Ecological and phylogenetic affinity of avian species that shape their co-occurrence patterns at spatial scales remains ill explored (Smith, 2011; Barnagaud et al., 2014). Several studies support for an extension of the tropical niche conservatism hypothesis to incorporate ecological and life-history traits beyond the climatic niche (Gaston and Blackburn, 2000; Hawkins et al., 2003; Wiens and Donoghue, 2004; Dehling et al., 2014). Morphological and physiological constraints are playing key role in shaping the foraging guilds in migratory wintering waterfowl in tropical wetlands (Chatterjee et al., 2020). Olsen (2017) points out that feeding ecology is a significant and primary driver of beak shape diversification in waterfowl. Although many descriptive studies of foraging behaviour have been made, the factors that underlie the evolution of foraging mode remain poorly understood. The morphological, ecological, and physiological correlates of foraging behaviour have received considerable attention, as has the possibility that foraging habitats and techniques are the product of correlated evolution as part of a behavioural syndrome (Sih et al., 2004; Johnson et al., 2008).

Winter migrant guilds are composed of species that use similar resources (food and nutrition) within a defined physical habitat in a comparable manner (Chatterjee et al., 2020). Differences in foraging habitat use, feeding techniques, food preferences and time of foraging play crucial roles in resource partitioning in these birds (Polla Baiocco et al., 2018). Moreover, according to Optimal Foraging Technique (OFT) by Pyke et al. (1977), diet selection, habitat choice, time allocation and movement patterns are the four major aspects for optimal foraging. Therefore, resource exploitation from different areas of the same aquatic habitat is the key to stable co-existence. For this to be successful, specialized foraging technique and major time investment behind that particular technique compared to others are of prime importance (Eadie et al., 1979; Guillemain et al., 2002). Such behaviour will enable a waterfowl species to obtain optimum food resources from a particular part of the habitat. This behavioural specialization could be a resultant of evolutionary force to a direction (Barnagaud et al., 2014). Such information on ducks, swans and geese suggest that these waterfowl might have diversified during the Miocene (23–25 Ma ago) reaching northern distributions in Holarctic and Afrotropical regions (Gonzalez et al., 2009). Present work records the foraging habitats and techniques of five waterfowl species of the family Anatidae to focus on the divergence based on the foraging behaviour as a consequence of evolution. Gonzalez et al. (2009) reports the phylogenetic relationships in Anatidae based on two mitochondrial genes and hybridization patterns. Mitochondrial genomic DNA has been widely used for phylogenetic analysis due to its rapid evolution and accurate tracking property (Moore, 1995). The mt-genome sequences of the birds used in the present study are reported by Sun et al. (2017). Johnsgard (1961) commented that utilization of waterfowl behaviour was primarily at the tribal and generic levels, and no real attempt was made to use behaviour for determining intra-generic relationships. The purpose of this paper is, therefore, to provide a more detailed set of behavioural definitions for five Anatid waterfowls and to suggest generic relationships in the light of genetic distances.

This study has been carried out to meet the following objectives: (1) to determine the foraging habitats and foraging techniques of five wintering Anatidae waterfowl (2) to construct phylogenetic tree of the birds based on mitochondrial genomic DNA (3) to determine the genetic distances between these five waterfowl species to highlight the similarity and dissimilarity in foraging behaviour of these nonbreeding waterfowl.

10.1 Results

10.1.1 Preferences of foraging habitats

Five species used different foraging habitats in different proportions within a wetland (Fig. 10.1). LWDU population (82.4±6.1) primarily used SLHV as their foraging habitat. Subsequent frequently used foraging habitats of LWDU were SWFV (8.8±1.2) and SWCS (7.0±1.3). Deep water areas (>1.5 m) of the wetlands were rarely used by this species. However, high percentage of TUDU (76.3±5.6), COPO (74.6±4.8) and RCPO (68.3±3.3) populations showed high preference for DWCS. However, a decent percentage of RCPO population also used the SWCS (14.4±2.4) habitat. High percentage of NOPI population showed preference for SWFV (58.6±4.9) followed by DWFV (19.3±3.1).

10.1.2 Time allocation for different foraging techniques

Study on time allocation for different foraging techniques by species populations showed a pattern of predominant foraging technique for each species population (Fig. 10.2). LWDU used all the eight foraging techniques observed during the study. Percentage of time allocated for HD (28.1±4.66) was highest in case of LWDU, followed by DI (17.0±2.78) and PI (13.9±2.73). In case of NOPI, percentage of time allocated for UP (52.8±4.94) was highest. However, TUDU (83.9±4.55) COPO (83.2±4.24) and RCPO (69.9±5.08) used DI as the most frequent foraging techniques. However, RCPO also used BD quite more frequently (23.1±5.67) than other two specialist divers, TUDU (2.1±0.83) and COPO (3.6±1.85). Species pairwise post hoc analyses significantly highlighted the differences between foraging techniques employed by these Anatidae birds (Table 10.1). Except COPO – TUDU, diving (DI) was significantly different for all other pairs. UP, HD, FI and GR in NOPI, on the other hand, were significantly different from other four waterfowls studied. Likewise, HD, FI, PI and GR in LWDU were significantly different from these techniques used by other species. Interestingly, when compared between RCPO, TUDU and COPO, they were not significantly different in using most of the feeding techniques. The projections in CCA plots were constructed using the data obtained on site-wise foraging habitats and techniques used by the waterfowl species (Fig. 10.3). CCA clearly demarcated the foraging preferences between three prominent clusters of waterfowl species under study. LWDU preferred SLHV as the foraging habitat and GR, HD and ND as foraging techniques. NOPI, on the hand, preferred both SWFV and DWFV as foraging habitats with larger preference for SWFV and depended mainly on UP, FI and BD as foraging techniques. Third cluster contained TUDU, COPO and RCPO; they preferred DI as the main foraging technique while RCPO also depended on BD and UP when in DWFV or SWFV.

10.1.3 Alignment of mitochondrial genome

From the pairwise alignment of entire mt-DNA of the target species using the Clustalw webserver, we found that the LWDU (NC_012844.1) is the least similar with any other species compared to other pairs. Considering the other pairs, it can be noted that, RCPO (genus *Netta*) scores higher with the *Aythya* spp. (TUDU and COPO) than with NOPI (genus *Anas*). (Table 10.2)

10.1.4 Molecular Phylogeny of the study-birds

The phylogenetic tree constructed with MEGA X software of mt-DNA genomes of six bird species resulted in a topology where LWDU branched apart early in the evolution and the other species clustered in another group (Fig. 10.4). Afterwards, NOPI, RCPO and *Aythya* spp. branched off serially.

10.1.5 Genetic distance between the waterfowls

Pair-wise genetic distances between the species calculated by the software are presented in the Table 10.3. The distance between LWDU and any other species ranged between0.1667 (COPO) and 0.1782 (RCPO), which is the highest among the distances between any other species. Lowest genetic distance was obtained between TUDU and COPO (0.0347). The genetic distance between NOPI and *Aythya* spp. (NOPI and TUDU: 0.0951; NOPI and COPO: 0.0994) was greater than that of RCPO and *Aythya* spp. (RCPO and TUDU: 0.0678; RCPO and COPO: 0.0666).

10.1.6 Correlation between genetic distance and similarity in foraging techniques

It was hypothesized that; birds tend to share the same feeding techniques with their close relatives (in terms of genetic distance). For this analysis we took two most predominant feeding techniques (namely, DI and UP) and the birds that are specialist in those techniques (Fig. 10.5). Significant Pearson correlation coefficient ($p < 0.01$) between genetic distance and time allocation for diving (DI) was 0.899 and upending (UP) was 0.876. If the coefficient values lie between ± 0.50 and ± 1, then it is said to be a strong correlation (Mukaka, 2012). The obtained results depict that genetic distance and time allocation for particular foraging technique have a strong positive linear correlation.

10.2 Discussion

Five waterfowl species under Anatidae exploited resources by means of various foraging techniques from various areas and depths of the wetlands under study. LWDU used all the eight recorded foraging techniques. This generalised nature of foraging technique of LWDU was also recorded by Chatterjee et al. (2020). TUDU and COPO showed more specialist nature of feeding as percentage of time allocated for a particular feeding technique (DI) were exceedingly high. NOPI was specialist in foraging at SWFV & DWFV with UP and FI techniques. RCPO was also a generalist so far as habitats and techniques are concerned. They were comfortable in DI at deeper waters while in using BD and UP in shallow waters. De Leeuw et al., 1999; Sutherland 2009; Pecsics et al., 2017; Chatterjee et al., 2020 recorded similar foraging behaviours in case of these species. CCA plots strongly suggested that different waterbird species were dependent on significantly different foraging habitats and techniques for collecting foraging resources. The projections in CCA plot generalized foraging techniques employed by LWDU population; RCPO, although had significant preference for DI, yet they showed potentials to utilize different techniques in different depths of the water. NOPI, TUDU and COPO more specialized foraging habitats and techniques.

Eadie et al. (1979), Guillemain et al. (2002), Schneider et al. (2014) and Osborn et al. (2017) pointed out that species compositions in waterfowl community could be attributed to differential macrohabitat utilization and foraging behaviour by the way of differential use of resources. In our findings we observed a clear pattern of specializing a particular foraging technique and using a particular foraging habitat by individual species during evolution. At the very beginning, LWDU and/or its recent ancestor could use all the techniques of foraging with more or less similar frequency to exploit all available resources. With rapid divergence and increasing rate of speciation, the number of inhabitants in the same water body increased, leading to the behavioural dominance on particular technique and resource partitioning. This might reduce the interference competition and interspecific conflict for resources and support stable co-existence. Similar kind of observation was reported by Rychilk and Zwolak (2005), where the shrews showed behavioural differences to avoid conflict between similar species and enhance stable co-existence. Beak dip technique was executed by both NOPI and RCPO, but BD is not a specialized feeding technique for any of them. This could be an auxiliary feeding technique, which, as being shared by a genetically distant co-inhabitant, has not been further selected to be a predominant one in any of them. Moreover, time invested for BD was more or less similar in LWDU, NOPI and RCPO, which further emphasized on our hypothesis.

The analysis of avian community by Brandl et al. (1994) and Katrin and Reik (1999) emphasized a correlation between phylogenetic contrasts and foraging preferences. Barnagaud et al. (2014) reported a novel species-oriented perspective on how biogeographic and evolutionary legacies interact with ecological traits to shape patterns of species coexistence in birds. The diversity of foraging behaviour, precisely preference for habitats and techniques, was strongly morphology-mediated and helped to structure the wintering waterfowl community (Olsen, 2017; Chatterjee et al., 2020). Present work studied the evolution of preference for foraging habitats and foraging techniques in Anatidae waterfowls using a cladistic phylogenetic analysis; the interspecific phylogenetic distances were calculated as the number of nodes connecting each pair of species. This approach reflected plausible evidence of divergence of foraging behaviour with that of phylogenetic relations. The molecular phylogenetic tree, constructed from mt-genome analysis, clearly showed that LWDU diverged from their common ancestor long before the other species did. Sun et al. (2017) reported the similar observation along with the probable divergence time, which indicated this branching off happened in the late Eocene (37.3 Ma), whereas, the genera Anas and Aythya -Netta diverged more recently, i.e. 10.2 and 6.7 Ma respectively. The genetic distance between the bird species also supported this theory. Therefore, it can be said that LWDU diverged long before from their common ancestors in the course of evolution. COPO and TUDU branched apart at the very end of this evolutionary history. Another interesting finding from this work is the phylogenetic position of RCPO. The RCPO, a Palearctic migrant species, is considered as a link between dabbling ducks (Anatinae) and pochards (Aythyinae), hence an interesting species from the phylogenetic point of view (Livezey 1986, 1996; Johnson and Sorenson 1999). However, foraging behaviour too was also interesting to attest their phylogenetic position between divers and dabblers. RCPO used the DI technique less frequently than *Aythya* spp. However, they invested high percentage of time in BD like other dabbler (NOPI).

Mode and mechanism of speciation is thought to be important for ecological adaptation. Many speciation proceedings showed that factors like accessibility of new resources or habitats or key innovation that endorse exploitation of new resources or habitats, promoted such rapid radiation in both terrestrial and lacustrine ecosystems (Sun et al., 2017). Considering this theory, our study can provide valuable insight as different foraging techniques may strengthen the adaptive characters in different waterfowls which may contribute to speciation.

This interpretation led us to think that, the genetic difference might be a silent driving force behind the niche separation by means of foraging techniques among birds, as similar observation was reported by Clay et al (2019). Although at a very basic level, our study supported this hypothesis with the strong positive correlation between genetic distance and time allocation for particular foraging technique. With the increase in genetic distance, birds tend to diverge behaviourally. However, waterfowls display similar foraging behaviour and share the same niche with their genetically close relatives. This finding creates an opportunity for further research on this hypothesis.

10.3 Conclusion

This is a pioneer study which suggests that the foraging techniques in waterfowls has evolved as a mechanism of resource partitioning within a habitat. Waterfowls share the same foraging habitats and foraging techniques, or in other words, the same 'guild' with genetically closer relatives. All the techniques were initially used by the most ancient species and eventually the more recent species specialized on any of those techniques. Understanding habitat selection and activities of waterfowl during the non-breeding period is important for directed habitat management on national wildlife refuges and in other wetlands important in meeting regional waterfowl conservation objectives. In the Indian context, waterfowl migrate southwards along Central Asia/South Asia Flyway (CAF/SAF) and East Asian-Australasian Flyway (EAAF) for foraging and resting in tropical areas during the winter months. In the wintering season, both resident and palearctic migrants use the wetlands of West Bengal as their foraging or staging grounds, therefore, the present study would be important to manage around 42.0 sq. km natural waterfowl habitats of this eastern State of India (West Bengal-India Water Portal; www.indiawaterportal.org › regions › west-bengal).

Table 10.1 Post hoc analysis showing the difference in foraging techniques employed by the waterbirds. Significant differences are denoted by red colour.

DI	LWDU			
RCPO	0.000126	RCPO		
TUDU	0.000126	0.000126	TUDU	
COPO	0.000126	0.000126	0.997564	COPO
NOPI	0.000126	0.000126	0.000126	0.000126

ND	LWDU			
RCPO	0.000126	RCPO		
TUDU	0.000641	0.067678	TUDU	
COPO	0.001141	0.039997	0.999422	COPO
NOPI	0.889557	0.000127	0.007093	0.012878

UP	LWDU			
RCPO	0.644476	RCPO		
TUDU	0.200952	0.920280	TUDU	
COPO	0.999984	0.700441	0.236611	COPO
NOPI	0.000126	0.000126	0.000126	0.000126

FI	LWDU			
RCPO	0.000154	RCPO		
TUDU	0.000154	1.000000	TUDU	
COPO	0.000154	1.000000	1.000000	COPO
NOPI	0.000126	0.000126	0.000126	0.000126

HD	LWDU			
RCPO	0.000126	RCPO		
TUDU	0.000126	0.040545	TUDU	
COPO	0.000126	0.969387	0.008365	COPO
NOPI	0.000126	0.000127	0.008365	0.000126

PI	LWDU			
RCPO	0.000126	RCPO		
TUDU	0.000126	0.713878	TUDU	
COPO	0.000126	0.107037	0.713878	COPO
NOPI	0.000126	0.518987	0.997765	0.875761

BD	LWDU			
RCPO	0.000126	RCPO		
TUDU	0.000156	0.000126	TUDU	
COPO	0.000692	0.000126	0.886069	COPO
NOPI	0.733743	0.000128	0.000126	0.000137

GR	LWDU			
RCPO	0.000126	RCPO		
TUDU	0.000126	1.000000	TUDU	
COPO	0.000126	1.000000	1.000000	COPO
NOPI	0.000126	0.000126	0.000126	0.000126

Table 10.2 Clustalw pair-wise alignment score between the mt-genome sequences.

	TUDU	COPO	RCPO	LWDU
NOPI	89.9934	89.6078	84.5834	56.6721
TUDU		96.1904	92.5193	59.3464
COPO			92.7299	59.6955
RCPO				58.9594

Table 10.3 Pair-wise Genetic distances with standard error (SE) as calculated by MEGA X

Species	**GENETIC DISTANCE±SE**			
	NOPI	**RCPO**	**TUDU**	**COPO**
LWDU	0.1732±0.0040	0.1782±0.0039	0.171±0.0039	0.1667±0.0039
NOPI		0.1122±0.0028	0.0951±0.0025	0.0994±0.0027
RCPO			0.0678±0.0021	0.0666±0.0022
TUDU				0.0347±0.0015

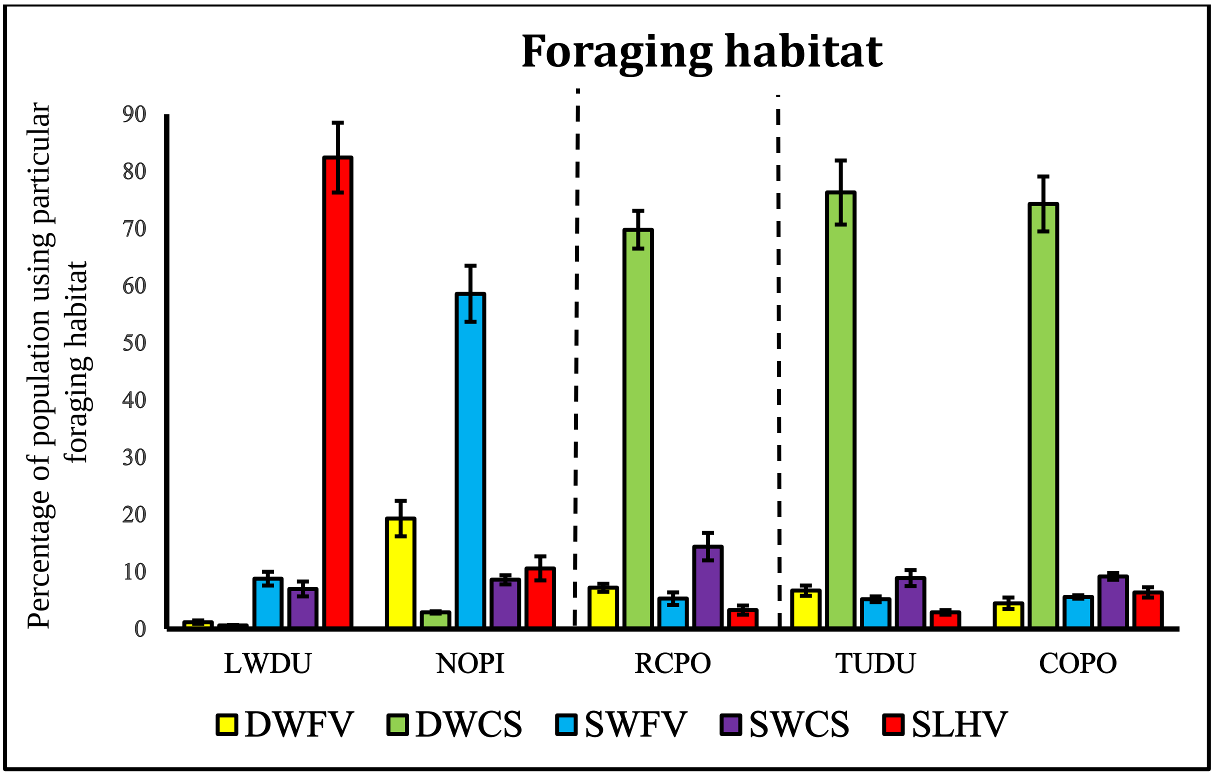


Fig. 10.1 Percentage population of five waterfowl using specific foraging habitat in selected wetlands (DWFV: Deep water with floating vegetation; DWCS: Deep water with clear surface; SWFV: Shallow water with floating vegetation; SWCS: Shallow water with clear surface; SLHV: Shoreline with hydrophytic vegetation)

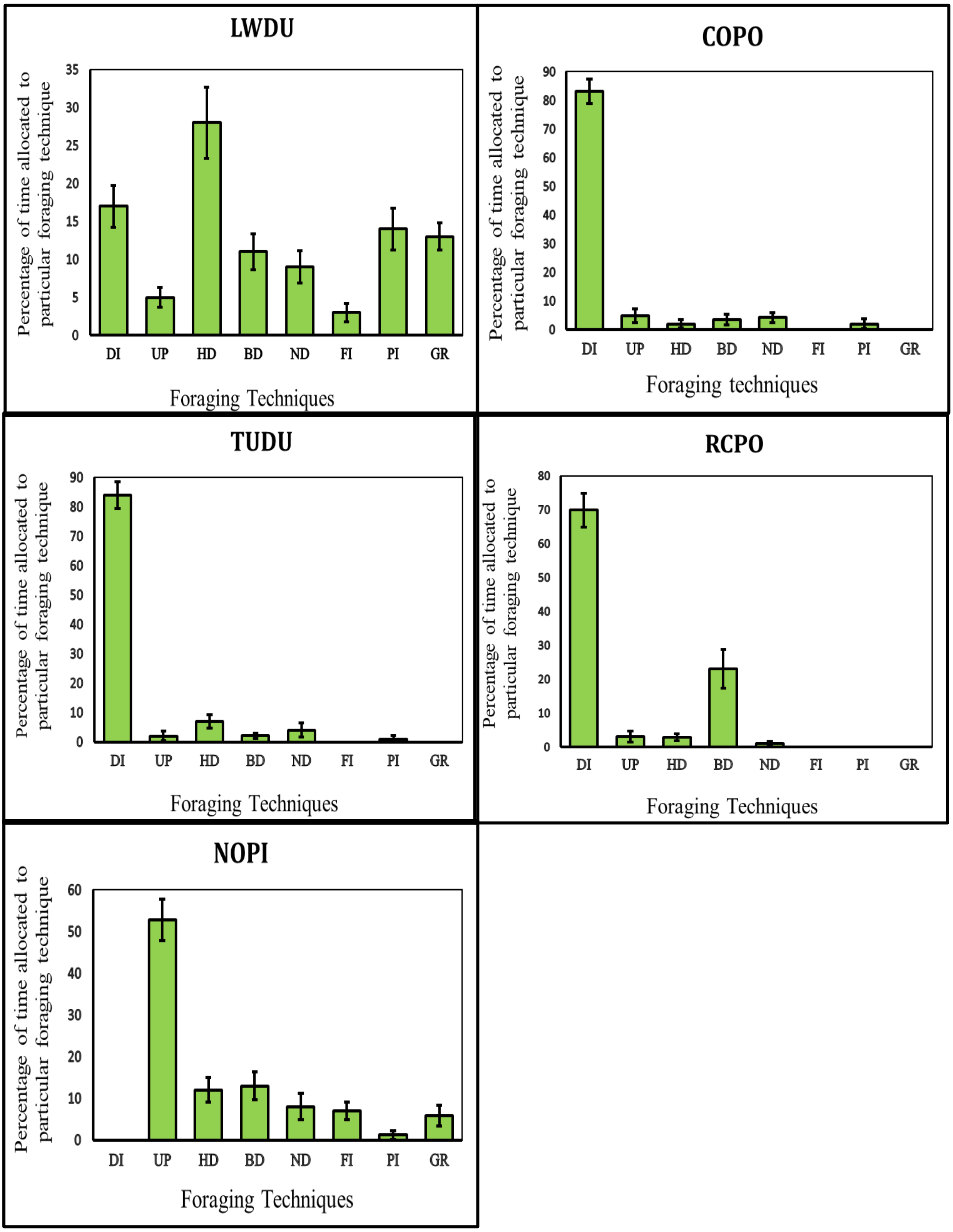


Fig. 10.2 Percentage of time allocated for different foraging techniques by five waterbirds (DI: Diving, UP: Upending, HD: Head-dip, BD: Beak-dip, ND: Neck-dip, FI: Filtering, PI: Picking, GR: Grazing)

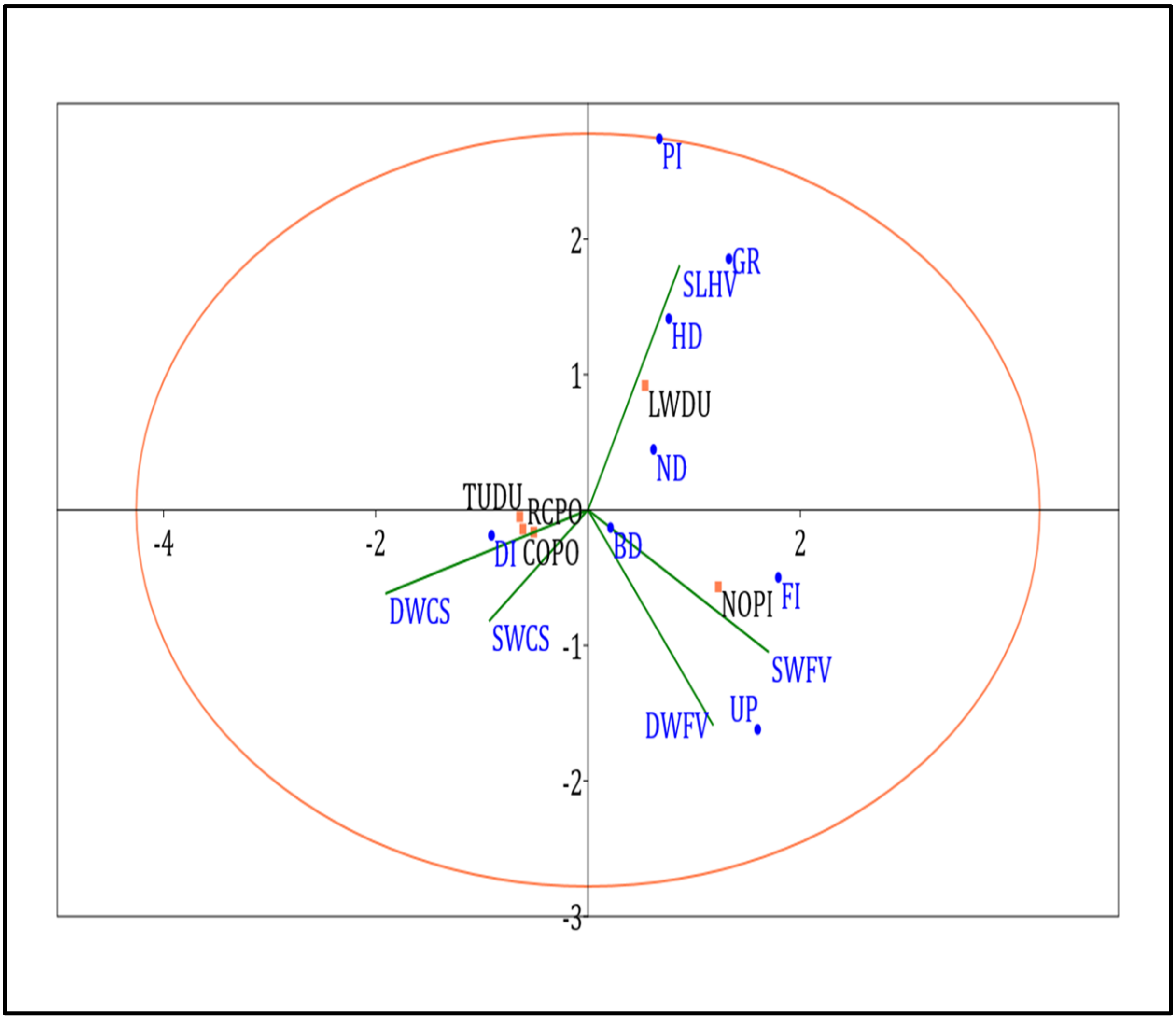


Fig. 10.3 CCA results showing the preferences of foraging habitats and foraging techniques of the five Anatidae waterfowl.

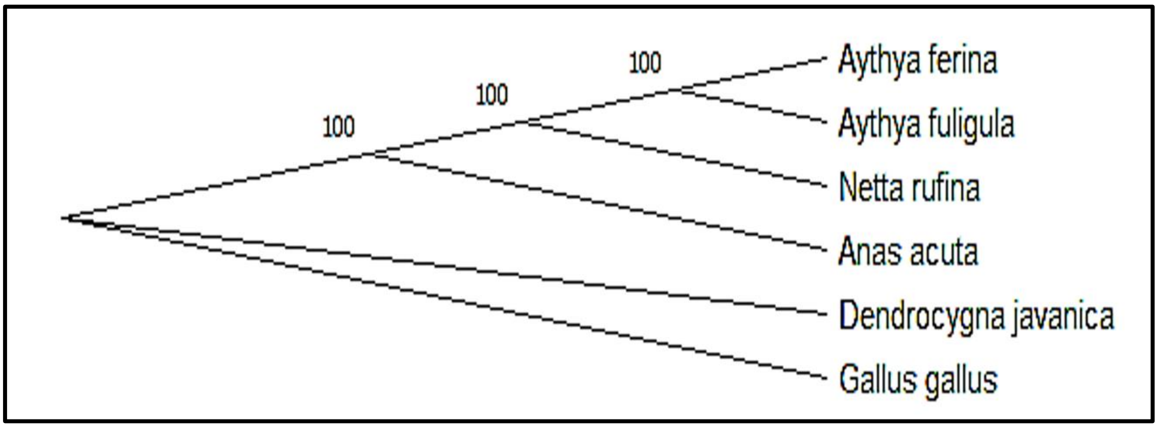
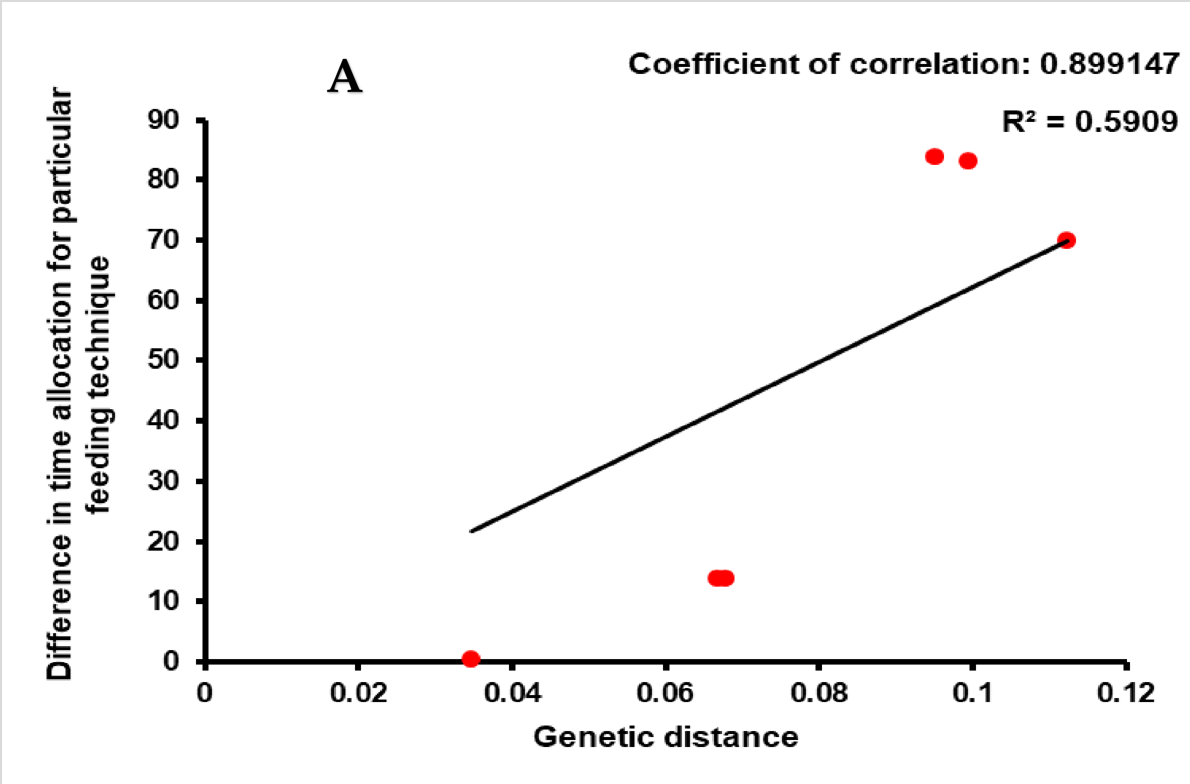


Fig. 10.4 Phylogenetic tree constructed with MEGA X software using Maximum-likelihood (ML) method. Each branching depicts the divergence of a new species. The branch support values are 100, which means branches are reliable.



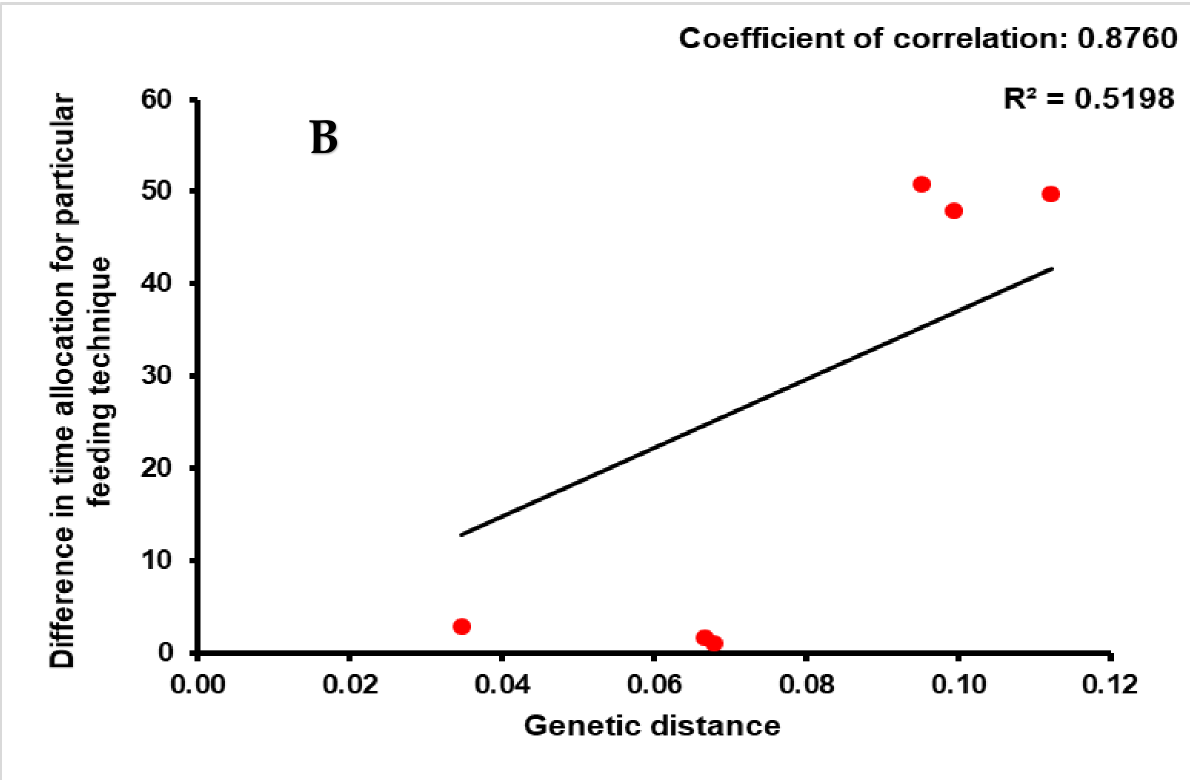


Fig. 10.5 Correlation between genetic distance and time allocation for diving (A) and upending (B). Coefficient of correlations are 0.899 and 0.876 respectively. R^2 represents the coefficient of determination. Data points are represented with red dots.

Chapter 11

Conclusion and synthesis

11. CONCLUSION AND SYNTHESIS

The present study was initiated to address the following major areas, a) ecosystem services rendered by the wetlands under study, b) physico-chemical conditions of selected wetland habitats used as wintering sites by waterbirds and changes in physico-chemical conditions due to anthropogenic interferences, c) quantification, distribution and spatio-temporal variations of waterbirds in study sites. d) foraging guild, niche characteristics and time-activity budget of both migratory and resident waterbirds. Detailed study of waterbird community structure and habitat quality in four important wetlands of the Bankura and Purulia districts would surely provide important information to conserve wintering habitats of these two districts of West Bengal. Moreover, a spatial beta-diversity study was also conducted to highlight the differences in habitat quality between wintering wetland habitats situated in the northern and southern districts of West Bengal.

Widespread wetland habitat alterations and fragmentations had significant effects on waterbirds throughout West Bengal thus conservation of suitable habitats for wintering migratory waterbirds on the CAF and EAAF needs a thorough understanding of the characteristics of physical habitats and the avian community attributes. 13 wetlands located on varied physiographic features and climatic heterogeneity along the north-south and east-west axes of the state of West Bengal were selected to study the effect of physical habitat attributes on waterbird community structure on mid-winter. A total of 117 species of birds belonging to 21 families were recorded from thirteen study sites and contrasting community compositions were also recorded between the sites of northern and southern West Bengal. Present information on migratory waterbird richness, evenness and abundance would be important for the future conservation strategies at major wintering sites of West Bengal. Wetlands protected by difficulties in approaching due to remote locations or the state laws or by the way of controlled anthropogenic interferences, such as at Nararthali, Gajoldoba, Nilnirjon, and Purbasthali, could have benefitted in harbouring diverse migratory waterbirds. However, complete clearing of the water hyacinth or clearing operations at the onset of the migratory period might have an impact on the richness and abundance of waterbirds which was evident in Purulia Sahebbandh. Thus, aquatic macrophytes, especially the floating blanket of water hyacinth, should be scientifically managed to sustain wintering waterbirds. Effective landscape planning is also immediately necessary to encourage migratory waterbird diversity. **The** present study shows that along the length of the state of West Bengal there are a good number of natural wetland habitats important to shelter diverse waterbirds that migrate through CAF and EAAF.

In recent times habitat quality of many wetlands was either depleted or degraded mainly due to many anthropogenic activities including unplanned urbanization and wastewater loadings. This study was designed to assess the heavy metal exposure risk to a migratory herbivorous waterfowl, Northern Pintail, a widespread winter migratory species in Indian wetlands and two important age-old wintering grounds with the contrasting location were selected to identify the priority pollutants. The present work focused on the four metals, *viz*, Cr, Pb, Cu and Zn, as the nature of the industrial activities around the said wetlands and the outfall received by the site was predominantly concerned about these elements. The waterfowl population wintering in Purulia Sahebbandh is facing a high exposure risk of heavy metals due to its urban location makes it more prone to human interference in several ways including increased discharges of untreated wastewaters. Unwanted metal sources in wastewater are to be identified and curbed for sustainable use of the wetland and Cr, Pb and Cu were considered to be the priority pollutants in this habitat. The presented method can also be used for exposure risk assessment of other pollutants to other waterfowl species and risk management around important wintering waterfowl habitats of India. Assessment of possible sublethal effects of waste elements in waterfowl habitats, including different other stress factors in aquatic situations, demands further research. Species, trophic position and foraging behaviour are important factors to determine toxicity due to heavy metals in waterfowl habitats. Future studies can consider detailed food composition of herbivore, piscivore and omnivore waterfowl and to include other toxic, yet not-so-uncommon heavy metals like Cd, As and Hg in urban wastewaters.

Four wetlands of the Bankura and Purulia districts are selected for the long-term study on the effect of bird colonization on the overall physico-chemical milieu of habitats. In these sites, the number of species varied from 37 to 61 during the study tenure. It is noteworthy that, a sharp decrease in the abundance of waterbirds from 2018-2019 to 2019-2020, and is prominent in Purulia Sahebbandh. Waterbirds play important role in nutrient cycling by the way of guanotrophy as guano is rich in nitrate and phosphate. Higher nutrient levels in wetlands could influence the growth of aquatic biota, which serve as a major food base for the waterbirds. Moreover, bird droppings also help to encourage the growth of the phytoplankton community, hydrophytes, micro and macroinvertebrates, benthic organisms, and fish. Avian guanotrophy in the waterbird wintering season conceivably sustained the nutrient prerequisite of the present study sites for the rest of the year. In these freshwater wetlands for phosphate and nitrate enrichments wintering waterbirds play an important role, mainly by the herbivore waterbirds followed by the carnivores. However, excess guano loading by large congregating flocks of waterbirds can lead to eutrophication in small wetlands. Therefore, the management of the wetland ecosystem, harbouring winter migratory birds, depend on the delicate balance of two factors, namely the effects of waterbirds on nutrient replenishment and the sustainability of habitats to invite the wintering waterbird guests. Besides that, one critically endangered species, three vulnerable and one near threatened species are recorded from these wetlands point out the importance of these gainful habitats from a conservation perspective.

Besides habitat attributes, inter and intra-specific interactions also play crucial roles in structuring communities in a habitat. Therefore, wetland management must be based on region-specific knowledge about waterbird communities, including the species composition and foraging preferences of the birds, especially in the wetlands that are important staging and wintering sites. Trophic guild structure and niche organization of 12 resident and migratory waterbirds in four wetlands has been studied during the present work. Besides that, a diurnal time-activity budget of those birds is also considered. In diurnal hours, the maximum percentage of time is allotted to resting by most of the migratory waterbirds except GCGR. It is also recorded that percentages of time allotted to feeding activities by four resident birds (LIGR, CPGO, EUCO, LWDU) and one migrant (GCGR) are comparatively evenly distributed throughout the day and slightly higher in the morning and evening time. Foraging guilds are constructed based on two dimensions i.e., foraging habitat and foraging techniques and five foraging habitats and eight foraging techniques highlight the niche sharing and partitioning by resident and migratory species during wintering months. The waterbirds are identified as four separate guilds: shallow water generalists, predominantly shallow water dabblers, predominantly divers, and specialist divers. It is interesting to point out that each guild comprises one resident bird along with other migratory birds during habitat-sharing wintering periods. Therefore, temporal resource partitioning between the resident and migratory waterbirds is evidently a major outcome of this work that portrays the sustainable resource utilization. Therefore, the quantum of time apportioned for different activities is critically important to understand the demands for specific resources and also to identify the challenges the waterbirds may face in wintering habitats. Foraging habitat requirements and/or foraging techniques vary between waterbird species, more specifically between different foraging guilds. This work suggests resource partitioning in waterbird species could depend on differences in time-activity and foraging behaviuor to cope with different niche dimensions.

My study attests that the foraging techniques in waterfowls has evolved as a mechanism of resource partitioning within a habitat. Five waterfowls were selected for the present study and basing on their genetic distances a phylogenetic tree is constructed. It is evident that waterfowls share the same foraging habitats and foraging techniques, or in other words, the same 'guild' with genetically closer relatives. All the techniques are initially used by the most ancient species like LWDU and eventually the more recent species specialized on any of those techniques. Understanding habitat selection and activities of waterfowl during the non-breeding period is important for directed habitat management on national wildlife refuges and in other wetlands important in meeting regional waterfowl conservation objectives. In the wintering season, both resident and palearctic migrants use the wetlands of West Bengal as their foraging or staging grounds, therefore, the present study would be important to manage around 42.0 sq. km natural waterfowl habitats of this eastern State of India.

My work points out that the physical habitat attributes of wetlands influence the community composition of wintering waterbirds. Study sites are within five physiographic regions of West Bengal and five sites are in northern West Bengal, while the rest are in southern West Bengal. Thereby, an overall picture regarding the diversity and habitat uses by resident and migratory waterbird species is dealt with. Future studies could focus on selecting more wetlands from each of the nine physiographic regions of West Bengal which will depict a more comprehensive picture of species turnover in wintering and staging habitats along EAAF and CAF. Furthermore, a continuance of this work over years could aid researchers to comment on patchy distribution in light of island biogeography, considering the profitability of the patches. In another experiment, a heavy metal risk exposure model is applied to a herbivorous bird, Northern Pintail; besides, such a non-invasive exposure risk method could also be applied to birds other than a herbivore. In this model, only ingestion is considered as the potent source of metal accumulation in waterbirds. Future studies could consider other two potent pathways of heavy metal toxicity, namely dermal contact and inhalation. Furthermore, metals other than Cu, Zn, Pb, Cr could be considered in risk exposure calculations. In the context of waterbirds' contribution to the ambient environment, I focus on guano loading and nutrient enrichment by guano input. In these freshwater wetlands for phosphate and nitrate enrichments wintering waterbirds' guano is helpful to sustain the overall biota of habitat. However, excess guano loading by a too-heavy waterbird congregation could also lead to eutrophication. Process-based modelling approaches could depict the nutrient dynamics of these freshwater ecosystems more precisely. Lastly, in the time-activity budget and foraging guild construction considered a limited number of residents/local migratory and long-distance migrant species; while by increasing the number of species and the tenure of study, one can minimize the errors in the ad-libitum study. Moreover, a two-dimensional foraging guild based on foraging habitat and techniques could be advanced to a three-dimensional guild by taking the time of foraging as another dimension and this indeed could open new vistas of resource partitioning study.

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Publications

PAPERS PUBLISHED AND COMMUNICATED

Journal Publications

1. Mukherjee A, Pal S, Das P, Mukhopadhyay SK. (2022). Heavy metal exposure to a migratory waterfowl, Northern Pintail (Anas acuta), in two peri-urban wetlands. **Science of the Total Environment**. 851: 158238. http://:dx.doi.org/10.1016/j.scitotenv.2022.158238. (IF: 10.753; H-index: 275)
2. Mukherjee A, Pal S, Adhikari S, Mukhopadhyay SK. (2022). Physical habitat attributes influence diversity and turnover of waterbirds wintering at wetlands on Central Asian and East Asian-Australasian Flyways in Eastern India. **Wetlands**. 42: 50. http://dx.doi.org/10.1007/s13157-022-01559-1. (IF: 2.074; H-index: 92)
3. Mukherjee A, Pal S, Das P, Mukhopadhyay SK. (2021). Mid-winter diversity of waterbirds in West Bengal, India. **Journal of Bombay Natural History Society.** 118. http://dx.doi.org/10.17087/jbnhs/2021/v118/147142. (H-index: 7)
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5. Mukherjee A, Pal S, Mukhopadhyay SK. (2020) Diurnal time activity budget and foraging techniques of red crested pochard (*Netta rufina*), wintering at wetlands of West Bengal, India. **Turkish Journal of Zoology**. https://doi.org/10.3906/zoo-2003-23. (IF: 0.932; H-index: 30)

Seminar publications

1. Mukherjee A, Pal S, Das P, Mukhopadhyay SK. (2022). Adverse limnological conditions of habitats affect wintering migratory waterbird diversity. **International Conference on Green Energy and Sustainable Environmental Technology** (15-16th September, 2022).
2. Mukherjee A, Mukhopadhyay SK. (2019). Foraging guilds of winter avian fauna of Kadamdeuli dam in Bankura district of West Bengal, India. **National seminar on Contemporary Era of Sciences: Biological and Chemical interface** (26-27th March, 2019).

Communicated papers (under review)

1. Mukherjee A, Pal S, Das P, Mukhopadhyay SK. Time activity budget and foraging behavior: Important determinants of resource sharing and guild structure in wintering waterbirds. Under review in **European Journal of Wildlife Research**.
2. Mukherjee A, Adhurya S, Pal S, Mukhopadhyay SK. Guanotrophy: Waterbirds pay for using resources at their wintering habitats. Under review in **Ornithological Applications**.

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