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Winged stewards of the rivers: A systematic review of avian ecosystem services in the Ganga River basin

Shuchismita DAS[1], Shivani BARTHWAL[2]*, Ruchi BADOLA[2] & Syed Ainul HUSSAIN[2]

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Abstract Birds are one of the prominent classes of vertebrates, occurring worldwide in nearly all habitat types, and providing a wide range of ecological functions, which in turn, generate a wide array of ecosystem services. While ornithological research on ecosystem services has become more prevalent, studies specifically focusing on the contributions of waterbirds in aquatic ecosystems have been largely overlooked.

We undertook a review of the ecosystem services provided by the waterbirds inhabiting the Ganga River, which is home to a wide variety of waterbirds that compete with the human-induced developments for habitat, and therefore, their survival is dependent on human understanding of their critical role within the ecosystem. The review highlighted that the waterbirds are efficacious bioindicators of different ecological conditions, control pests, maintain the diversity of other organisms, act as predators, herbivores, vectors of aquatic plants, invertebrates, and nutrients, and also play the role of ecosystem engineers. Furthermore, they provide cultural services to human society. Understanding the functional role of waterbirds, through natural history research, can inform conservation-oriented decision making by policymakers as well as public. The findings of this study would increase public support for the conservation of biodiversity in a holistic manner.

Keywords: waterbirds, ecosystem services, bioindicator, ecosystem engineer, seed dispersal, freshwater ecosystem

Összefoglalás A madarak a gerincesek egyik jelentős osztályát alkotják, világszerte csaknem minden élőhelytípusban előfordulnak, és számos ökológiai funkciót látnak el, amelyek révén sokféle ökoszisztéma-szolgáltatást nyújtanak. Bár az utóbbi időben egyre gyakoribbá váltak az ökoszisztéma-szolgáltatásokat vizsgáló ornitológiai kutatások, a vízimadarak szerepével, kifejezetten az édesvízi rendszerekben, továbbra is kevés tanulmány foglalkozik.

Tanulmányunkban áttekintettük a Gangesz folyó mentén élő vízimadárfauna által nyújtott ökoszisztéma-szolgáltatásokat. A térségben számos vízimadárfaj él, melyek élőhelyeit egyre inkább veszélyeztetik az emberi tevékenységek, így fennmaradásuk nagymértékben azon múlik, hogy az ember felismeri-e ökológiai jelentőségüket. Az áttekintés rávilágított arra, hogy a vízimadarak hatékony bioindikátorai a különféle ökológiai állapotoknak, szerepet játszanak a kártevők gyérítésében, más élőlények diverzitásának fenntartásában, továbbá ragadozóként, növényevőként, valamint vízi növények, gerinctelenek és tápanyagok terjesztőiként is funkcionálnak. Emellett ökoszisztéma-mérnök szerepet is betöltenek. A vízimadarak ezen túlmenően kulturális szolgáltatásokat is nyújtanak az emberi társadalom számára.

A vízimadarak funkcionális szerepének természetrajzi kutatásokon alapuló mélyebb megértése segítheti a természetvédelmi célú döntéshozatalt, mind a szakpolitikai szinten, mind a lakosság körében. Jelen tanulmány eredményei hozzájárulhatnak a biodiverzitás megőrzését célzó társadalmi támogatottság erősítéséhez, holisztikus szemléletben.

Kulcsszavak: vízimadarak, ökoszisztéma-szolgáltatások, bioindikátor, ökoszisztéma-mérnök, magterjesztés, édesvízi ökoszisztéma

[1] *Amity Institute of Forestry and Wildlife, Amity University, Sector-125, Noida 201313, Uttar Pradesh, India*
[2] *Wildlife Institute of India, Post Box # 18, Dehradun 248001, Uttarakhand, India*
* *corresponding author, e-mail: shivani.chandola@gmail.com*

Introduction

Birds are one of the most diverse groups of vertebrates, with more than 10,000 extant species distributed globally (BirdLife International 2004). They occupy an extensive range of ecological niches and range, and widely vary in size from the Ostrich *(Struthio camelus)* (~2.4–2.7 m) to the Cuban Bee Hummingbird *(Mellisuga helenae)* (~5.7 cm) (Pettingill 2013). Birds occupy almost all the ecosystems and have association with forest vegetation, agroecosystem, riverine habitat, grassland, and marine ecosystems, involving a wide range of feeding niches (Whelan *et al.* 2008, Wenny *et al.* 2011, Mariyappan *et al.* 2023). Being a diverse group occupying diverse habitats and niches the birds' diversity signifies environmental stability (Şekercioğlu 2006). They play an important role in biogeographical cycling, nutrient, and energy transfer; thus, they are critically important in regulating and supporting ecosystem services. Some of the services provided by the birds include pest control, seed dispersal, pollination, nutrient cycling, soil formation, waste management, and ecosystem engineering (Bock & Jones 2004, Şekercioğlu 2006, Whelan *et al.* 2008, Wenny *et al.* 2011, DeVault *et al.* 2016, Chain-Guadarrama *et al.* 2019, Díaz-Siefer *et al.* 2022, Valkó *et al.* 2022, Green *et al.* 2023).

With the growing concern to conserve natural ecosystems, it is becoming impertinent to document the avian ecological functions that sequentially bring about ecosystem services that are of immense value to human beings (Whelan *et al.* 2008, 2015).

The functions provided by birds and the methodologies to quantify their values are well-studied in terrestrial ecosystems (Bock & Jones 2004, Şekercioğlu *et al.* 2004, Şekercioğlu 2006, Whelan *et al.* 2008, Wenny *et al.* 2011, Karp *et al.* 2013, Lindell *et al.* 2018, Grilli *et al.* 2019, Chain-Guadarrama *et al.* 2019), but there is a lack of consolidated information for their role in aquatic ecosystems. Birds that are ecologically dependent on wetlands have been identified as 'waterbirds' by Ramsar Convention (Wetlands International 2012). They have many fascinating features in their biology that include long-distance migration, large congregation, colonial breeding and ground nesting. Though waterbirds are one of the best-studied groups of birds, from the view of ecosystem services, however, the studies focusing on their role are largely overlooked (Green & Figuerola 2005, Green & Elmberg 2014, Green *et al.* 2016, 2023, Sebastián-González *et al.* 2020).

Wide altitudinal range from sea level extending up to the summit pinnacle of the Himalayas, highly varied climate and corresponding diversified vegetation, and overlapping of three biogeographical provinces namely, the Indo-Malayan, Palearctic and Afrotropical realms, make the Indian subcontinent one of the unique hotspots for birds (Grimmett *et al.* 2014). Due to these features, three flyways namely, Central Asian, East Asian Australian, and Asian East African Flyway, pass through the Indian subcontinent. India is known to have about 243 species of waterbirds and 1,383 avian species in total (Avibase 2024), and has a strategic role in the Central Asian Flyway, as it provides critical stopover sites to over 90% of the bird species known to use this migratory route (MoEFCC 2018). The Ganga River basin in the Indian subcontinent harbors many of these important aquatic avian species. This basin is the largest and most diverse river basin in India, and encompasses five ecologically different biogeographical regions, namely, Himalayan, Semi-arid, Deccan Plateau, Gangetic Plains, and Coastal Region (Rodgers & Panwar 1988). Due to copious rainfall in the Gangetic plains and the Himalayas, this region comprises numerous floodplain wetlands, which are extremely productive in terms of vegetation biomass and avian diversity (Rawat 2004). Out of 467 Important Bird and Biodiversity Areas (IBAs), 12 are present here with significant populations of waterfowls (Islam & Rahmani 2004, BNHS-ENVIS 2021). Being an integral part of Central Asian Flyway, all these wetlands in the basin are not only the crucial habitat for resident breeders but also provide wintering ground to many migratory waterbirds. The Ganga basin has approximately 128 species including 52 species of migratory and 76 species of resident water- and water-associated birds, which are indicators of the health of the fragile riverine ecosystem (WII-GACMC 2018). According to the IUCN Red List of threatened species, 15 of these species are globally threatened, of which one is critically endangered, five are endangered and seven are vulnerable.

The Government of India's (GOI) initiative to restore the ecological and hydrological integrity of the Ganga River through its ambitious Namami Gange Program, with biodiversity as one of its thrust areas, calls for a comprehensive understanding of the role the avian species play in ecological functioning of the Ganga River and its surrounding areas. Understanding the functional role of waterbirds, through natural history research can aid in informed decision-making. Such studies would also increase public support for conservation of the waterbirds and their habitats, in a holistic manner. Thus, the aim of this paper is to review the aquatic avian ecology literature, congruent with the species found in the Ganga River area, to assess the ecosystem services generated from their functional role.

Material and Methods

This review focused on the ecosystem services provided by waterbirds. 128 species of waterbirds found in the Ganga River area have been restricted in the study. Peer-reviewed papers published from 1990 to 2024 were searched using the search engines of Google Scholar and Publish or Perish software (Harzing 2007). General search statistics are reported in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analysis) guidelines (Page *et al.* 2021) *(Figure 1)*. The keywords related to supporting and regulating services provided by birds through their functional roles were used for literature search. The Publish or Perish database was searched with a combination of keywords such as "Ecosystem services" and "waterbirds", which resulted in a total of 493 records. Functional roles of different waterbird species were also searched in the Google Scholar database to obtain species-wise information, which resulted in another 132 records. All these 625 publications were screened for repetitive articles, titles and abstracts to check the adequacy of the study's aim. The screening further reduced the number of articles to 174.

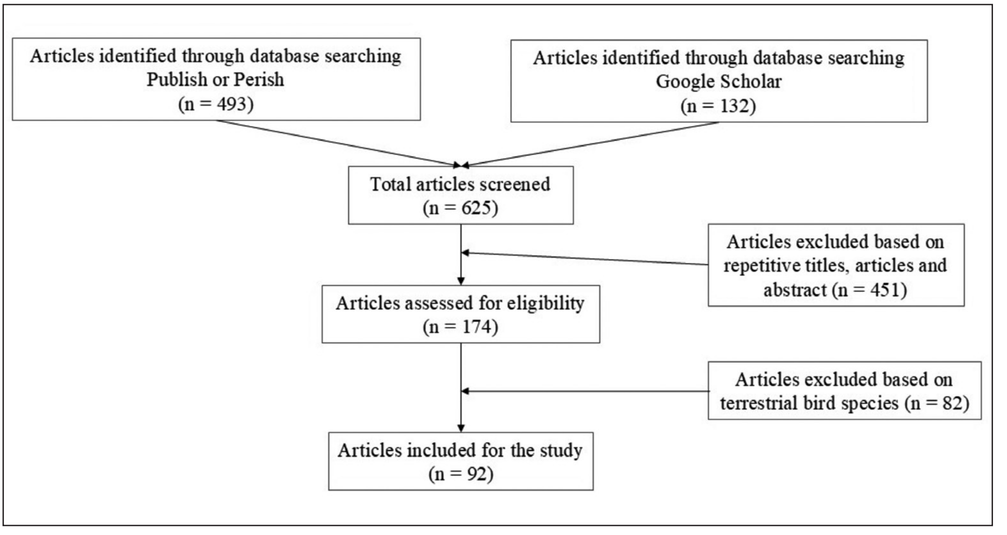

Figure 1. PRISMA flowchart summarizing the workflow adopted for this review
1. ábra Az áttekintő tanulmány munkafolyamatát összefoglaló PRISMA-folyamatábra

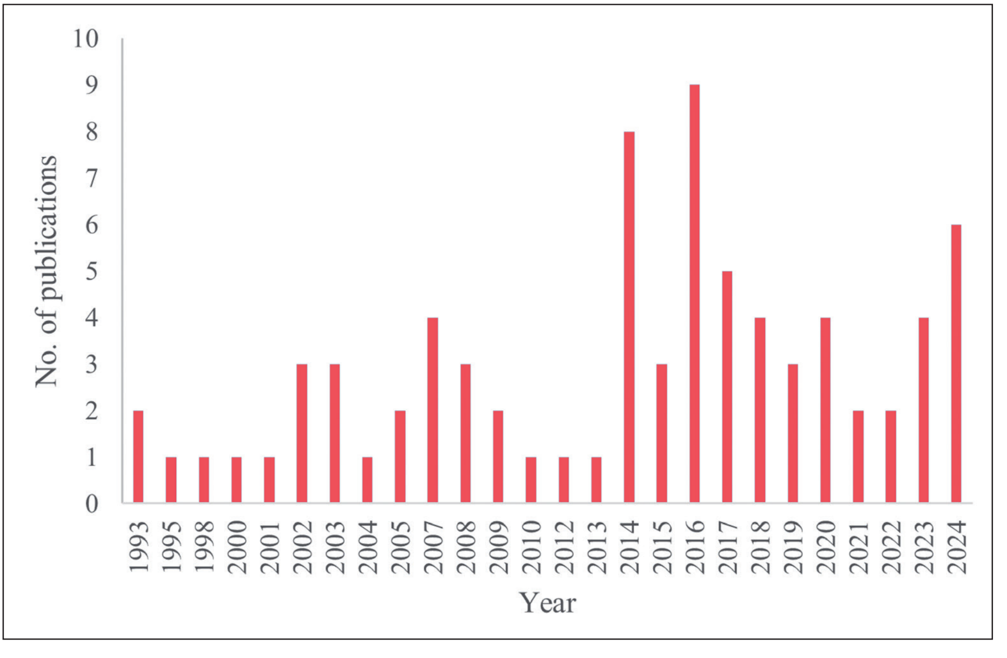

Figure 2. Number of publications on ecosystem services of waterbirds
2. ábra A vízimadarak ökoszisztéma-szolgáltatásait elemző cikkek száma

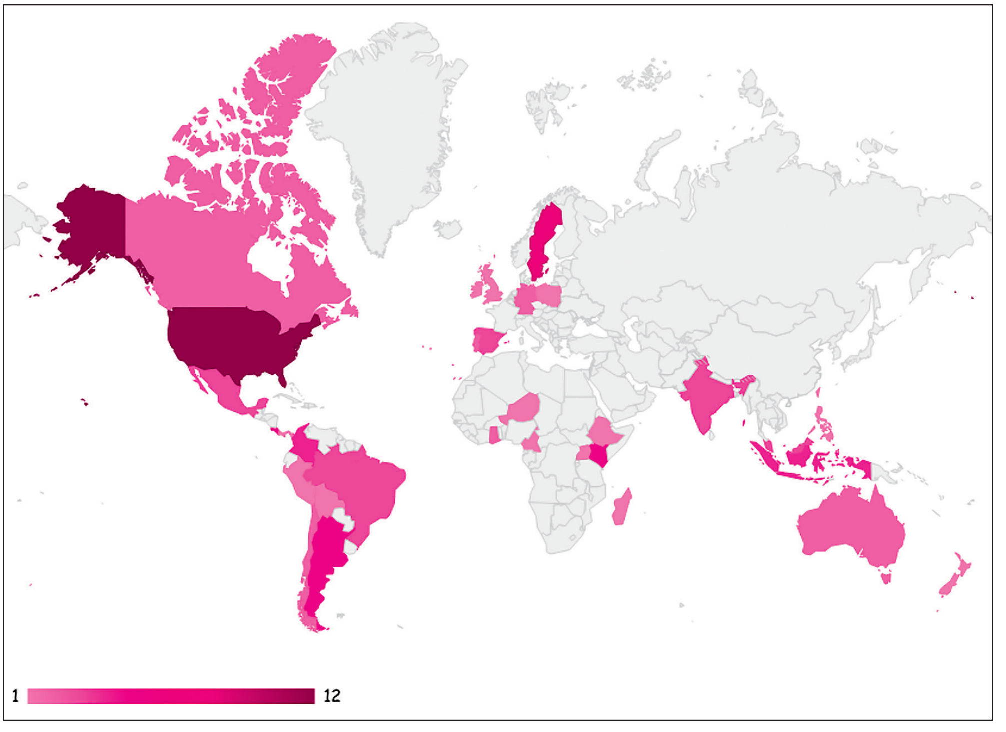

Figure 3. World map showing country-wise publications on ecosystem services provided by birds
3. ábra A madarak általi ökoszisztéma-szolgáltatásokat elemző cikkek országonkénti megoszlása, világtérképen ábrázolva

Scientific publications on ecosystem services of waterbirds were scant prior to the Millennium Ecosystem Assessment in 2003. Thereafter, there was an increase in the number of publications on ecosystem services of waterbirds, which was brought about by the concept of ecosystem services to the vanguard of the global policy debate *(Figure 2)*. Of 174 articles, a total of 92 publications described the functions and services provided by both waterbirds and terrestrial birds; of these, only 77 were specific to the functions of waterbirds, and the remaining 15 described both aquatic and terrestrial birds. Papers with the most relevance to Ganga River, in terms of similar species or genus, were segregated further for in-depth study. These 92 articles on avian ecosystem services were mapped to show the country of origin of these articles *(Figure 3)*.

Results and Discussion

The functional role of waterbirds determined through their feeding, and the behavioral pattern suggests that there is a close relationship between the feeding guilds and the ecosystem services provided by different families *(Table 1)*. They have a profound positive effect on aquatic biodiversity, contribute to biological pest control, act as indicators of conditions of

Table 1. Feeding guild and family-wise delivered services
1. táblázat Táplálkozási guildek és családonkénti szolgáltatásaik

Family	Feeding guild	Ecosystem Service	References
Podicipedidae	Piscivorous	Bioindicator of absence of large predatory fish (Avoid water with large predatory fish)	Konter 2001
Phalacrocoracidae	Piscivorous	Biological pest control, Indicator of regime shift of wetland	Engström 2001
Anhingidae	Piscivorous	Indicator of unpolluted and deep waterbody, Indicator of presence of fish	Rahmani 2005
Ardeidae	Insectivorous	Biological pest control, Seed dispersal, Dispersal of aquatic invertebrates	Nachuha *et al.* 2014, IUCN-SCC Heron Specialist Group 2021
Pelecanidae	Piscivorous	Secondary dispersers of propagules, Nutrient cycling	Michel *et al.* 2020, Green *et al*. 2023
Threskiornithidae	Carnivorous	Indicator of spatial variability of prey availability, Indicator of habitat condition	Frederick *et al.* 2009
Ciconiidae	Carnivorous/ Omnivorous	Biological pest control, Seed dispersal, Animal propagule dispersal	Nachuha *et al.* 2014
Anatidae	Herbivorous/ Omnivorous	Animal propagule dispersal, plant propagule dispersal, Biological pest control, Indicator of presence of fish, Indicator of presence of healthy riverine habitat, Birdwatching and ecotourism, Nutrient recycling	Ormerod & Tyler 1993, Green *et al.* 2002, Charalambidou & Santamaria 2005, Green & Figuerola 2005, Frisch *et al.* 2007, Navedo *et al.* 2015, Boros *et al.* 2016
Accipitridae	Carnivorous/ Piscivorous	Biological pest control, Nutrient cycling, Waste removal, Disease control, Religious symbol	Grande *et al.* 2018
Pandionidae	Piscivorous	Nutrient cycling	Green & Elmberg 2014
Falconidae	Carnivorous	Biological pest control, Religious and cultural symbol	Wilkinson 2003, Grande *et al.* 2018
Gruidae	Omnivorous	Nutrient recycling; Religious and cultural symbol	Navedo *et al.* 2015, Green *et al.* 2016
Rallidae	Herbivorous, Omnivorous	Indicator of presence of macrophyte, Indicator of regime shift of wetland	Mitchell & Perrow 1998, Frisch *et al.* 2007, Green *et al.* 2016
Charadriidae	Carnivorous	Seed dispersal	Green *et al.* 2002
Scolopacidae	Carnivorous	Seed dispersal, Animal propagule dispersal, Indicator of presence of wet grassland habitat, Indicator of alteration of physical structure of mudflat habitat, Nutrient recycling	Green *et al.* 2002, Green & Figuerola 2005, Fisher *et al.* 2011, Navedo *et al.* 2015, Boros *et al.* 2016

Family	Feeding guild	Ecosystem Service	References
Recurvirostridae	Carnivorous	Biological pest control, Disease control, Indicator of presence of polluted water	Ueng *et al.* 2009, Singh *et al.* 2016
Burhinidae	Carnivorous	Seed dispersal	Green *et al.* 2002
Glareolidae	Carnivorous/ Insectivorous	Seed dispersal	Green *et al.* 2002
Laridae	Carnivorous, Omnivorous	Regulation of intertidal food web, Secondary dispersers of propagules, Bioindicator of plastic pollution	Ellis *et al.* 2007, Green *et al.* 2023, Mansfield *et al.* 2024
Alcedinidae	Carnivorous/ Piscivorous	Ecosystem engineering, Nutrient cycling, Bioindicators of plastic pollution	Whelan *et al.* 2015, Belaústegui *et al.* 2018, Winkler *et al.* 2020, Qaiser *et al.* 2023
Hirundinidae	Insectivorous	Sediment transport and biodeposition	Belaústegui *et al.* 2018, McLendon 2019 Tokunaga *et al.* 2023

freshwater ecosystems, help in nutrient influx from terrestrial to aquatic ecosystem, and contribute to waste removal and disease control.

Members of the family Phalacrocoracidae (Cormorants) are chiefly piscivorous and are represented by three species in the mainstream Ganga. Since the early 1990s, rapid increase in cormorant population in Europe and North America (Carss 2003) led to numerous studies on fish consumption by these birds, to reduce the negative conception of the local fishermen who consider these birds responsible for fish exploitation (Zydelis & Kontautas 2008). Studies proved that cormorants are generally predators of artificially stocked fish which are considered a pest to the fishery industry (Bzoma 1998, Engström 2001, Carss 2003). They also increase water transparency by predating on benthivorous fish (Dirksen *et al.* 1995). Reduction of benthivorous fish is necessary to get macrophytes which keep the algal biomass low. Thus, cormorants act as indicators of regime shift of wetlands.

The Little Grebe *(Tachybaptus ruficollis)*, a member of the Podicipedidae family, serves as bioindicator by avoiding waterbodies with large predatory fish (Konter 2001). Oriental Darter *(Anhinga melanogaster)* is the only representative of the family Anhingidae in India. Being an obligate piscivorous bird, its presence indicates the presence of fish species in the waterbody (Ryan 2007, Niangthianhoi & Khudsar 2015). They are also indicators of unpolluted and deep-water bodies (Rahmani 2005).

Agricultural fields – specifically the rice paddies – are favorable foraging grounds for Ciconiidae and Ardeidae, represented by seven and eleven species, respectively, in the Ganga River area. These birds – particularly egrets, herons and storks – feed extensively on rats, snails, crayfish, and tadpole shrimps, and thus, control potential pests in rice paddies (Hafner & Britton 1983, Negro *et al.* 2000, Green & Elmberg 2014, Nachuha *et al.* 2014). By predating upon snails, Asian Openbill *(Anastomus oscitans)* indirectly reduces the incidence of schistosomiasis infection in humans working in agricultural fields (Nachuha *et al.* 2014). Yellow Bitterns *(Ixobrychus sinensis)* also help in pest control by catching flying insects and stem-boring crickets from rice fields (Lansdown & Rajanathan 1993, IUCN SSC Heron Specialist Group 2021). Other valuable representatives of the order Ciconiiformes are Greater Adjutants *(Leptoptilos dubius)*, having an important role in scavenging discarded waste material including unburied corpses as well as large carrions, thus saving the populace from pestilence (BirdLife International 2016). Now having only a few records from the Gangetic basin, the Greater Adjutants were once common in the streets of Kolkata, West Bengal, and even figured prominently in the first emblem of Calcutta Municipal Corporation (1896).

Ibises (Threskiornithidae) are colonially nesting waders and tactile feeders, hence they require concentrated prey in shallow water. That is why they are important indicators of spatial variability of prey abundance, because they quickly abandon feeding sites when prey availability begins to decline due to longer patterns of precipitation or drying (Frederick *et al.* 2009). Though their conservation status is Least Concern, their population trend is decreasing globally owing to ongoing habitat destruction.

Sarus Crane *(Antigone antigone)*, one of the important members of the family Gruidae, is traditionally protected in India due to its association with the Hindu scriptures and is thus considered sacred. The earliest literary evidence of Sarus Crane is in the ancient Sanskrit literature Ramayana (Sundar & Choudhury 2003). The ubiquitousness of sarus in the Gangetic floodplains, their unison calls, and the legends of life-long pair-bonds have given the species an eminent position in Indian culture and folklore. This crane aids in nutrient cycling and pest management in the agricultural fields (Sundar 2018). Another member of this family, Common Crane *(Grus grus)* has proved to be helpful in nutrient recycling in rice agroecosystems through guanotrophication (Navedo *et al.* 2015).

Due to their widespread distribution and abundance, Anatids (ducks and geese) are important for the dispersal of aquatic plant and animal propagules, employing ecto- and endozoochory (Green *et al.* 2002, Frisch *et al.* 2007). They are responsible for the dispersal of some keystone species of aquatic ecosystems like *Daphnia* sp. (Green & Elmberg 2014), which are abundant in the Ganga River basin too (Padhye *et al.* 2016). These crustaceans cannot move between wetlands or river catchments on their own and depend largely on ducks for their dispersal. Studies have provided evidence that they are dominant zooplanktons that regulate phytoplankton abundance, and thus, also help to reduce the turbidity of water (Wurtsbaugh 1992, Scheffer 2001), and promote the growth of aquatic macrophyte population and associated benthic invertebrate communities (Leah *et al.* 1980). Herbivorous dabbling ducks including Eurasian Teal *(Anas crecca)*, Mallard *(Anas platyrhynchos)*, Northern Pintail *(Anas acuta)*, Northern Shoveler *(Spatula clypeata)*, and Gadwall *(Mareca strepera)* play a crucial role in dispersing viable plant propagules, many of which are important components of the ecosystem and offer valuable indirect benefits to humans (Green *et al.* 2016). The Gangetic basin is one of the important wintering grounds of Anatidae (Grimmett *et al.* 2014, WII-GACMC 2018), and their presence in the agricultural fields, specifically in the rice paddies, can reduce the biomass of weeds during harvest times and increase the rate of residue decomposition (van Groenigen *et al.* 2003), and also help in nutrient recycling through defecation (Navedo *et al.* 2015). Besides, ducklings also help to control the mosquito population by feeding on their larvae (Miles *et al.* 2002). There is a positive correlation between the presence of piscivorous Anatids like Goosander *(Mergus* *merganser)* and the smaller fish population in the large lotic water body because they feed mostly on larger fish. They also need an adequate supply of fish population to raise many ducklings (McNicol *et al.* 1995, Kajtoch *et al*. 2014). Furthermore, their existence is congruent with the healthy riverine habitat, as they avoid the river stretch altered due to bank regulation or, dam or barrage construction (Kajtoch & Figarski 2013). It has been reported that the distribution of aquatic mammals, like Eurasian Otter *(Lutra lutra)*, is positively influenced by Goosander (Kajtoch *et al.* 2014).

Apart from all these functions, Anatidae and colonially nesting waders are also valuable from the perspective of bird watching and ecotourism (Edgell & Williams 1992, MacMillan & Leader-Williams 2008), and thus, have the potential to contribute to the rural economy and also to the conservation of the species and their habitat (Şekercioğlu 2002, Green & Elmberg 2014, Gaston *et al.* 2018). Furthermore, the presence of ducks and geese is revered in the ancient Indian scriptures where their long migratory flight and family loyalties have been mentioned (Kumar *et al.* 2005).

Many of the raptor species inhabiting the Gangetic basin have a globally decreasing population trend due to habitat loss and degradation. Some of them inhabit agricultural ecosystems and control the population of rodents and other small mammals (Korpimaki *et al.* 1996, Kross *et al.* 2018). Their presence also helps to control rodent activity in the respective agricultural fields (Abramsky *et al.* 1996). This evidence suggests that they have the potential to contribute to biological pest control services. Other birds of prey like Fish-eagles (*Icthyophaga* spp.) and Osprey *(Pandion haliaetus)* are chiefly piscivorous, and they help in transporting nutrients from aquatic to terrestrial ecosystems. The input of their phosphate-rich guano influences wetland productivity and fish production (Green & Elmberg 2014, Whelan *et al.* 2015). Obligate scavengers like Egyptian Vultures *(Neophron percnopterus)* have a potential role in transporting a large amount of energy and nutrients from carcasses to the food web, and thus, they contribute to waste removal, disease control, and also nutrient cycling (Whelan *et al.* 2015, DeVault *et al.* 2016). Their decreasing population in India, particularly in the Ganga basin could have increased the population of facultative scavengers like feral dogs, which have a negative impact on predation on other wildlife (Pain *et al.* 2003, DeVault *et al.* 2016) and also serve as reservoirs and vectors of several zoonotic diseases (Pain *et al.* 2003). This near extirpation of vultures also disrupted the sky burial tradition of the Parsi and Tibetan Buddhists in which human corpses are exposed to open area to be consumed by sacred vultures, which are symbolized for purification and resurrection (DeVault *et al.* 2016, Bhusal *et al.* 2020). Another predatory bird, the Peregrine Falcon *(Falco peregrinus)* has religious importance for being present in the history of Ancient Egypt (Wilkinson 2003).

The decline in Eurasian Coot *(Fulica atra)* population indicates the decreasing abundance of submerged macrophytes caused by eutrophication (Mitchell & Perrow 1998, Green & Elmberg 2014). Hence, they serve the role of bioindicator of the presence of macrophyte and regime shift of wetland. This species also aids in dispersing viable diaspores of several aquatic plants and is reported to consume more seeds than one of the Anatids, Gadwall (Green *et al.* 2016). The Common Moorhen *(Gallinula chloropus)*, another species within the Rallidae family, serves as vectors of seeds of birdcatcher tree

(Pisonia grandis) which has a wide distribution in India (Green *et al.* 2016). All the members of the family Scolopacidae are winter visitors to the Gangetic basin. Owing to their long-distance migration, their role in seed and invertebrate propagule dispersal is globally important (Green *et al.* 2002, 2005), and they help to maintain the biotic connectivity between the world's wetlands (Amezaga *et al*. 2002). Some of them like Common Snipe *(Gallinago gallinago)* and Common Redshank *(Tringa totanus)* also serve the function of indicator species of the presence of wet grassland habitat (Fisher *et al.* 2011). By grazing on epibenthic biofilm, sandpipers are estimated to be turning over tons of sediments. Thus, biofilm grazing by large flocks of scolopacids results in bioturbation, which can potentially alter the physical structure of mudflat ecosystem (Mathot *et al.* 2018, Beninger & Elner 2020). The presence of another Scolopacid, Black-tailed Godwit *(Limosa limosa)*, in paddy fields, aids in nutrient recycling (Navedo *et al.* 2015).

Black-winged Stilt *(Himantopus himantopus)* helps to control malaria by preying upon mosquito larvae (Ueng *et al.* 2009). It also feeds on chironomid midges, and thus, may have a role in preventing the allergic response in humans caused by chironomid larvae (Ueng *et al.* 2009, Nandi *et al.* 2014). Besides, stilts act as indicators of the presence of polluted water and can easily be seen foraging in the water just beside the source of pollution (Singh *et al.* 2016). They have a globally increasing population trend and are also well distributed throughout the Gangetic basin, which may be due to their tolerance to contaminated water.

Represented by three species in the Ganga River area, members of the Burhinidae and Glareolidae families help in the dispersal of seeds (Green *et al.* 2002); ecosystem functions of these families at species level still have not been quantified.

Gulls (Laridae) are one of the prominent bioindicators of plastic pollution (Mansfield *et al*. 2024). Being predatory, they facilitate the secondary dispersal of propagules either inside or attached to their prey (Green *et al.* 2023). Additionally, gulls play a role in regulating intertidal food webs by consuming highly mobile predators and augmenting the population of other mesopredators during low tide (Ellis *et al*. 2007).

Kingfishers and martins are primary tunnel nesters. These 'ready-made nesting tunnels' are often used by secondary nesters (Goodfellow 2011, Smalley *et al.* 2013, Belaústegui *et al.* 2018), and thus, these species shape the microenvironment for other species (Ali *et al.* 2010, Smalley *et al.* 2013). Such tunnel nests also help in bioturbation (Belaústegui *et al.* 2018). Being largely piscivorous, all the representatives of the family Alcedinidae have an important role in nutrient influx from terrestrial to aquatic ecosystem (Whelan *et al.* 2015). Among them, Common Kingfisher *(Alcedo atthis)* and White-throated Kingfisher *(Halcyon smyrnensis)* also act as a bioindicator of plastic pollution (Winkler *et al.* 2020, Qaiser *et al.* 2023) by feeding on plastic-bioaccumulating prey (Mansfield *et al.* 2024). Furthermore, swallows (Hirundinidae) transport sediment and play role in biodeposition while building their nests with sediment and saliva (Belaústegui *et al*. 2018, McLendon 2019). Barn Swallows *(Hirundo rustica)* function as bioindicators of air-borne microplastic pollution (Tokunaga *et al.* 2023). The members of these families are widely distributed along the Ganga River.

The literature suggests that waterbirds are extremely valuable from the perspective of ecosystem functions they provide, yet the roles of many families are still not clear and require further studies. As Asia represents only 11.43% of studies on avian ecosystem services, there is an urgent need to qualitatively study the ecosystem services of the waterbirds in India, particularly in the context of the Ganga River.

The sheer diversity of waterbirds in India is primarily due to the diversity of aquatic habitats, hence understanding the linkage between aquatic habitat and waterbirds is crucial. Any threats to the aquatic ecosystem will affect waterbirds that are dependent on these. The population trend of many of these waterbirds is decreasing due to the decline in their habitat and other threats they face in their foraging and breeding grounds and stopover sites. The expansion of human habitation and consequent land use changes along the river bank, river bed, and the associated wetlands, use of mechanized boats, commercial exploitation of the birds, disturbances in the nesting and foraging ground of birds in the floodplains due to extensive loss of vegetation cover, and use of chemical pesticides have resulted in the population decline of migratory as well as resident birds of the Ganga River (Sinha *et al.* 2009). About 10% of waterbirds of Ganga are threatened and have been placed under several threatened categories by IUCN (WII-GACMC 2018).

Conclusion

Understanding the functional role of waterbirds, through natural history research, can aid in informed decision-making by the policymakers as well as the public. It has been documented that biodiversity has a pivotal role in all the levels of the ecosystem service hierarchy, hence combining biodiversity with the ecosystem services implies that managing one will enhance the other (Mace *et al.* 2012). Higher biodiversity stabilizes and diversifies the ecosystem functions which in turn ensures the delivery of ecosystem services (Jacobs *et al.* 2013). Hence for effective ecosystem management, it is required to identify and analyze the roles of biodiversity in optimization of ecosystem service delivery and conservation of species and their habitat.

Ecosystem service co-benefits are a lens through which the conservation of birds, and the habitat they rely on, can illuminate potential options for maintaining a larger suite of services derived to people now and into the future. Globally, over 60% of the ecosystem services are already degenerating or overused (Millennium Ecosystem Assessment 2005). An understanding of the functional roles of waterbirds and the resultant ecosystem services will aid in informed decision making, particularly in the wake of United Nations' call for decade of Ecological Restoration and the "nature-based solution" to achieve the restoration. Avian ecologists can demonstrate that maintaining diversity can be useful for building resilience of the ecosystem and adaptive capacity of the communities. The findings of this study would increase public support for the conservation of biodiversity in a holistic manner. National Mission for Clean Ganga's objective of intensifying and augmenting the conservation efforts at Ganga and its tributaries, for aquatic biodiversity conservation and maintenance of ecosystem services for a clean Ganga, also provides a gateway for research on ecosystem services delivered by waterbirds.

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References

Abramsky, Z., Strauss, E., Subach, A., Riechman, A. & Kotler, B. P. 1996. The effect of Barn Owls *(Tyto alba)* on the activity and microhabitat selection of *Gerbillus allenbyi* and *G. pyramidum*. – Oecologia 105(3): 313–319. DOI: 10.1007/BF00328733

Ali, A. M. S., Asokan, S. & Manikannan, R. 2010. Observations on nesting ecology of White-breasted Kingfisher *Halcyon smyrnensis* (Aves: Coraciiformes) in Cauvery Delta, Southern India. – Journal of Ecology and the Natural Environment 2(7): 134–139.

Amezaga, J. M., Santamaría, L. & Green, A. J. 2002. Biotic wetland connectivity – supporting a new approach for wetland policy. – Acta Oecologia 23(3): 213–222. DOI: 10.1016/S1146-609X(02)01152-9

Avibase 2024. Avibase – Bird Checklists of the World, India. – https://avibase.bsc-eoc.org/checklist.jsp?region=IN. Accessed 22 May 2024

Belaústegui, Z., Muñiz, F. & de Carvalho, C. N. 2018. Bird Ichnology: Bioturbation, Bioerosion and Biodeposition. – Revista de Geistória e Pré-História 2(1): 29–33.

Beninger, P. G. & Elner, R. W. 2020. On the tip of the tongue: natural history observations that transformed shorebird ecology. – Ecosphere 11: e03133. DOI: 10.1002/ecs2.3133

Bhusal, K. P., Chaudhary, I. P. & Rana, D. B. 2020. Vultures and people: Some insights into an ancient relationship and practice of sky burial persisting in Trans-Himalayan Region of Nepal. – Vulture Bulletin 9: 43–45.

BirdLife International 2004. State of the World’s Birds 2004: Indicators for Our Changing World. – BirdLife International, Cambridge, U.K.

BirdLife International 2016. *Leptoptilos dubius*. – The IUCN Red List of Threatened Species 2016: e.T22697721A93633471. DOI: 10.2305/IUCN.UK.2016-3.RLTS.T22697721A93633471.en

BNHS-ENVS 2021. Important Bird and Biodiversity Areas in India. – ENVIS Resource Partner on Avian Ecology, Bombay Natural History Society http://www.bnhsenvis.nic.in/Database/Important-Bird-And-Biodiversity-Areas-In-India_18738.aspx. Accessed 05 March 2022

Bock, C. E. & Jones, Z. F. 2004. Avian habitat evaluation: should counting birds count? – Frontiers in Ecology and the Environment 2: 403–410. DOI: 10.1890/1540-9295(2004)002[0403:AHESCB]2.0.CO;2

Boros, E., Pigniczki, Cs., Sápi, T., Balogh, K. V., Vörös, L. & Somogyi, B. 2016. Waterbird-mediated productivity of two soda pans in the Carpathian Basin in Central Europe. – Waterbirds 39(4): 388–401. DOI: 10.1675/063.039.0408

Bzoma, S. 1998. The contribution of Round Goby (*Neogobius melanostomus* Pallas, 1811) to the food supply of Cormorants (*Phalacrocorax carbo* Linnaeus, 1758) feeding in the Puck Bay. – Bulletin of the Sea Fisheries Institute 2: 39–48.

Carss, D. N. 2003. Reducing the Conflict between Cormorants and Fisheries on a Pan-European Scale. – REDCAFE Final Report, Report to the European Commission

Chain-Guadarrama, A., Martínez-Salinas, A., Aristizábal, N. & Ricketts, T. H. 2019. Ecosystem services by birds and bees to coffee in a changing climate: A review of coffee berry borer control and pollination. – Agriculture, Ecosystems & Environment 280(1): 53–67. DOI: 10.1016/j.agee.2019.04.011

Charalambidou, I. & Santamaría, L. 2005. Field evidence for the potential of waterbirds as dispersers of aquatic organisms. – Wetlands 25(2): 252–258. DOI: 10.1672/2

DeVault, T. L., Beasley, J. C., Olson, Z. H., Moleón, M., Carrete, M., Margalida, A. & Sánchez-Zapata, J. A. 2016. Ecosystem services provided by avian scavengers. – In: Şekercioğlu, C. H., Wenny, D. G. & Whelan, C. J. (eds.) Why Birds Matter: Avian Ecological Function and Ecosystem Services. – University of Chicago Press, Chicago, pp. 235–270. DOI: 10.7208/9780226382777-010

Díaz-Siefer, P., Olmos-Moya, N., Fontúrbel, F. E., Lavandero, B., Pozo, R. A. & Celis-Diez, J. L. 2022. Bird-mediated effects of pest control services on crop productivity: a global synthesis. – Journal of Pest Science 95(2): 567–576. DOI: 10.1007/s10340-021-01438-4

Dirksen, S., Boudewijn, T. J., Noordhuis, R. & Marteijn, E. C. L. 1995. Cormorants *Phalacrocorax carbo sinensis* in shallow eutrophic freshwater lakes: prey choice and fish consumption in the non-breeding period and effects of large-scale fish removal. – Ardea 83(1): 167–184.

Edgell, J. & Williams, G. 1992. The financial value and economic valuation of goose grazing in the European Community. – In: van Roomen, M. & Madsen, J. (eds.) Waterfowl and Agriculture: Review and Future Perspective, IWRB Special Publication 21, pp. 79–80.

Ellis, J. C., Shulman, M. J., Wood, M., Witman, J. D. & Lozyniak, S. 2007. Regulation of intertidal food webs by avian predators on New England rocky shores. – Ecology 88(4): 853–863. DOI: 10.1890/06-0593

Engström, H. 2001. Long term effects of cormorant predation on fish communities and fishery in a freshwater lake. – Ecography 24(2):127–138. DOI: 10.1034/j.1600-0587.2001.240203.x

Fisher, B., Bradbury, R. B., Andrews, J. E., Ausden, M., Bentham-Green, S., White, S. M. & Gill, J. A. 2011. Impacts of species-led conservation on ecosystem services of wetlands: understanding co-benefits and tradeoffs. – Biodiversity and Conservation 20: 2461–2481. DOI: 10.1007/s10531-011-9998-y

Frederick, P., Gawlik, D. E., Ogden, J. C., Cook, M. I. & Lusk, M. 2009. The White Ibis and Wood Stork as indicators for restoration of the Everglades ecosystem. – Ecological Indicator 9: S83–S95. DOI: 10.1016/j.ecolind.2008.10.012

Frisch, D., Green, A. J. & Figuerola, J. 2007. High dispersal capacity of a broad spectrum of aquatic invertebrates via waterbirds. – Aquatic Sciences 69: 568–574. DOI: 10.1007/s00027-007-0915-0

Gaston, K. J., Cox, D. T., Canavelli, S. B., García, D., Hughes, B., Maas, B., Martinez, D., Ogada, D. & Inger, R. 2018. Population abundance and ecosystem service provision: The case of birds. – BioScience 68(4): 264–272. DOI: 10.1093/biosci/biy005

Goodfellow, P. 2011. Avian Architecture: How Birds Design, Engineer, and Build. – Princeton University Press, Princeton DOI: 10.1515/9781400838318

Grande, J. M., Orozco-Valor, P. M., Liébana, M. S. & Sarasola, J. H. 2018. Birds of prey in agricultural landscapes: The role of agriculture expansion and intensification. – In: Sarasola, J., Grande, J. & Negro, J. (eds.) Birds of Prey. – Springer, Cham DOI: 10.1007/978-3-319-73745-4_9

Green, A. J. & Elmberg, J. 2014. Ecosystem services provided by waterbirds. – Biological Review 89(1): 105–122. DOI: 10.1111/brv.12045

Green, A. J., Figuerola, J. & Sánchez, M. I. 2002. Implications of waterbird ecology for the dispersal of aquatic organisms. – Acta Oecologica 23(3): 177–189. DOI: 10.1016/S1146-609X(02)01149-9

Green, A. J. & Figuerola, J. 2005. Recent advances in the study of long-distance dispersal of aquatic invertebrates via birds. – Diversity and Distributions 11(2): 149–156. DOI: 10.1111/j.1366-9516.2005.00147.x

Green, A. J., Lovas-Kiss, Á., Reynolds, C., Sebastián-González, E., Silva, G. G., van Leeuwen, C. H. & Wilkinson, D. M. 2023. Dispersal of aquatic and terrestrial organisms by waterbirds: A review of current knowledge and future priorities. – Freshwater Biology 68(2): 173–190. DOI: 10.1111/fwb.14038

Green, A. J., Soons, M. B., Brochet, A. L. & Kleyheeg, E. 2016. Dispersal of plants by waterbirds. – In: Şekercioğlu, C. H., Wenny, D. G. & Whelan, C. J. (eds.) Why birds matter: Avian Ecological Function and Ecosystem Services. – University of Chicago Press, pp. 147–195. DOI: 10.7208/9780226382777-008

Grilli, M. G., Bildstein, K. L. & Lambertucci, S. A. 2019. Nature's clean-up crew: quantifying ecosystem services offered by a migratory avian scavenger on a continental scale. – Ecosystem Services 39: 100990. DOI: 10.1016/j.ecoser.2019.100990

Grimmett, R., Inskipp, C. & Inskipp, T. 2014. Birds of the Indian Subcontinent. – Helm Field Guides, London

Hafner, H. & Britton, R. H. 1983. Changes of foraging sites by nesting Little Egrets (*Egretta garzetta* L.) in relation to food supply. – Colonial Waterbirds 6: 24–30. DOI: 10.2307/1520963

Harzing, A. W. 2007. Publish or Perish. – https://harzing.com/resources/publish-or-perish. Accessed 19 March 2025

Islam, M. Z. & Rahmani, A. R. 2004. Important Bird Areas in India: Priority Sites for Conservation. – Indian Bird Conservation Network: Bombay Natural History Society and BirdLife International, UK.

IUCN SSC Heron Specialist Group. Yellow Bittern. – https://www.heronconservation.org/herons-of-the-world/list-of-herons/yellow-bittern/ Accessed 02 August 2021.

Jacobs, S., Haest, B., de Bie, T., Deliège, G., Schneiders, A. & Turkelboom, F. 2013. Biodiversity and ecosystem services. – In: Jacobs, S., Dendoncker, N. & Keune, H. (eds.) Ecosystem Services. – Elsevier, pp. 29–40. DOI: 10.1016/B978-0-12-419964-4.00003-2

Kajtoch, Ł. & Figarski, T. 2013. Short-term restoration of riverine bird assemblages after a severe flood. – Bird Study 60(3): 327–334. DOI: 10.1080/00063657.2013.798260

Kajtoch, Ł., Żmihorski, M. & Piestrzyńska-Kajtoch, A. 2014. The Goosander as potential indicator of naturalness and biodiversity in submontane river valleys of northern Carpathians. – Ecological Indicator 45: 83–92. DOI: 10.1016/j.ecolind.2014.03.021

Karp, D. S., Mendenhall, C. D., Sandí, R. F., Chaumont, N., Ehrlich, P. R., Hadly, E. A. & Daily, G. C. 2013. Forest bolsters bird abundance, pest control and coffee yield. – Ecology Letters 16(11): 1339–1347. DOI: 10.1111/ele.12173

Konter, A. 2001. Grebes of Our World: Visiting All Species on 5 Continents. – Lynx Edicions, Barcelona

Korpimaki, E., Koivunen, V. & Hakkarainen, H. 1996. Microhabitat use and behavior of voles under weasel and raptor predation risk: predator facilitation? – Behavioral Ecology 7(1): 30–34. DOI: 10.1093/beheco/7.1.30

Kross, S. M., Ingram, K. P., Long, R. F. & Niles, M. T. 2018. Farmer perceptions and behaviors related to wildlife and on-farm conservation actions. – Conservation Letters 11(1): e12364. DOI: 10.1111/conl.12364

Kumar, A., Sati, J. P., Tak, P. C. & Alfred, J. R. B. 2005. Handbook on Indian Wetland Birds and Their Conservation. – Zoological Survey of India

Lansdown, R. V. & Rajanathan, R. 1993. Some aspects of the ecology of *Ixobrychus* bitterns nesting in Malaysia ricefields. – Colonial Waterbirds 16(1): 98–101. DOI: 10.2307/1521564

Leah, R. T., Moss, B. & Forrest, D. E. 1980. The role of predation in causing major changes in the limnology of a hyper-eutrophic lake. – Internationale Revue der Gesamten Hydrobiologie und Hydrographie 65(2): 223–247. DOI: 10.1002/iroh.19800650205

Lindell, C., Eaton, R. A., Howard, P. H., Roels, S. M. & Shave, M. E. 2018. Enhancing agricultural landscapes to increase crop pest reduction by vertebrates. – Agriculture, Ecosystems & Environment 257(1): 1–11. DOI: 10.1016/j.agee.2018.01.028

Mace, G. M., Norris, K. & Fitter, A. H. 2012. Biodiversity and ecosystem services: a multilayered relationship. – Trends in Ecology & Evolution 27(1): 19–26. DOI: 10.1016/j.tree.2011.08.006

MacMillan, D. C. & Leader-Williams, N. 2008. When successful conservation breeds conflict: an economic perspective on wild goose management. – Bird Conservation International 18: S200–S210. DOI: 10.1017/S0959270908000282

Mansfield, I., Reynolds, S. J., Lynch, I., Matthews, T. J. & Sadler, J. P. 2024. Birds as bioindicators of plastic pollution in terrestrial and freshwater environments: A 30-year review. – Environmental Pollution 348: 123790. DOI: 10.1016/j.envpol.2024.123790

Mariyappan, M., Rajendran, M., Velu, S., Johnson, A. D., Dinesh, G. K., Solaimuthu, K., Kaliyappan, M. & Sankar, M. 2023. Ecological role and ecosystem services of birds: a review. – International Journal of Environment and Climate Change 13(6): 76–87. DOI: 10.9734/IJECC/2023/v13i61800

Mathot, K. J., Piersma, T. & Elner, R. W. 2018. Shorebirds as integrators and indicators of mudflat ecology. – In: Beninger, P. (ed.) Mudflat Ecology. – Aquatic Ecology Series, Springer, Cham, pp. 309–338. DOI: 10.1007/978-3-319-99194-8_12

McLendon, A. K. 2019. Sediment Transport by Mud-Nesting Barn Swallows in White Sands National Monument, New Mexico. – Master's Thesis, Texas State University, San Marcos, Texas https://digital.library.txstate.edu/handle/10877/8335

McNicol, D. K., Ross, R. K., Mallory, M. L. & Brisebois, L. A. 1995. Trends in waterfowl populations: evidence of recovery from acidification. – In: Gunn, J. M. (ed.) Restoration and Recovery of an Industrial Region. – Springer Series on Environmental Management, Springer, New York, pp. 205–217. DOI: 10.1007/978-1-4612-2520-1_16

Michel, N. L., Whelan, C. J. & Verutes, G. M. 2020. Ecosystem services provided by Neotropical birds. – The Condor 122(3): 1–21. DOI: 10.1093/condor/duaa022

Miles, A. K., Lawler, S. P., Dritz, D. & Spring, S. 2002. Effects of mosquito larvicide on Mallard ducklings and prey. – Wildlife Society Bulletin 30(3): 675–682. https://www.jstor.org/stable/3784219

Millennium Ecosystem Assessment 2005. Ecosystems and Human Well-being: Summary for Decision Makers. – Island Press, Washington, DC.

Mitchell, S. F. & Perrow, M. R. 1998. Interactions between grazing birds and macrophytes. – In: Jeppesen, E., Søndergaard, M., Søndergaard, M. & Christoffersen, K. (eds.) The Structuring Role of Submerged Acrophytes in Lakes. – Ecological Studies (Analysis and Synthesis). – Springer, New York, NY, pp. 175–196. DOI: 10.1007/978-1-4612-0695-8_9

MoEFCC 2018. India's National Action Plan for Conservation of Migratory Birds and their Habitats along Central Asian Flyway (2018–2023). – Ministry of Environment Forest and Climate Change, Government of India https://moef.gov.in/uploads/2018/03/CAF_NAP_Final-with-CL.pdf

Nachuha, S., Ejotre, I. & Mwima, P. M. 2014. The role of Ciconiiformes in controlling pests in rice paddies of Kibimba, Eastern Uganda. – Advances in Research 2(12): 797–806. http://hdl.handle.net/20.500.12309/129

Nandi, S., Aditya, G., Chowdhury, I., Das, A. & Saha, G. K. 2014. Chironomid midges as allergens: evidence from two species from West Bengal, Kolkata, India. – Indian Journal of Medical Research 139(6): 921–926.

Navedo, J. G., Hahn, S., Parejo, M., Abad-Gómez, J. M., Gutiérrez, J. S. & Villegas, A. 2015. Unravelling trophic subsidies of agroecosystems for biodiversity conservation: Food consumption and nutrient recycling by waterbirds in Mediterranean rice fields. – Science of the Total Environment 511: 288–297. DOI: 10.1016/j.scitotenv.2014.12.068

Negro, J. J., Tella, J. L., Blanco, G., Forero, M. G. & Garrido-Fernández, J. 2000. Diet explains interpopulation variation of plasma carotenoids and skin pigmentation in nestling White Storks. – Physiological and Biochemical Zoology 73(1): 97–101. DOI: 10.1086/316724

Niangthianhoi, S. L. & Khudsar, F. A. 2015. The nesting success of the Oriental Darter *Anhinga melanogaster* (Aves: Suliformes: Anhingidae) in the Yamuna Biodiversity Park, New Delhi, India. – Journal of Threatened Taxa 7(14): 8148–8153. DOI: 10.11609/jott.2430.7.14.8148-8153

Ormerod, S. J. & Tyler, S. J. 1993. Birds as indicators of changes in water quality. – In: Furness, R. W. & Greenwood, J. J. D. (eds.) Birds as Monitors of Environmental Change. – Springer, Dordrecht DOI: 10.1007/978-94-015-1322-7_5

Padhye, S. M., Kotov, A. A., Dahanukar, N. & Dumont, H. J. 2016. Biogeography of the 'water flea' *Daphnia* O. F. Müller (Crustacea: Branchiopoda: Anomopoda) on the Indian subcontinent. – Journal of Limnology 75(3): 571–580. DOI: 10.4081/jlimnol.2016.1476

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P. & Moher, D. 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. – British Medical Journal 372:n74. DOI: 10.1136/bmj.n71

Pain, D. J., Cunningham, A. A., Donald, P. F., Duckworth, J. W., Houston, D. C., Katzner, T., Parry-Jones, J., Poole, C., Prakash, V., Round, A. & Timmins, R. 2003. Causes and effects of temporospatial declines of *Gyps* vultures in Asia. – Conservation Biology 17(3): 661–671. https://www.jstor.org/stable/3095223

Pettingill, O. S. 2013. Ornithology in Laboratory and Field. – Elsevier

Qaiser, N., Sidra, S., Javid, A., Iqbal, A., Amjad, M., Azmat, H., Arooj, F., Farooq, K., Nimra, A. & Ali, Z. 2023. Microplastics abundance in abiotic and biotic components along aquatic food chain in two freshwater ecosystems of Pakistan. – Chemosphere 313: 137177. DOI: 10.1016/j.chemosphere.2022.137177

Rahmani, A. R. 2005. Common Birds of India. – Ministry of Information and Broadcasting, Government of India

Rawat, G. S. 2004. Vegetation characteristics within various biogeographic zones of India. – In: Islam, M. Z. & Rahmani, A. R. (eds.) Important Bird Areas in India: Priority Sites for Conservation. – Indian Bird Conservation Network: Bombay Natural History Society and Birdlife International, UK.

Rodgers, W. A. & Panwar, S. H. 1988. Biogeographical Classification of India. New Forest, Dehra Dun, India.

Ryan, P. G. 2007. Diving in shallow water: the foraging ecology of darters (Aves: Anhingidae). – Journal of Avian Biology 38(4): 507–514. DOI: 10.1111/j.0908-8857.2007.04070.x

Scheffer, M. 2001. Alternative attractors of shallow lakes. – The Scientific World Journal 1: 254–263. DOI: 10.1100/tsw.2001.62

Sebastián-González, E., Lovas-Kiss, Á., Soons, M. B., van den Broek, B. & Green, A. J. 2020. Waterbird seed-dispersal networks are similarly nested but less modular than those of frugivorous birds, and not driven by functional traits. – Functional Ecology 34(11): 2283–2291. DOI: 10.1111/1365-2435.13657

Şekercioğlu, C. H. 2002. Impacts of birdwatching on human and avian communities. – Environmental Conservation 29(3): 282–289. DOI: 10.1017/S0376892902000206

Şekercioğlu, C. H. 2006. Increasing awareness of avian ecological function. – Trends in Ecology & Evolution 21(8): 464–471. DOI: 10.1016/j.tree.2006.05.007

Şekercioğlu, C. H., Daily, G. C. & Ehrlich, P. R. 2004. Ecosystem consequences of bird declines. – Proceedings of the National Academy of Science 101(52): 18042–18047. DOI: 10.1073/pnas.0408049101

Singh, C. P., Tirpathi, A. & Mishra, S. B. 2016. A preliminary survey of River Yamuna from Bhareh confluence to Betwa confluence at Hamirpur District UP India. – International Journal of Fauna and Biological Studies 3(3): 9–12.

Sinha, R. K., Khan, K. M., Sharma, G., Kedia, D. K. & Sinha, S. K. 2009. A preliminary survey of the bird diversity along the lower middle reaches of the River Ganga, Bihar, India. – Newsletter Birdwatchers 49(5): 65–70.

Smalley, I., O'Hara-Dhand, K., McLaren, S., Svircev, Z. & Nugent, H. 2013. Loess and bee-eaters I: ground properties affecting the nesting of European Bee-eaters (*Merops apiaster* L. 1758) in loess deposits. – Quaternary International 296: 220–226. DOI: 10.1016/j.quaint.2012.09.005

Sundar, K. S. G. 2018. Sarus Cranes and Indian farmers: an ancient coexistence. – In: Austin, J. E., Morrison, K. L. & Harris, J. T. (eds.) Cranes and Agriculture: A Global Guide for Sharing the Landscape. – International Crane Foundation, Wisconsin, USA, pp. 206–210.

Sundar, K. S. G. & Choudhury, B. C. 2003. Nest sanitation in Sarus Cranes *Grus antigone* in Uttar Pradesh, India. – Forktail 19: 144–145.

Tokunaga, Y., Okochi, H., Tani, Y., Niida, Y., Tachibana, T., Saigawa, K., Katayama, K., Moriguchi, S., Kato, T. & Hayama, S. I. 2023. Airborne microplastics detected in the lungs of wild birds in Japan. – Chemosphere 321: 138032. DOI: 10.1016/j.chemosphere.2023.138032

Ueng, Y. T., Wang, J. P., Hou, P. C. L. & Perng, J. J. 2009. Diet of Black-winged Stilt chicks in coastal wetlands of Southwestern Taiwan. – Waterbirds 324(4): 14–522. DOI: 10.1675/063.032.0404

Valkó, O., Borza, S., Godó, L., Végvári, Z. & Deák, B. 2022. The Eurasian Crane *(Grus grus)* as an ecosystem engineer in grasslands: Conservation values, ecosystem services, and disservices related to a large iconic bird species. – Land Degradation & Development 33(12): 2155–2165. DOI: 10.1002/ldr.4314

van Groenigen, J. W., Burns, E. G., Eadie, J. M., Horwath, W. R. & van Kessel, C. 2003. Effects of foraging waterfowl in winter flooded rice fields on weed stress and residue decomposition. – Agriculture, Ecosystem & Environment 95(1): 289–296. DOI: 10.1016/S0167-8809(02)00097-X

Wenny, D. G., Devault, T. L., Johnson, M. D., Kelly, D., Sekercioglu, C. H., Tomback, D. F. & Whelan, C. J. 2011. The need to quantify ecosystem services provided by birds. – The Auk 128(1): 1–14. DOI: 10.1525/auk.2011.10248

Wetlands International 2012. Waterbird Population Estimates, 5th ed. Summary Report. – Wetlands International, Wageningen, The Netherlands

Whelan, C. J., Şekercioğlu, Ç. H. & Wenny, D. G. 2015. Why birds matter: from economic ornithology to ecosystem services. – Journal of Ornithology 156(1): 227–238. DOI: 10.1007/s10336-015-1229-y

Whelan, C. J., Wenny, D. G. & Marquis, R. J. 2008. Ecosystem services provided by birds. – Annals of the New York Academy of Sciences 1134: 25–60. DOI: 10.1196/annals.1439.003

WII-GACMC 2018. Macro Fauna of the Ganga River: Status and Conservation of Select Species. – Ganga Aqualife Conservation Monitoring Centre, Wildlife Institute of India, Dehradun, Uttarakhand, India

Wilkinson, R. H. 2003. The Complete Gods and Goddesses of Ancient Egypt. – Thames & Hudson, New York, pp. 103–111.

Winkler, A., Nessi, A., Antonioli, D., Laus, M., Santo, N., Parolini, M. & Tremolada, P. 2020. Occurrence of microplastics in pellets from the Common Kingfisher *(Alcedo atthis)* along the Ticino River, North Italy. – Environmental Science and Pollution Research 27: 41731–41739. DOI: 10.1007/s11356-020-10163-x

Wurtsbaugh, W. A. 1992. Food-web modification by an invertebrate predator in the Great Salt Lake (USA). – Oecologia 89: 168–175. DOI: 10.1007/BF00317215

Zydelis, R. & Kontautas, A. 2008. Piscivorous birds as top predators and fishery competitors in the lagoon ecosystem. – Hydrobiologia 611: 45–54. DOI: 10.1007/s10750-008-9460-7