International Journal of Ecology and Environmental Sciences 50: 557-575, 2024
ISSN: 2320-5199 (Online); https://doi.org/10.55863/ijees.2024.0098

Habitat Quality Characterization and Management of Asan Wetland Biodiversity

SARNAM SINGH[1,*], RAJASHREE NAIK[2], ARCHANA BAHUGUNA[3], ANIL KUMAR[3] AND NARENDER SHARMA[4]

[1]*Indian Institute of Remote Sensing, Indian Space Research Organisation, Dehradun, 248001, India*
[2]*Department of Chemistry, Vellore Institute of Technology-Andhra Pradesh (VIT-AP) University, Amaravati, 522237, India*
[3]*Zoological Survey of India, Dehradun, 248 001, India*
[4]*Zoological Survey of India, APRC, Itanagar, 791111, India*
Email: profsarnam.singh@gmail.com, rajashree.bini06@gmail.com, archana.bahuguna65@gmail.com, anilsonta@gmail.com, narendersharma70@gmail.com
***Corresponding author**
ORCID: 0000-0003-1829-7941(SS), 0000-0002-8303-0015(RN)

ABSTRACT
The present study is an attempt to characterize the significance of different micro-habitats in the context of habitat quality, complex food-web within and surrounding environs of the Asan Conservation reserve wetland in outer Himalayan tract. The unceasing nutrient-rich water flow supports vegetation growth and the occurrence of biological elements at different trophic levels of the food chain supply. A mix of swamp-marsh, shallow and deep water, floating, and terrestrial vegetation make it a good environmental setup to meet various life-cycle needs of the migratory and resident birds. Four dominant biotic groups: primary producers and consumers at different trophic levels such as butterflies, amphibians, and birds were studied. We used two-season IRS LISS IV satellite data of 2016 for characterizing the micro-habitat of the wetland. The analyses of water quality for pH, electrical conductivity, total dissolved solids, and total soil organic content indicates that these are within permissible limits for the survival of larvae, prey, and predators species to complete their lifecycle. The unique ecological setup formed by the permanent source of flowing and stagnant water, natural and semi-natural vegetation, the mosaic of tree-grassland-marsh-swamp land, seasonal crops, prey species, etc. and the presence of peripheral vegetation are some of the ecological niceties and reasons for attracting a large number of migratory birds. Habitat used by birds, amphibians, and butterflies in the core wetland and adjacent ecosystems were characterized. We recommend adaptive scientific management for maintaining 'Hemi marsh' in the ratio of 60:40 between the water and vegetation, controlling water pollution and eutrophication, and fixing of dredging policy after thorough studies on the soil benthic fauna before and after desilting.

Key Words: Reservoir, Hemi marsh, Water quality, Food-web, Remote sensing, LISS IV, Land Use/Land cover, Adaptive management.

INTRODUCTION

The northern region of India, between the Central Asian-Indian and East Asian-Australian Flyways, is one of the vital target locations for migratory birds for wintering (Prasad et al. 2002, Kumar et al. 2005). The high density of wetlands, rivers, and streams across the Ganga basin and in the catchments of Yamuna, Kali, and several small rivers are the most prominent habitats for migratory birds in the North-Western Himalaya. In India, freshwater wetlands support nearly 20 percent of the biodiversity (Deepa and Ramachandra 1999). These are very significant to maintain the ecological balance and interface between terrestrial-aquatic ecosystem/environmental services, resource and genetic linkers, trophic and non-trophic process linkers, seed dispersers, pollinators, ecosystem engineers, raptors, scavengers, insectivores, soil formation, and nutrient depositors (Sekercioglu 2006, Xiong et al. 2020). In totality, the wetlands are more diverse and represent almost all taxonomic groups, from unicellular algae to woody angiosperms and from unicellular protozoans to large mammals (Gopal et al. 2000). However, the typical environmental setup of the wetlands is changing fast due to diversion and

reclamation, altering the basic nature and biodiversity (Meena and Sharma 2019, Prasad et al. 2002). Water and vegetation provide critical ecosystem services that include sites for feeding, breeding, nesting, molting, roosting, and grazing for various species of birds, amphibians, annelids, fishes, turtles, mammals, etc., and are important linkers and part of food chain. These "biological supermarkets" also provide significant provisioning and regulatory services including habitats of pollinators (butterflies, insects, etc.), climate regulation, primary and secondary productivity, etc., and habitats for more than 100,000 species of plants and animals (Gawler 2000, Prasad et al. 2002, Ghermandi et al. 2008, ten Brink et al. 2012). Productivity-wise, the secondary productivity in wetlands is about 9.0 g/m^2 per year, which is 3.5 times higher than terrestrial ecosystems (Whittaker and Likens 1973, Keddy 2010), therefore, deserve special attention.

Solid waste disposal is a big challenge to most of the countries. Wetlands are now becoming dumping grounds of waste consisting of a mixture of non-biodegradable objects like polythene, Thermocol, metals, old bricks, concrete debris, glass, e-waste, etc., and biodegradable waste like vegetable waste, clothes, paper, sewage, dung, untreated industry effluent, etc. are impacting microhabitats and biodiversity. Microplastic presence has been reported in the fishes, a health hazard to fishes and consumers as well. Amaraneni et al. (2004) analyzed geospatially the impact of air and water pollutant in Kolleru lake and growth of macrophytes. Due to eutrophication and water level variations, change in species composition of macrophytes (from 20 species in 1978 to 27 species in 2006) has been reported in Shalbug wetland of Kashmir Himalaya (Siraj et al. 2011). Waste dumping to the tune of 3500 tonnes every day in Pallikarnai wetland in Tamil Nadu with precious germplasm of wild rice (*Oryza ruifipogon*) has been reported (Vijayan et al. 2004). The callous attitude of the government systems and society has led to the large-scale diversion and reclamation of wetlands. One of the significant reasons for land use/land cover (LULC) change and wetland loss is the non-existence of 'wetland(s)' as a LULC category in India's statistical records and revenue maps. Even though the wetlands in India are indirectly influenced by different policies and legislations, many wetlands in rural and sub-urban are not governed by the Indian Forest Act of 1972 or the Wildlife Protection Act of 1972 and are classified as 'wastelands' in revenue records (Anonymous 2006). This gap allows government agencies to 'change' LULC and/or diversion. Therefore, prevention of land use diversion and lack of governance and management becomes challenging (Kumar et al. 2013). With the increase in concrete jungles, the soil excavation and recycling from wetlands-soil are decreasing day-by-day, leading to the cumulative impact on silting, filling, and then disappearance. The '*jhabar*', the shallow wetlands in Northern India, are the nesting sites for several birds such as 'Saras' crane (a Schedule IV species), Cranes, Egrets, ducks, etc. Nearly 30% of the wetland area lying in between the Sikandra-Sahajpur, Kanpur Rural district decreased due to siltation and LULC change from 1970. One can see plot-boundaries in the middle of the wetland. The population of 'Saras' and ducks is reduced to about 5% (personal observations).

Doon valley has several natural and man-constructed wetlands, and is one of the critical destinations for migratory birds in India. Asan Conservation Reserve (ACR) is the first Conservation Reserve of the country declared in 2005, and Grewal and Sen (2008) described it as a "Lake of the Unexpected". ACR environs has unique habitat conditions, ecological/environmental setup formed by Asan barrage and Yamuna River as it fans out in Doon valley forming an elliptical bowl with braided channels. The dominant life-forms in ACR are (a) migratory and resident birds, (b) butterflies, (c) amphibians, and (d) other groups of fishes (vertebrates), annelids, Mollusks (invertebrates), etc (Fig. 1). As a part of the food chain, it has a vibrant faunal diversity consisting of invertebrate animal groups (Tak et al. 2003). The interdependence, interrelationships and the habitat requirement of different predator-prey groups is important for sustainable management. The ACR has food-chain biota of aquatic, marshy and terrestrial vegetation-butterflies-insects-annelids-frogs-fishes-mollusks-snakes-transboundary and local migratory and resident birds, may be considered as good bioindicators (Burger 2006, Bhardwaj et al. 2012). Tak et al. (2003) and Kaushik and Gupta (2013) reported 29 and 60 wetland birds in ACR region,

respectively. Mohan et al. (2016) reported 327 species and Chandra et al. (2021) reported 332 bird species with more than 78 species of invertebrates, 51 fishes, four amphibians, one reptile, and 20 mammals. Hussain (2015a) reported 44 species of fish species. In ACR, the count of migratory avifauna is increasing day by day and therefore, has drawn the attention of researchers and government agencies for better habitat management (Tak et al. 2003, Kumar et al. 2005, Mohan et al. 2009, Bharadwaj et al. 2012, Mohan and Sondhi 2015, Hussain 2015b, Bhatt et al. 2016, Singh et al. 2016, Rahmani et al. 2016, Chandra et al. 2021). The number of visiting rare, endangered, and threatened (RET) bird species is increasing with the reported presence of critically endangered Red-headed Vulture (*Sarcogyps calvus*), White-rumped Vulture (*Gyps bengalensis*), Slender-billed Vulture (*Gyps tenuirostris*), and Baer's Pochard (*Aythya baeri*). Mohan et al. (2016) reported 11 species under the vagrant category, six vulnerable, 13 near threatened, three critically endangered, and two endangered. Rahmani et al. (2016) reported eight species critically endangered, two endangered, eight vulnerable, and 14 near threatened. The floral diversity has been studied by Singh and Srivastava (2000).

Wetlands usually have a good representation of amphibians, as it provides aquatic and terrestrial habitats for reproduction, feeding, overwintering, migration, dispersal, etc., and has rich faunal diversity (Pellet et al. 2007, Lien 2007). At lower trophic level Annelids, amphibians and butterflies form core of the food chain and are vulnerable to changes due to biotic pressure. The population of frogs is impacted by LULC changes and water pollution. Frogs of the genus *Fejervarya* are distributed throughout South and Southeast Asia (Frost 2007) and consumed by humans and killed for making novelties and curios. In China 32 species are used in traditional Chinese medicine (Carpenter et al. 2007). *Fejervarya cancrivora* is the source of around three fourth of Indonesia's exported frog legs. It is estimated that between 180 million to a billion frogs are collected from the wild in Asia alone each year (http://www.amphibiaweb.org/declines/exploitation.html), (Patel 1993). Butterflies form an important node in the food-web and provide ecosystem services in the form of pollinators and prey species of amphibians, reptiles, birds, etc. (Ghazanfar et al. 2016) and are valuable flagship species for aesthetic and cultural reasons (Ferris and Humphrey 1999). About 30 percent of reported butterflies in India are found in Garhwal Himalaya, ACR is part of it. About 407 species of butterflies are reported from Uttarakhand Himalaya (Singh and Sondhi 2016). In the ACR environs and Doon valley: 323 species have been reported from Mussoorie hills (Mackinnon and de Niceville 1989); 94 species from Tons valley (Bharadwaj et al. 2012); 90 species from Wildlife Institute of India campus (Bharadwaj and Uniyal 2012), and 70 species from Simbalbara Wildlife sanctuary (Kittur et al. 2006), and Bharadwaj et al. (2012) reported higher diversity in the agriculture fields than natural and seminatural habitats, which might negate the concept of butterflies as surrogate indicators of pristine vegetation as natural habitats. The butterfly richness strongly relates to plant species richness, canopy cover, and herb and shrub density across gradient in Doon valley. Amphibian larvae can alter the nutrient dynamics of the food web and are reported to have economic values through food and medicines (Hocking and Babbitt 2014). Tak et al. (1997) studied the waterfowl potential of Asan. For sustainable and scientific management, status monitoring (Simberloff 1988) the conservation of wetlands can best be understood by using time-series satellite data (Garg et al. 1998, Vijayan et al. 2004, Anonymous 2011, Panigrahy et al. 2012, Patel et al. 2015 and Naik et al. 2022) and water quality assessment (Amaraneni et al. 2004). In Uttarakhand state, 994 small and large wetlands were mapped (Anonymous 2011, Manjrekar and Singh 2012). Kumar and Porwal (1998) and Kumar et al. (2005) mapped LULC of ACR for the period of 1996-98. Naik et al. (2022) mapped and analyzed vegetation cover dynamics and LULC using a high resolution (5.8 m) IRS LISS IV data. The present study relates to habitat characterization for dominant life-forms in ACR environs and is continuation of Naik et al. (2022).

MATERIAL AND METHODS

Study area

ACR is a Ramsar Wetland on Asan river with an area of about 4.44 km^2 in west Doon valley, very close to

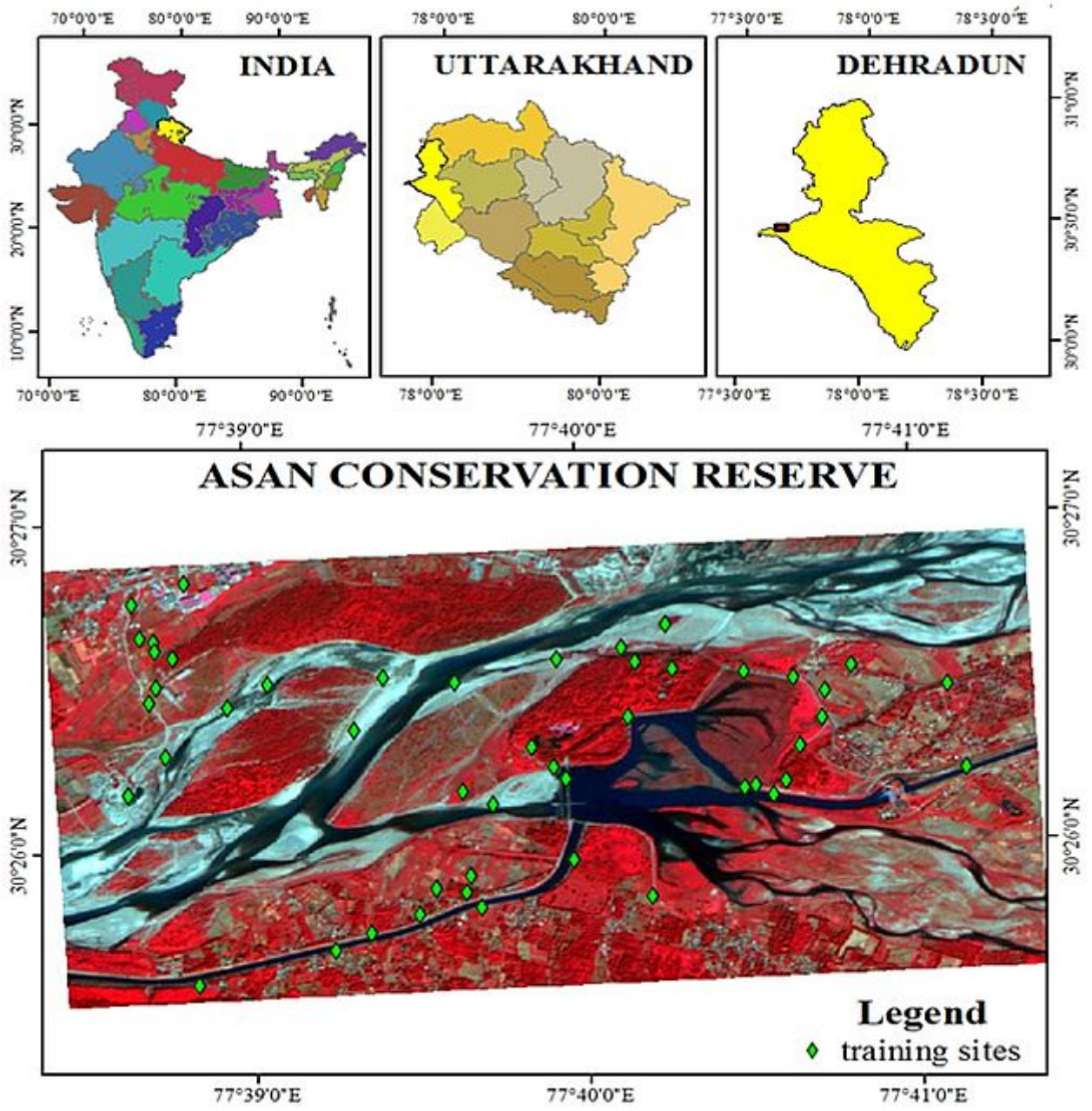

Figure 1. Study area with False Colour Composite of LISS IV (RGB 4,3,2) of October 2016 indicating sampling locations (green points)

the confluence with river Yamuna. It lies between latitude 30°24'N to 30°28'N and longitude 77°40'E to 77°44'E (Fig. 1), and is part of biogeographic province 4.8.4 (Indo-Gangetic monsoon forest) and wetland Type 17 (Water storage reservoirs, dams) (Hussain and De Roy 1993). It is fed by waters from several smaller rivers originating from Mussoorie hills, and a canal from barrage on Yamuna River near Dakpatthar. Two lakes were also constructed to provide an alternate habitat for the migratory and resident waterbirds (Tak et al. 2003). Wetland is a well-known 'home' away from home for migratory birds in Central Asian-flyway (Naik et al. 2022). Habitat-wise area is quite heterogeneous with a mosaic of various natural, seminatural and artificially controlled ecosystems. Habitats/niches formed by swampy-marshy-clear water, shallow and deep water, sand, tall grasses, floating vegetation, algal growth, and nearby riverine forest, swamps, agriculture-orchards make it very diverse for breeding, roosting, perching, molting, feeding, etc. and en-route halting of migratory and resident birds (Mohan et al. 2009,

Naik et al. 2022). In immediate environs, the patches of riverine forests are comprised mainly of *Acacia catechu* and *Dalbergia sissoo* with sporadic occurrence of *Bombax ceiba, Phoenix sylvestris, Ficus palmata*, etc. Aquatic vegetation includes *Hydrilla verticillata, Polygonum* spp., *Eichhornia crassipes, Potamogeton crispus, Ceratophyllum demersum,* etc. *Schoenoplectiella mucronata* and *Cyperus digitatus* are two dominant sedges. *Typha elephantina* (Cattail) is the dominant grass. Other terrestrial herbaceous plants, under-shrubs, and shrubs on the banks and nearby areas are *Ageratum conyzoides, Abrus precatorius, Senna tora, Artemisia* sp.*, Ocimum basilicum, Trevia nudiflora, Gomphrena serrata, Bidens pinnata, Adenostemma lavenia, Pogostemon benghalensis, Veronica anagallis-aquatica,* etc. Shrubs like *Lantana camara, Murraya koenigii, Colocassia* spp. *Ipmoea nil, I. fistulosa, I. carnea, Vitex negundo, Solanum torvum*, etc.*,* are conspicuous and dominant floristics forming pure stands as well as associations. Other vegetated areas are mango and litchi orchards, Riverine vegetation with *Dalbergia sissoo* and *Acacia catechu* is key indicator of early successional stage. There are about 78 invertebrate species, including odonatan, Coleoptera, Annelida, and mollusks, and 332 vertebrate species, including Pisces, amphibians, reptilians, Aves, and Mammalia, indicating the rich faunal diversity in a small area (Fig. 2)

Data

High-resolution satellite data of the Resourcesat-2 LISS-IV sensor (5.8 m spatial resolution) of October 2016 were used to map wetland habitat and Land use/Land cover (Naik et al. 2022) (Fig. 1). Identification of floral and faunal components was done with the help of experts from the Botanical Survey of India (BSI), Dehradun and Zoological Survey of India (ZSI), Dehradun, respectively. Ancillary data of recent surveys available with ZSI such as list of the birds (ZSI 2016), butterflies (2017) and amphibians (2017), BSI on plant diversity of Asan Wetland (Singh and Srivastava 2000); and Chakrata Forest Division Management Plan of Asan (2009-2014) were used to determine the identities of birds, butterflies and amphibians. Additional ground data on vegetation types, LULCs, wetland vegetation community, water quality, etc., were also collected and collated covering the study area.

METHODOLOGY

Land use/land cover mapping and analysis

Wetland types and LU/LC mapping was done on a 1:10,000 scale (Fig. 3). A purposive Level-III classification scheme and a supervised approach of classification was adopted (Naik et al. 2022). Core wetland area has very heterogenous LU/LC consisting of water bodies, aquatic vegetation, *Typha*, grasses and sedges, swamps, and marsh land and other categories in the wetland-neighbourhood include riverine forest, forest of Sal, *Acacia* and *Dalbergia sissoo*, mixed scrub, orchards, dry riverbed, cropland, fallow land, settlement, and wet riverbed. The map formed the basis for sampling designing and data collection strategies for observations on different life-forms, water quality and soil organic content assessment. The environmental setup indicates that ACR is very heterogeneous, and its environs have plenty of good water sources and various LULC types. Aquatic vegetation is about 38%, Grasses and Sedges 17%, Swampy area 16%, Marshy area 15%, and Typha 14%.

Sampling and analyses of water and soil samples

We carried out several joint surveys consisting of subject experts in remote sensing, Zoological and Botanical taxonomy, and ecology to collect data on a few environmental indicators, LULC pattern, and distribution of vegetation and its composition targeting birds, butterflies, soil, water, amphibians, fishes, etc. Soil and water samples were collected randomly from 10 sites after stratification. The soil profiles were dug up to 30 cm deep to collect soil samples. Soil samples were analyzed for total soil organic carbon (SOC). Water samples were analyzed for pH and electrical conductivity (EC), total dissolved solids (TDS) in the laboratory of Agriculture & Soil Department, IIRS using standard analytical methods.

RESULTS

Water quality and soil analyses

LULC-wise details of parameters were analyzed for

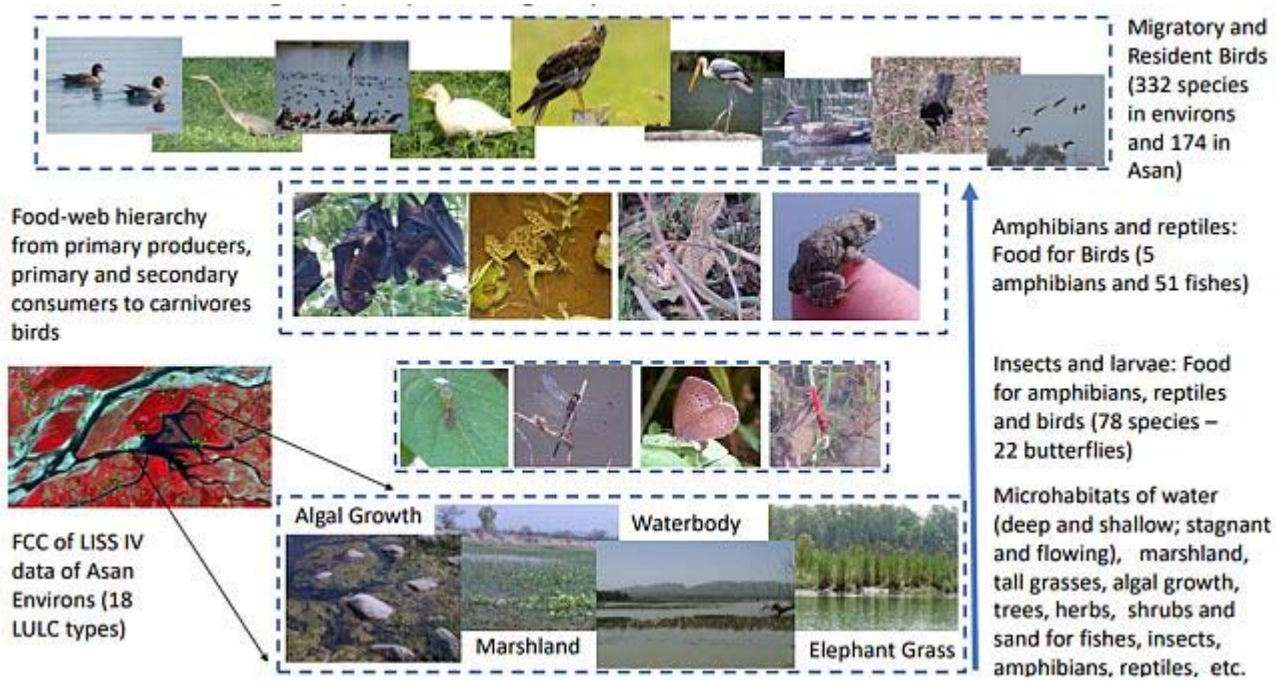

Figure 2. Aquatic and terrestrial biodiversity and habitat heterogeneity in and around Asan Conservation Reserve indicating complex food-web for migratory and resident birds

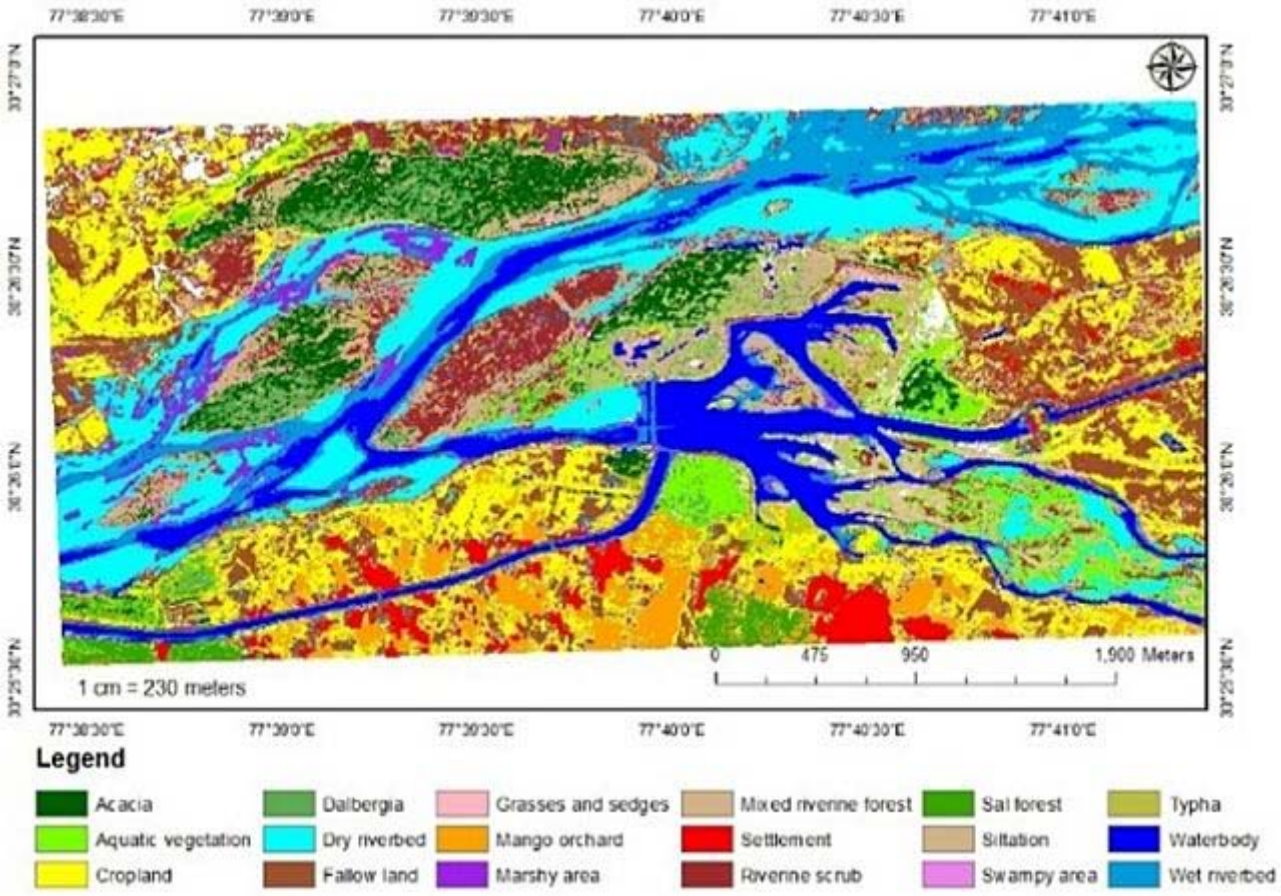

Figure 3. Wetland and Land Use/Land Cover type map (October 2016)

physicochemical characteristics (Table 1) and compared with the Bureau of Indian Standards (BIS: 10500:1991). While the pH level of birds residential area is acidic (5.61), various swampy and marshy patches near barrage and canal area are slightly acidic, ranging from 6.16 to 6.53, good for the survival of larvae, and pH level from the Asan riverside area is neutral (7.2). The TDS ranged from 53.24 to 285.5 µS/cm. TSOC range varied from 0.4 to 1.7%, therefore, there is no harm to aquatic life in the current situation.

Habitat characterization for butterflies

22 species of butterflies were recorded. Herbaceous and shrubby vegetation and agricultural land are more preferred habitats than forests. The congregation of butterflies feeds on small puddles on the ground, wet riverbed, sandy areas, fresh animal dung, and on leaves. Both frugivorous and non-frugivorous butterflies rely primarily on vegetation for nutrition, mating, and reproduction (Bharadwaj et al. 2012). Butterflies can feed on anything that can dissolve in water, such as nectar from flowers, tree sap, pollen, or rotting fruit. The food plants of larvae and adults are very much specific. The host plants (plants fed upon by caterpillars) often differ entirely from the vegetation required by adult butterflies, which are commonly nectar sources. Caterpillars feed on leaves of various trees, shrubs, herbs, legumes, forbs, grasses, and sedges, whereas adult butterflies feed on different flowering plants and wildflowers (Schmitt and Rakosy 2007). Since ACR is a heterogeneous mosaic, the requirements of larvae and adult are met within the riverine forest and grasslands, shrubs, orchards of mango and litchi, excellent and abundant fertile croplands, and wetland areas with different flowering and non-flowering plants. These microhabitats become highly suitable for butterflies, which are at the bottom of the trophic level in the food web. Since the area has a very diverse landscape, it supports the growth of butterflies during all the stages of the life cycle. Species-wise habitat requirements are summarized in Table 2.

Habitat characterization of amphibians

Amphibians are prey and predators, and play a significant role in ecological food webs in and around wetland ecosystems, and require aquatic and terrestrial habitats because of their unique and complex life cycles. ACR also provides a wide range of terrestrial habitats adjacent to wetlands and streams, typically consisting of leaf litter, coarse woody material, boulders, small mammal burrows, crack in rocks, rocky pools for foraging, etc. Damp areas, river streams, swamps, marshy areas, mud puddles, moist soil, wet and dry riverbed are helpful to burrow to keep their skin moist. Frogs and Salamanders breed in vernal pools (Keddy 2010) and live in forests, riverine vegetation, marshy areas, etc., in the periphery of the core wetland. Wetland provides appropriate habitat for laying the eggs, tadpole/larval development, and adult stage feeding and mating. They generally breed and lay eggs in a

Table 1. Hydro-chemical parameters of water and soil samples at study locations

Sampled areas	Latitude (decimal degree)	Longitude (decimal degree)	pH	EC (µS/cm)	TDS (ppm)	TOC (%)
Swamp	30.43577	77.676196	6.35	53.24	53.24	1.32
Marsh	30.43623	77.675326	6.37	68.40	68.40	0.79
Marsh	30.43616	77.674768	6.19	83.32	83.32	1.70
Residential	30.43644	77.676839	5.61	96.76	96.76	0.40
Swamp	30.43671	77.665819	6.31	66.61	66.61	0.32
Near Canal	30.44175	77.660381	6.37	79.71	79.71	1.42
Near riverbed	30.44451	77.670978	6.53	131.8	131.80	0.49
Near riverbed	30.44561	77.670978	7.20	186.4	186.40	0.43
Near barrage	30.44261	77.669457	6.31	118.1	118.10	0.93
Swamp	30.44225	77.671292	6.22	285.5	285.50	0.79

wetland where they remain throughout their larval stage. Because of their close contact with air, water, and soil, amphibians are considered good indicators of environmental health. We noted the presence of several *Fejervarya* spp. (Complex group) and *Euphlyctis cyanophlyctis*. These two amphibian species belong to the two families of the order Anura: (a) family: Dicroglossidae, sub-family: Dicroglossinae, and (b) family: Dicroglossidae, sub-family: Dicroglossinae, respectively. The reported occurrence of *Fejervarya* species in ACR and Doon valley needs the attention of conservationists and management for protection. Although no illegal trade of the species is reported from India, there may be a possibility of unlawful trade as it is going on in other Asian countries. Since the area is rich in vertebrate and invertebrate diversity, it provides food during the larval and adult stages of amphibians. The frog and toad tadpoles feed on algae, plant detritus, leaves, and other tadpoles. Adult frogs, toads, and salamanders take worms, insects including butterflies, mice, reptiles, small snakes, snails, slugs, spiders, termites, and other invertebrates. The larvae of salamanders feed on insects and other invertebrates, small crustaceans, tadpoles, zooplankton, other salamander larvae (Table 3).

Habitat characterization for birds

Birds prefer heterogeneous habitat conditions, and open landscapes. ACR environs is a heterogeneous mix of submerged and aquatic vegetation, mix of terrestrial natural and man-made vegetation of trees, shrubs, grassland, sedges, marsh and swamp patches, silted areas, dry sand, etc. The bird species of duck, egret, dove, cormorant, coot, hornbill, grebe, stork, heron, eagle, hawk, tern, cuckoo, owl, kingfisher, bee-eater, hoopoe, barbet, woodpecker, parakeet, minivet, shrike, drongo, treepie, magpie, fantail, crow, lark, bulbul, babbler, robin, myna, bush chat, starling, sunbird, sparrow, etc. reside in the area throughout the year. During the present study, the Zoological Survey of India team recorded 174 species of birds, categorized as summer migrants, winter migrants, passage migrants, and resident birds. The habitats are suitable for about 17 winter migrants, 26 summer migrants, eight passage migrants, and 122 resident birds (Mohan et al. 2016, Anonymous 2016). Aquatic birds rely on aquatic plants to meet a large variety of needs during their life cycles. A few birds nest directly on aquatic plants, whereas others use plants as nesting material, foraging platforms, resting, and refuge from predators. Red-crested Pochards, Eurasian Wigeons, Cormorants, and Ruddy Shelducks are found near the deep-water area of the barrage. In contrast, others are found near shallow water, where they can roost and forage. Birds prey on 23 species of fishes that belong to 7 families (Malik et al. 2015). Most of the visiting migratory birds belong to the family Anatidae of order Anseriformes, and Accipitridae of Accipitriformes to complete their life cycle. *Anser indicus* (Bar-headed Goose) feeds mainly at night in cultivated field or grassland on riverbanks and roosts during day time on sandbanks of large river. The area is also suitable for a substantial number of resident aquatic birds and passerines. *Tadorna ferruginea* (Ruddy Shelduck) comes to this wetland for wintering. It feeds by grazing on banks of rivers and lakes, also by wading in shallow, dabbling, and upending. Species like *Anas penelope* (Eurasian Wigeon) feed chiefly by grazing on the waterside, grasslands, wet paddy fields and reservoirs, rivers, swamps, and marshes. *Anas acuta* (Northern Pintail) forages at night and in early morning and evening hours in marshes and shallow water in paddy fields, roosts during the day on the open water surface, and under aquatic reeds. These two aquatic birds are known to use agricultural fields adjoining the wetlands (Fig. 4).

The presence of wet grassland, agricultural land, rivers, fresh waters, plentiful submerged and fringing vegetation along with reservoirs with large areas of open water, reed beds, marshes, and swamps known to attract several Anatidae like *Anser anser* (Graylag Goose), *Anas clypeata* (Northern Shoveler), *Anas crecca* (Green-winged Teal), *Netta rufina* (Red-crested Pochard), *Aythya ferina* (Common Pochard), *Aythya fuligula* (Tufted Duck), raptors such as *Pandion haliaetus* (Osprey), *Circus aeruginosus* (Eurasian Marsh-Harrier), and waders namely *Tringane bularia* (Common Greenshank) and *Tringa tetanus* (Common Redshank) find it suitable for their feeding activities. An endangered and rare species of eagle namely Pallas's Fish Eagle (*Haliaeetus leucoryphus*) breeds at ACR. Occurrence of this species at ACR is the main attraction for many visitors, and it is regarded as 'flagship species'. Gradual increase in the riverine forest and water in

Table 2. Habitat requipments of butterflies

Species	Habitats/Requirements
Ariadne merione and ***tapestrina*** Moore	prefers forested to lightly wooded areas, also seen in gardens; feed on *Ricinus communis, Tragia involucrata Tragia plukenetii.*
Castalius rosimon Fabricius	prefers sunshine, mud puddles, visits flowers, dead insects, and bird droppings and found in open-lands and the forested region and feeds on *Ziziphus mauritiana*, *Z. rugosa*, etc.
Catopsilia pyranthe pyranthe L.	visits gardens, damp patches, and city roads and feeds on *Cassia auriculata, C. fistula, C. occidentalis, C. tora, Sesbania bispinosa*, etc.
Cepora nerrisa phryne Fabricius	prefers scrublands and farmlands, and puddles mud in hot weather and its food plants are *Cadaba fruticosa, Capparis decidua, C. sepiaria, C. zeylanica, Cratavea adansonii, Maerua oblongifolia,* etc.
Danaus genutia genutia Cramer	inhabits open forests and scrub and its food plants are *Asclepias curassavica* (Curassavian Swallow-wort), *Cynanchum dalhousiae, Cynanchum liukiuense, Marsdenia roylei* (Riyong), *Raphistemma pulchellum, Stepha notis floribunda, Tylophora carnosa* and other wild Asclepids, *Ageratum conyzoides, Celosia argentia, Crotalaria retusa, Heliotropium indicum, Lantana camara., Tagetes erecta, Trichodesma indicum* and *Tridax procumbens.*
Danus chrysippus chrysippus L.	prefers mostly open regions, forest glades, gardens, etc. and its food plants are *Antirrhinum majus* and *Viola* sp.
Euploea core core Cramer	is a slow-flying butterfly and it sails lazily along in different types of trees, shrubs, and bushes for its foodstuff. It feeds on *Ficus benghalensis*, *F. glomerata*, *F. indica, F. religiosa, Hemidesmus indicus*, *Nerium oleander*, etc
Eurema hecabe hecabe L.	visits flowers and damp places for resting and its larva feeds on mostly on leguminous plants such as *Acacia* sp., *Senna obtusifolia, S. grandiflo, Cassia fistula, C. mimosoides, C. tora, Albizia procera*
Junonia almana almana L.	is one of the prettiest of the Indian butterflies and prefers the hottest and sunniest places, and is particularly fond of dry river beds, stony uncultivated ground, and roads. It flies just above the ground, often settling on flowers and the ground and it feeds on *Barleria* sp., *Gloxinia* sp., *Hygrophila auriculata, Nelsonia canescens, Oryza sativa,* etc.
Leptosia nina nina Fabricius	is found mainly on shrubs and jungles and it flies almost incessantly, close to the ground and it feeds on *Cleome viscosa, Capparis rheedii, C. sepiaria, C. spinosa, C. zeylanica, Crataeva adansonii,* etc.
Leptotes plinius Fabricius	prefers open, drier regions, but also seen at the edges of the forest, bushes, seen on damp patches, and feed on *Albizia lebbek, Indigofera* spp., *Sesbania bispinosa, Mimosa* spp., *Dyerophytum indicum, Plumbago zeylanica*
Melanitis leda ismene Cramer	is fond of ripened fruits. During the daytime, it takes shelter in under-growth or among bushes or on the roots of trees, or even in residential areas to avoid predators. In the monsoon months, it flies over the rice fields in the morning and evening, most probably in quest of a mate. Its food plants are *Ficus religiosa*, Grasses, *Oryza sativa*, *Panicum maximum, Sorghum vulgare, Zea maize*.
Neptis hylas L.	found in hot and dry weather resting on wet patches or damp stones to suck up moistures and it keeps its wings closed over the back in the usual manner. It is widespread in woods, gardens, damp places, and forested nullahs in the hills. Its food plants are trees of various species of Fabaceae, Malvaceae, and Oleaceae family plants.
Papilio polytes romulus Cramer	prefers the shelter of bushes, thick jungle, and hedges. It does not come to wet locations but is fond of visiting flowers and it occurs commonly in open woods and gardens at low elevations. Its food plants are mostly *Murraya koenigii*, *Glycosmis pentaphylla*), *Grewia sclerophylla*.
Parantica aglea Stoll	congregates on marshy and swampy areas.
Phalanta phalantha phalantha Drury	is found at the forest edges and comes to flower and damp patches and feed on *Flacourtia ramontchi, F. sepiaria.*
Pieris canidia indica Evans	is the most ubiquitous butterfly in the hilly areas. Flies around bushes and shrubs and it comes to flowers and damp patches on hot and dry days. It feeds on *Nasturtium* spp*, Rorippa dubia,* Cabbage, and related plants
Pseudozizeeria maha Kollar	is fond of the sunshine and basks with its wings partly open, but when it feeds or rests, it keeps its wings closed. It is abundant in the hills but much less on the plains. The females are found in the well-shaded positions, along ditches, by the sides of the water, and under trees.
Symbrenthia lilaea Hewitson	settles on rocks near moist sand and feeds on *Debregeasia* sp., *Elatostema* sp.
Vanessa cardui L.	flies firmly and swiftly in open places - wasteland and gardens. It frequently settles on the ground or a leaf and returning to these spots when disturbed. While feeding on low-growing flowers or bask on the ground, it keeps its wings half open and gently oscillates to and fro. Its food plants are *Argemone mexicana*, *Artemisia vulgaris*, *Blumea* sp., *Corius arvensis, Debregeasia bicolor, Zornia diphylla*, many other plants of families Boraginaceae and Malvaceae.
Ypthima hüebneri Kirby	prefers forested hills as well as open country and feeds on grasses.
Zizeeria karsandra Moore	is found in a low, ground-level grassy patch, visits flowers, feeds on *Amaranthus spinosus, Zornia gibbosa, Polygonum plebejum* and *Tribulus terrestris.*

Table 3. Details of the habitat characterization of amphibians of Asan wetland

Amphibian Species	Habitat Requirement	Food Requirement	Behavior
Fejervarya spp.	Various aquatic habitats such as ponds, marshes, rice fields, and slow-moving streams. May inhabit areas with standing water, including temporary water bodies.	Insect larvae, small invertebrates, and aquatic organisms.	Nocturnal or crepuscular activity. Known for distinctive calls during the breeding season.
Euphlyctis cyanophlyctis	Freshwater habitats, including ponds, marshes, ditches, and slow-flowing streams. Adapts to natural and human-altered environments. Found in rice fields and agricultural water bodies.	Insects, small invertebrates, and aquatic prey.	Nocturnal or crepuscular. Often basks in the sun. Vocalizations during breeding season.

Table 4. Details of habitat for birds and their significance of Asan wetland

Bird species	Habitat requirement	Food requirement	Behavior	Migration status	Importance
Tadorna ferruginea	Wetlands, marshes, lakes, and coastal areas	Aquatic plants, insects, and small invertebrates	Social, often found in flocks	Partial migratory	Important for maintaining wetland ecosystems
Anas penelope	Lakes, ponds, marshes, and coastal areas	Aquatic plants, seeds, and small invertebrates	Social, forms large flocks during migration	Partial migratory	Ecological balance, contributes to seed dispersal
Anas acuta	Lakes, ponds, rivers, and wetlands	Aquatic plants, seeds, insects, and small crustaceans	Social, forages by dabbling	Migratory (long-distance)	Important for controlling aquatic invertebrates
Anser anser	Wetlands, grasslands, and agricultural areas	Grasses, grains, and agricultural crops	Social, forms large flocks during migration	Partial migratory	Culturally significant, contributes to nutrient cycling in agricultural fields
Anas clypeata	Shallow lakes, ponds, and marshes	Aquatic plants, seeds, and small invertebrates	Social, often seen in small groups	Migratory (long-distance)	Important for maintaining biodiversity in wetlands
Anas crecca	Ponds, lakes, marshes, and wet grasslands	Aquatic plants, seeds, and small invertebrates	Social, forms dense flocks during migration	Migratory (long-distance)	Important for nutrient cycling in wetland ecosystems
Netta rufina	Lakes, ponds, and rivers	Aquatic plants, seeds, and small invertebrates	Social, often seen in small groups	Migratory (long-distance)	Plays a role in controlling aquatic plants

Bird species	Habitat requirement	Food requirement	Behavior	Migration status	Importance
Aythya ferina	Lakes, reservoirs, and slow-flowing rivers	Aquatic plants, seeds, and small invertebrates	Solitary or in small groups, dives for food	Migratory (long-distance)	Important for controlling aquatic invertebrates
Aythya fuligula	Lakes, ponds, and rivers	Aquatic plants, seeds, and small invertebrates	Social, often seen in small groups	Migratory (long-distance)	Important for maintaining biodiversity in aquatic ecosystems
Pandion haliaetus	Coastal areas, lakes, and rivers	Fish	Solitary, known for hovering over water before diving	Migratory (long-distance)	Apex predator in aquatic ecosystems, helps regulate fish populations
Circus aeruginosus	Marshes, wetlands, grasslands, and agricultural areas	Small mammals, birds, and insects	Agile fliers, often seen gliding low over the ground	Migratory (long-distance)	Important for controlling rodent populations in agricultural areas
Tringane bularia	Tundra, marshes, and wetlands	Insects, larvae, and small invertebrates	Energetic feeders, often seen running along the ground	Migratory (long-distance)	Plays a role in regulating insect populations in tundra ecosystems
Tringa tetanus	Coastal areas, mudflats, and estuaries	Insects, worms, and small crustaceans	Forages by wading, often in shallow water	Migratory (long-distance)	Important for controlling invertebrate populations in coastal ecosystems
Haliaeetus leucoryphus	Large rivers, lakes, and marshes	Fish, birds, and carrion	Solitary, powerful fliers	Resident	Apex predator in aquatic ecosystems, maintains ecological balance
Clamator jacobinus	Wooded areas, forests, and open habitats	Fruits, insects, and small vertebrates	Loud calls, often conspicuously perches in trees	Resident	Contributes to seed dispersal in forest ecosystems
Cuculus canorus	Woodlands, forests, and open areas	Insects and caterpillars	Brood parasitism, lays eggs in the nests of other birds	Migratory (long-distance)	Regulates insect populations, contributes to forest health
Surniculus lugubris	Wooded areas, open habitats, and gardens	Insects and small vertebrates	Active hunters, often seen catching insects on the wing	Resident	Helps control insect populations in and around human settlements
Phylloscopus trochiloides	Woodlands, forests, and shrublands	Insects, spiders, and small invertebrates	Active foragers, often seen in tree canopies	Migratory (long-distance)	Important for controlling insect populations in forests
Niltava sundara	Forests, wooded areas, and foothills	Insects, fruits, and berries	Active foragers, often perches in the forest understory	Resident	Contributes to seed dispersal in forest ecosystems
Petronia xanthocollis	Open habitats, grasslands, and scrub areas	Seeds, grains, and small invertebrates	Social, often seen in large flocks	Resident	Important for seed dispersal in open habitats

the reservoir and adjacent agricultural land attracts migratory birds. Forest birds like *Clamator jacobinus* (Pied Cuckoo), *Cuculus canorus* (Common Cuckoo), *Surniculus lugubris* (Square-tailed Drongo-Cuckoo), *Phylloscopus trochiloides* (Greenish Warbler), and *Niltava sundara* (Rufous-bellied Niltava) are regularly attracted by the mixed forest patches. Birds like *Petronia xanthocollis* (Chestnut-shouldered Petronia) prefer open dry forest, thorn scrub trees, at the edge of cultivation and near the plantation.

The agricultural land, plantations, and orchards attract birds like *Streptopelia decaocto* (Eurasian Collared-Dove), *Cuculus canorus* (Common Cuckoo), *Eumyias thalassinus* (Verditer Flycatcher), and *Phoenicurus ochruros* (Black Redstart). *Motacilla alba* (White Wagtail) visits the reserve. Birds like *Ciconia episcopus* (Woolly-necked Stork) and *Ixobrychus sinensis* (Yellow Bittern) require flooded paddy and other irrigated agricultural land in addition to aquatic vegetation. Birds like *Phalacrocorax carbo* (Great Cormorant), *Nycticorax nycticorax* (Black-crowned Night-Heron), *Circus aeruginosus* (Eurasian Marsh-Harrier), *Milvus migrans* (Black Kite), etc. visit for roosting, nesting, and feeding as feed on fish, amphibians, turtles, snakes, lizards, adult and larval insects (beetles, bugs, grasshoppers, crickets, flies and dragonflies), spiders, crustaceans, mollusks, leeches, small rodents, bats and the eggs and chicks of other bird species which are primarily available. The landscape mosaic of village tanks, reservoirs, ditches, swampy, marshy ground, wet grasslands, riverine scrubland, and slow-moving rivers attracts birds like *Tachybaptus ruficollis* (Little Grebe), *Apus apus* (Common Swift), *Merops philippinus* (Blue-tailed Bee-eater), *Phylloscopus trochiloides* (Greenish Warbler), *Niltava sundara* (Rufous-bellied Niltava), *Luscinia svecica* (Bluethroat) and *Saxicola caprata* (Pied Bushchat). Based on the habitat requirements and preferences of the different birds, prey species, and

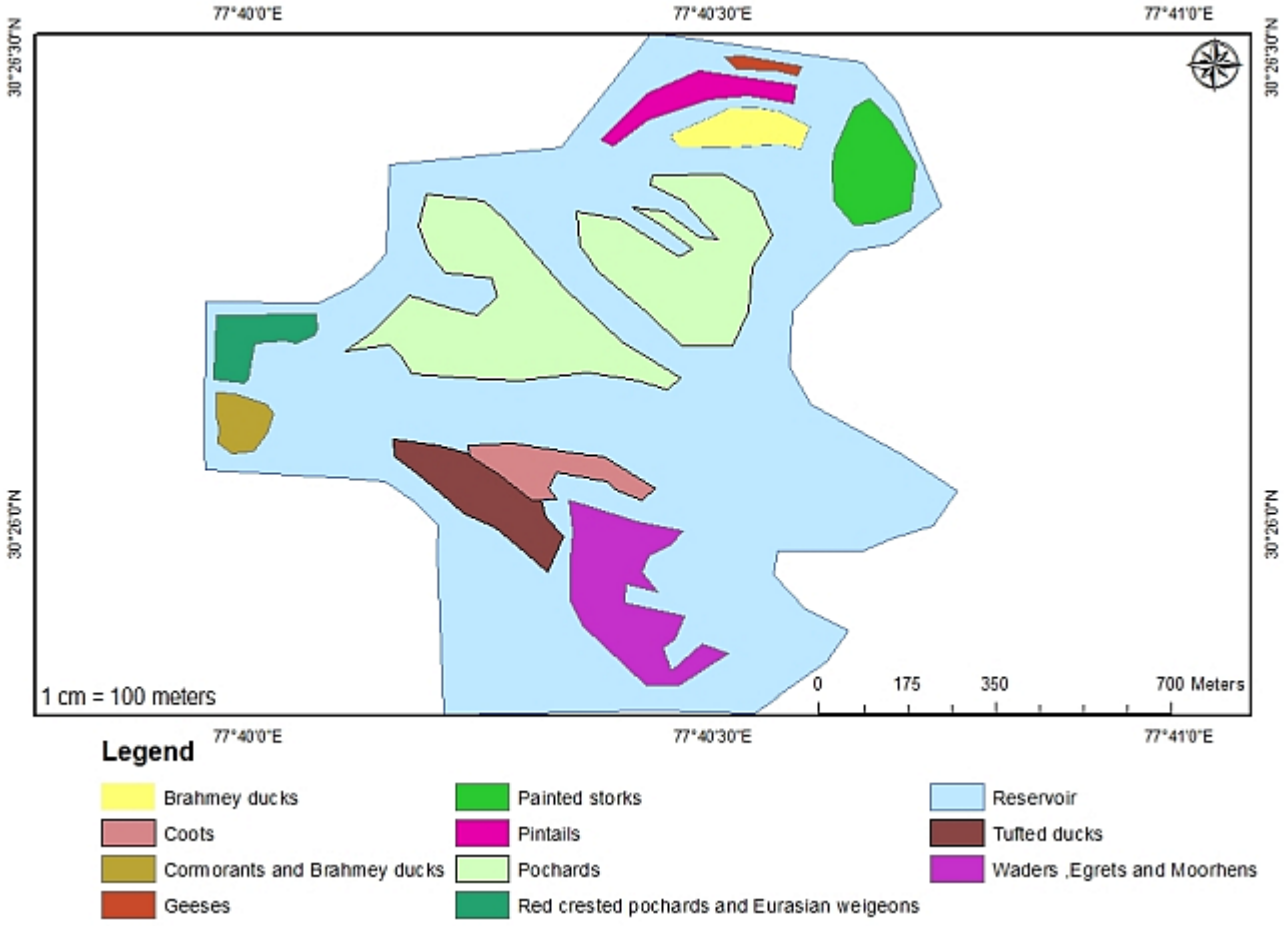

Figure 4. Micro-habitat map for different migratory and residents birds

Table 5. Summary of habitat use by prominent birds/bird-groups

Description
Most of the migratory birds visiting belong to the order: Anseriformes, family Anatidae; and order: Accipitriformes, family Accipitridae. One of the purposes to visit is to complete their life cycle. *Anser indicus* (Bar-headed Goose) feeds mainly at night in cultivation or grassland on riverbanks; roosts by day on sandbanks. *Tadorna ferruginea* (Ruddy Shelduck) comes for wintering. It feeds by grazing on banks of rivers and lakes, also by wading in shallow, dabbling, and upending.
Species like *Mareca penelope* (Eurasian Wigeon) feed chiefly by grazing on watersides, grasslands, reservoirs, rivers, swamps, marshes, and wet paddy fields. *Anas acuta* (Northern Pintail) forages at night and in the early morning and evening in marshes and flooded paddy fields, roosts by day on open waters in aquatic vegetation and fresh waters (Grimmet et al. 2011).
The availability of marshland, agricultural land, rivers, fresh waters, plentiful submerged and fringing vegetation along with reservoirs with large areas of open water, reed-beds, marshes, and swamps attracts birds like *Anser anser* (Graylag goose), *Anas clypeata* (Northern Shoveler), *Anas crecca* (Green-winged Teal), *Netta rufina* (Red-crested Pochard), *Aythya ferina* (Common Pochard), *Aythya fuligula* (Tufted Duck), *Pandion haliaetus* (Osprey), *Circus aeruginosus* (Western Marsh-Harrier), *Tringa nebularia* (Common Greenshank) and *Tringa totanus* (Common Redshank) and find it suitable for wintering.
Gradual increase in the riverine forest, water in the reservoir, and adjacent agricultural land, attracts summer migratory birds. The mixed forest patches are a habitat for forest birds such as *Clamator jacobinus* (Pied Cuckoo), *Cuculus canorus* (Common Cuckoo), *Surniculus lugubris* (Square-tailed Drongo-Cuckoo), *Phylloscopus trochiloides* (Greenish Warbler), and *Niltava sundara* (Rufous-bellied Niltava. Birds like *Gymnoris xanthocollis* (Chestnut-shouldered Petronia) prefer open dry forest, thorn scrub trees, at the edge of cultivation and near the plantation.
As ACR is amidst agriculture field along with plantation and orchard offering another set of ecological requirements for birds like *Streptopelia decaocto* (Eurasian Collared-Dove), *Cuculus canorus* (Common Cuckoo), *Eumyias thalassinus* (Verditer Flycatcher), and *Phoenicurus ochruros* (Black Redstart). *Motacilla alba* (White Wagtail) visits the reserve regularly (Grimmet et al. 2011). Birds like *Ciconia episcopus* (Woolly-necked Stork) and *Ixobrychus sinensis* (Yellow Bittern) require flooded paddy and other irrigated agricultural land in addition to aquatic vegetation.
The current landscape mosaic of village tanks, reservoirs, ditches, swamps, marshy ground, wet grasslands, and riverine scrubland in slow-moving and shallow rivers attracts birds like *Tachybaptus ruficollis* (Little Grebe), *Apus apus* (Common Swift), *Merops philippinus* (Blue-tailed Bee-eater), *Phylloscopus trochiloides* (Greenish Warbler), *Niltava sundara* (Rufous-bellied Niltava), *Luscinia svecica* (Bluethroat) and *Saxicola caprata* (Pied Bushchat). Woodpeckers are considered keystone species (Johnson 1993). The presence of high species richness of birds is an indicator of the range of conditions and habitats wider biodiversity in forests (Ferris and Humphrey 1999).
Various passage migrants, such as *Phalacrocorax carbo* (Great Cormorant), *Nycticorax nycticorax* (Black-crowned Night-Heron), *Circus aeruginosus* (Western Marsh-Harrier), and *Milvus migrans* (Black Kite), halt for roosting, nesting and feeding. And forage on a wide range of prey species, such as amphibians, turtles, snakes, lizards, adult and larval insects (beetles, bugs, grasshoppers, crickets, flies, and dragonflies), spiders, crustaceans, mollusks, leeches, small rodents, bats; and eggs and chicks of other bird species.
Wildlife managers often strive to maintain “Hemi-marsh” with a 50:50 ratio of emergent vegetation and open water and sources of plant diversity (Verry 1989, Keddy 2010). The Spatio-temporal analysis indicates that ACR has a balance of 60:40 with very high plant and ecosystems diversity in adjoining areas with Riverine forests, shrubs, marshes, grassland, dry and moist sand, cropland, floating vegetation, etc. The management needs to maintain this ratio and wetland quality to main the aquatic biodiversity of fishes and amphibians for attracting migratory as well as resident birds. More growth of macrophytes would negatively affect the fish numbers (Malik et al. 2015). Ongoing eutrophication and silting will enhance the succession speed and will alter the wetland characteristics.
Desilting needs to be carefully done to maintain the desired mixture of habitat types, heterogeneity, different biota, succession, and water levels. A slight or moderate level of eutrophication needs to be held to keep the low turbidly level, survival of different life-forms, and increased productivity. The experience says that wetlands are to be maintained for birds and amphibians and species like dragonflies and diving beetles (Clegg 1986, Mead 2003). Conservation of single species (flagship, umbrella, or keystone) is neither advisable nor ecologically sustainable in tropical countries. The landscape-level approach is essential (Simberloff 1998). However, the single-species conservation has not been very successful in Europe, N. America, S. Africa, Australia, and Japan, where biodiversity richness is relatively less, and understanding of the ecosystems is advanced (New et al. 1995). Therefore, management should not focus on single species or groups of species such as birds alone or only wetland areas. Still, the entire landscape of Doon valley on both banks of river Yamuna spread in the states of Uttarakhand and Himachal Pradesh, as biodiversity does not recognize administrative boundaries instead ecological boundaries.

their presence-absence information from field observations, the entire wetland is broadly categorized into different zones of microhabitats (Fig. 4, Table 4). Based on literature (Grimmet et al. 2011) and our observations, habitat use by the prominent birds is summarized in Table 5.

DISCUSSION

'U'-shaped Doon valley, a vast mosaicked heterogeneous landscape of natural forests of tropical riparian, subtropical pine to temperate broadleaf forests interspersed by large rivers to innumerable streams of different orders and variety of ecosystems, is a perfect setting for birds. The spatial habitat heterogeneity of forests and canopy stratification, pattern of landscape mosaic, microclimatic variations, etc. are crucial for high biodiversity at different trophic levels. However, river-terraces upstream of the Asan River are fast changing to intensive agriculture, urbanization, and industrialization and therefore, LULC change is a potential cause of eutrophication and a threat to ACR environs. The nutrient supply alters both primary and secondary productivity in any ecosystem, and biota may respond drastically with changes in species composition, species richness and ecosystem productivity (Prasad et al. 2002). In the aquatic environment, the life forms are in continuous contact with chemical solutions and suspended material, which enter their body through membranes, gills, skin, and mouth. Therefore, periodic water quality assessment for its chemical constituents is important to maintain the optimum nutrients, pH, oxygen, N:P ratios, and other micronutrients. The acid-base status regulates physiological process of aquatic living organism, especially fishes (Truchot and Forgue 1998, Nunan et al. 2019). The blood pH of fishes varies from 7-8, and less than 5 and more than 10 causes stress and death (Wurtz and Durborow 1992). Decreased pH levels will promote the growth of fen species (Keddy 2010). The O_2 and CO_2 (high concentration at night due to respiration) balance is maintained due to continuous flow of fresh water in ACR. The pH, one of the most primary factors to affect life forms, is slightly acidic in the marshy and swampy areas (6.16 to 6.53) and neutral (7.2) in the riverside. The alkaline (8.5 to 9.5) water does not harbor living organisms (Devi et al. 2017). Malik et al. (2015) reported pH ranged from 7.1-7.5 in the core wetland area in ACR. The desirable range of water pH in the wetland area should lie within 6.5 to 8.5. Excessively high or low pH would lead to the death of aquatic animals. EC indicates the ionic concentration in the presence of salts, silts, and sediments in a freshwater ecosystem (Koul 1990), which is within the range of 53.24 to 285.5 µS/cm, and is also contributed by the nearby agricultural fields, rainfall, and benthic biodiversity. This range supports the survival of aquatic fauna within. According to Bureau Indian Standards (BIS) less than 500 µS/cm is suitable for aquatic flora and fauna. Salinity decreases biodiversity richness, therefore, it is critical to maintain optimum limits. A balance of vegetated and water (60:40) is important to maintain the pH of the water nearly neutral as decomposition of aquatic macrophytes is attributed to lower the pH. pH level is an indicator of good fish community habitat and structure (Koul 1990). TDS is directly related to trophodynamics and its concentrations determine the flow of water into and out of an organism's cells through osmosis. High salinity and low soil oxygen can limit growth (Keddy 2010). If it becomes higher then it increases the density of water, which ultimately leads to an increase in osmoregulation. Higher carbon or organic content leads to more oxygen consumption. A high organic content would increase the growth of microorganisms, which contributes to the depletion of oxygen supplies. In ACR, the oxygen-balance is maintained with the continuous freshwater flow from the catchment. However, faster water currents have negative impact on number of fishes (Malik et al. 2015). The constant and nearly controlled flow carrying sediments and nutrient-rich water helps in good growth of aquatic vegetation, primary productivity, and linked secondary productivity of animals in the food chain of birds. Cattails plant-like *Typha elephantina* (Family Poaceae) has perennial rhizomatous root-system and can grow in shallow and moderately deep water contributing hugely to the productivity and enriching soil of the wetland. The water and soil analyses showed that pH, EC, TDS, and TOC are in permissible range and it may be said that ACR is currently a healthy habitat and the continuous flow of water maintains the

desired level TDS, pH, total solid sediments, and other pollutants.

Physicochemical analysis indicates that the pH, EC, TDS and total organic carbon are within the permissible limits indicating the high habitat suitability of wetland supporting various life stages of amphibians. pH level of 6 or more helps spawn and tadpole development successfully (Baker et al. 2011). As the primary water parameters are within the acceptable range, benthic organisms (such as odonatan, Coleoptera, Annelida, mollusks, and larvae) can complete their part or whole of their lifecycle. Among the large number of invertebrates, which belong to 78 species of 53 genera belonging to 21 families (Tak et al. 2003), inhabiting sediments and silts, are part of food-chain. Their number rises where streams are converted to reservoirs (Johnson et al. 1993). Butterflies, the flying flowers, form a crucial component in the food web-chain and are at the primary trophic level and important pollinators (anthophilous) and ACR with mosaic of LULC fulfills habitat requirements to complete their life cycle. High butterfly diversity indicates healthy ecosystem. These are the primary food sources for small and big bottom feeders along with vertebrate species such as amphibians, reptilians, Aves, and Mammalia associated with each other in the strong food web. The best amphibian breeding sites also tend to be 'good wildlife ponds' (Baker et al. 2011). Large birds mostly feed on fish and frogs. Birds are mainly insect eating, feeding on bark, gleaning the foliage surface (woodpeckers), presence of woodpeckers indicates old, dead trees and supply of invertebrates (Ferris and Humphrey 1999). Keystone species such as the black woodpecker promotes the development of habitat for other species. Wood and Gillman (1998) suggested to maintaining a heterogeneous mosaic of the landscape with undisturbed and natural vegetation; a network of other forest patches, different land use, and land covers with varied levels of management and disturbance. To maintain the community composition, the management interventions are recommended to control the monotypic stands of vegetation (Manral et al. 2012). Loss of wetlands quality by introducing new-age chemicals in agriculture threatens the life support system. Bird conservation practices like reduction in habitat loss, habitat deterioration, and habitat fragmentation need to focus on the small details like shielding bird nests, protecting migratory neighborhoods, and providing an eco-friendly environment to appreciate the large spectrum of life. Butterflies require multiple habitats (vegetation types) to satisfy their food and cover needs to complete their life cycle. In ACR, more butterflies have been reported from cropland. A few specific areas for butterflies may be identified and protected to enhance ecotourism. The use of pesticides needs to be regulated to maintain butterflies because these are highly susceptible to eutrophication and acidification (Oostermeijer and Swaay, 1998). Stephen Dickie (vide Chyb 2021) explains: "Birds plan their whole breeding season around when caterpillars will be most abundant. If the butterfly and caterpillar numbers are depleted, then there's not going to be a lot of food for developing chicks". The loss of butterflies may disturb the food chain (New et al. 1995).

The dredging causes abrupt changes in the habitat of narrow range invertebrates. Rahmani et al. (2016) recommended dredging after mid of March. Removing silt disturbs and reduces the population of annelids, amphibians, butterflies, etc., drastically. Therefore, the interval and impacts of dredging on various aspects need to be studied. The physicochemical properties in the aquatic ecosystem change more drastically than in the terrestrial ecosystem. Of-late eutrophication has enhanced the growth of exotic species belonging to the families of Poaceae, Asteraceae, and Verbenaceae. The minor change in hydrological parameters can alter the growth, reproduction, and development of aquatic fauna and their number and diversity, ultimately impacting the succession (Anitha et al. 2005). Maintaining different and appropriate water levels is essential. Shallow water increases the population of floating algae that can kill macrophytes. Decaying algae and macrophytes will consume oxygen and lead to hypoxic conditions harmful to fishes (Keddy 2010).

CONCLUSIONS

The presence of high number of migratory and resident birds and other fauna signifies the importance of ACR in Central-Indian Flyway and

East-Australian Flyway. Water analyses indicate that at present the water quality is within permission limits for various inhabiting species. The heterogeneous landscape provides suitable habitats for predatory and prey species to survive and possibly adapt to changing environmental set up. The mosaic of *Typha* (cattails), water and other vegetation favors the successful existence of the fauna. Butterflies and amphibians are crucial part of food chain, and therefore, maintenance and management of an optimal ratio of vegetation and marsh (60:40) is important for them to complete their lifecycle. As more butterflies have been reported from the agriculture field, the use of pesticides needs to be regulated and level of pesticides needs to be monitored particularly in winter and cropping seasons. Information on soil micro-fauna is scarce and impact of desilting/dredging on biota needs to be studied. The structural and functional dynamics of aquatic vegetation communities need to be studied because of the changing chemistry of the wetland and the possibility of changes in the fundamental character of the wetland due to eutrophication. More systematic studies and development of protocols are required to establish the "real" indicators and umbrella-flagship-keystone species and their interrelationship and influence, because conservation and sustainable management requires a good knowledge of abundance, distribution, and vulnerability of all species as the single species conservation may not serve the purpose. To save wetlands from encroachment and easy diversion there is strong need to change the legal status in land records.

ACKNOWLEDGMENTS

Authors are thankful to the authorities of the Indian Institute of Remote Sensing, ISRO, Dehradun for procuring and providing high-resolution LISS IV satellite data and extending facilities at Agriculture and Soils Lab, Forestry & Ecology Lab. Authors are grateful to the authorities of State Forest Department, Uttarakhand, Zoological Survey of India, Dehradun, and Botanical Survey of India, Dehradun, for facilitating the study and sharing expert knowledge in the identification of fauna and flora, respectively, and access to the reports and unpublished information.

Author's contribution: SS- conceptualization, study coordination, overall supervision, geospatial analyses, manuscript preparation, and editing, designing graphical abstract; RN geospatial data processing, LULC mapping, field data collection and analyses on soil and water and habitat, geospatial data integration and analyses, water analyses, manuscript writing and editing, AB (ZSI team lead) with AK and NS did field data and determination of fauna and microhabitats identification and editing and ZSI library consultation.

Conflict of interest: Authors declare that there is no conflict of interest.

REFERENCES

Amaraneni, S.R., Singh, S. and Joshi, P.K. 2004. Mapping the spatial distribution of air and water pollutants in Kolleru lake, India using geographical information systems (GIS). Management of Environmental Quality: An International Journal, 15(6), 584-607. https://doi.org/10.1108/14777830410560683.

Anitha, G., Chandrasekhar, S.V.A. and Kodarkar, M.S. 2005. Hydrography in relation to benthic microinvertebrates in Mir Alam Lake. Records of Zoological Survey of India, Hyderabad. Occasional Papers. dli.zoological.occpapers. 235

Anonymous 2006. Wildlife Protection Act 1972. Natraj Publishers, Dehradun.

Anonymous. 2011. National Wetland Atlas Space Applications Centre. SAC/EPSA/ABHG/NWIA/ ATLAS/34/2011 National Wetland Atlas - Uttarakhand, Space Applications Centre (ISRO) Ahmedabad, India. 130 pages.

Anonymous. 2016. Birds of Asan. Zoological Survey of India, NRC, Dehradun

Baker, J., Beebee T., Buckley, J., Gent, A. and Orchard, D. 2011. Amphibian Habitat Management Handbook. Amphibian and Reptile Conservation, Bournemouth.

Bhardwaj, M. and Uniyal, V.P. 2012. Butterflies of Wildlife Institute of India Campus, Chandrabani, Dehradun. Wildlife Institute of India, Dehradun, India.

Bhardwaj, M., Uniyal, V.P., Sanyal, A.K. and Singh, A.P. 2012. Butterfly communities along an elevational gradient in the Tons valley, Western Himalayas: implications of rapid assessment for insect conservation. Journal of Asia-Pacific Entomology, 15, 207-217. https://doi.org/10.1016/j.aspen.2011.12.003

Bhatt, B.J., Nissa, K.U. and Awaz, F. 2016. Study of fish fauna, species diversity and relative abundance of fishes in River Asan in Western Dehradun, Uttarakhand. International Journal of Pure & Applied Bioscience, 4 (4), 159-166. http://doi.org/10.18782/2320-7051.2314.

Burger, J. 2006. Bioindicators: Types, development, and use

in ecological assessment and research. Environmental Bioindicators, 1, 22-39. https://doi.org/10.1080/15555270590966483.

Carpenter, A.I., Dublin, H., Lau, M., Syed, G., McKay, J.E. and Moore. R.D. 2007. Overharvesting. Amphibian conservation action plan. International Union for Conservation of Nature, Glanz, Switzerland.

Chandra, K., Bharti, D., Kumar, S., Raghunathan, C., Gupta, D., Alfred, J.R.B. and Chowdhury, B.R. 2021. Faunal Diversity in Ramsar Wetlands of India, Zoological Survey of India and Wetland Division, Ministry of Environment, Forest and Climate Change, Government of India.

Chyb, A., Jedlikowski, J., W³odarczyk, R. and Minias, P. 2021. Consistent choice of landscape urbanization level across the annual cycle in a migratory waterbird species. Scientific Reports, 11(1), 1-10. https://doi.org/10.1038/s41598-020-80872-3.

Clegg, J. 1986. Pond Life. Frederick Warne, London

Deepa, R.S. and Ramachandra, T.V. 1999. Impact of Urbanization in the Interconnectivity of Wetlands. Paper presented at the National Symposium on Remote Sensing Applications for Natural Resources: Retrospective and Perspective (XIX-XXI 1999), Indian Society of Remote Sensing, Bangalore.

Devi, P.A., Padmavathy, P., Aanand, S. and Aruljothi, K. 2017. Review on water quality parameters in freshwater cage fish culture. International Journal of Applied Research, 3(5), 114-120. https://www.allresearchjournal.com/archives/2017/vol3issue5/PartB/3-4-180-123.pdf

Ferris, R. and Humphrey, J.W. 1999. A review of potential biodiversity indicators for application in British forests. Forestry, 72(4), 313-328. https://doi.org/10.1093/forestry/72.4.313.

Frost, D.R. 2007. Amphibian Species of the World: An Online Reference. Version 5.0 (1 February, 2007). Electronic Database accessible at http://research.amnh.org/herpetology/amphibia/index.php

Garg, J.K., Singh, T.S. and Murthy, T.V.R. 1998. Wetlands of India. Project Report: Space Applications Centre, Ahmedabad. RSAM/sac/resa/pr/01/98, 240 pages.

Gawler, M. 2000. Strategies for wise use of wetlands: Best practices in participatory management. IUCN – The World Conservation Union, Wetlands International and the World Wide Fund for Nature. 22 pages.

Ghazanfar, M., Malik, M.F., Hussain, M., Iqbal, R. and Younas,M. 2016. Butterflies and their contribution in ecosystem: A review. Journal of Entomology and Zoology Studies, 4(2), 115-118.

Ghermandi, A., van den Bergh J.C.J.M., Brander, L. and de Groot, H.L.F. 2008. The economic value to Wetland Conservation and Creation: A meta-analysis. FEEM Working paper No.79.2008. Available at SSRN http://dx.doi.org/10.2139/ssrn.1273002.

Gopal, B., Junk, W. J. and Davis, J. A. 2000. Biodiversity in Wetlands: assessment, function and conservation. Vol. 1. Backhuys Publishers, Leiden

Grewal, B., Sen, S.K. and Singh, A.P. 2008. Asan Barrage: The Lake of the Unexpected. Sanctuary Asia, 28(2), 64-65.

Grimmet, R., Inskipp, C. and Inskipp, T. 2011. Birds of the Indian Subcontinent. Helm Field Guides. Oxford University Press, UK.

Hocking, D.J. and Babbitt, K.J. 2014. Amphibian contributions to ecosystem services. Herpetological Conservation Biology, 9(1), 1-17. http://www.herpconbio.org/Volume_9/Issue_1/Hocking_Babbitt_2014.pdf.

Husain, A. 2015b. Amphibians of Doon Valley (Dehra Dun, Uttarakhand) with Their Systematics, Distribution, Ecology, Conservation Status and Threats. Pp. 217-230. In: Rawat, M., Dookia, S., Sivaperuman, C. (Eds.) Aquatic Ecosystem: Biodiversity, Ecology and Conservation. Springer, New Delhi.

Husain, A. 2015a. Fish Fauna of Asan River and its Tributaries, Western Doon Valley, Dehradun (Uttarakhand), with Conservation Status of Species and Threats. Pp. 231-270. In: Rawat, M., Dookia, S., Sivaperuman, C. (Eds.) Aquatic Ecosystem: Biodiversity, Ecology and Conservation. Springer, New Delhi.

Hussain, S.A. and De Roy, R. 1993. Directory of Indian Wetlands. WWF- India, New Delhi and A WB, Kuala Lumpur. xxvi +263 pages.

Johnson, K. 1993. The Black Woodpecker *Drycocopus martius* as a Keystone Species in Forest. Swedish University of Agricultural Sciences, Department of Wildlife Ecology, Uppsala, Report 24.

Johnson, R.K., Wiederholm, T. and Rosenberg, D.M. 1993. Freshwater Biomonitoring Using Individual Organisms, Populations and Species Assemblages of Benthic Macro-Invertebrates. Chapman & Hall, New York. 488 pages.

Kaushik, T.K. and Gupta, R.C. 2013. Understanding and analysing the coordinates of diversity of wetland birds of Asan Barrage near Ponta Sahib, Northern India. Our Nature, 11(2), 192-200.

Keddy, P.A. 2010. Wetland Ecology: Principles and Conservation, Cambridge University Press, 2nd edition, i-xvi, 497 pages.

Kittur, S., Padmawathe, R., Uniyal, V.P. and Sivakuamr, K. 2006. Some observations on the Butterflies of Simbalbara Wildlife Sanctuary, Himachal Pradesh. Indian Forester, 132 (12), 116-122.

Koul, V. 1990. Effect of industrial wastes and sewage on abiotic and biotic (macro benthos and fish) components of Behlol nullah, Jammu, Ph.D. Thesis, Jammu University, Jammu.

Kumar, A. and Porwal, M.C. 1998. Habitat evaluation of migratory waterfowls using remote sensing techniques. Project Report, Zoological Survey of India and National Remote Sensing Agency, Dehra Dun.

Kumar, A., Sati, J.P., Tak, P.C. and Alfred, J.R.B. 2005. Handbook on Indian Wetland Birds and their Conservation. Zoological Survey of India, Kolkata. i-xxvi; 468 pages.

Kumar, M.D., Panda, R., Niranjan, V. and Bassi, N. 2013. Technology choices and institutions for improving economic and livelihood benefits from multiple uses tanks in western Orissa. In: Kumar, M.D., Sivamohan, M.V.K., Bassi, N. (Eds.), Water Management, Food Security and

Sustainable Agriculture in Developing Economies. Routledge, Oxford, UK.

Lien, V.V. 2007. Ecological indicator role of butterflies in Tam Dao National Park, Vietnam. Russian Entomology Journal, 16 (4), 476-486. https://archive.org/details/rusentj-16-4-479-486

Mackinnon, P.W. and de Nicéville. L. 1899. List of butterflies of Mussoorie in the Western Himalayas and neighbouring region. Journal of Bombay Natural History Society, 11, 205-221, 368–389, 585–605.

Malik, D.S., Kumar, K. and Panwar, S. 2015. Status of fish diversity and their distribution in relation to habitat ecology in Asan reservoir of Garhwal Himalaya (India). Journal of Sustainable Environmental Research, 4 (1&2), 79-87.

Manjrekar, N. and Singh, R.L. (Eds.). 2012. Wetlands of Uttarakhand – A Documentation. Report jointly published by the Uttarakhand Forest, Department and World Wildlife Fund India, Dehradun, 194 pages.

Manral, U., Raha, A., Solanki, R., Hussain, S.A., Mohan, D., Talukdar, G. and Govindan, G.V. 2012. Hydrological characteristics and flood plain vegetation of human impacted wetlands: A case study from Okhla Bird Sanctuary, National Capital Region, India. Asian Journal of Conservation Biology, 1(2), 110-119.

Mead, K. 2003. Dragonflies of the North Woods. Kollath-Stensaas, Duluth, MN.

Meena, A.K. and Sharma, C. 2019. Wetlands in India: Ecosystem Benefits, Threats and Management Strategies pp, 117-131. In: Jayakumar, R. and Reddy, R. (Eds.) Research Trends in Multidisciplinary Research, AkiNik Publications, New Delhi.

Mohan, D. and Sondhi, S. 2015. An Updated Checklist of the Birds of Uttarakhand. Uttarakhand Forest Department, Dehradun.

Mohan, D., Singh, A.P., Sondhi, S., Kumar, R., Singh, P. and Datta, S.B. 2016. A checklist of Birds of Asan Conservation Reserve, Uttarakhand Forest Department, i-vi, 27 pages.

Mohan, D., Sinha, B.C., Bharadwaj, A.K., Udhayan, S.A., Hussain, V.P.O. and Sharma, R. 2009. Management Plan of Asan Conservation Reserve for 2009-10 to 2013-14. Wildlife Institute of India and Forest Department, Govt. of Uttarakhand, Dehradun.

Naik, R., Singh, S. and Bahuguna A. 2022. Monitoring and Management of Asan Reservoir Wetland and Environs using High Resolution Satellite data. International Journal of Ecology and Environmental Sciences, 48 (4), 423-438. http://dx.doi.org/10.55863/ijees.2022.0423.

New, T.R., Pyle, R.M., Thomas, J.A., Thomas, C.D. and Hammond, P.C. 1995. Butterfly conservation management. Annual Review of Entomology, 40, 57-83. https://doi.org/10.1146/annurev.en.40.010195.000421.

Nunan, B.L.C.Z., Silva, A.S., Wang, T. and Silva, G.S.F. 2019. Respiratory control of acid-base status in lungfish. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 237, 110533. https://doi.org/10.1016/j.cbpa.2019.110533.

Oostermeijer, J.G.B. and van Swaay, C.A.M. 1998. The relationship between butterflies and environmental indicator values: a tool for conservation in a changing landscape. Biological Conservation, 86, 271-280. https://doi.org/10.1016/S0006-3207(98)00040-8.

Panigrahy, S., Murthy, T.V.R., Patel, J.G. and Singh, T.S. 2012. Wetlands of India: inventory and assessment at 1/: 50, 000 scale using geospatial techniques. Current Science, 102(6), 852-856. https://www.jstor.org/stable/24084499

Patel, J.G., Panigrahy, S. and Parihar, J.S. 2015. National wetland database and information system: a step towards integrated planning for conservation of wetlands in India. Journal of Geomatics, 9(2),184-192.

Patel, T. 1993. French may eat Indonesia out of frogs. New Scientist, 1868, 7.

Pellet, J., Fleishman, E., Dobkin, D.S., Gander, A. and Murphy, D.D. 2007. An empirical evaluation of the area and isolation paradigm of meta population dynamics. Biological Conservation, 136, 483-495. doi:10.1016/j.biocon.2006.12.020.

Prasad, S.N., Ramchandra, T.V., Ahalya, N., Sengupta, T., Kumar, A., Tiwari, A.K., Vijayan, V.S. and Vijayan, L. 2002. Conservation of Wetlands in India – An overview. Tropical Ecology, 43(1), 173-186.

Rahmani, A.R., Islam, M.Z. and Kasambe, R.M. 2016. Important bird and biodiversity areas in India: Priority sites for Conservation (Revised and updated). pp. 1776-1837. In: Gayatri, U. and Maithreyi, M.R (Eds.). Indian Bird Conservation Network, Royal Society for the Protection of Birds and Bird Life International, U.K.

Schmitt, T. and Rakosy, L. 2007. Changes of traditional agrarian landscapes and their conservation implications: a case study of butterflies in Romania. Diversity Distributions 13, 855-862. https://doi.org/10.1111/j.1472-4642.2007.00347.x.

Sekercioglu, C.H. 2006. Increasing awareness of avian ecological function. Trends Ecology and Evolution 21 (8), 464-471. https://doi.org/10.1016/j.tree.2006.05.007.

Simberloff, D. 1998. Flagships, umbrellas and Keystones: Is single-species management passé in the landscape era? Biological Conservation, 83(3), 247-257. https://doi.org/10.1016/S0006-3207(97)00081-5.

Singh, A.P. and Sondhi, S. 2016. Butterflies of Garhwal, Uttarakhand, Western Himalaya, India. Journal of Threatened Taxa, 8(4), 8666-8697. http://doi.org/10.11609/jott.2254.8.4.8666-8697.

Singh, M.K, Tripathi, A.K. and Jeeva, V. 2016. Limnological study of Asan Wetland in Relation to Water Quality in Doon Valley, Uttarakhand, India. Asian Journal of Water, Environmental Pollution, 13 (1), 17-26. https://doi.org/10.3233/AJW-160003.

Singh, N.P. and Srivastava, R.C. 2000. Diversity and economic importance of wetland flora of Eastern Uttar Pradesh. Bulletin. Botanical Survey of India, 42(1-4), 91-108. https://doi.org/10.20324/nelumbo/v42/2000/74268.

Siraj, S., Yousuf, A.R. and Parveen, M. 2011. Spatio-temporal dynamics of macrophytes in relation to ecology of a Kashmir Himalayan Wetland. International Research Journal of Biochemistry and Bioinformatics, 1(4), 084-088.

Tak, P.C., Sati, J.P. and Kumar, A. 1997. Waterfowl potential

of Asan reservoir (Dehra Dun Valley, India). Zoology, 5(2), 111-132.

Tak, P.C., Sati, J.P. and Kumar, A. 2003. Fauna of Asan Wetland: An Overview in Fauna of Asan Wetland (Dehra Dun Valley: Uttaranchal). Zoological Survey of India, Wetland Ecosystem Series, 5, 1-5.

ten Brink ten Brink P., Mazza L., Badura T., Kettunen M. and Withana S. 2012. Nature and its Role in the Transition to a Green Economy. A TEEB report. www.teebweb.org and www.ieep.eu.

Truchot, J.P. and Forgue, J. 1998. Effect of water alkalinity on gill CO_2 exchange and internal PCO_2 in aquatic animals. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 119(1), 131-136. https://doi.org/10.1016/s1095-6433(97)00398-x

Verry, E.S. 1989. Selection and management of shallow water impoundments for wildlife. pp. 1177-1194. In: Sharitz, R.R. and Gibbons, J.W. (Eds.) Freshwater Wetlands and Wildlife. U.S. Department of Energy, Washington, DC.

Vijayan, V.S., Prasad, S.N., Vijayan, L. and Muralidharan, S. 2004. Inland Wetlands of India: Conservation Priorities. Vedams eBooks (P) Ltd. New Delhi.

Whittaker, R.H. and Likens, G.E. 1973. Carbon in the biota. pp. 281-302. In: Woodwell, G.M. and Peacan, E.R. (Eds.) Carbon in the Biosphere, National Technical Information Service, Springfield, VA.

Wood, B. and Gillman, M.P. 1998. The effect of disturbance on forest butterflies using two methods of sampling in Trinidad. Biodiversity and Conservation, 7, 597-616. https://doi.org/10.1023/A:1008800317279.

Wurtz, W.A. and Durborow, R. 1992. Interactions of pH, Carbon Dioxide, Alkalinity and Hardness in Fish Ponds. Southern Regional Aquaculture Center. SRAC Publication No. 464.

Xiong, Y., Zhou, J., Chen, L., Jia, B., Sun, N., Tian, M. and Hu, G. 2020. Land use pattern and vegetation cover dynamics in the Three Gorges Reservoir (TGR) intervening Basin. Water, 12(7), 2036. https://doi.org/10.3390/w12072036.

Website: http://www.amphibiaweb.org/declines/exploitation.html accessed on 31st December 2023.

Received:4th January 2024
Accepted: 14th May 2024