



MANIPAL
ACADEMY of HIGHER EDUCATION
(Institution of Eminence Deemed to be University)

**DIVERSITY AND DISTRIBUTION
OF BIRDS IN BHARATHAPUZHA
RIVER BASIN, KERALA**

A THESIS SUBMITTED TO
MANIPAL ACADEMY OF HIGHER EDUCATION

FOR FULFILLMENT OF THE REQUIREMENT FOR THE
AWARD OF THE DEGREE
OF
DOCTOR OF PHILOSOPHY

BY
ANOOP RAJ. P.N
(Reg.no: 179000027)

UNDER THE GUIDANCE OF
DR. P. PRAMOD
SENIOR PRINCIPAL SCIENTIST



SALIM ALI CENTRE FOR ORNITHOLOGY AND NATURAL HISTORY,
ANAIKATTY, COIMBATORE, TAMIL NADU-641 108

2024



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DECLARATION BY THE CANDIDATE

I declare that this thesis, submitted for the degree of Doctor of Philosophy to Manipal Academy of Higher Education, is my original work, conducted under the supervision of my guide Dr P Pramod, Senior Principal Scientist, SACON. I also wish to inform you that no part of the research has been submitted for a degree or examination at any university. References, help and material obtained from other sources have been duly acknowledged.

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25th June, 2024



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CERTIFICATE

This is to certify that the work incorporated in this thesis “**Diversity and distribution of birds in Bharathapuzha River Basin, Kerala**” submitted by Mr Anoop Raj PN was carried out under my supervision. No part of this thesis has been submitted for a degree or examination at any university. References, help and material obtained from other sources have been duly acknowledged.


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ABSTRACT

Bharathapuzha also known as the Nila River is the second-longest river in Kerala. It is considered as one of the most important rivers in Kerala for its ecological, cultural, and historical importance. Thus, it is known as the cradle of civilisation in Kerala. This river originates from the northern and southern rims of the Palakkad Gap. It flows towards the west through the Coimbatore district in Tamil Nadu and the Palakkad, Thrissur, and Malappuram, districts of Kerala before draining into the Arabian Sea. The river's total length is 209 km with a drainage area of 6186 km². *Chitturpuzha*, *Kalpathipuzha*, *Gayathripuzha*, and *Thoothapuzha* are major tributaries of this river.

Birds are considered as indicators of habitat quality. They play an important role as predators, prey, pollinators and scavengers in nature. Understanding the natural bird assemblage, its patterns, and its process will help prioritize the potential conservation areas. Many researchers have attempted to study bird communities in the different habitats in the Western Ghats. Their observations on birds provided useful information to understand the distribution trend of birds. Most of such studies focused on the forest ecosystems in the protected area network. Understanding the distribution pattern of birds and their drivers in highly disturbed ecosystems outside the protected area network is less attempted.

From the origin to the mouth, the river passes through various ecosystems and topographic conditions. Bharathapuzha originates and runs through forest ecosystems in the Western Ghats hill ranges initially, then travels through various human habitations, and agrarian lands and finally reaches the Arabian Sea. So, it supports bird communities of different forest ecosystems, agrarian lands, water bodies, and human habitations including the urban areas. Most of these ecosystems are located outside the protected area network and are vulnerable to anthropogenic pressures. Deforestation in the hill region, construction of check dams, indiscriminate sand mining, the spread of weeds and invasive plants inside the river channel, expansion of monoculture plantations, encroachment and water pollution are the major threats to the river ecosystem. This study attempted to understand the patterns of avifaunal assemblage in the Bharathapuzha river basin which is highly disturbed due to anthropogenic pressures that destroyed the riverine habitats, water quality, and natural water flow.

The study was conducted from October 2017 to March 2019. A total of 262 species belonging to 20 orders and 71 families were recorded. The study recorded 49% of the total birds recorded

from Kerala. From the available literature, 143 bird species were recorded from the river basin. This study added new observations of 119 bird species to the river basin. The study recorded 17 Western Ghat endemic bird species in the area. There was one endangered, five vulnerable, six near-threatened bird species as per the IUCN categories. The 20% of birds recorded in the study were migrants and 80% were residents.

The mean species richness in the river basin was 58.84 ± 12.53 and the mean species abundance was 527.85 ± 342.17 . The bird species taxonomic composition shows that the most dominant group in the river basin was Passeriformes (42%) followed by Charadriiformes (13%), Pelecaniformes, and Accipitriformes (6%). Insectivore (48%) birds are found to be the most dominant feeding guild followed by semi-aquatic carnivores (14%) and carnivores (12%). Passerine birds were the most dominant group (N= 146) followed by waders (N= 33), raptors (N= 20), and shorebirds (N= 19).

There were 119 bird species recorded from all ecological zones. Sixty bird species were reported only in the upper reaches, four in the middle reaches and 16 in the lower reaches of the river basin. The bird species diversity and richness were found higher in the upper reaches than in the middle and lower reaches. The migratory season was found to be more diverse in all ecological zones. Rank abundance-based distribution models show that the Zipf-Mandelbrot distribution as the best-fit model for upper reaches (deviance = 401.60) and lower reaches (deviance = 465.40). However, bird species in the middle reaches followed a log-normal abundance distribution (deviance = 615.83). Most of the wetland birds are distributed in the upper and lower reaches of the river basin. The middle reaches of the river show less preference for wetland birds. The unavailability of larger waterbodies affected the distribution of wetland birds in the middle reaches. The bird communities show variation between the ecological zones in the seasons except for feeding guilds. The availability of large similar foraging grounds in the upper and lower reaches affected the distribution of similar feeding guilds. The reason for variation in the bird species composition between the ecological zones can be because of habitat differences in the ecological zones, seasonal movement patterns, changes in the population size, availability of food, space and climatic conditions.

Little Cormorant, Brown-headed Gull, Black-headed Gull, White-breasted Waterhen, Palla's Gull, Oriental darter, River Tern and Lesser Whistling-duck, Cattle Egret, Brahmini Kite, Little Egret, Green Bee-eater, Indian Pond Heron, Asian Openbill, White-throated Kingfisher, Red-wattled Lapwing, Black-headed Ibis, Large-pied Wagtail, Common Sandpiper, Intermediate

Egret, Chestnut-headed Bee-eater, Marsh Sandpiper, House Crow, Asian Palm-swift, Rock Pigeon, Common Myna, Yellow-billed Babbler, Large-billed Crow, Barn Swallows, Black Kite, Purple-rumped sunbird have different abundance estimates in different ecological zones and hence contributed to the bird community variation between the ecological zones. Most of the species contributing to the community change are flocking birds, colonial breeding birds and synanthropic birds. The high abundance of synanthropic species indicated a strong anthropogenic influence on the basin. The resident birds contributed maximum to the changes in the species composition between the ecological zones. The presence of migratory birds in high abundance in the lower reaches indicates that it is an important zone for migratory birds.

The area of mudflats, area of water flow, riverside vegetation, distance from forest, and distance from farmland are the environmental parameters that positively influence the water-dependent birds and water-associated bird communities in different seasons. No significant correlations between most variables and species were found in our study, especially in the non-migratory season. The non-migratory season data collection was conducted from April 2018 to September 2018 during the unusual Kerala flood occurred. The flood in the Bharathapuzha River affected the distribution of microhabitats and riverine ecosystems, reflecting on the environmental parameters collected during the survey. The study identified ten conservation-importance locations in the river basin. Nelliampathi, Pothundi, Mangalam, Malampuzha, Chulliyar and Kanjirapuzha are the most important locations for conserving avian diversity in the Upper reaches. Kuthampully and Athipotta in the Middle reach and Chamravattom and Mundaya in the lower reaches were found to be important locations for conservation. The study recommends the protection of forests in the upper reaches and natural habitats like mudflats, sand banks, and agricultural lands, in the lower reaches for the conservation of birds. The water carrying capacity, obstructions, and quality of the natural habitats in the middle reaches or tributaries need to be studied in detail. Conservation measures need to be brought into action for river rejuvenation in the region. Based on the study, it is recommended that community-mediated policy interventions are required to reduce sand mining and rebuild the riverine ecosystem. The findings of the study highlight the importance of the locations outside the protected area in the conservation of biodiversity, particularly birds. The identified potential sites for the conservation of avifauna should be given high priority for the conservation of avian diversity. This information will help the policymakers to design appropriate conservation action plans for the river rejuvenation. Largely this study contributes more to the stocktaking of the state of art of the avian diversity of the region supported by Bharathapuzha, current problems, mitigation measures, and gives futuristic suggestions for conservation.



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Declaration of originality of research work and thesis by the student and supervisor

I have not committed plagiarism in any of the forms described in the ‘Manipal Academy of Higher Education Plagiarism Policy’. I have documented all methods, data and processes truthfully and I have not manipulated any data. I have mentioned all the persons who were significant facilitators of the work. The work has been screened electronically for plagiarism.

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Date: 25/06/2024

I, Dr P Pramod certify and attest that the work done by my Ph.D. student Mr. Anoop Raj PN is original and vouch that there is no plagiarism. The work has not been submitted for the award of any other degree/diploma of the same University / Institution where the work was carried out, or to any other University / Institution.

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LIST OF ABBREVIATIONS

- AIC - Akaike Information Criterion
BSD - Bird Species Diversity
CESS - Centre for Economic and Social Studies
CWRDM - Centre for Water Resources Development and Management
Db-RDA - Distance-based Redundancy Analysis
FHD - Foliage Height Diversity
IUCN - International Union for Conservation of Nature
MSL - Mean Sea level
nMDS - Nonmetric multidimensional scaling
NWAB - Non-water-associated birds
PAs – Protected Areas
SIMPER - Similarity Percentage
VIF - Variance Inflation Factors
WAB - Water-associated birds
WDB - Water -dependent birds

CHAPTER 1

INTRODUCTION

General Overview

India is a biodiversity-rich country and harbours roughly about 7-8% of global biodiversity. The variations in climatic conditions make the country biodiversity-rich, and become the 17th mega diverse nation in the world (Tripathi 2015). The varied geography of India, which stretches from the Himalayas in the north to the Western Ghats in the south, has produced different ecosystems and biodiversity (Rodgers & Panwar 1988). India's forests and wetlands are the most important ecosystems in the conservation of biodiversity. There are 1,03,258 species of fauna and 55,048 species of flora have been documented in the country, in which 12,095 species of plants and 28,948 species of animals are endemic (Envi Stats India 2022). This diverse range of flora and wildlife has long captivated the interests of many naturalists and scholars.

The country has about 8% of the world's forest cover, and these forests are home to a large number of endangered species, including the Royal Bengal Tiger (*Panthera tigris*), Indian Elephant (*Elephas maximus indicus*), Indian Rhinoceros (*Rhinoceros unicornis*), several endemic primates and birds. The country's protected areas, reserve forests, and national parks serve as important breeding grounds and habitats for several of these rare, endemic and threatened species.

The Western Ghats Mountain range is a unique biodiversity hotspot in the country. It is a major source of water and crucial to the country's ecological balance. This chain of mountains runs parallel to the west coast of India and is recognized as one of the biodiversity hotspots in the world. This region is home to several endemic species of plants and animals, such as Lion-tailed Macaque (*Macaca silenus*), Nilgiri Tahr (*Nilgiritragus hylocrius*) and Malabar Grey Hornbill (*Ocyeros griseus*).

India is a land of several great rivers. Riverine ecosystems have a major role in supporting the extraordinary biodiversity of the country. This rich biodiversity is facing several threats to its ecosystems and species. Major problems associated with biodiversity loss are habitat fragmentation and climate change (Sala et al. 2000). Rapid urbanization and industrialization destroyed several important habitats and ecosystems and brought many species at risk of extinction.

This biodiversity is a crucial part of the country's ecological heritage and contributes to its unique cultural identity. However, the country must take urgent action to conserve its ecosystems and species to maintain its biodiversity for future generations. This requires a combination of measures such as better regulation of human activities, establishment and management of protected areas, and promotion of sustainable development practices.

The wetland ecosystem is home to unique freshwater and marine diversity. The presence of freshwater dolphins in Ganga is one such example. The Chilika Lake in Odisha, Pulicat Lake in Andhra Pradesh, and East and West coastal regions are important habitats for migratory birds. Also, several species of turtles use these coastal zones for breeding and nesting.

Importance of Indian River Systems

Rivers in India played an important part in the development of the country. The Ganga, Brahmaputra, Godavari, Narmada, Krishna, and Kaveri River systems nourish and safeguard biodiversity, promote socioeconomic sustainability, maintain cultural heritage and become a lifeline for those living here. These rivers offer water for irrigation, transit, and hydropower generation. Hence it is critical to protect these river systems and preserve their long-term viability for future generations.

A wide range of species depend on the riverine environments for food, water, shelter, and breeding. The riverine systems play an important role in the conservation of avian diversity by providing food, water and stopover sites for many migratory birds, especially in the dams, estuaries, and larger agricultural areas. The waterfowl and waders depend heavily on the rivers for their survival. They use river-associated habitats such as mudflats and sandbanks intensively for feeding, foraging, and breeding. The riverside vegetation provides shelter from predators making it an ideal site for nesting and breeding of many birds. In addition, the availability of a variety of microhabitats, including shallow pools and riffles, rocks with different water depths and flow speeds increase food availability, and form various bird communities across the different stream flow regimes (Sinha et al. 2019a).

Most of the riverine systems in India are vulnerable to various anthropogenic pressures such as damming, water extraction, and pollution. In this scenario, protecting and restoring wetlands, improving water quality, and regulating water usage play major roles in preserving vital riverine habitats. River protection and rejuvenation activities can help in the long-term survival of many

bird species. Intern birds can be an indicator of the health and functioning of riverine ecosystems.

Birds and Bharathapuzha River Basin

Birds are considered as indicators of habitat quality. They play an important role as predators, prey, pollinators, and scavengers in nature and are capable of living in almost every type of environment. They are easy to observe, so their ecology is relatively well-known. The diversity and distribution of birds in nature is very dynamic. It changes over time and space (Rosenzweig 1995). The bird assemblage of an ecosystem varies depending on the availability of resources, seasonality, vegetation, and environmental conditions. Understanding the natural bird assemblage and its patterns, and the process behind it will help to prioritize the potential area for conservation, and prepare conservation action plans (Wiens 1989). The distribution and ecology of birds in Indian river drainage basins are less explored, and less known, especially in the state of Kerala.

Bharathapuzha is the second-largest river in Kerala. It travels through various kinds of ecosystems and covers a wide range of habitats. Several ecological studies on Aquatic biodiversity, Watershed management, Wetland ecology, Forest ecology, and Climate change were conducted in the Bharathapuzha River. This river supports rich and diverse bird populations. It is a seasonal home for several migratory bird species such as ducks, sandpipers, plovers, and stilts. It also home various resident bird species such as herons, egrets, cormorants, kingfishers, sunbirds, and woodpeckers. However, knowledge about the bird communities from the basin is scattered and are short-term observations (Kurup 1991; Kumar 2001; Kumar 2006; Arif et al. 2010). Systematic documentation of the bird diversity of this river basin is essential for designing conservation action plans for managing riverine habitats and bird diversity.

This study was planned to understand the bird species diversity, distribution, community assemblages, and factors affecting the diversity, distribution and community assemblages in different flow regimes in the river basin. The study identified potential areas for the conservation of avifauna, which can be given high priority for the conservation of avian diversity in the river basin.

Objectives

- To understand species diversity and distribution of avian fauna in different ecological zones of the Bharathapuzha river basin.
- To understand the structure of the bird community and its changes within and between different ecological zones in the river basin.
- To study the factors influencing the diversity and distribution of birds in the Bharathapuzha river basin
- Identification of locations important for the conservation of avian diversity in the Bharathapuzha river basin.

Organization of the Thesis

1. Chapter 1: Chapter 1 is formulated to give an overall idea about the subject of the thesis. It included a general overview of the subject, study area, and Objectives.
2. Chapter 2: Review of Literature: The detailed literature review is focused on bird community studies and riverine bird studies across the world and in India. It also detailed the biodiversity studies conducted in the Bharathapuzha river basin concerning the birds.
3. Chapter 3: Study area and methodology
4. Chapter 4: Technical chapter 1 which explains objectives 1 and 2
5. Chapter 5: Technical chapter 2 which explains the objective 3
6. Chapter 6: Technical chapter 3 which explains the objective 4
7. Chapter 7: Summary and Concussion

CHAPTER 2 REVIEW OF LITERATURE

Introduction

Birds attracted humans from time immemorial. They have always been viewed as indicators of environmental quality, because they are responsive to environmental change and they have indicative ecological functions. Monitoring bird communities from a limited number of study sites can provide knowledge about a vast landscape and its ecology. Ornithology has evolved from simple taxonomy and natural history to a serious discipline of science during the 20th century through theoretically oriented researchers such as G.E. Hutchinson, Robert MacArthur, and David Lack. The contribution of Robert MacArthur and his colleagues to community ecology (1957, 1965, 1968, and 1970) inspired many scientists across the world. From checklists of birds, science has developed further to discover patterns and processes behind the natural assemblage of species in nature. MacArthur pointed out that vegetation has an influence on the bird diversity of an area and community structure and characteristics were determined by natural selection which is influenced by competition (MacArthur 1960; MacArthur & MacArthur 1961; MacArthur et al. 1962).

Bird Community Studies in the World

Understanding bird life from the community ecology perspective will help us to understand the dynamics of bird populations much better. Community ecology is concerned with identifying the patterns that characterize natural assemblages of species, understanding what has caused these patterns and determining how general they are (Wiens 1989). These patterns vary both in space and time. In the last five decades, the bird community of different temperate and tropical forests all over the world have been studied most intensively and extensively by many legendary scientists in ecology such as Robert MacArthur, Holmes, Terborgh, Robinson, Pearson, Kikkawa, Wiens and their colleagues.

Globally, various aspects of bird communities of neotropical forests were studied intensively by Terborgh (1985), Terborgh et al. (1990), Karr et al. (1990), Robinson (1986), Robinson & Holmes (1984), Robinson & Terborgh (1990), Thiollay (1994), Munn & Terborgh (1979), Munn (1985) and Fitzpatrick (1985). During the middle of this century, avian community ecology took a clear new turn from the old Gleansian and Clementian approaches (Wiens 1989). David Lack (1945a, 1945b, 1947; Lack & Gillmor 1971) emphasized the importance of interspecific

competition in structuring communities. MacArthur's writing (1957, 1965, 1968, 1969, and 1970) and his students and colleagues (Cody 1974; Cody & Diamond 1975; Ricklefs 1975; Diamond 1978; Hutchinson et al. 1978; Wiens 1989) provided a special impetus to investigations of bird communities. MacArthur visualised community patterns in clear and simple theories. As a result, community ecologists started putting forward innumerable questions related to species packing in communities, resource partitioning, diversity geographical variation in community structure and patterns in biogeography, leading to the rapid progress in the understanding of bird communities (Wiens 1989).

MacArthur & MacArthur 1961 and Recher 1969, discuss the factors that influence local vegetation diversity and the assemblage of birds. They correlated the Bird Species Diversity (BSD) with vegetation structure and plant species composition. The correlation of bird species diversity with plant species diversity (Tomoff 1974; James & Wamer 1982), habitat openness (Willson 1974) and habitat patchiness (Karr & Roth 1971; Roth 1976) were also widely discussed. As vegetation strongly influences the foraging behaviour of birds and their success, it receives primary consideration in avian community ecology (Wiens 1989). MacArthur & MacArthur (1961) were the first to suggest that the structural complexity of vegetation measured by the vertical layering of the foliage (Foliage Height Diversity) in temperate forests influences the bird species diversity positively. Later many studies in different types of temperate forests were found to support this theory (Erdelen 1984; Pyrovesti & Crivelli 1988). However, the studies on birds in the tropical rain forest have failed to furnish any evidence towards this end (Wines 1983). In 1982, James and Wamer showed that the diversity of birds is high at intermediate levels of tree species richness. Daniels et al. 1992 observed that bird species richness negatively correlated with woody plant species, vertical stratification, canopy density and tree density in natural vegetation in Uttara Kannada forests. Studies by Terborgh (1973) and Galli et al. (1976) showed that the larger the area of the habitat, the greater, the bird species diversity. In monoculture, Clout & Gaze (1984) pointed out that bird species diversity increased with the maturity of vegetation.

Many more studies were conducted to reveal the complexity of bird-vegetation association. Rice et al. (1983, 1984) studied the importance of different habitat attributes like FHD, Patchiness, the density of vegetation etc, to an avian community organization. Pearson (1975) worked on the relationship of foliage complexity to avian communities in three Amazonian Forest areas.

Studies by Meents et al. (1983) exposed the curvilinear relationships between birds and vegetation.

The diverse models of community structure were discussed by Thomson (1980) who emphasized equilibrium conditions of competitive interactions between species as a major structuring force (Pianka 1974; Diamond 1978) whereas others advocated the importance of predation, variable environment habitat or climatic disturbances and other factors that minimize the potential for competition (Connell 1975, 1978, Caswell 1978, 1982, Huston 1979, Wiens & Rotenberry 1981 and Lawton & Strong 1981). Thus, competition was widely believed to restrict the range of habitats. The idea of food resource competition as a structuring force in communities gained popularity from the theoretical arguments and analyses of Hutchinson (1959) and Cody (1974). Wiens (1983) summarised many of these criticisms pointing out the problem with assuming equilibrium conditions, the heavy use of inference in analysing what he terms resource systems and the general lack of rigorous field checking of hypotheses concerning the importance of food resources. Several studies have shown that food resources can be a limiting factor (Moore 1986, Martin 1987, Arcese & Smith 1988), that competition for food does occur (Minot 1981), and that community patterns are affected (Sherry & Holmes 1988). Holmes critically reviewed (1990) information on food resource availability and use by forest birds, including the problems of quantitative sampling and of assessing the factors that influenced birds' food utilization patterns.

Holmes & Robinson (1981) studied the tree species' preference for foraging insectivorous birds. Holmes & Recher (1986) studied the search tactics of insectivore birds in Australian Eucalyptus forests; Remsen and Robinson (1990) classified and explained the different foraging methods and behaviour of birds. Bird species have been assigned to foraging guilds based on a general knowledge of their feeding behaviour. The bird community pattern of any region has a close correlation with the vegetation structure of that area (MacArthur & MacArthur 1961; MacArthur et al. 1962, 1966). Tropical areas have substantially greater diversities than temperate zones of the same size (MacArthur 1969; Karr 1971).

Bird Community Studies in India

The varied geography of the country ranges from the Himalayas in the north to the tropical forests in the south, providing potential habitats for a high diversity of bird species. This also has led to a wealth of studies on the ecology of birds in India in the last two centuries. With the entry

of the Britishers, a systematic and scientific recording of birds has come to India. Systematic documentation of Indian birds started in the 19th century with Jerdon's (1862) pioneering investigations. In the 20th century, it got the strongest push through the effort of Salim Ali (Ali & Ripley 1983a, 1983b; Ali 1999). In recent years, there have been several field guides such as Inskipp (1998, 2014) and Rasmussen & Anderson (2012) in the hands of ornithologists and bird watchers. Thousands of published and unpublished works by a very large number of bird watchers and ornithologists remain as the background to all these works.

However, this knowledge background on avian identity has not been properly used in the studies of ecology. Birds are the right group of organisms which can be utilized to study the ecosystem function and monitoring of the system on a long-term basis. In a natural ecosystem, the birds express the variation in their species composition based on the availability of resources. They do vary according to the seasonality of the ecosystem and the environmental quality parameters as well. Ramakrishnan (1983), Beehler et al. (1987), Daniels (1989), Danielset al. (1990, 1992, and 1994), Jayson (1994), Pramod (1995), Ramanet al. 2001 and 2005 have made attempts to study forest bird communities in India. These studies agreed with Robert MacArthur's view. These bird studies in India have provided a wealth of information on avian diversity, behaviour, and ecology. The Western Ghats have unique ecosystems which support the local diversity of birds (Daniels 1989). In any part of the Western Ghats region, about 150-170 species of birds may be present in an area of less than 15 sq. Km. Studies on bird behaviour and ecology have focused on topics such as migration patterns, breeding behaviour, and food habits. For example, studies have shown that birds in India have adapted to the changing seasons and make long migrations to escape harsh weather conditions (Deomurari et al 2023). Additionally; studies on bird-habitat relationships have shown that different bird species have unique preferences for different habitats, such as forests, grasslands, or wetlands. This emphasized the importance of habitat protection and management. It is also identified that deforestation, habitat destruction, and hunting are some of the major threats to bird populations in India. Hence, these studies have contributed more to the scientific knowledge and practical conservation efforts of avian bird communities. Understanding the rich bird diversity and its ecology in India needs extensive and meticulous research. Collective and long-term monitoring of heterogonous habitats and various ecological aspects of birds is the way to it. However, there are avenues available for research which can contribute to a better understanding of the ecology of bird species to develop effective conservation strategies for the future.

Ecological Studies on Riverine Bird Communities

India's riverine ecosystems are diverse and ecologically significant by providing habitat for the survival of a wide range of flora and fauna. These ecosystems are crucial for the biodiversity, people, and overall health of the environment. The Indian River system supports a wide variety of bird species. It is one of the major bird habitats and stop-over sites for migratory birds. Hence knowing the ecology of birds in these habitats is essential for habitat and species conservation. However, there haven't been many serious studies along these lines.

Historically most of the bird studies concentrated on the diversity and distribution of birds (Abdul 1966; Ali & Reply 1983; Praveen et al. 2014). In India, 302 species of birds depend on the wetlands for their survival. This includes waders, shorebirds, kingfishers, passerine birds and pelagic birds. Out of these five were critically endangered, six were endangered, and 12 were in the vulnerable categories of the IUCN Red list (Kumar et al. 2003). Hence the wetlands and water bodies in India are a good avenue for conducting ecological research on wetlands and water-associated birds.

There were several anecdotal accounts and sighting records of these birds from various wetlands and riverine habitats in the country. The recent development in scientific research has influenced researchers to develop long-term monitoring studies, especially on migration. Most such studies were concentrated in the East Coast region, especially in Chilika Lake and Point Calimere. Sandilyan et al. 2015 studied the density and factors influencing the wader (Ciconiformes and Charadriiformes) population in the Pichavaram wetland. Nagarajan&Thiyagesan1996, Manikannan et al. 2012 and Jagadheesan et al. 2021 studied the ecology of waterbirds of the Point Calimere sanctuary in Tamil Nadu.

The ecological studies on the inland wetland birds were not many. Several agro biodiversity studies and heronry monitoring studies documented the population dynamics of birds in the inland wetland ecosystems (Subramanya 2005; Chullakattil 2022). However, the rivers and their bird communities were less explored. The recent studies in the Himalayan Mountain regions and Brahma Putra River focused more on the ecological aspects of birds in the river basins. Sinha et al. 2019a studied the Himalayan rivers and their ecological importance keeping birds as an indicator species. Such studies created an avenue to conduct ecological studies keeping the river basin as a central theme. Though there are several landscape-level conservation

action programs and guidelines were prepared, the river basin approach can provide a different perspective for conservation actions in the country.

The development of Citizen Science and e-bird largely influenced the community's involvement in bird monitoring and conservation action. e-Bird is a valuable citizen science project managed by the Cornell Lab of Ornithology. It allows bird watchers from around the world to record their observations and share them online. This collective effort provides a massive and constantly updated database that helps scientists and researchers understand bird distribution, migration patterns, and population trends. The data collected through eBird is used in various conservation efforts, and ecological studies, and to inform environmental policies. Additionally, eBird offers tools for bird enthusiasts to track their sightings, explore maps and data, and connect with the birding community. This provided an opportunity for nature enthusiasts to monitor birds and be involved in research and conservation initiatives. As a result, the population trends and migration of birds were monitored and updated regularly and ensured the health of the ecosystems (SoIB 2023). It also developed a sense of empathy among the local people towards nature and created awareness about environmental problems.

Bird Diversity Studies Bharathapuzha River Basin

Neelakantan et al. 1993 initiated well-designed and systematic bird surveys in Kerala. Ramakrishnan (1983), Jayson (1994) Pramod (1995) and Nameer (2005) studied the species assemblages in different habitats in Kerala. The studies showed that there are multiple factors affecting the community composition of birds in a forest ecosystem. The community ecology of birds in the riverine systems of Kerala was not well documented.

The introduction of the river continuum concept (Vannote et al. 1980) has created a new approach to the landscape-level conservation of biodiversity. It debated the importance of considering the river and its basin as a larger single ecological system. The rivers in the Western Ghats are one of such ideal locations for conducting such studies.

Bharathapuzha River is a biodiversity-rich area which is relatively less explored. Historically documentation on the faunal and floral wealth of this river basin has been attempted by many from different parts of the river basin (Ayyar 1939; Subramanyam 1959; Henry 1963; Subramaniyan 1966; Manilal 1988; Arun 2000; Sushama 2003; Murugesan 2003; Das 2008). Fish diversity in the Bharathapuzha River was documented by Kumar & Sushama 2001 and Sushama 2003. Meteorological, hydrological and environmental impact studies on sand mining have also been

published from this river basin (Kumar et al. 2008; Raj 2010a). This river is highly exposed to ecological and environmental issues (CESS 1997; Kumar et al. 2008; Raj 2010b).

According to Kumar 2006, 143 species of birds were reported from the river basin. Sighting of endangered Black-bellied Tern reported from this river basin (Susanthkumar 2004; Arif et al.2010). Parathoor in the Bharathapuzha river basin is a known stopover site for migratory birds (Kurup 1991; Kumar 2001). Long-term monitoring studies on birds are very scanty from this river basin. The heterogeneous ecosystems of the river basin should be monitored with priority to understand the role of the river in supporting bird communities.

CHAPTER 3 STUDY AREA AND METHODS

Study Area

The selected study area, Bharathapuzha (10.416–11.25 N and 75.833–76.916 E) is the second-longest river in Kerala. This river is also known as the “NILA” River. The name “NILA” means “moonlight” and was given by the poets in the state after experiencing the aesthetics of this river. This river was mentioned in ancient literature. The river Pratichi in Mahabharata is said to be this river. It is considered as one of the most important rivers in Kerala for its ecological, cultural, and historical significance. Hence it is also known as the cradle of civilization in Kerala (George 2007). The agricultural bloom in the Palakkad district made it popular as the rice bowl of Kerala. This agricultural prosperity was supported by this river. Thus, Bharathapuzha serves as a lifeline for millions of people and the biodiversity of the region.

Bharathapuzha originates from the northern and southern rims of the Palakkad Gap and flows towards the west. It runs 209 km from Thirumoorthy hills to Ponnani through the Coimbatore district in Tamil Nadu and the Palakkad, Thrissur, and Malappuram, districts of Kerala before draining into the Arabian Sea. Figure 1 gives the map of the river with all its streams from the first order to the estuary (the main course is the sixth order river). The accumulated total length of all streams including the main course is 453 km. The total drainage basin area is 6186 km², out of this 4400 km² falls in the Kerala state and remaining in the state of Tamil Nadu (Raj 2010b). There are four major tributaries for this river. They are *Chitturpuzha*, *Kalpathipuzha*, *Gayathripuzha* and *Thoothapuzha*. Among these tributaries, at present, the *Thoothapuzha* contributes the majority of the water supply to the river. Eleven dams, two diversion bunds, two regulators cum bridges, and several check dams were constructed in the river. Malampuzha Dam in Palakkad is the largest and oldest dam in the river. Meenkara, Chuliar Mangalam, Pothundi, Walayar, Kanjirapuzha, Aliayar, and Thirumurthy dams are the other dams built in the headwater region of the river basin. The main purpose projected for these dams was irrigation and power generation.

The Bharathapuzha River runs through an ecologically complex system interdependent between the biodiversity and socio-cultural fabric of the embedded society. The ecological health of the river and its associated habitats is closely tied to the well-being of the humans and biodiversity of the area. Bird community is known as a good indicator for understanding broad-scale ecological

assessments. Hence this river system is identified as a suited location to study the bird community of the region with the stated objectives.

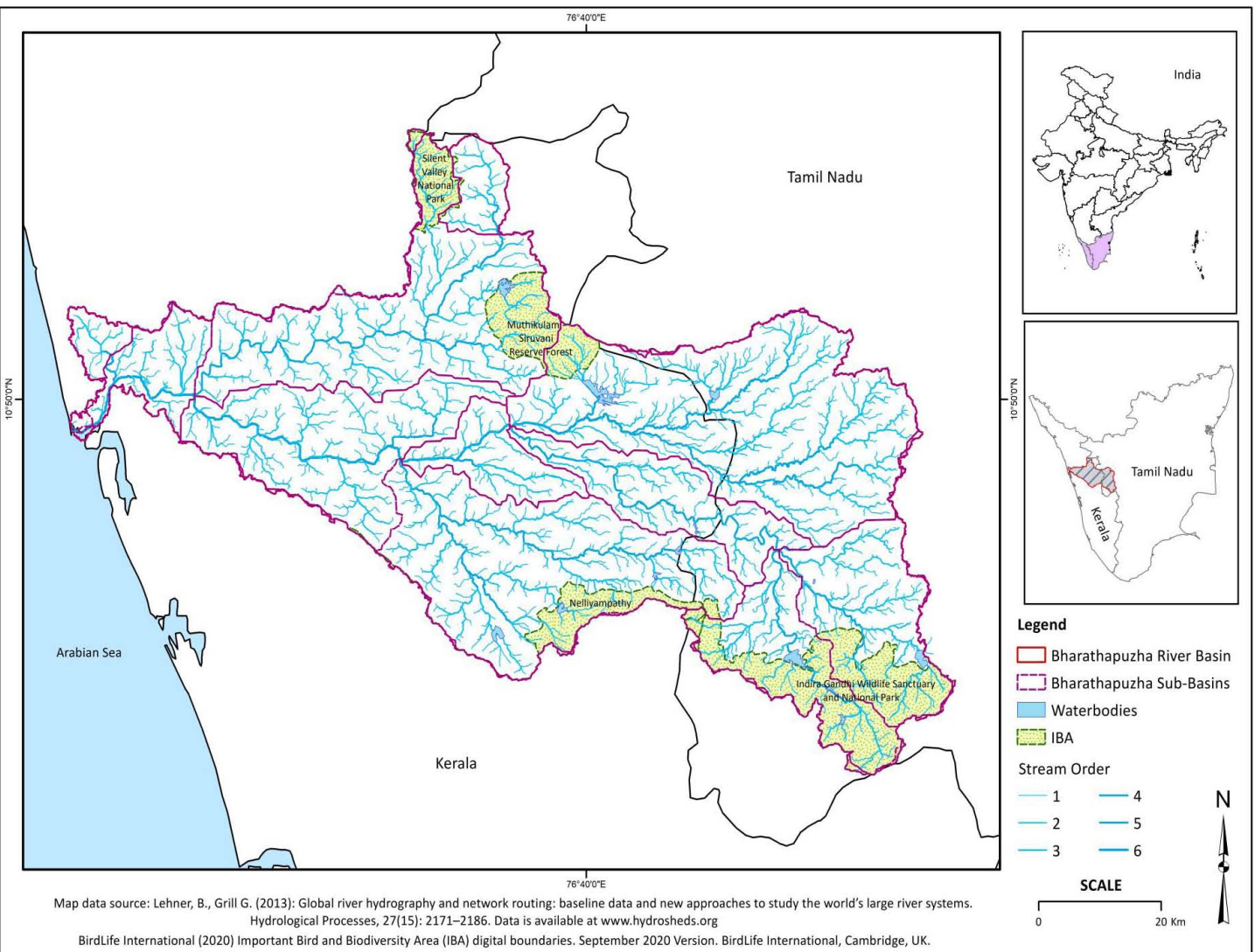


Figure 1: Map of Bharathapuzha river with sub basins

Geography and Drainage System

Bharathapuzha River is located in the Western Ghats (Figure 2). According to the river classification, Bharathapuzha was classified as a medium-sized river (Jacob & Narayanaswami 1954; Strahler 1964). The river basin has 50 major watersheds and 290 mini watersheds. The small rivulets flow from the different parts of the Western Ghat Mountains forming four major tributaries namely *Chittur puzha*, *Kalpathi puzha*, *Gayathri puzha*, and *Thootha puzha*. When the *Chittur puzha* enters Kerala, it is known as *Kannadipuzha* till it meets the *Kalpathipuzha*. *Kalpathipuzha* and *Chittoor puzha* join together at Parali in Palakkad and form the first tri-junction and form the mainstream of Bharathapuzha. After the confluence with the *Kalpathipuzha* in Parali, the river is called as Bharathapuzha or Ponnani River. *Gayathripuzha* joins with Bharathapuzha in Kuthampulli near Ottapalam in the Palakkad district. *Thootha puzha* joins with Bharathapuzha at Pallipuram in the Palakkad district, then continues flowing west and debouches in the Arabian Sea at Ponnani on the Malabar Coast. These tributaries maintain the water flow in the river and support several ecosystems and agriculture in the regions.



Image 1: Bharathapuzha River at Kuthampully

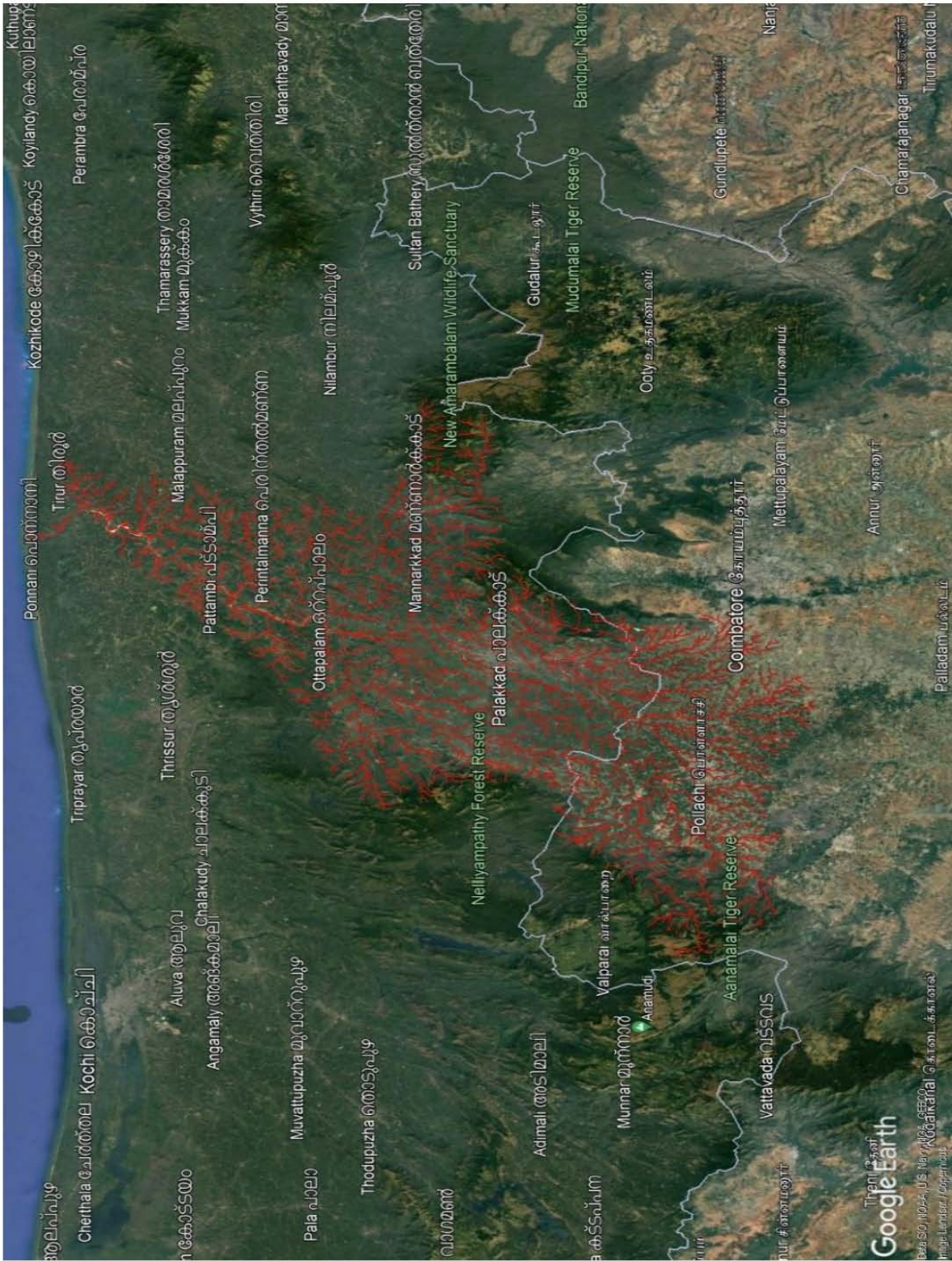


Figure 2: Map of Bharathapuzha River in the Palakkad gap

Geology

The geologists considered Bharathapuzha as a west-flowing paleo-river during the post-Miocene period (Jacob & Narayanaswami 1954; Vaidyanadhan 1971; Subramanian & Muraleedharan 1985). The LANDSAT imagery evidence shows the trace of paleo-river channels towards the Amaravathi River basin from the present river channels (Vaidyanadhan 1971). The formation of the Palghat gap in the river basin continued as a mystery for many researchers. However, it is believed that the proterozoic tectonic events caused the gap formation. This river flows through between the Palghat gap and is prone to seismic activities and tsunami waves (D'Cruz et al. 2000).

A wide variety of geological formations were reported from the Bharathapuzha river basin which broadly includes Archean crystalline, laterites, coastal sand, and alluvium. Archean crystalline covers the entire river basin except for the river mouth and mainstream. In several places of the river basin, the crystalline rocks were seen capped with laterites. Pyroimite, amphibolite, dolerite, pegmatite, and quartz were the metamorphic bodies and acid intrusive found in the river basin. The coastal sand and alluvium sediments were found in the river mouth. This forms semi-consolidated tertiary sandstones and clay stones (CESS 2004).

Soil

The major soil type of the Bharathapuzha river basin are laterite soil, brown hydro-morphic soil, red sandy soil, black soil, forest loam, and riverine alluvium (CESS 2004). The texture and distribution of these soil types vary based on the region. The soil in the coastal region of the river basin was characterized by more alluvial deposits. The texture of these alluvial deposits varies from sandy loam to clay loam. Riverine alluvium soil was found in the flood plains and midland regions of the river basin. Laterite soil was found more in the midland and highland regions. Brown hydromorphic soil was found in patches in the midland region. Black soil and forest loam were found in the highland region (Geological Survey of India 1976; CWRDM 1991; CESS 2004). The availability of diverse soil with different nutrient loads supported agriculture and became an important resource for the local communities for maintaining the ecological balance and supporting the diverse range of life forms in the region.

Fauna and Flora

Bharathapuzha river basin holds various types of ecological systems which include high-altitude grasslands, tropical evergreen forests, moist deciduous forests, riparian forests, marshlands,

wetlands, mangroves, cultivation lands, and urban areas. Twenty-five percent of the river drainage basin comes under various protected areas, such as reserve forests, sanctuaries, and national parks. Silent Valley National Park, is one of the important biodiversity areas in the country which comes under this river basin. Anamalai Tiger Reserve and Karimpuzha Wildlife Sanctuary are the other protected areas located in this river basin.

These protected areas are home to various unique fauna and flora and become an important repository of biodiversity. Silent Valley is known for its endemism of fauna and flora. This reserve also protects a viable population of endangered Lion-tailed macaques. Anamalai Tiger Reserve protects the endangered Bengal Tiger (*Panthera tigris*), Indian Gaur (*Bos gaurus*), Indian Elephant (*Elephas maximus*), Spotted Deer (*Axis axis*), Sambar Deer (*Rusa unicolor*), Dhole (*Cuon alpinus*), and Leopard (*Panthera pardus*). It is a home for various conservation important frogs such as the Purple Frog (*Nasikabatrachus sahyadrensis*), the Malabar Gliding Frog (*Rhacophorus malabaricus*), and several species of bush frogs. It is also home to venomous snakes such as the King Cobra (*Ophiophagus hannah*), Common Krait (*Bungarus caeruleus*), Russell's Viper (*Daboia russelii*), and Spectacled Cobra (*Naja naja*).

The floral diversity of the river basin was explored by many (Ayyar 1939; Manilal 1988). The upper reaches of Silent Valley is a home for several of *Strobilanthus spp.* It also supports the blooming of Malabar Daffodil Orchid (*Ipsea malabarica*) an endangered orchid in the grasslands of Silent Valley. A good population of *Cullenia exarillata* is seen in the upstream region of the river basin which is one of the most preferred foods for Lion-tailed Macaque.

Annual Weather Pattern

The tropical climates and monsoon winds influence the weather pattern of the river basin. The climate is characterised by hot and humid summers, with temperatures ranging from 25°C to 35°C, and cool and mild winters, with temperatures ranging from 20°C to 25°C (Figure 3). The region experiences heavy rainfall from June to September due to the Southwest Monsoon, and lighter rainfall from October to December due to the Northeast Monsoon. The average annual rainfall in the region is around 3000 mm (CWRDM 1991; Raj 2010b).

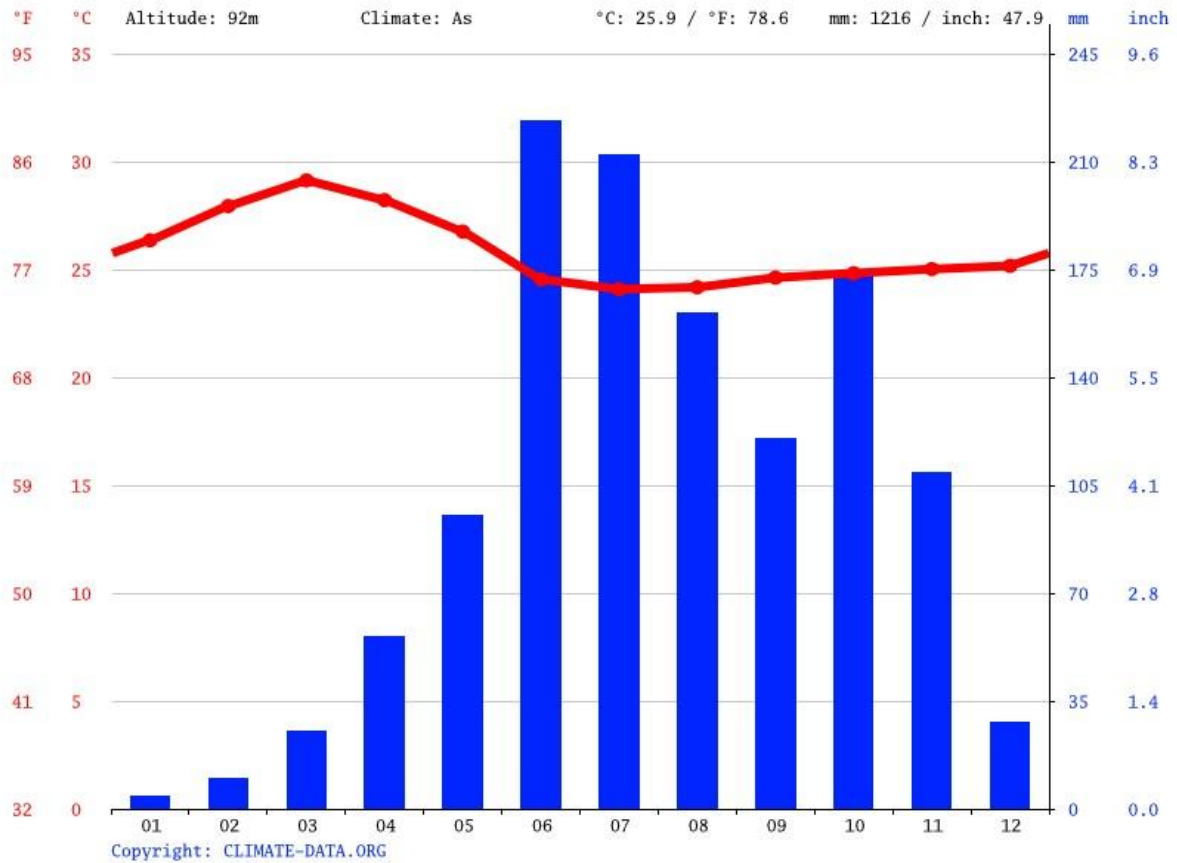


Figure 3: Annual rainfall and temperature pattern of Bharathapuzha river basin.

The rainfall patterns and associated weather conditions have a significant impact on the Bharathapuzha River and its surrounding ecosystems. During the monsoon season, the river swells with increased rainfall and runoff, which can result in flooding in some areas. On the other hand, during dry periods, the water levels in the river can drop significantly, which can affect the river's ecosystems.

In August 2018, unusually high rainfall resulted in a flood in the western slope of the Western Ghats in Kerala. Bharathapuzha River also had a share of that devastating flood which made several changes in the distribution of microhabitats of organisms (Joshi & Balakrishnan 2018).

Study Design

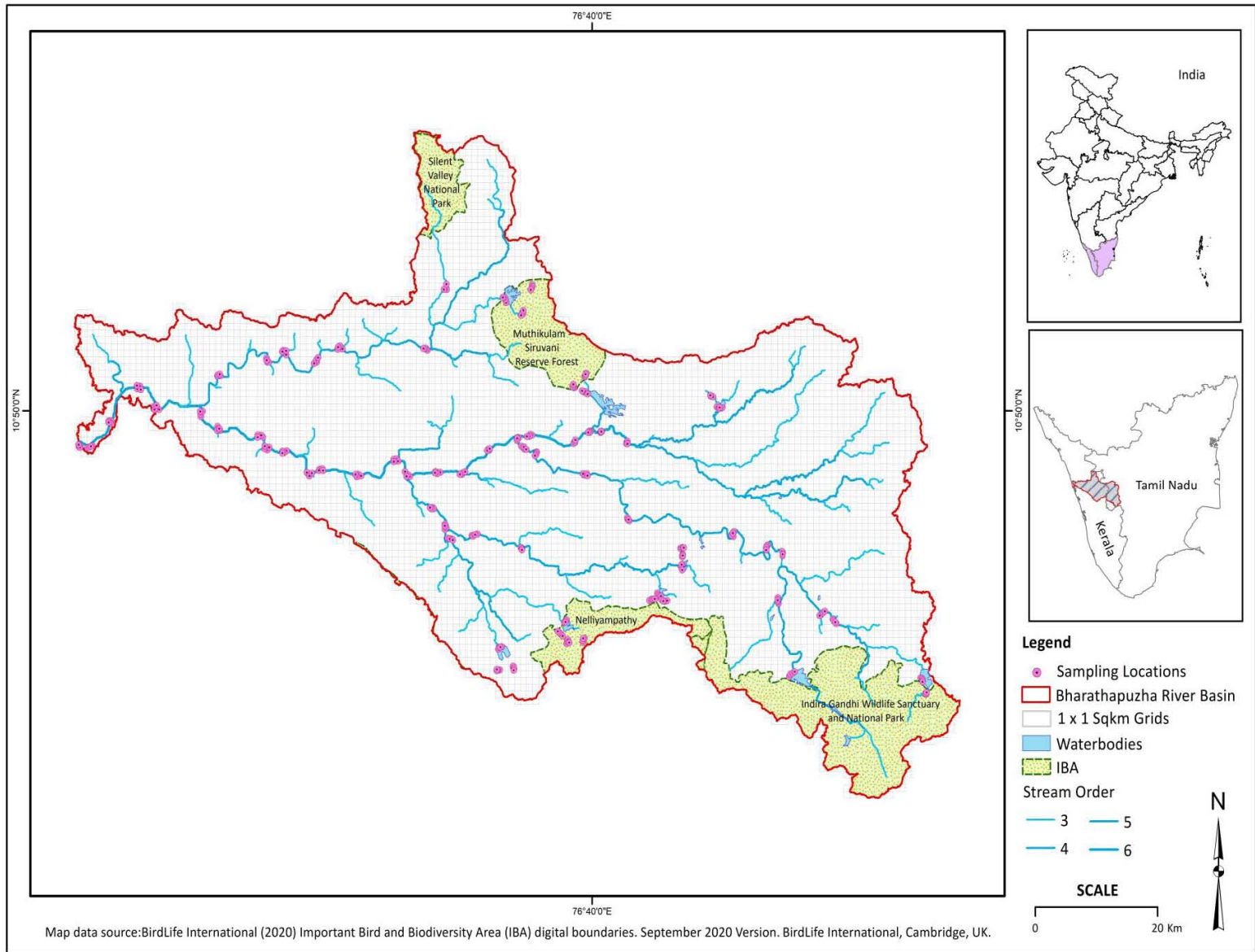
Field surveys were conducted in 453 km stretches (from second-order streams to sixth-order streams) of the river between the elevation gradient of 621 M to zero M MSL. The intensive sampling area was selected using stratified sampling techniques. The area was stratified into

three ecological zones based on the altitude of the streams, river flow, geomorphology, and ecological setting of the river. Thus, the sampling locations were classified into the upper reaches (headwaters from first-order to 3rd order streams, >76 m), middle reaches (tributary, fourth and fifth-order streams, 76-8 m), and lower reaches (main course and estuary; sixth-order streams, < 8 m) of the river which are henceforth termed ecological zones (Abell et al. 2008). Considering the extent of area available in these zones, the sampling locations and sampling efforts were distributed. The riverine area in the basin was gridded into 1 km² grids. From these, 70 grids along the river channel were selected through random sampling for intensive study (Figure 4). In each grid, 4-point counts (each 15-minute long) were conducted using the fixed width point count method (Reynolds et al. 1980) to collect the data on birds and associated environmental parameters. Sampling was done in one non-migratory (April to October 2018) and two migratory seasons (November 2017 to March 2018, and November 2018 to March 2019). Thus, for the three seasons together, a total of 840-point counts of bird data collection were conducted from the sampling area. Observations were done between 6:00 a.m. to 11:00 a.m. and 3:30 p.m. to 7:00 p.m. Bird identification was done using field guides and photographs (Ali & Ripley 1983; Ali 1999; Karmierczak 2000; Grimmett et al. 2014).



Image 2: Study location in Ottapalam

Figure 4: Distribution of sampling sites



Description of the Ecological Zones

Upper reaches

The primary order streams to third order streams that fall in the ghat areas were considered as upper reaches. Here the rivulets and streams flow through mostly the forest ecosystem. The streams were characterized by riverine vegetation with tall trees, dense canopy, rocks and pebbles, and river beds. The primary order streams are smaller in size and originate from the grasslands. Second and third-order streams are long and separated by different forest habitats. Hence for an effective data collection, the bird surveys were conducted in second-order and third-order streams in this ecological zone. All dams in the river basin are located in the upper reaches. Most of the second and third-order streams end in these dams.

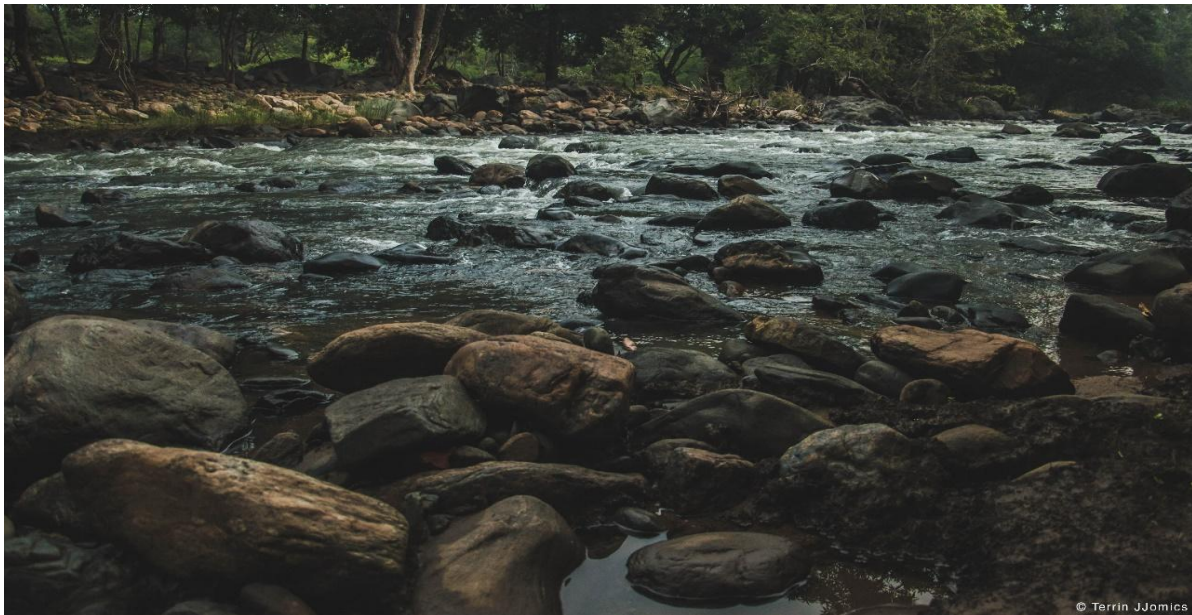


Image 3: Upper reaches of the river basin

Middle reaches

The middle reaches of the river are primarily tributaries of the river. These tributaries are mostly classified as fourth and fifth-order streams. Most of these tributaries except *Thuthapuzha* streams originate from these outlets of the dams in the river basin. These parts of the river streams are large and carry water throughout the year. In deep summer some of the tributaries dry up and show seasonal fluctuations in the river flow. Most of these stream's flow through human settlement areas along with horticultural plantations and agricultural lands.



Image 4: Middle reaches of the river basin

Lower reaches

Lower reaches include the main course of the river along with the estuary. It is a large sixth-order stream with a maximum width up to one km wide. It carries water and sediments from the upper reaches and middle reaches. Mudflats and sand banks are common characteristics of the lower reaches. It flows mostly through human-dominated and agricultural landscapes.



Image 5: Lower reaches of the river basin

Field Sampling Methods

Bird survey

The bird observations were made from October 2017 to March 2019 using point count with the fixed-width method (Reynolds et al. 1980). A total of 280 sampling locations were identified for field observation. These selected locations were sampled in three cycles (840 bird point counts) during this period (Table 1).

Table 1: Total survey effort

Number of grids	Number of sampling points in each grid	Number of replications	Total number of samplings	Total effort in the hour	Number of sampling days
70	04	03	840	480	240

All birds seen and heard within the fixed radius of 50 m were recorded over 15 minutes in each sampling location between 6:00 a.m. to 11:00 a.m. and 3:30 p.m. to 6:30 p.m. Opportunistic observations were made after the survey time. Birds were identified and counted using 8×40 Nikon binoculars and a standard field guide (Ali & Ripley 1983; Ali 1999; Karmierczak, 2000; Grimmett et al. 2014). Classification of the birds identified by following Praveen et al. 2020 and updated by Chandran et al. 2023.

Bird Group Categories

The bird species recorded during the study period were classified into three groups based on the water dependency of birds as Water-dependent birds (WDB), Water-associated birds (WAB) and Non-water-associated birds (NWAB).

Water water-dependent birds (WDB) are the birds that use water as their most preferred habitat. This includes birds such as ducks, cormorants and terns.

Water-associated birds (WAB) include the taxonomic groups such as Pelecaniformes, Ciconiformes, Gruiformes, Charadriiformes, and a few members of Coraciiformes, Passeriformes and Accipitriformes.

Non-water-associated birds (NWAB) are the birds that don't use riverine habitats as primary habitats. Galliformes, Podicipediformes, Cuculiformes, Caprimulgiformes, Accipitriformes, Strigiformes, Trogoniformes, Bucerotiformes, Coraciiformes, Falconiformes, Psittaciformes and Passeriformes come under this category.

Environmental and Location-specific Parameters

Data on 16 environmental parameters were collected. These parameters on bird habitats were divided into categories such as permanent and seasonal environmental parameters. Permanent parameters were collected one time from the sampling location. Area of water channels, presence of dams and check dams, waste dumping, artificial perches, canopy cover, distance from the nearest forest, agricultural land, and human settlements, were the permanent parameters. The seasonal parameters were the water flow, natural vegetation, mudflats, sandbanks, rocks, and barren land. The parameters such as the dams and check dams, waste dumping, and artificial perches were recorded as presence or absence. Area of water channel, water flow, riverside vegetation, mudflats, sandbanks, rocks, barren land and canopy cover were recorded in percentage (%) by visual estimation. The canopy cover was recorded using the Canopeo app (Patrignani & Ochsner 2015). The distance from the nearest forest, agricultural land, and human settlements was collected on a km scale using the Google Earth Pro application.

Secondary Data

The data available in the e-bird portal collected through the coordinated program of Kerala Bird Atlas were used as the baseline data for the reconnaissance (Praveen & Nameer 2021). The survey location and grids used in the Kerala bird atlas were also visited for cross-verification of rare species of birds which were considered opportunistic data. Temperature and rainfall data were collected from the 'WorldClim' database for the study period (Fick & Hijmans 2017).

CHAPTER 4

BIRD DIVERSITY AND DISTRIBUTION

Introduction

Biological diversity always fascinated researchers and biologists. There are various levels of diversity expressed by life on Earth. Species is the fundamental unit of biological organization and hence important unit of assessing the biological diversity of an area. Species diversity is considered as one of the most basic and distinct levels which has many practical considerations. The changes in the species diversity indicate changes in ecosystem structure, functioning and services. Species diversity is perceived and analysed by using various factors such as species richness, abundance and evenness which can be attempted to express quantitatively (Fisher et al. 1943; Simpson 1949; Smith et al. 1996; Purvis & Hector 2000).

Rivers are an important ecological entity that supports rich biodiversity. The water flow, geographical and geological factors, the interaction between the terrestrial and aquatic ecosystems, and the dynamic nature make the rivers one of Earth's most complex biophysical systems (Naiman et al. 1993; Sinha et al. 2019). The rivers in the Western Ghats are very dynamic. The river channels are unique in terms of their flow regimes and channel characteristics. The hill streams are turbulent and filled with energy due to the higher flow gradients. Riffles and pools are more in the foothills. In the plains, the river meanders over larger distances with a slow flow. This has distributed the nutrients and energy flow across the basin (Tanida 2009). These ecological processes occurring in the upper stream affect the ecosystems in lower reaches and the biological communities capitalize on it. As a result, the species assemblage and its community characteristics vary according to the physical conditions of the river system (Sidhu et al. 2010; Sinha et al. 2019b).

The natural habitats of the river contain various animal communities. Birds are one of the dominant and common animal communities in the ecosystem. The diverse habitats of the river corridors support many birds (Stauffer & Best 1980; Knopf 1985). They play a crucial role as pollinators, seed dispersers, and insect pest controllers (Whelan et al. 2015). Therefore, understanding the bird communities of the river system can provide insights into its management and conservation prioritization of rivers and associated habitats (Rice et al. 1980; Naiman et al. 1993; Gergel et al. 2002). The habitats, availability of resources, predatory pressure and

competition, and vegetation structure are some of the factors that determine the species distribution (Fitzherbert et al. 2008; Jayapal et al. 2009). The variation in these factors and the seasonality of birds shape the bird community (Wiens 1989). Recent studies show that the population trends of many birds are showing a decline (Praveen et al 2021; SoIB 2023). Hence long-term monitoring of bird species and its populations is necessary. This information can provide the effect of climate change and resource availability in a landscape. But such attempts are very less in the country.

Kerala is a land gifted with several rivers and a high diversity of birds. (Neelakantan 1969, 1970, 1981; Neelakantan et al. 1980; Neelakantan & Sureshkumar 1980; Ali & Ripley 1983; Pramod 1995; Pramod et al. 1997; Ali 1999). Particularly, the wetlands in Kerala are rich in avian diversity both resident and migratory (Jayson 2002; Nameer 2005).

The Bharathapuzha River basin is considered an ideal study site for conducting avian ecological studies due to the complex relationships between the river and its surrounding habitats. The river is limited to its ecological boundaries, however, the birds they support use the entire landscape. We considered the river basin as a single ecological entity in this investigation to understand the bird community pattern of the area. The holistic approach in river basin study can include the structure, function, and stability of riverine ecosystems and is essential for understanding the biological communities and their interactions (Vannote et al. 1980). However, in most cases, the research was confined to a specific location or a stream due to the objective nature of the research question, the practical difficulty in data collection, and the complexity of the community interactions (Buckton & Ormerod 1997; Buckton 1998; Kumar 2006; Sinha et al. 2019b). We employed a ridge-to-reef approach for sampling to document the bird diversity from the estuary, mainstream, main tributaries, and headwaters. The long-term and high levels of anthropogenic pressures have created structural changes in the river channel. Since birds are considered as indicators of habitat quality, understanding the bird community assemblages and their distribution can provide deeper insights into the quality of the river system.

This chapter explores the bird species diversity and distribution of the Bharathapuzha river basin, focusing on variations of species composition in different ecological zones of the river basin. We hypothesized that the diversity, distribution, and composition of bird species may vary across the different ecological zones in different seasons. The results of the study may help in the development of a management strategy for the conservation of birds and riverine ecosystems.

Data

The bird observation data was collected from 280 locations in three cycles using the point count method. A total of 840 points were surveyed during the survey period. The data collection protocol and sampling design were explained in Chapter 3. This data is used to analyze the bird species distribution and community assemblages in the ecological zones.

Data Analysis

Species diversity

Basic descriptive statistics tools were used to summarise and comprehend the details of bird species richness and abundance data of the three seasons studied and its partitioning in different ecological zones. All the data was tested for normality and homogeneity of variance before parametric tests were applied. (Magurran 1988). Bird abundance data was arranged in the Species vs Sites contingency table to analyze the distribution pattern in space. Sampling adequacy and expected species richness were estimated using the Chao-1 index (Chao et al. 2005). All diversity analysis, tables, and graphs were prepared using Ms. Excel and PAST.

The following community attributes were analysed following Magurran 1988.

1. Species Richness: The number of species in different special and temporal scales.
2. Shannon Index: This is a measure of diversity that takes into consideration the number of species and their abundance.
3. Dominance: This index takes into account the abundance of each species in a community. Dominance has been calculated as $D = \sum_i (n_i/n)^2$ where n_i is the number of individuals of taxon
i. The values of D range from 0 to 1. If the D value is 0 the community has an even distribution of all taxa. If the D value tends towards 1 it denotes the community is dominated by one or few species.
4. Simpson's index: Simpson's index is an evenness measure calculated as 1-D.
5. Evenness: Evenness is calculated as $e^{H/S}$ where H is the Shannon index, and S is the total number of species.

Species distribution

Ven diagram is used to represent the partitioning of species richness among ecological zones. Heat maps were prepared using the package ggplot2 (Wickham 2016) to understand the species

occurrence in different ecological zones. The species were classified into two, such as residents and migrants for further clarity of the distribution, and separate graphs were generated in each ecological zone. The more abundant birds were clubbed towards the right side of the graph and the rare species to the left side. Rank abundance models were generated to understand the species distribution pattern in each ecological zone.

Bird community variability

Species richness and relative abundance were used as the primary factors in the analysis of community patterns and variability. The nested ANOVA model was used to understand the significant difference among the bird communities within and among all ecological zones in different seasons in the Bharathapuzha river basin.

Species distribution patterns, rank abundance distribution patterns, and community variability were examined using R statistical language V4.3.0 with R Studio. Diversity indices and Rank Abundance Distributions were estimated using ‘vegan’: Community Ecology Package 2.6-4 (Oksanen et al. 2018). All distribution tables and graphs were prepared using Ms. Excel and PAST.

Results

The study was conducted from October 2017 to March 2019. Table 2 shows the quantification of the effort along with the diversity and abundance of birds recorded during the study period. A total of 267 species were recorded during the study period from the study area, these birds fall into 20 orders and 71 families (Appendix 1). Out of 262 bird species recorded in the study area 235 species of birds were recorded through the systematic sampling process. Twenty-seven bird species were listed in the opportunistic observations.

Table 2: Ecological zone-wise sampling effort for avifauna diversity survey in Bharathapuzha river basin.

Ecological Zone	Grids (N)	Point counts(N)	Total effort(Hrs)	Species observed(N)	Individuals encountered (n)
Upper reaches	25	300	75	209	11280
Middle reaches	27	324	81	145	10602
Lower reaches	18	216	54	155	14929
Overall	70	840	210	235	36811

The last updated and authentic publication of bird diversity of the Bharathapuzha River listed only 143 species of birds from the river basin (Kumar 2006). This study adds 119 species more to the authentic list of the birds in the basin (Raj et al. 2023). A total of 36811 individuals of birds were observed in three seasons of systematic sampling data. Sampling of two post-monsoon seasons recorded 27242 individuals from 70 grids including several migratory species. Only one sampling was done in the monsoon season and recorded 9569 resident birds in the basin during that period. Table 3 and 4 gives the descriptive statistics of the species richness and abundance in the river basins with a brake up of ecological zones.

Table 3: Descriptive statistics of Species Richness of the river basin and ecological zones

Ecological zones	No of grids	Sp. richness	Mean	Stand. dev	Min	Max	Coeff. Var
Lower reaches	18	145	62.50	10.52	48	89	16.8
Middle reaches	27	155	52.26	8.54	36	69	16.34
Upper reaches	25	209	63.32	14.65	34	88	23.13
Total	70	235	58.84	12.53	34	89	21.30

Table 4: Descriptive statistics of bird abundance of the river basin and ecological zones

Ecological zones	No of grids	Sp. abundance	Mean	Stand. dev	Min	Max	Coeff. var
Lower reaches	18	14929	829.39	438.21	358	2200	52.835
Middle reaches	27	10602	392.67	135.55	154	625	34.52
Upper reaches	25	11280	451.20	292.95	173	1366	64.93
Total	70	36811	525.87	342.17	154	2200	65.07

Arrhenius plot obtained by plotting the logarithm of abundance measure of each grid to the species observed in the grid is given in Figure 5. It shows a linear trend. Similarly, the logarithm of the abundance measure of each species plotted to the number of grids each one of them sighted also gives a similar trend (Figure 6). R value is on lower side due to the out layers.

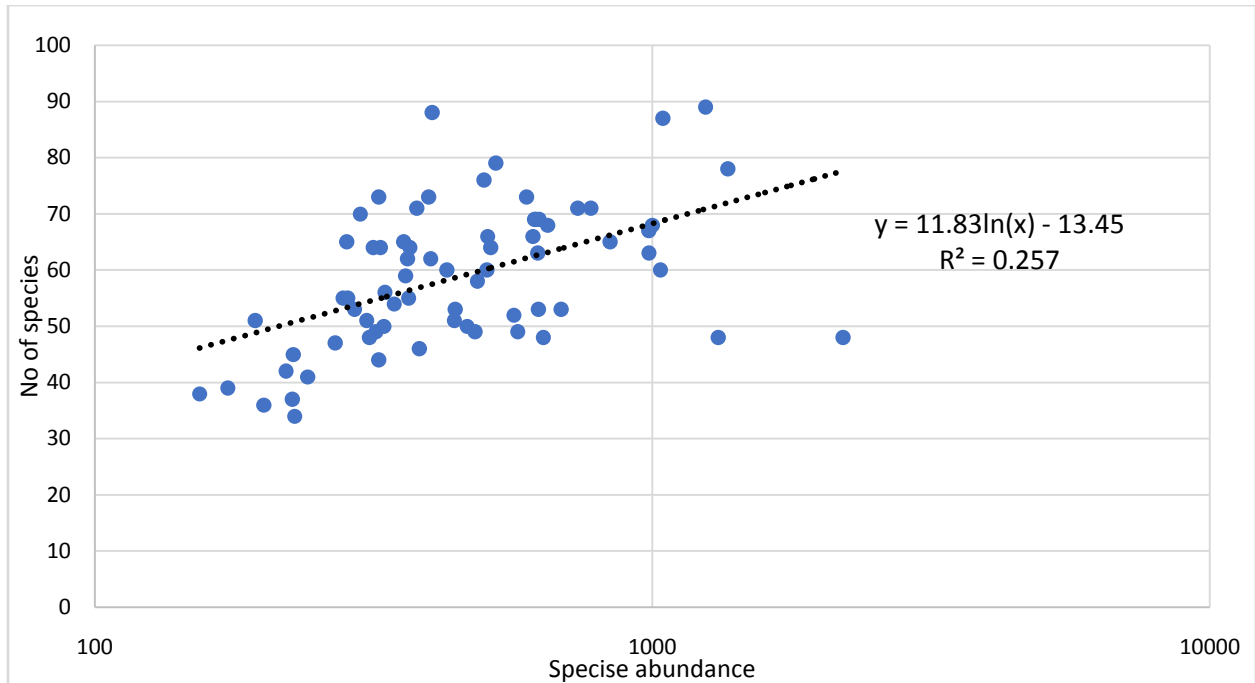


Figure 5: Area and species abundance relationship trend

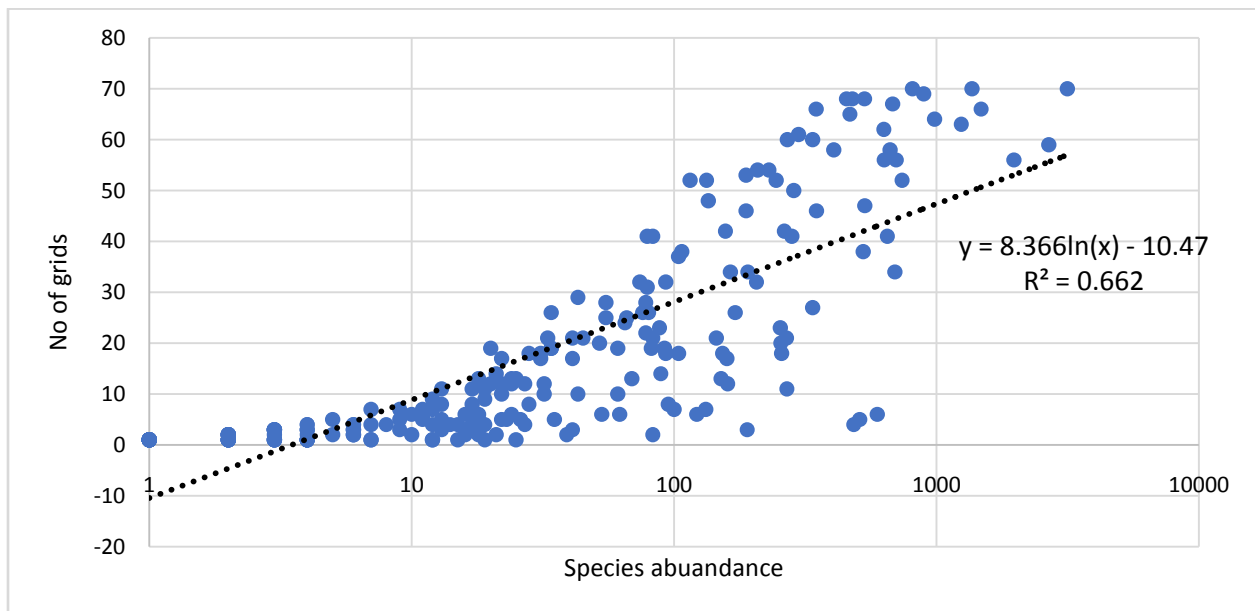


Figure 6: Species and area relationship trend

Species diversity

Expected species richness calculated using Chao-1 was closer to the observed richness during the sampling indicating the adequateness of the sampling (Table 5). The Shannon-Weiner index (H') shows higher species richness in upper reaches than in middle and lower reaches indicating

the rarer species in that region as expected due to the forested habitat of the hill areas. Evenness and dominance were similar across the river basin.

Table 5: Diversity indices calculated for various ecological zones.

Diversity indices	Upper reaches	Middle reaches	Lower reaches
Dominance (D)	0.021	0.038	0.035
Simpson (1-D)	0.98	0.96	0.96
Shannon (H')	4.35	3.82	3.88
Chao-1	220.70	158.20	158.50
Observed species richness	209	145	155

Taxonomic composition (Order)

The taxonomic composition of the bird species recorded in the study shows that the most dominant group in the river basin was Passeriformes (42%) followed by Charadriiformes (13%), Pelecaniformes, and Accipitriformes (6%) (Figure 7). As the study is on the total riverine ecosystem birds, this pattern was expected.

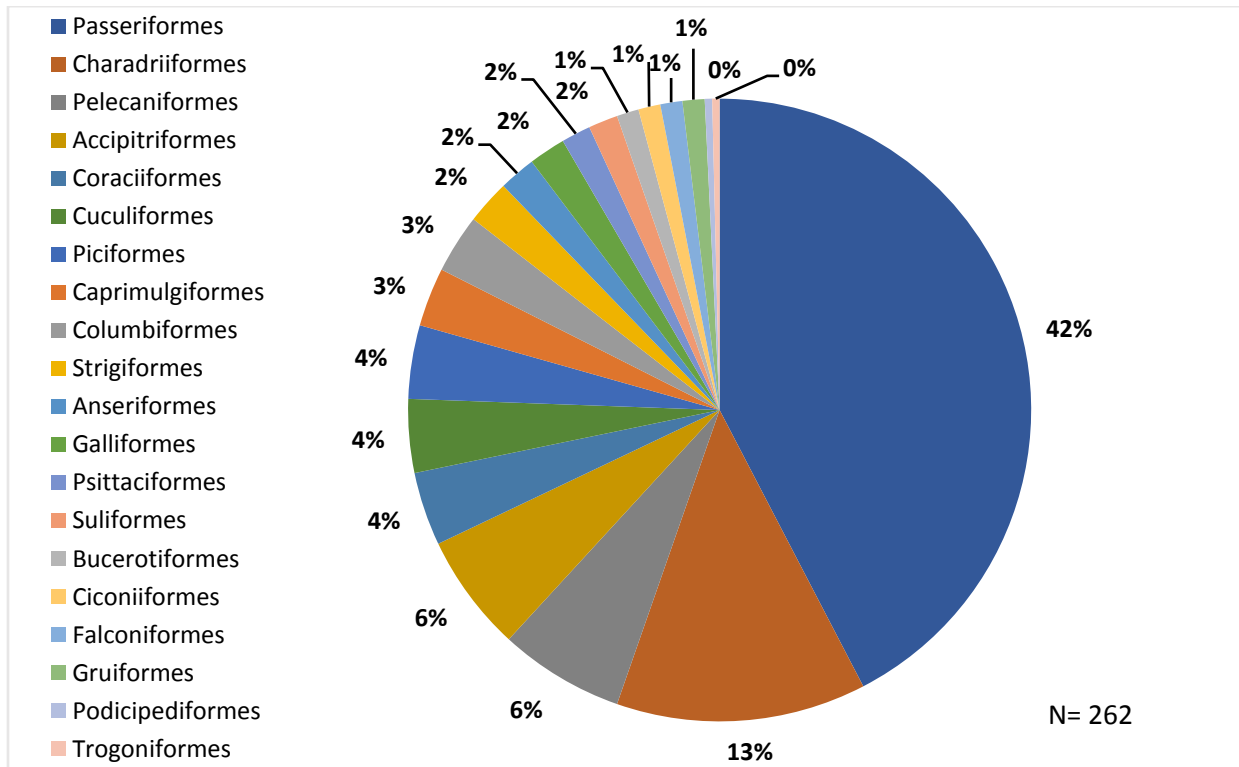


Figure 7: Taxonomic composition (Order) of birds in the Bharathapuzha River basin

Taxonomic composition (Popular bird group)

The birds recorded in the study are divided into six popular bird groups. Among them, passerines (50%) were found to be the most dominant group, followed by waders (15%), near passerines (11%) and water birds (10%) (Figure 8). The popular bird group richness in each ecological zone is shown in Figure 9.

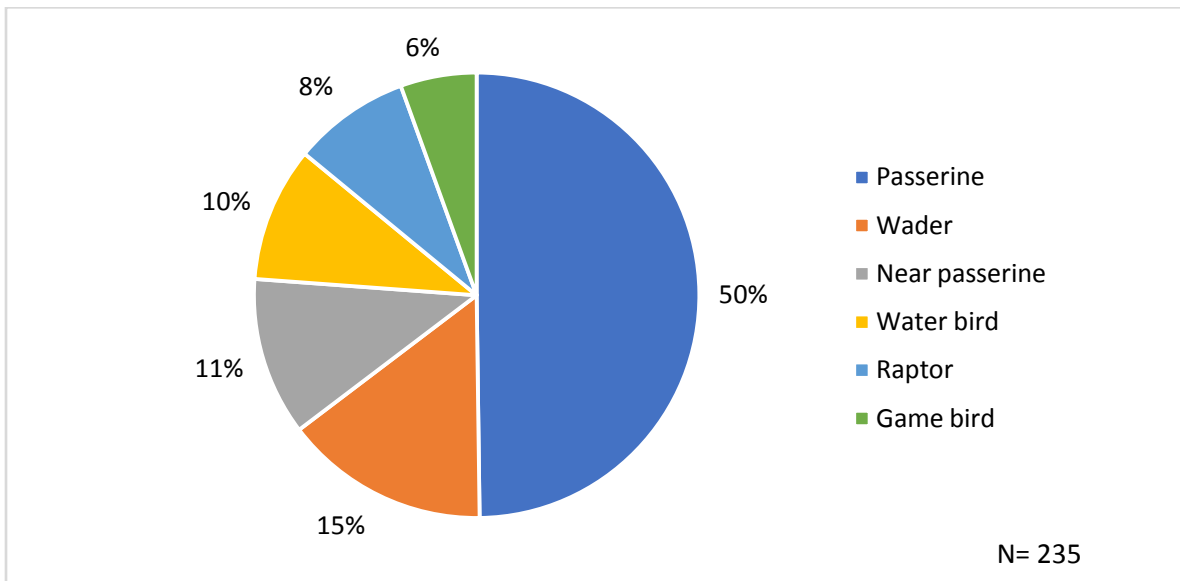


Figure 8: Taxonomic composition (popular bird group) in Bharathapuzha river basin

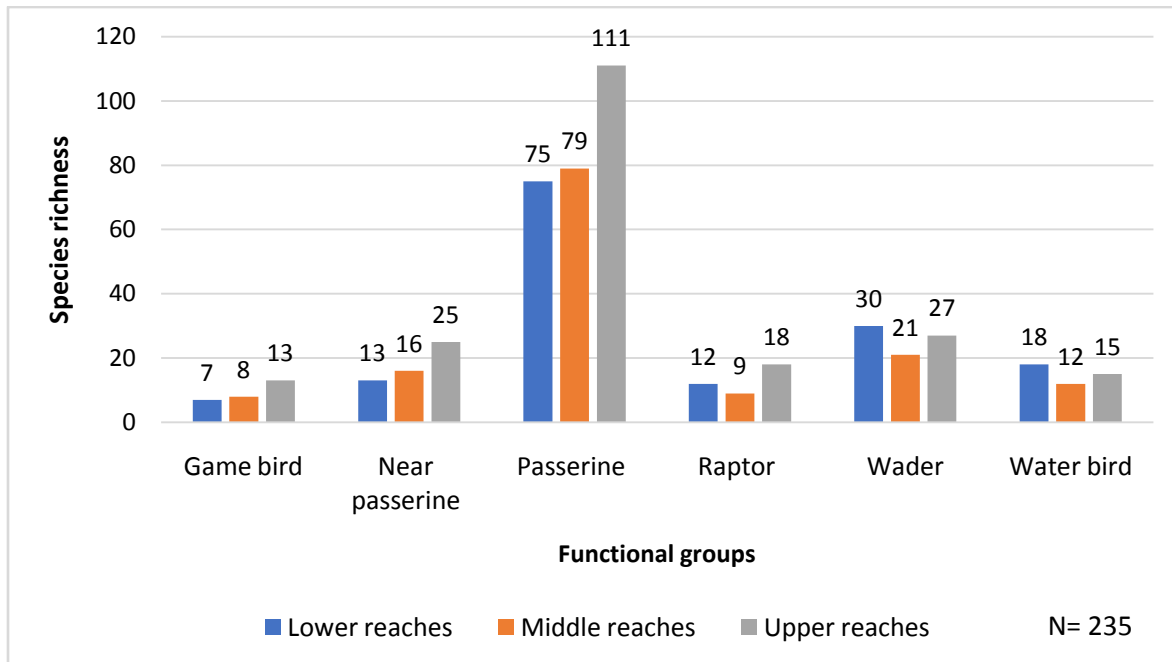


Figure 9: Popular bird group richness in each ecological zone

The passerine birds were the most abundant group in all ecological zones. The abundance of water birds, raptors, and waders was found higher in the lower reaches. Game birds and near passerines were higher in abundance in the middle reaches (Figure 10).

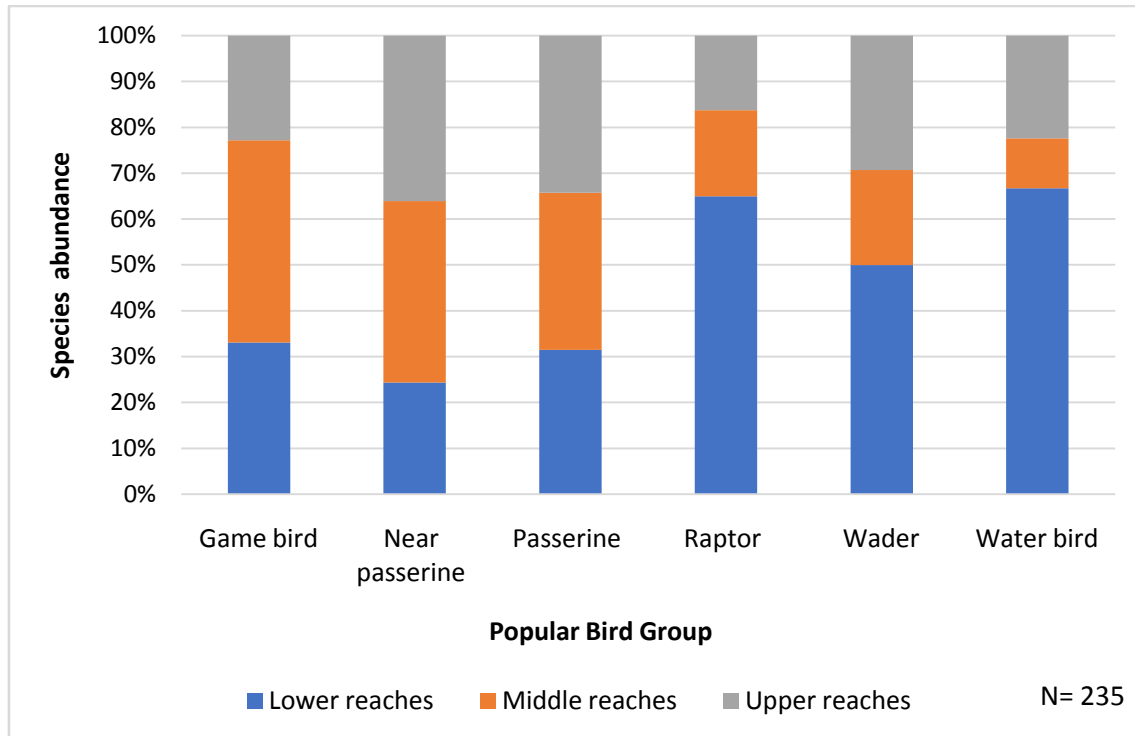


Figure 10: Popular bird group abundance in different ecological zones.

Feeding guild composition

The birds were classified into eight feeding guilds on the major diet of the bird (Ali & Reply 1983) such as insectivore, nectarivore, frugivore, granivore, omnivore, carnivore, aquatic carnivore, and semi-aquatic carnivore. Insectivore (48%) birds were found to be the most dominant birds in the river basin, followed by semi-aquatic carnivores (14%) and carnivores (12%)(Figure 11).

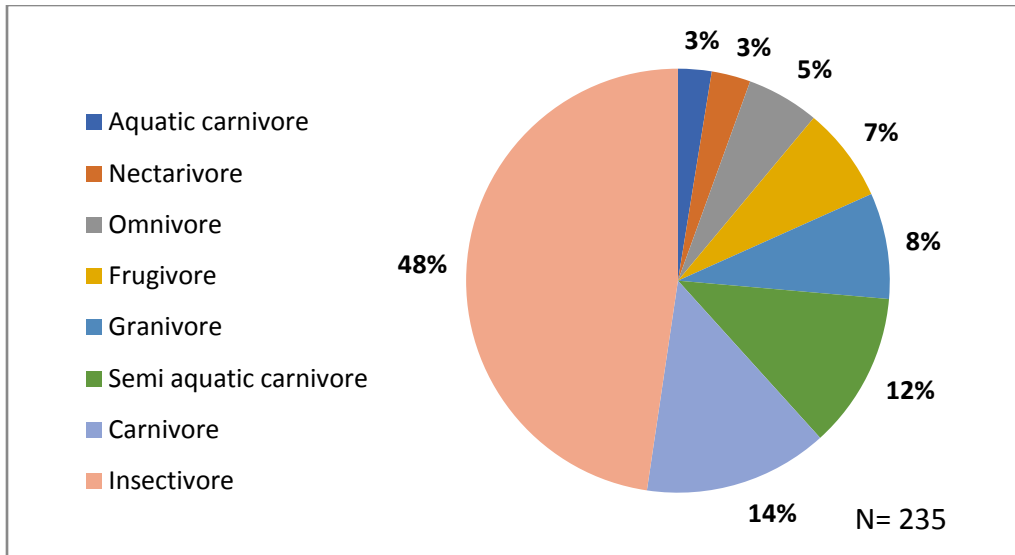


Figure 11: Feeding guild composition of Birds in the Bharathapuzha river basin

The feeding guild composition of each ecological zone was compared. The semi-aquatic carnivores, omnivores, and frugivores were found higher in the lower reaches and lesser in the Upper reaches. Carnivores and aquatic carnivores were more in the lower reaches and lesser in the middle reaches. Granivores were more in the middle reaches followed by upper reaches and lower reaches. The insectivores were found to be higher in the Upper reaches and lower in the lower reaches. The nectarivores were more in the higher in the upper reaches (Figure 12).

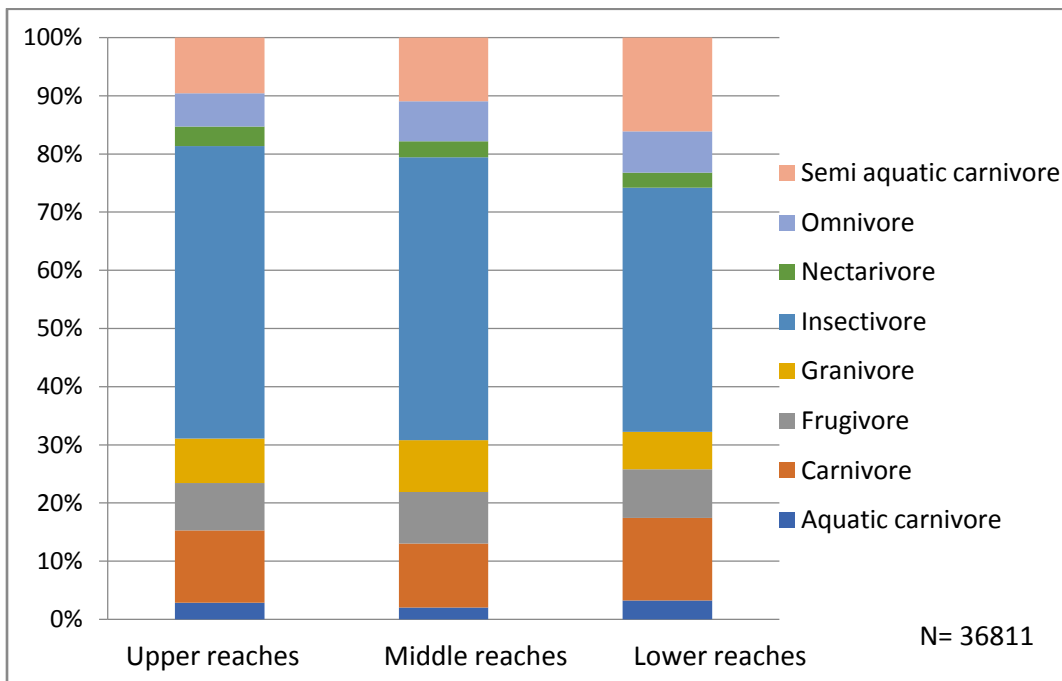


Figure 12: Feeding guild composition of birds in different ecological zones Bharathapuzha river basin.

Species distribution and occurrence in the river basin

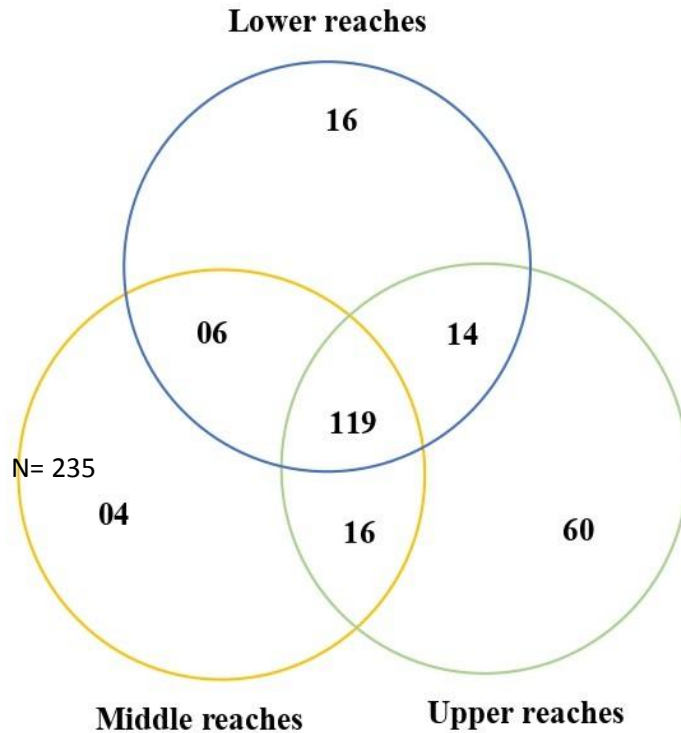


Figure 13: Partition of species richness between ecological zones.

The bird species occurrence in each ecological zone is shown in Figure 13. There were 119 bird species reported common to all three ecological zones. At the same time, 60 bird species were reported only in the upper reaches, four in the middle reaches and 16 in the lower reaches of the river basin (Figure 13).

To understand the distribution pattern of bird species in the river basin rank abundance-based distribution models were attempted. Zipf-Mandlebrot distribution was found to be a best-fit model for upper reaches (deviance = 401.60) and lower reaches (deviance = 465.40). However, bird species in the middle reaches followed a log-normal abundance distribution (deviance = 615.83) (Table 6).

Table 6: Estimated RAD of bird species from distinct ecozones based on stream order in the Bharathapuzha River Basin.

		Null	Log-Normal	Preemption	Zipf	Zipf-Mandelbrot
Upper reaches	Deviance	3698.84	622.88	1028.77	2780.50	401.60*
	AIC	4660.40	1588.44	1992.32	3746.05	1369.15
	AICc	3291.25	219.29	623.17	2376.9	0
Middle reaches	Deviance	5204.45	615.83*	1280.85	2491.06	1280.85
	AIC	5876.61	1291.99	1955.01	3167.22	1959.01
	AICc	4584.62	0	663.02	1875.23	667.02
Lower reaches	Deviance	7401.81	742.92	1571.21	3466.99	465.40*
	AIC	8163.55	1508.65	2334.94	4232.73	1233.14
	AICc	6930.41	275.51	1101.80	2999.59	0

Lower reaches had a steeper distribution than upper reaches and middle reaches indicating a high species turnover rate. While upper and lower reaches show shallow slopes, Middle reaches have more even abundances with species ranked with log-normal distribution. (Figure 14). The competitive exclusion of bird species due to the migrant birds can be a reason for the even distribution of birds in the middle reaches. The presence of dams in the upper reaches and estuaries in the lower reaches is also a factor in this distribution pattern.

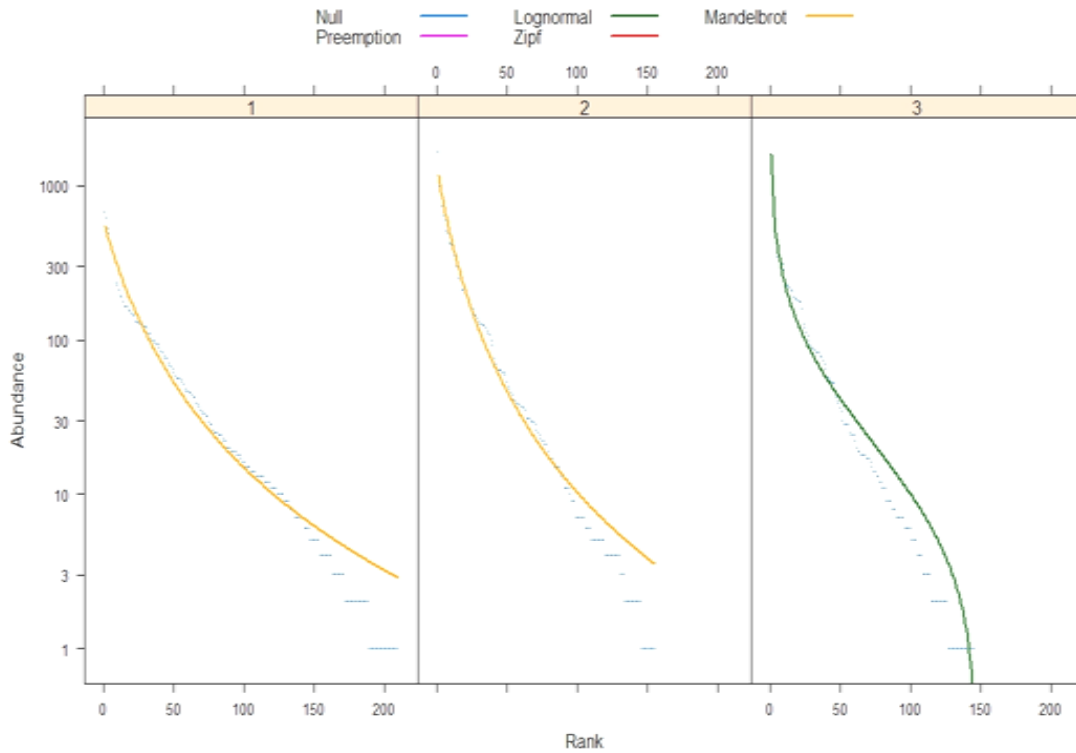


Figure 14: Best fit rank abundance model for birds observed in different regions of Bharathapuzha River Basin (1 – Upper reaches, 2 – Lower reaches, 3 – Middle reaches)

To know the specific distribution pattern of birds, relative abundance was used. Heat maps were prepared to understand the grid-wise abundance in different ecological zones.

The study recorded 48 species of migrants and 187 species of resident bird species from the river basin (Figure 15, Table 7).

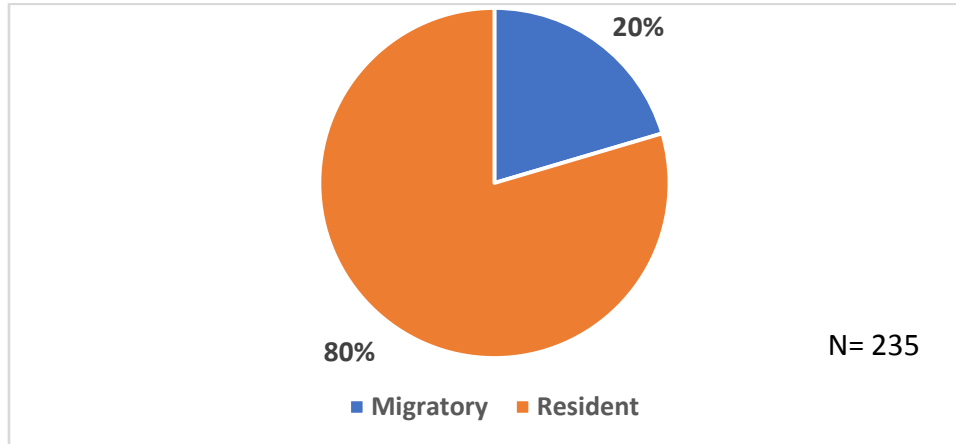


Figure 15: Migratory status of birds in the Bharathapuzha River basin

Table 7: Migratory status of birds in the river basin

Bird attribute	Bird category	Upper reaches	Middle reaches	Lower reaches	Grand Total
Species abundance	Migratory	617	2834	948	4399
	Resident	9985	12095	10332	32412
Species richness	Migratory	36	26	36	48
	Resident	173	119	119	187

There were 36 migrants and 173 residents in the upper reaches of the river basin. Heat maps for upper reaches show that there are 25 species of residents and four species of migrants occur in all grids with high relative abundance while 26 resident and four migrant species had rare occurrences (Figures 16a and 16b). In the middle reaches, there were 26 migrants and 119 resident birds were recorded (Table 8). 24 residents and three migrants had the highest occurrence and 15 resident species and three migrant species had rare occurrence (Figures 17a and 17b). In lower reaches, there were 36 migrants and 119 resident bird species were recorded (Table 8). 33 resident and eight migrant species had high occurrences and ten resident, and eight migrant species had rare occurrences (Figures 18a and 18b).

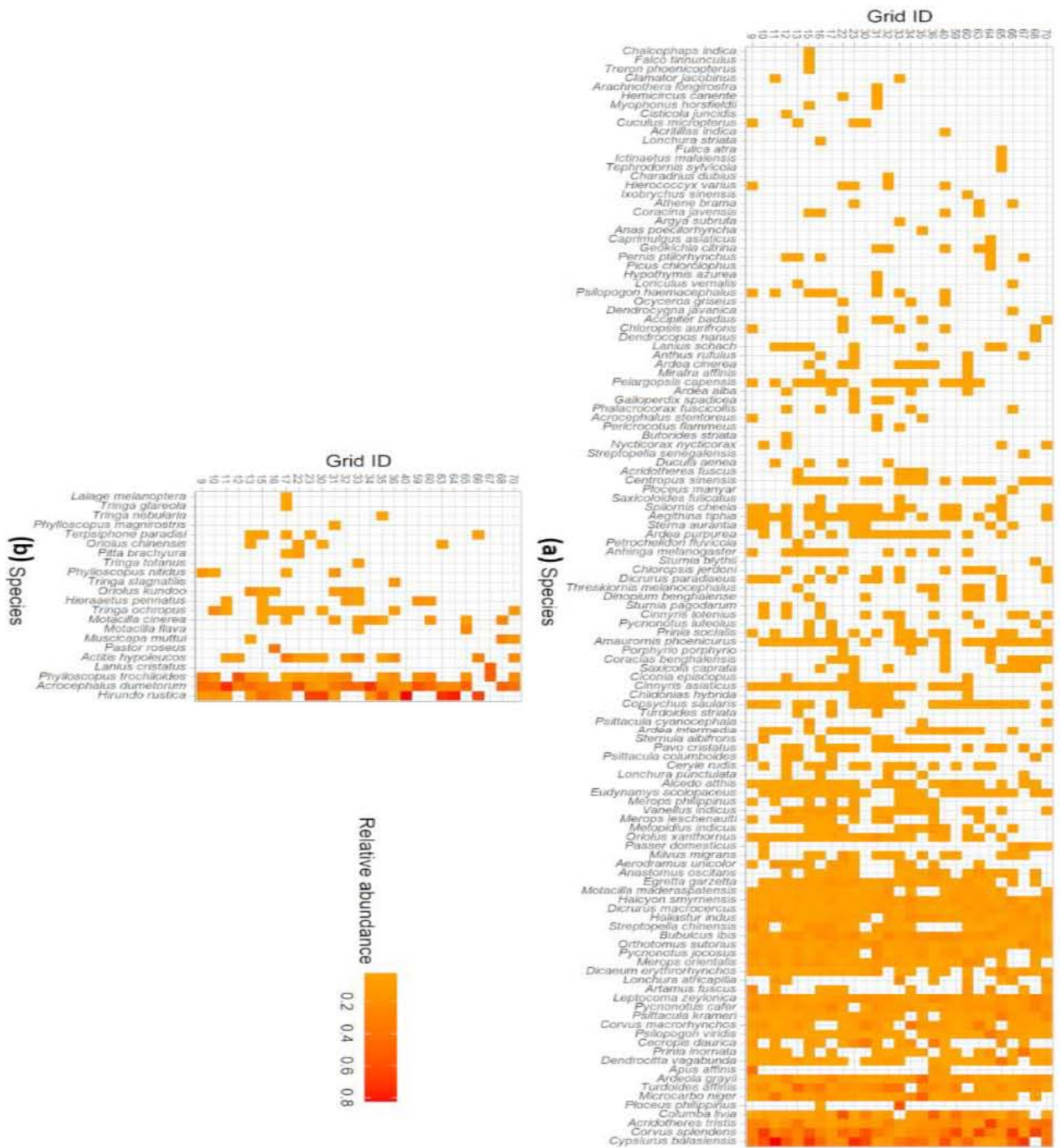


Figure 17: Distribution and relative abundance of birds across grids in middle reaches (a – Resident, b – Migrants).

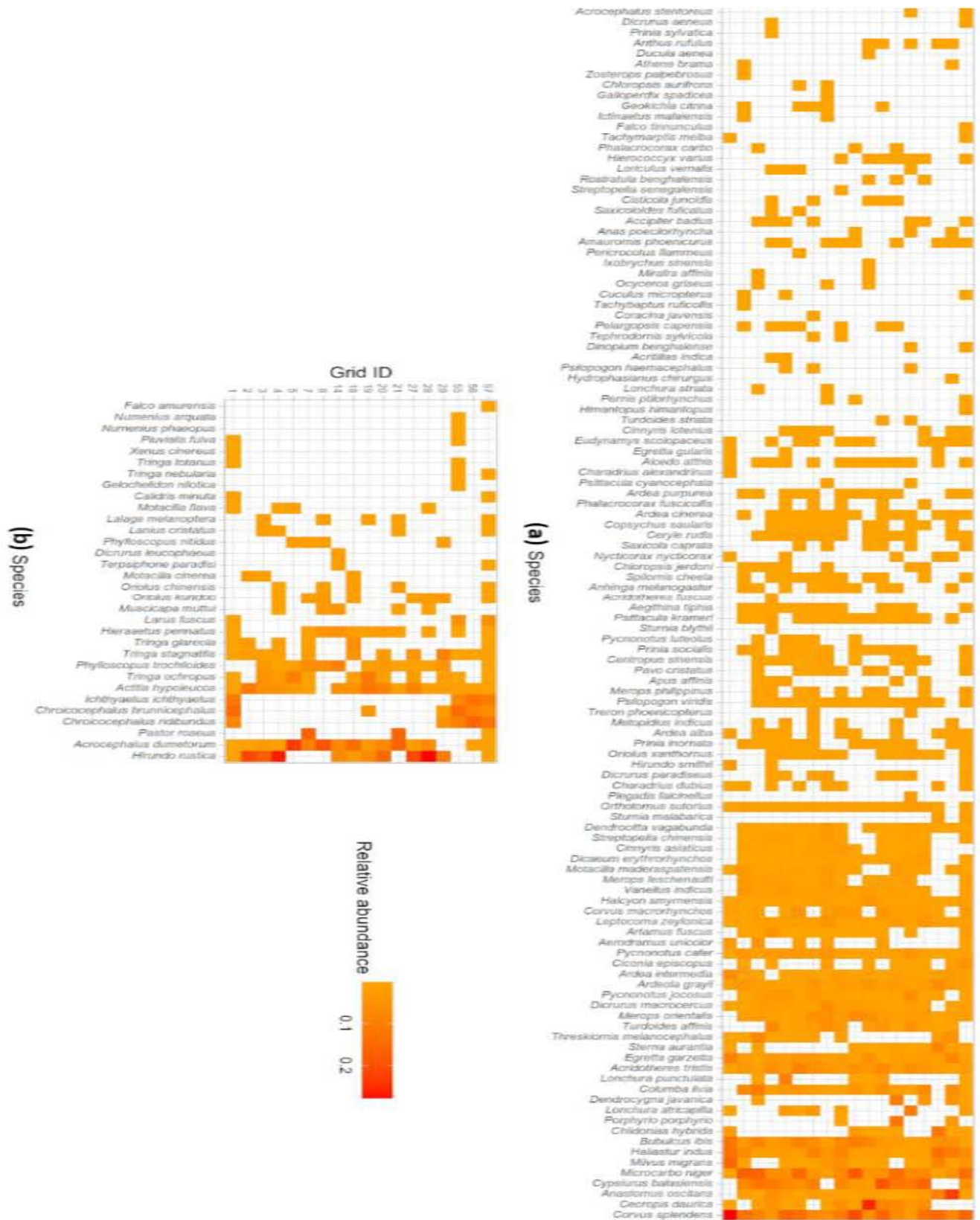


Figure 18: Distribution and relative abundance of birds across grids in lower reaches (a – Resident, b – Migrants).

Common and dominant birds in the river basin

The common birds are the most frequently sighted birds and dominant birds are the most abundant birds in the study locations. House Crow, Asian-palm Swift, Little Cormorant, Cattle Egret, Common Myna, Yellow-billed Babbler, Brahmini Kite, Red-vented Bulbul, Purple-rumped Sunbird, Blue Rock-pigeon White-throated Kingfisher, Common Tailorbird and Black Drongo found to be the most common and dominant birds in the river basin (Figure 19 & 20).

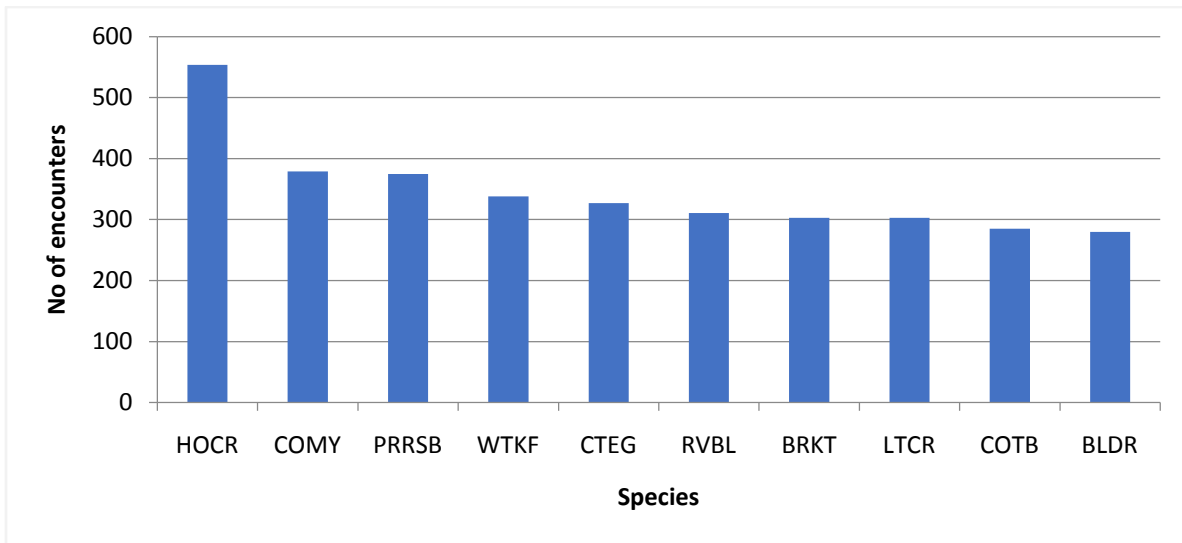


Figure 19: Ten most common birds in the river basin

(HOCCR-House crow, COMY-Common Myna, PRRSB-Purple-rumped Sunbird, WTKF-White-throated Kingfisher, CAEG-Cattle Egret, RVBL-Red-vented Bulbul, BRKT-Brahmini Kite, LTCR-Little cormorant, COTB-Common Tailorbird, BLDR-Black Drongo)

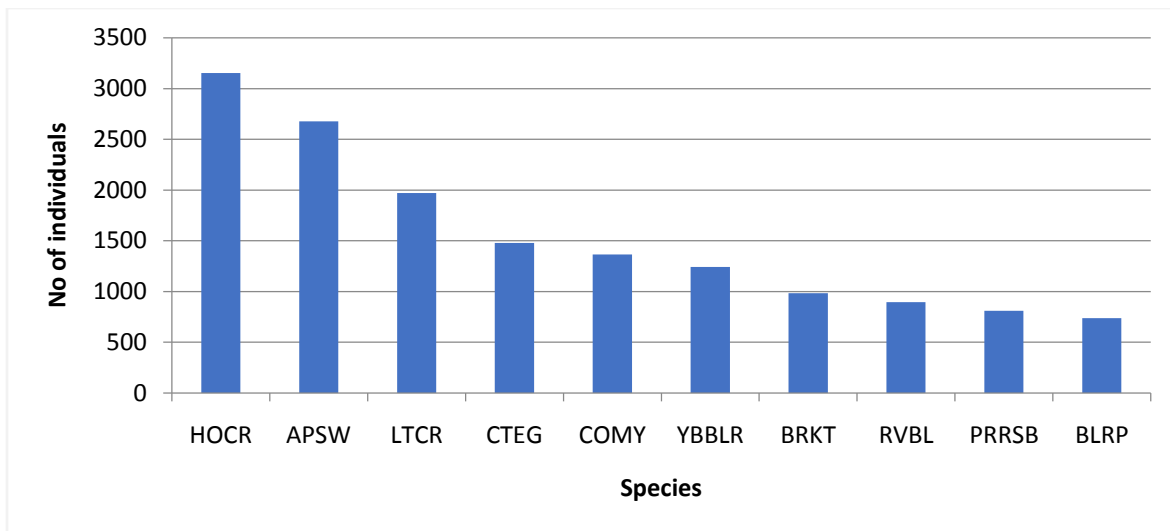


Figure 20: Ten most dominant birds in the river basin

(HOCCR-House crow, APSWAsian-palm Swift, LTCR-Little cormorant,CAEG-Cattle Egret, COMY-Common Myna, YBBLR- Yellow-billed Babbler, BRKT-Brahmini Kite, RVBL-Red-vented Bulbul, PRRSB-Purple-rumped Sunbird, BLRP-Blue Rock-pigeon)

Distribution of birds and their water dependency

To understand the bird distribution based on their water dependency the birds recorded in the study are classified into three categories such as water-dependent birds (WDB), water-associated birds (WAB) and non-water-dependent (NWAB). WDB includes all water birds such as cormorants, ducks and terns. WAB include egrets, herons, plovers and sandpipers. WAB includes passerines, raptors and fowls. The study recorded 23 species of water birds, 49 species of water-associated birds, and 163 non-water-associated birds, in the river basin (Table 8).

Table 8: Species richness of water-dependent, water-associated and non-water-dependent birds

Category	Lower reaches	Middle reaches	Upper reaches	Grand Total
NWAB	96	101	153	163
WAB	41	32	41	49
WDB	18	12	15	23
Grand Total	155	145	209	235

The abundance of non-water-associated birds is linear in the three ecological zones. The water-associated and water-dependent birds show similar abundance in the upper and lower reaches and lesser in the middle reaches (Figure 21). This indicates that the larger water bodies in the upper reaches such as dams and estuaries in the lower reaches are very important ecosystems for the water-dependent and associated birds in the basin.

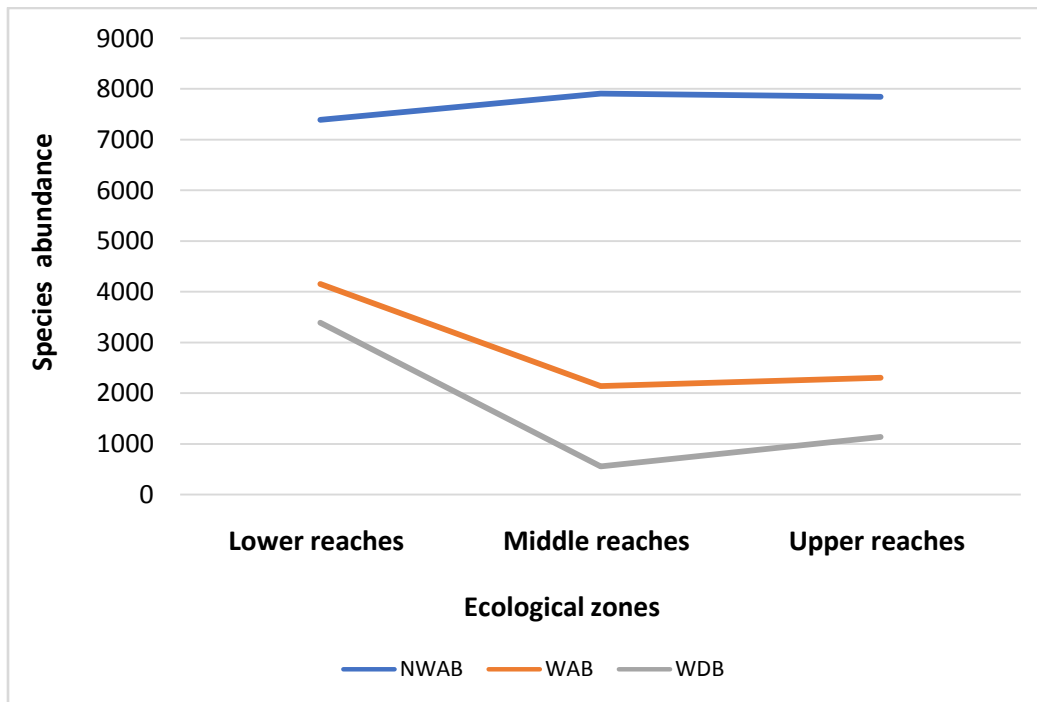


Figure 21: Distribution of birds and their water dependency in ecological zones

Most common and dominant Water dependent birds

Little Cormorant, Brown-headed Gull, Black-headed Gull, Palla’s Gull, Lesser Whistling-duck, Whiskered Tern, Huggins’s Gull, River Tern, Grey-headed Swamp-hen, White-breasted Waterhen, Oriental Darter, Bronze-winged Jacana, Indian Cormorant and Indian Spot-billed Duck found to be the most common and dominant water depended on bird in the study area (Figures 22&23).

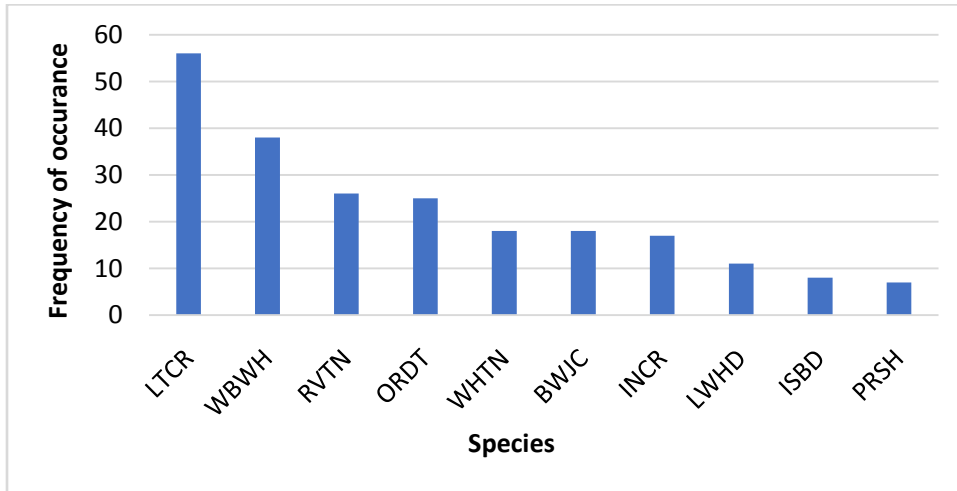


Figure 22: Ten most common water-dependent birds (WDB) in the Bharathapuzha River basin (LTCR- Little Cormorant, WBWH-White-breasted Waterhen, RVTN-River Tern, ORDT- Oriental Darter, WHTN- Whiskered Tern, BWJC-Bronze-winged Jacana, INCR- Indian Cormorant, LWHD-Lesser Whistling-duck, PRSH- Purple Swamp-hen, ISBD-Indian Spot-billed Duck)

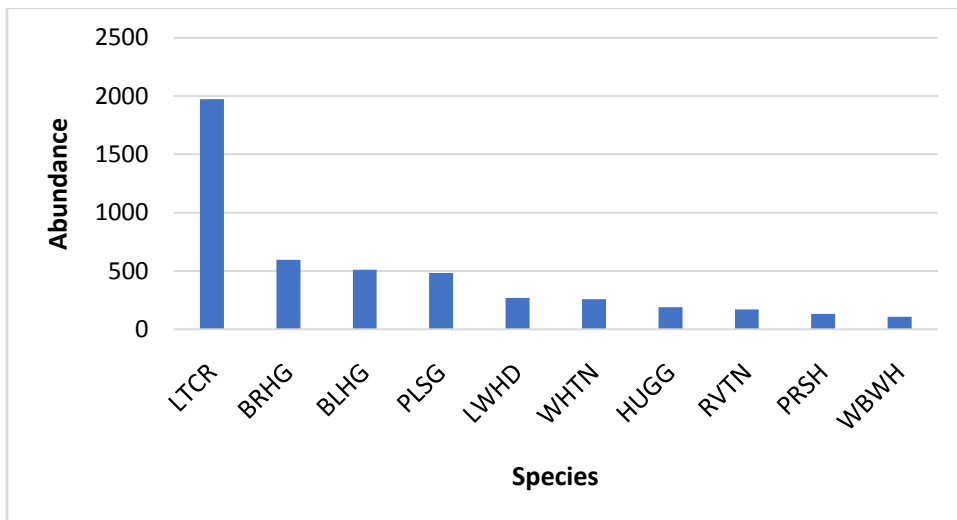


Figure 23: Ten most dominant water-dependent birds (WDB) in the Bharathapuzha River basin (LTCR- Little Cormorant, BRHG-Brown-headed Gull, BLHG-Black-headed Gull, PLSG-Palla’s Gull, LWHD- Lesser Whistling-duck, WHTN-Whiskered Tern, HUGG-Huggins’s Gull, RVTN-River Tern, PRSH-Purple Swamp-hen, WBWH- White-breasted Waterhen)

Most common and dominant water-associated birds

Cattle Egret, Brahmini Kite, Little Egret, Indian Pond Heron, Green Bee-eater, Asian Openbill, White-throated Kingfisher, Red-wattled Lapwing, Black-headed Ibis, Large-pied Wagtail and Small Blue Kingfisher are some of the most dominant and common water-associated birds in the study area (Figures 24& 25).

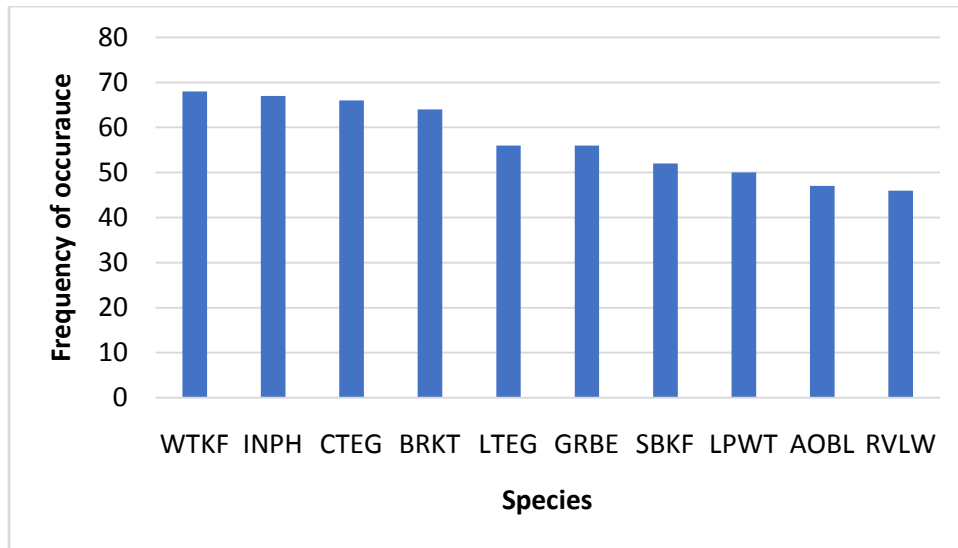


Figure 24: Ten most common water-associated birds (WAB) in the Bharathapuzha River basin (WTKF-White-throated Kingfisher, INPH-Indian Pond Heron, CTEG-Cattle Egret, BRKT-Brahmini Kite, LTEG-Little egret, GRBE-Green Bee-eater, SBKF- Small Blue Kingfisher, LPWT-Large-pied Wagtail, AOBL-Asian Open bill, RVLW-Red-wattled Lapwing)

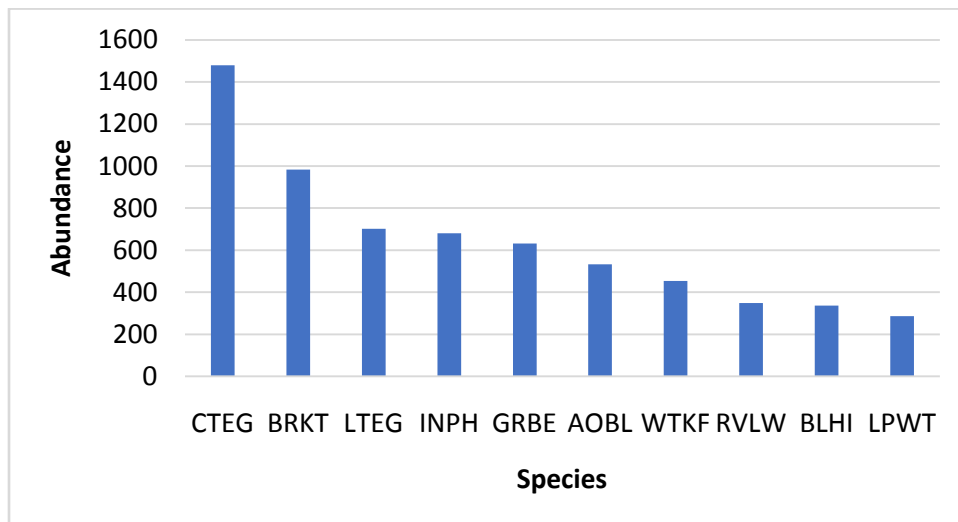


Figure 25: Ten most dominant water-associated birds (WAB) in the Bharathapuzha River basin (CTEG-Cattle Egret, BRKT-Brahmini Kite, LTEG- Little egret, INPH-Indian Pond Heron, GRBE-Green Bee-eater, AOBL-Asian Open bill, WTKF-White-throated Kingfisher, RVLW-Red-wattled Lapwing, BLHI-Black-headed Ibis LPWT-Large-pied Wagtail.)

Common and dominant non-water-associated birds

House Crow, Asian-palm Swift, Common Myna, Yellow-billed Babbler, Red-vented Bulbul, Purple-rumped Sunbird, Blue Rock-pigeon, Red-rumped Swallow, Large-billed Crow, Barn Swallow, White-cheeked Barbet and Blyth’s Reed-warbler are the most dominant and common non-water associated birds in the region (Figures 26&27).

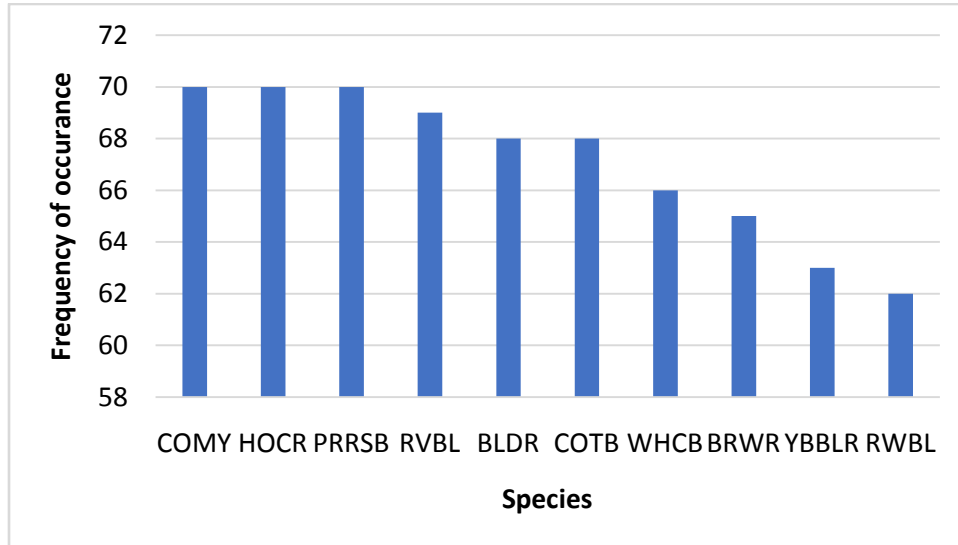


Figure 26: Ten most common non-water associated birds (NWAB) in the Bharathapuzha river basin.

(COMY-Common Myna, HOCR-House crow, PRRSB-Purple-rumped Sunbird, RVBL-Red-vented Bulbul, BLDR-Black Drongo, COTB-Common Tailorbird, WHCB-White-cheeked Barbet, BRWR-Blyth’s Reed-warbler, YBBLR-Yellow-billed Babbler, RWBL- Red-whiskered Bulbul)

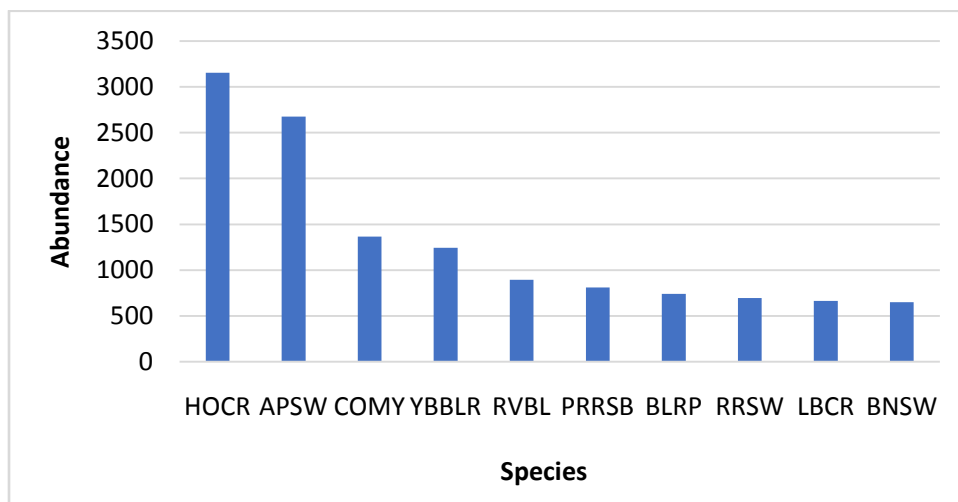


Figure 27: Ten most dominant non-water associated birds (NWAB) in the Bharathapuzha river basin

(HOCR-House crow, APSW-Asian-palm Swift, COMY-Common Myna, YBBLR-Yellow-billed Babbler, RVBL-Red-vented Bulbul, PRRSB-Purple-rumped Sunbird, BLRP-Blue Rock-pigeon, RRSW-Red-rumped Swallow, LBCR-Large-billed Crow, BNSW-Barn Swallow)

Bird Community Variation in Different Ecological Zones

To understand the bird community variation in among the ecological zones, diversity indices and community parameters were estimated for each ecological zone in each season (Table 9). The migratory season was found to be more diverse in each ecological zone. The community parameters such as species richness, Shannon diversity, Simpson diversity, and feeding guild were used in the assessment.

Table 9: Diversity of birds in each ecological zone in each season.

	Season	Sp richness	Simpsons	Shannons	Order richness	Feeding guild richness
Upper	Migratory -1	32.76 ± 10.33	0.92 ± 0.08	3.00 ± 0.47	8.48 ± 2.29	6.16 ± 1.11
	Non migratory	32.2 ± 8.93	0.93 ± 0.03	3.03 ± 0.28	7.92 ± 2.06	5.36 ± 0.86
	Migratory - 2	39.12 ± 12.01	0.94 ± 0.03	3.24 ± 0.32	9.68 ± 2.19	7.00 ± 1.22
Middle	Migratory - 1	34.41 ± 7.59	0.92 ± 0.03	3.00 ± 0.25	10.56 ± 1.65	6.52 ± 0.51
	Non migratory	26.37 ± 5.67	0.90 ± 0.05	2.80 ± 0.29	7.74 ± 2.14	5.37 ± 0.63
	Migratory - 2	30.48 ± 7.59	0.92 ± 0.03	2.95 ± 0.26	9.44 ± 1.69	6.15 ± 0.46
Lower	Migratory – 1	38.67 ± 12.76	0.89 ± 0.05	2.79 ± 0.43	10.61 ± 2.17	6.33 ± 1.03
	Non migratory	30.94 ± 7.94	0.91 ± 0.04	2.84 ± 0.30	8.56 ± 1.82	5.39 ± 0.61
	Migratory -2	38.06 ± 7.34	0.92 ± 0.04	3.02 ± 0.32	9.11 ± 2.14	6.22 ± 0.88

Species richness

The species richness was compared between the three ecological zones among the two seasons using the Nested ANOVA test. The results show that the species richness varied across all ecological zones between the seasons. There was a significant difference in the species richness across the ecological zones (p value= 0.0005). The Lower reaches of the river show higher species richness in the migratory season. Upper reaches show higher species richness in the non-migratory season (Figure 28). There are observations of high species richness in the upper reaches during migratory season due to the high incidents of passerine migratory birds. Similarly, during the non-migratory season relatively higher species richness points were recorded in the lower reaches.

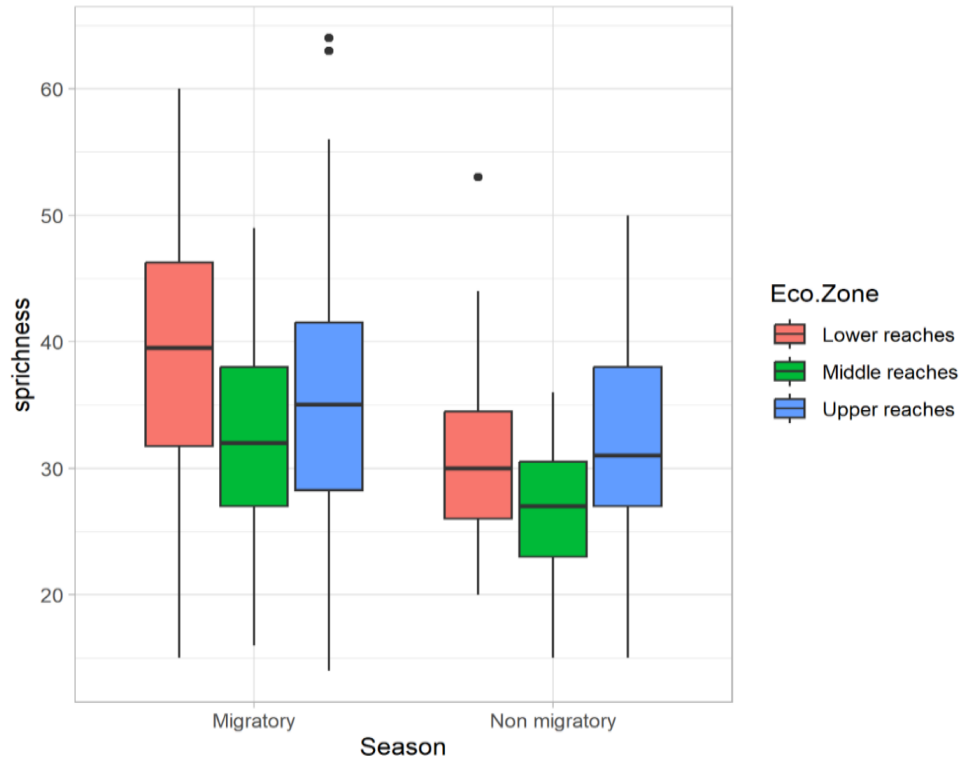


Figure 28: Species richness in different ecological zones in different seasons

Shannon Diversity

Nested ANOVA test was performed to understand the variation in Shannon Diversity between the three ecological zones among the two seasons. The results show a significant difference in the Shannon diversity between the three ecological zones (p value= 0.0004), but there was no significant difference found in the seasons in the ecological zones. The diversity is found higher in Upper reaches, especially in the migratory seasons, in all three ecological zones (Figure 29). Occurrence of migrant passerine birds in the upper reaches expressed as outliers.

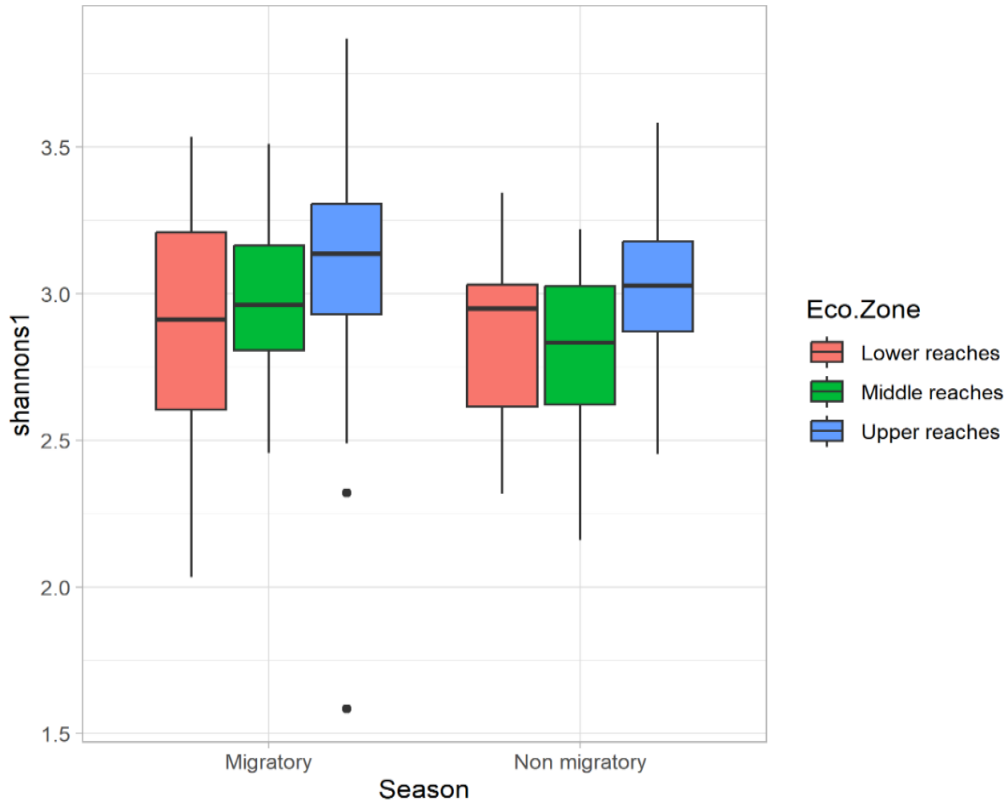


Figure 29: Shannon Diversity in different ecological zones in different seasons

Simpson Diversity

The Simpson diversity values were compared using the Nested ANOVA test to understand the community variation between the three ecological zones among the two seasons. It is found that high evenness in the upper and middle reaches of the river basin (p value= 0.008). There was no significant difference found in Simpson diversity values within the three ecological zones among all seasons (Figure 30). Occurrence of migrant passerine birds in the upper reaches and middle reaches in migratory season and resident passerines in the non-migratory seasons expressed as outlayers.

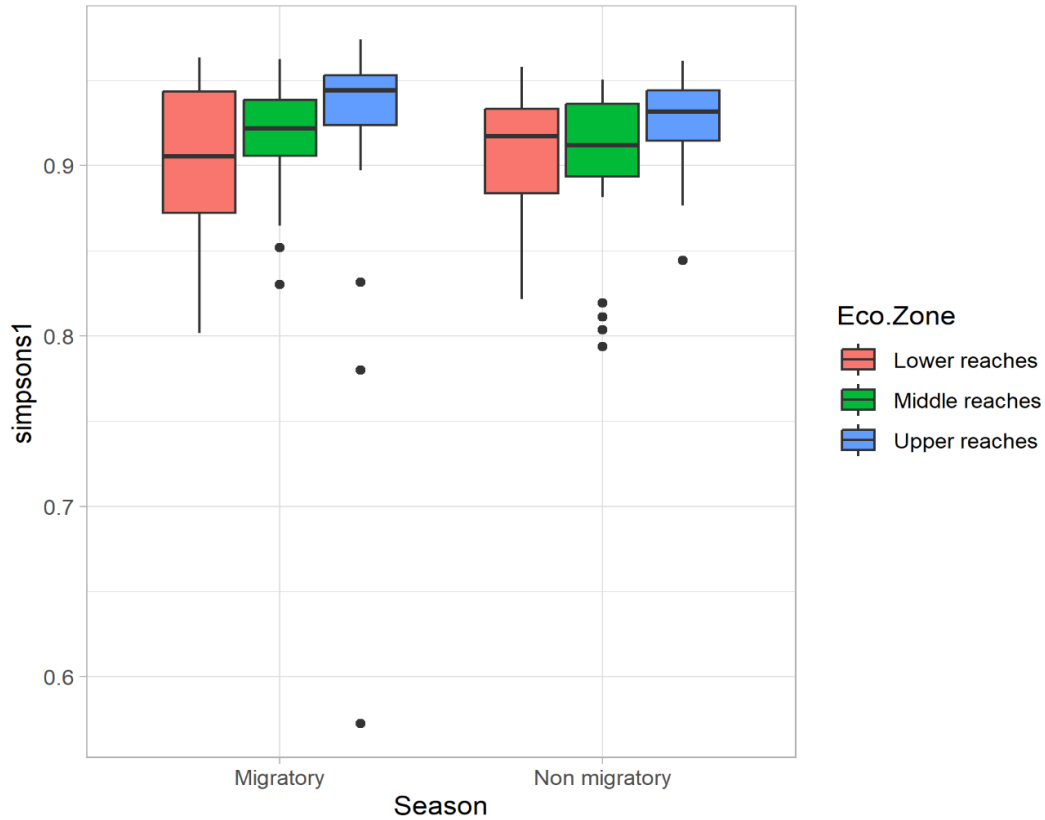


Figure 30: Simpson's Diversity in different ecological zones in different seasons

Feeding guild

The feeding guild composition was compared between the three ecological zones among the two seasons using the Nested ANOVA test. The results show that there was no significant difference in feeding guild between the seasons and ecological zones (p value= 0.37) (Figure 31). The high abundance of migratory passerine birds and waders expressed as outliers in the migratory seasons in different ecological zones.

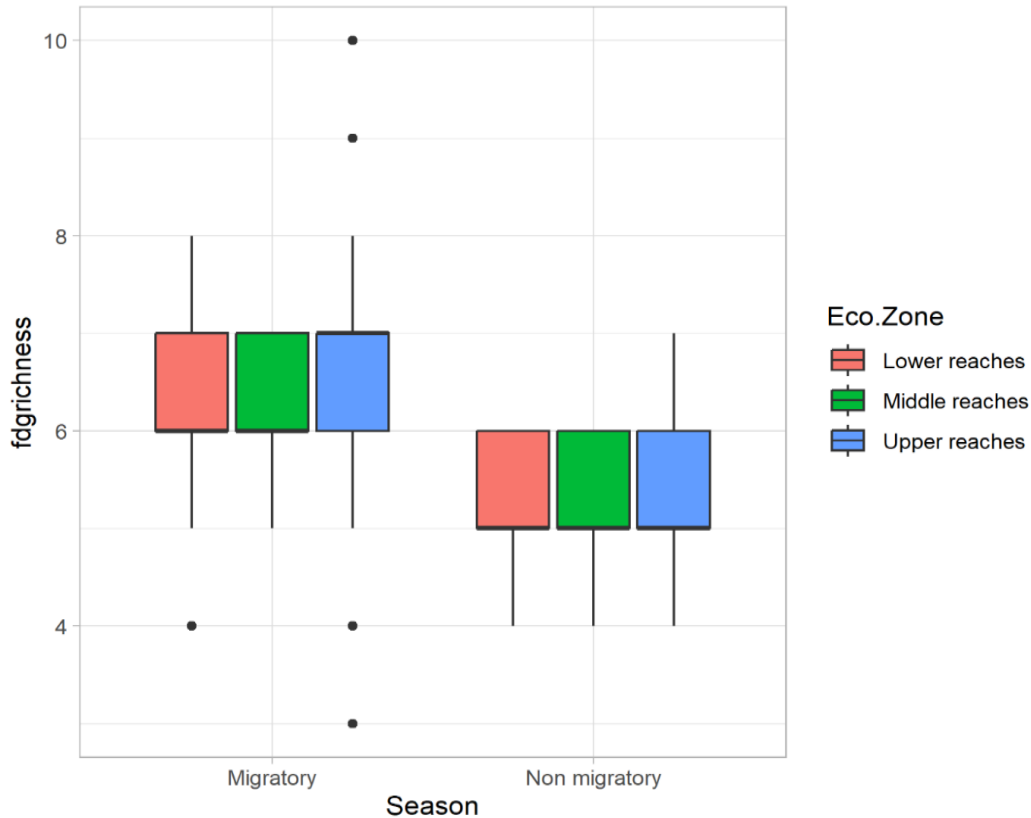


Figure 31: Feeding guild in different ecological zones in different seasons

Discussion

The study recorded 49% of the total birds recorded from Kerala (Chandran et al. 2023). Kumar 2006 has recorded 143 bird species from the river basin. This study updated the existing checklist to 262 bird species from the river basin. The study identified 60 species that are specific to the upper reaches, four to middle reaches and 16 to the lower reaches. There were 119 bird species common to all regions. This indicates that productive and heterogeneous habitats of the Bharathapuzha river basin support birds from different niches and foraging guilds from forest to wetland birds including synanthropic species.

Being a human-dominated landscape, some synanthropic species such as the Common Myna *Acridotheres tristis* and House Crow *Corvus splendens* were dominant in the region. However, common birds of the landscape were the Purple-rumped Sunbird *Leptocoma zeylonica*, Red-vented Bulbul *Pycnonotus cafer*, Black Drongo *Dicrurus macrocercus*, Common Tailorbird *Orthotomus sutorius*, Asian Palm Swift *Cypsiurus balasiensis*, and Yellow-billed Babbler *Turdoides affinis*. Being a wetland, birds such as White-throated Kingfisher *Halcyon smyrnensis*,

Indian Pond Heron *Ardeola grayii*, Cattle Egret *Bubulcus ibis*, and Little Cormorant *Microcarbo niger* were also found common in the river basin. These birds are generalist feeders and adapt themselves to survive in any condition. Malayan night heron *Gorsachius melanolophus*, Chestnut-winged Cuckoo *Clamator coromandus*, Black-bellied Tern *Sterna acuticauda*, and Indian Spotted Eagle *Clanga hastate* were some of the interesting sightings during the study period. These birds are rare and require conservation attention. The maximum single species flock size recorded was Little Cormorants with <300 individuals in a single location at Walayar dam. Several Gull species were recorded in congregations with high numbers (<2200) in the estuarine region of the river basin at Ponnani during the migratory season between November and January months. The heterogeneous habitats such as forest vegetation, plantations, dams, and human settlements in the river basin, availability of microhabitats, and plenty of food resources influenced the species distribution (Wiens 1989).

The study recorded 17 endemic bird species of the Western Ghats which indicates the uniqueness of the riverine habitat of the basin and its conservation importance (Table 19). The upper reaches and middle reaches have more endemic birds (Table 19). The lower reaches have fewer endemic birds compared to the other two ecological zones. The lower reaches of the river basin are highly disturbed and fragmented. The habitat preference of endemic birds and the competition with generalists restrict the distribution of most of the endemic birds to the upper and middle reaches. The study recorded endangered Black-bellied Tern from the upper reaches. Several sightings and breeding of Black-bellied Terns were reported from lower reaches earlier (Susant Kumar 2004; Arif et al. 2010) which indicates the importance of the river and associated habitats in the conservation of this endangered bird. The study recorded the breeding population of Black-headed Ibis, Oriental Darters, and Spot-billed Pelican in the river basin. The heronry in Chulliyar recorded the breeding of Black-headed Ibis in 2019. A breeding pair of Spot-billed Pelican was recorded in Meenkara in the same year. The heronry in Thirunavaya holds a breeding population of Oriental Darters along with the Asian Openbill. These locations need high conservation attention to protect the breeding colony.

It is known that 60% of total bird species across the world are passerines. Hence the dominance of Passeriformes (42%) in the Bharathapuzha river basin was expected. The Charadriiforms were the second dominant order in the study area. The presence of large flocks of Gulls in the estuary, and Asian Openbill and Cormorants in the river channels of the lower reaches influenced the bird abundance. The presence of various heronries in the river bank was also observed which makes

the region suitable for nesting of community living birds. Black Eagle, Changeable Hawk Eagle, Crested Serpent Eagle, Legge's Hawk Eagle, Oriental Honey Buzzard, and Peregrine Falcon are some of the rare finds in the upper reaches. They are mostly hunters and prefer to live in the hill region. Indian Spotted Eagle, Western Marsh Harrier, and Grey-headed Fish Eagle were the rare sightings. Black Kites, Brahmini Kites, Black-shouldered Kites and Shikras found common in the middle and lower reaches. Black Kites and Brahmini Kites are scavengers often found in larger groups in the estuarine area. The dominance of Charadriiformes, Pelecaniformes and Accipitriformes shows the influence of the river and associated habitats like estuaries, agricultural lands, human settlements, and valleys.

The habitat heterogeneity of the river basin promoted a bird community with a diverse feeding guild. The presence of water bodies, large open foraging spaces in the dams and estuaries, production landscapes in the lower reaches and diverse food preferences influenced the semi-aquatic and aquatic carnivores in the study area. The semi-aquatic carnivores such as waders were dominant in the upper and lower reaches. The mudflats and sand banks in lower reaches provide ample habitat for large populations of waders.

The small frugivores and granivores are generally more tolerant of disturbance (Sekercioglu 2012). The larger frugivore birds are highly sensitive to habitat disturbance (Gomes et al 2008). Hence most of them are confined to the forest ecosystem. For example; The frugivores such as Asian fairy Bluebird, Malabar Grey-hornbills, Flame-throated Bulbul, and Yellow-browed Bulbul were mostly confined to the upper reaches. The generalists such as Red-vented Bulbul, Red-whiskered Bulbul, and Rose-ringed Parakeets were also common in the upper reaches. The non-flocking granivorous birds such as Grey Junglefowl, Red Spurfowl, Asian Emerald Dove, and Laughing Dove were also seen on the upper reaches.

Upper reaches show higher species richness than middle and lower reaches because of the presence of the forests in the upper reaches. Change in climate and related altitude shift, resource depletion can also contribute to the high richness in the upper reaches (Sekercioglu et al 2012). Most of the birds reported in the upper reaches are non-water-dependent birds. The influx of migratory birds into the upper reaches due to the presence of dams is also a reason for the increase in the species richness in the upper reaches. Protection of the primary forests in the upper reaches ensures water flow which is essential for the protection of river and its habitats and the long-term conservation of birds in the region.

The majority of the sampling locations in the lower reaches are associated with human settlements and paddy fields which increased the abundance of birds in the lower reaches. The larger production landscapes with human habitations and estuaries in the mainstream region provide space for larger flocking birds in the region. The open habitat and fish drying and processing areas in the estuarine region increase the number of scavenging and omnivorous birds congregating in huge numbers.

The wetland birds in the region depend on the larger water bodies in the upper and lower reaches of the study area. Due to the lesser availability of water bodies and marshlands in the middle reaches, fewer wetland birds were recorded. This is evident from the rank abundance curves showing high dominance and high rarity in the upper and lower reaches and comparatively even distribution of species in the middle reaches. The middle reaches of the river are experiencing huge anthropogenic pressure due to the unscientific construction of check dams. The inter-state water issues of Parambikulam Aliyar water sharing and unscientific water management systems reduced the flow of water. Hence this study emphasises that the middle reaches of the river required rejuvenation action to ensure the water flow for the protection of birds.

The large extent of paddy fields associated with this river basin provides foraging ground for many migratory and flocking birds. The presence of dams in the upper reaches and the presence of estuary and check dams in the lower reaches attracted a large number of migratory birds such as Little-ringed Plover *Charadrius dubius*, Marsh Sandpiper *Tringa stagnatilis* and Barn Swallows *Hirundo rustica*. Purathur in the lower reaches of the Bharathapuzha River basin was identified as one of the major stop-over sites for many migratory birds (Kurup 1991, 1996; Kumar 2001; Uthaman & Namassivayan 1991). Large flocks of gulls (<5000), terns (<100), and egrets (<100) were recorded from the Purathur region during the study period. Smaller migratory bird flocks were reported from the dams and several other locations in the lower reaches. Solitary and passage migrant birds such as the Amur Falcon (*Falco amurensis*) were reported from the upper reaches of the river basin. There were consecutive sightings of these passage migrants in the river basin in December 2017 (Malampauzha Dam), December 2018 (Thirunavaya), and January 2019 (Malambuzha Dam). The middle reaches of the river found lesser occurrence of migratory bird species due to the lack of wintering grounds.

The study results show that the bird communities are showing remarkable variations in species composition and abundance between the ecological zones and the seasons. This is largely influenced by the ecological structure and variation in the resource availability in each ecological

zone. The variability in the bird species composition is mostly driven by the structural characteristics of habitats, niche variability (Margar et al. 2021) and the availability of foraging stratum in the upper and lower reaches. This indicates that habitat alteration in the ecological zones is important and forms the main reason for changes in the composition of birds in the river basin (Mas & Dietsch 2004; Sekercioglu et al. 2007).

Major Threats

The holistic approach of the river as a single ecological entity helps to understand the avian diversity and distribution in different ecological zones. The study also showcased the importance of the conservation of habitats in the upper reaches, especially the primary forests. The upper reaches and lower reaches of the river basin play a pivotal role in the conservation of resident migratory birds. The protection of forests in the upper reaches and all-natural habitats in the lower reaches are equally important for the conservation of birds.

The river basin is prone to various anthropogenic pressures such as deforestation, encroachment, sand mining, check dams, and land conversion. It is observed that natural vegetation in the upper reaches was cleared for the expansion of agriculture especially for cash crops like rubber, teak, coffee, and coconut. The construction of dams also cleared significant areas of the natural forests in the upper reaches. The expansion of human settlements, land conversions, agriculture expansion, encroachment, and deforestation were reported earlier from the upper reaches (Nossiter 1982; Kumar 2006; Eapen 2009; Raj & Azeez 2009; Raj & Azeez 2010ab; John et al. 2019).

Bharathapuzha River is one of the most affected rivers in Kerala due to the predominant sand mining. Sand mining can be detrimental to the benthic ecosystem on which many bird species are dependent. Hence sand mining may have cascading effects on the biodiversity of the entire river basin. Legal and illegal sand mining altered the river ecosystem, especially in the mainstream. There were 48 Kadavus (landing areas) and 10 Government Centres actively operated for legal sand mining (Sreedhar & Irfan 2016). The natural replacement rate of sand in the river is lower than the rate of sand mining. Hence, over-exploitation of sand mining resulted in many pit formation in the river channel. Due to the sedimentation processes, the pits were filled with sediments which induced the growth of weeds in the river channel. This formed smaller islands in the middle of the river in several places. These islands support many bird species and other animals such as otters and tortoises. Nesting of Munias, White-breasted Waterhens and Purple swamphens were recorded from these islands. In several locations, these

islands are continuously burned in the summer by the local people for easy access to the river. In the rainy season, these islands force the alterations in the river flow. Such river islands need more focused research attention for effective management.

Sand mining is still prevalent in the lower reaches of the Bharathapuzha river basin. Due to the strong opposition by the local people, nature enthusiasts and NGOs, there have been various regulations and restrictions imposed on sand mining activities in different regions of the Bharathapuzha river basin. Recently, most of the legal sand mining has been concentrated in the estuary region, at Ponnani but illegal sand mining was observed at places like Parali, Ottapalam, Cheruthuruthy, Pattambi, Tirur, and Kuttipuram. Bringing back the natural ecosystem of the river is important. Community-mediated policy interventions are very much required to reduce sand mining and rebuild the riverine ecosystem, which ultimately protects the biodiversity, especially the avian community.



Image 6: Sand mining in the Ponnani estuary (lower reach)

CHAPTER 5

FACTORS INFLUENCING THE BIRD DIVERSITY

Introduction

Birds are an important component of forest ecosystems (Wiens 1989) and are considered as one of the important indicators of habitat quality (Gregory et al. 2008). Hence knowledge about the diversity, population, and community assemblage of birds in an ecosystem is important for the conservation of biodiversity. The tropical ecosystems harbour the world's greatest diversity of avian species. The complex ecological interactions competition and niche differentiation shape the avian community in the region. Also, several local and environmental factors influence the bird assemblage. Previous studies show that bird communities respond strongly towards altitude (Suárez-Seoane et al. 2002; Raman et al 2005), temperature (Benton et al. 2003; Marjakangas et al 2022), vegetation structure (Waide et al. 1999; Donald et al. 2001; Ramachandran & Ganesh 2012), land use changes (Varun & Dutta 2020), grazing (McCracken & Tallowin, 2004; Ilyas & Shah 2022), and anthropogenic activities (Batáry et al. 2007; Caprio et al 2023). Bird migration, natality, mortality, and availability of food and niches also determine the avian species diversity, richness and abundance (Fitzherbert et al. 2008; Jayapal et al. 2009). Observations on environmental factors can provide useful information about trends in nature (Donald et al. 2001). Hence, understanding the drivers of community assembly can contribute to better conservation outcomes.

The Western Ghats is one of the 36 global biodiversity hotspots in the world. The heterogeneous habitats and the resource availability in the Western Ghats support a rich bird diversity. Many researchers have attempted to study bird community compositions and assemblage in the Western Ghats (Danials 1991, Jaison 1994, Pramod, 1995; Raman & Sukumar 2002, Karanth et al. 2016; Chandran et al. 2018; Varier et al. 2021). During the flow from origin to mouth the river has created a series of interaction systems with biotic and abiotic components and ensures the flow of energy, nutrients, and organic matter to various tropic levels (DeFries et al. 2007).

In the upper reaches, the hill streams are turbulent and filled with energy due to the higher flow gradients. In the middle reaches, the streams have riffles and pools. In the lower reaches, the river meanders over larger distances with a slow flow. This has created various riverine habitats which are rich in nutrients. The river represents various forest types, riparian zones, mud flats, sandbanks, agrarian planes, and estuaries. All these habitats are unique with various

microhabitats and niches. The variation in the resource availability in these habitats influences the bird communities. Various anthropogenic activities such as deforestation, construction of dams and check dams, water pollution, sand mining, waste and sewage dumping destroyed the river and river-associated habitats. This affected the biological community of the river system, especially the bird communities. The riverine area of Western Ghats is not restricted to its protected areas. Studies show that various ecosystems outside PAs support considerable biological diversity (Garcia et al. 2009; Anand et al. 2010). Most of the study locations are located in the outside protected area network. All these ecosystems outside the protected areas are more vulnerable to anthropogenic pressures than the PAs. This chapter discusses the bird species that contribute to the community variation in the different ecological zones in different seasons and the effect of selected environmental parameters on the bird communities. The study findings are useful to develop conservation management plans for birds in the Western Ghats, especially outside protected areas. This also helps in prioritizing the conservation importance of the Bharathapuzha river basin.

Data

The bird observation data was collected from 280 locations in three cycles using the point count method. A total of 840 points were surveyed during the survey period. The data collection protocol and sampling design were explained in Chapter 3. The bird species recorded were categorized based on water dependency which is explained in the methodology. The environmental parameters collected from each sampling location were used for analysis.

A total of 70 grids and 210 sampling points were surveyed across three seasons which covered two migratory, and one non-migratory season. Point counts in each sample were pooled. Contingency tables were created as species vs. samples and raw abundance as scores for each season using the pivot table function in the spreadsheet package.

Environmental parameters collected at each sampling point were pooled. Discrete and continuous variables such as area and altitude were averaged. For binomial variables, presence in minimum single point count was recorded as present or else was marked as absent. Categorical variables such as ecological zone and season were given uniform codes while entering the data. All environmental parameters were arranged in a table with the same unique sample codes as that of the contingency table.

Data Analysis

To assess the community structure and its variation across ecological zones and seasons, non-metric multidimensional scaling (nMDS) was performed (Kruskal 1964; Borcard et al. 2011). For nMDS, a contingency table containing only one of each non-migratory and migratory season was used. Analysis was performed separately for WDB, WAB and NWAB. The contingency table shows few dominant species present in most of the samples and many species having limited occurrences. Bray Curtis dissimilarity index being sensitive to differences in abundances and does not rely on absences has been used extensively in community ecology (Schroeder & Jenkins 2018; Lorenzón, et al. 2019). Hence, a distance matrix with Bray Curtis dissimilarities was used for nMDS ordination. To determine if the clusters shown in nMDS ordination are statistically significant, ANOSIM was performed using the same Bray Curtis dissimilarity matrix (Anderson & Walsh 2013). ANOSIM was performed using ecological zone and season as grouping variables.

Similarity Percentage (SIMPER) analysis was employed to assess the contribution of the species to the dissimilarities between the grouping variables (Clarke 1993; White et al. 2005; Asefa et al. 2017).

To test the impact of environmental parameters on the community structure of WDB and WAB in migratory and non-migratory seasons, distance-based redundancy analysis (Legendre & Anderson 1999) was used. First, a global model was performed by incorporating all non-auto-correlated environmental variables. Linear dependencies for all environmental variables were checked by computing Variance Inflation Factors (VIF) for each variable. The variable reduction was performed using the forward selection method (Borcard et al. 2011) by including variables with VIF below 10. A most parsimonious model was computed using the environmental variables within $\alpha=0.05$ during the forward selection method. The proportion of variation explained by each variable was calculated by adjusting the R^2 value with the R^2 value of the global model as the threshold.

All statistical analysis was performed in R statistical language (v4.3.2) with R Studio IDE (v2023.06.0). Vegan, a community ecology package was used to perform ordination and significance testing (Oksanen et al. 2018). Ordination graphs were generated using the package ggplot2 (Wickham et al. 2016).

Results

Bird assemblage patterns across ecological zones and seasons

Water dependent birds

Some water-dependent birds distinctly favoured sites from either upper or lower reaches (nMDS: stress = 0.15, Non-metric R²= 0.97). Ordination also shows that the avifaunal community in the middle reaches is not distinct and completely overlaps within the upper and middle reaches (Figure 32). The variation between ecological zones is more significant than within ecological zones (ANOSIM: R=0.132, p<0.05). However, no significant variation in bird community was observed between migratory and non-migratory seasons (ANOSIM: R=0.007, p<0.7).

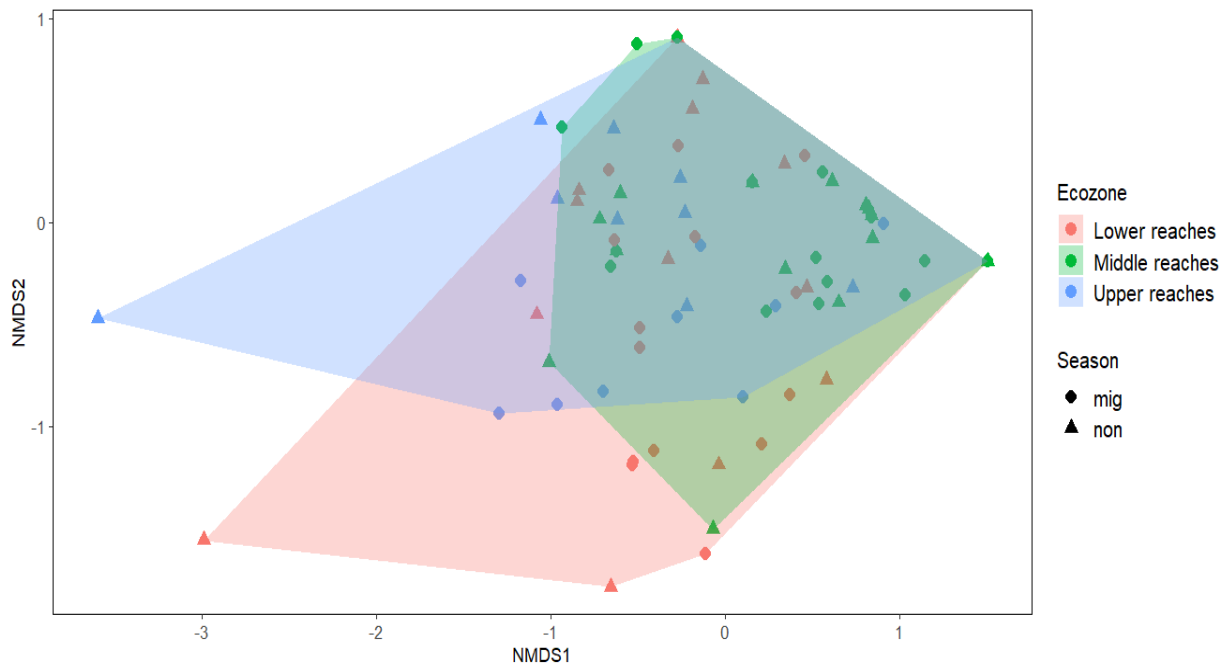


Figure 32: nMDS for water-dependent birds

Little Cormorants *Microcarbo niger*, Brown-headed Gull *Chroicocephalus brunnicephalus*, Black-headed Gull *Chroicocephalus brunnicephalus*, White-breasted Waterhen *Amaurornis phoenicurus*, Palla's Gull *Ichthyaetus ichthyaetus* and Oriental Darter *Anhinga melanogaster* were contributed to the community variation in the lower and middle reaches. Along with the above-mentioned bird species, the presence of River Tern *Sterna aurantia* and Lesser Whistling Duck *Dendrocygna javanica* contributed to the community variation in the lower And Upper Reaches. Little Cormorants, White-Breasted Waterhen, River Tern And Lesser Whistlingduck

contributed to the community variation between the middle and upper reaches. SIMPER values of each species are given in the Table 10.

Table 10: SIMPER Water-dependent birds

	Average dissimilarity	Percentage contribution	Cumulative percentage
Lower reaches - Middle reaches			
Little Cormorant	0.3443	44.5	44.5
Brown-headed Gull	0.0568	7.3	51.8
Black-headed Gull	0.0554	7.2	59
White-breasted Waterhen	0.0511	6.5	65.5
Palla's Gull	0.0491	6.4	71.9
Oriental Darter	0.0405	5.2	77.1
Lower reaches - Upper reaches			
Little cormorant	0.3098	39.6	39.6
Lesser Whistling Duck	0.07706	9.9	49.5
Brown-headed Gull	0.05341	6.8	56.3
Black-headed Gull	0.05076	6.5	62.8
River Tern	0.05048	6.5	69.3
Palla's Gull	0.04579	5.9	75.2
Middle reaches - Upper reaches			
Little Cormorant	0.3402	45.8	45.8
White-breasted Waterhen	0.1033	13.9	59.7
Lesser Whistling Duck	0.0823	11.1	70.8
River Tern	0.0711	9.5	80.3

Water associated birds

Concerning the water-associated birds, the lower reaches and middle reaches have sites with similar composition though there are some sites distinct from them (nMDS: Stress = 0.219, Non-metric $R^2 = 0.94$) (Figure 33). However, the majority of the sites in the middle and lower reaches are similar in composition to the upper reaches. Also, lower and upper reaches have sites with unique compositions concerning ecological zones. The variation between ecological zones is

more significant than within ecological zones (ANOSIM: $R = 0.159$, $p < 0.05$). Lower reaches and upper reaches also have sites with unique compositions during migratory and non-migratory seasons. Due to this, species composition between seasons is significantly different (ANOSIM: $R = 0.039$, $p < 0.05$).

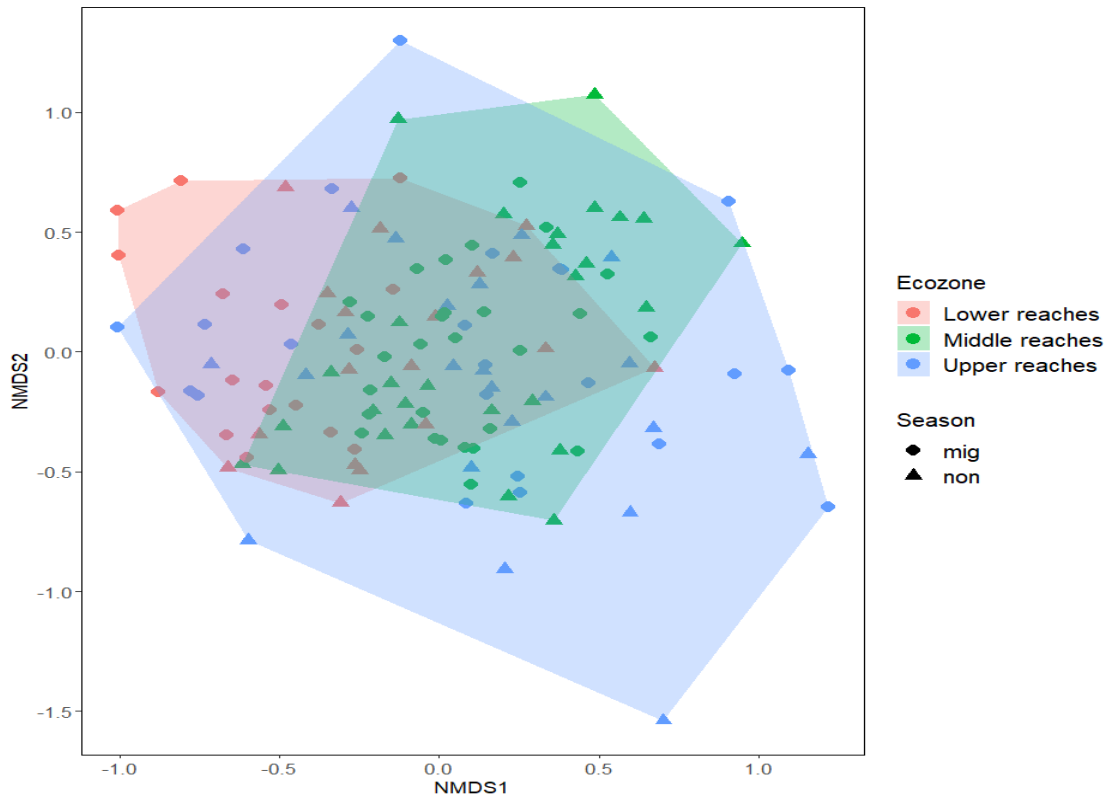


Figure 33: nMDS for water-associated birds

Cattle Egret *Bubulcus ibis*, Brahmini Kite *Haliastur indus*, Little Egret *Egretta garzetta*, Green Bee-eater *Merops orientalis*, Indian Pond Heron *Ardeola grayii*, and Asian Openbill *Anastomus oscitans* contributed maximum to the bird community variation between lower and middle reaches. A similar pattern was seen in the lower and upper reaches. The presence of other species like Red-wattled Lapwing *Vanellus indicus* Black-headed Ibis *Threskiornis melanocephalus*, Large-pied Wagtail *Motacilla maderaspatensis*, Common Sandpiper *Actitis hypoleucos*, Intermediate Egret *Ardea intermedia*, Chestnut-headed Bee-eater *Merops leschenaulti* and Marsh Sandpiper *Tringa stagnatilis* had differential abundances between ecological zones which resulted in dissimilarities evident in nMDS and ANOSIM. SIMPER values of each species are given in the Table 11.

Table 11: SIMPER Water- associated birds

	Average dissimilarity	Percentage contribution	Cumulative percentage
Lower reaches - Middle reaches			
Cattle Egret	0.07582	10.8	10.8
Brahmini Kite	0.07275	21.1	10.3
Little Egret	0.04837	28	6.9
Green Bee-eater	0.04641	34.5	6.5
Indian Pond Heron	0.04485	40.9	6.4
Asian Openbill	0.04219	46.9	6
Red-wattled Lapwing	0.03852	52.4	5.5
White-throated Kingfisher	0.03234	57	4.6
Black-headed Ibis	0.03167	61.4	4.4
Large-pied Wagtail	0.03123	65.9	4.5
Common Sandpiper	0.03086	70.3	4.4
Intermediate Egret	0.02786	74.2	3.9
Chestnut-headed Bee-eater	0.02712	78.1	3.9
Marsh Sandpiper	0.01926	80.8	2.7
Lower reaches_Upper reaches			
Cattle Egret	0.08245	10.4	10.4
Brahmini Kite	0.08223	20.8	10.4
Little Egret	0.05387	27.7	6.9
Black-headed Ibis	0.05056	34.1	6.4
Asian Openbill	0.04801	40.2	6.1
Green Bee-eater	0.04615	46	5.8
Indian Pond Heron	0.04425	51.6	5.6
Red-wattled Lapwing	0.03845	56.5	4.9
Common Sandpiper	0.03312	60.7	4.2
Chestnut-headed Bee-eater	0.03037	64.5	3.8
White-throated Kingfisher	0.02966	68.3	3.8
Large-pied Wagtail	0.02937	72	3.7
Intermediate Egret	0.02891	75.6	3.6
Marsh Sandpiper	0.02167	78.4	2.8
Middle reaches_Upper reaches			
Cattle Egret	0.08569	11.4	11.4
Green Bee-eater	0.07678	21.6	10.2
Indian Pond Heron	0.06936	30.8	9.2
White-throated Kingfisher	0.05858	38.6	7.8
Brahmini Kite	0.05782	46.2	7.6

Little Egret	0.04395	52.1	5.9
Red-wattled Lapwing	0.03685	57	4.9
Black-headed Ibis	0.03558	61.7	4.7
, Large-pied Wagtail	0.03319	66.1	4.4
Asian openbill	0.03289	70.5	4.4
Common Sandpiper	0.02637	74	3.5
Grey Wagtail	0.02475	77.3	3.3
Small Blue Kingfisher	0.02096	80	2.7

Non-water associated birds

The lower reaches, middle reaches and upper reaches are distinct in species compositions (nMDS: Stress = 0.19, Non-metric R² = 0.96) (Figure 34). However, most of the sites in the middle are similar in composition with upper and lower reaches. Lower and upper reaches have more unique sites with non-water-associated birds than with water-dependent and water-associated birds. The variation between ecological zones is higher than within ecological zones (ANOSIM: R = 0.154, p<0.05). Due to few sites having unique compositions of birds in the migratory seasons, seasonal variation was also found significant (ANOSIM: R= 0.053, p<0.05).

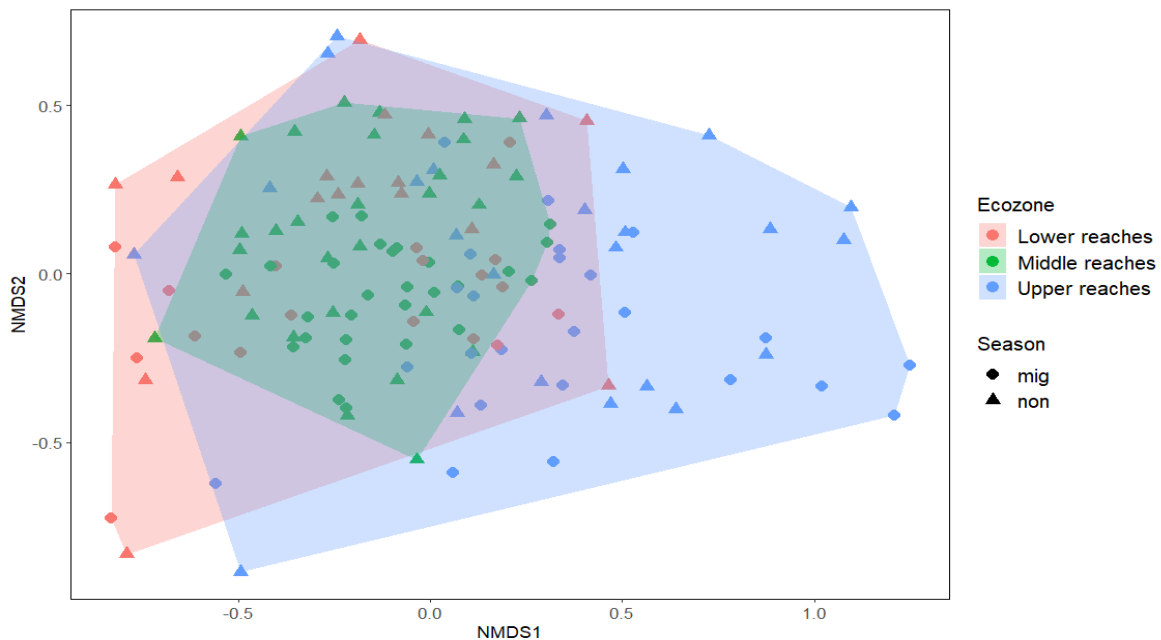


Figure 34: nMDS for Non-water associated birds

In non-river-associated birds, differential abundances of synanthropic species were found to be contributing factors to dissimilarity between ecological zones. House Crow *Corvus splendens*,

Asian Palm Swift *Cypsiurus balasiensis*, Rock Pigeon *Columba livia*, Common Myna *Acridotheres tristis*, Yellow-billed Babbler *Turdoides affinis*, Large-billed Crow *Corvus macrorhynchos* and Barn Swallows *Hirundo rustica* were contributed to the bird community variation in the lower and middle reaches, middle and upper reaches and lower and upper reaches. The abundance variation of Black Kite *Milvus migrans govinda* and Purple-rumped Sunbird *Leptocoma zeylonica*, also contributed much to these variations. SIMPER values of each species are given in the Table 12.

Table 12: SIMPER Non-water associated birds

	Average dissimilarity	Percent contribution	Cumulative percentage
Lower reaches - Middle reaches			
House Crow	0.09508	13.8	13.8
Asian Palm Swift	0.07161	24.2	10.4
Rock Pigeon	0.03615	29.5	5.3
Yellow-billed babbler	0.03152	34.1	4.6
Common Myna	0.031	38.6	4.5
Red-rumped Swallow	0.02727	42.6	4
Large-billed Crow	0.02578	46.3	3.7
Barn Swallow	0.0233	49.7	3.4
Black Kite	0.02294	53	3.3
Red-vented Bulbul	0.02215	56.3	3.3
Red-whiskered Bulbul	0.01917	59.1	2.8
Purple-rumped Sunbird	0.01634	61.4	2.3
Black-headed Munia	0.01588	63.7	2.3
Spotted dove	0.0147	65.9	2.2
Common Tailor Bird	0.01388	67.9	2
Blyt's Reed Warbler	0.01387	69.9	2
Black Drango	0.01176	71.6	1.7
Pale-billed Flowerpecker	0.01067	73.2	1.6
Rose ringed Parakeet	0.00978	74.6	1.4

	Average dissimilarity	Percent contribution	Cumulative percentage
Rufous Treepie	0.00957	76	1.4
Lower reaches - Upper reaches			
House Crow	0.09524	12.7	12.7
Asian Palm Swift	0.05775	20.4	7.7
Common Myna	0.03498	25.1	4.7
Yellow-billed babbler	0.03403	29.7	4.6
Rock Pigeon	0.02974	33.6	3.9
Barn Swallow	0.02325	36.8	3.2
Black Kite	0.02256	39.8	3
Red-vented Bulbul	0.0221	42.7	2.9
Red-rumped Swallow	0.02179	45.6	2.9
Large Billed Crow	0.02118	48.5	2.9
Purple-rumped Sunbird	0.01924	51	2.5
Red-whiskered Bulbul	0.01768	53.4	2.4
Greenish Leaf Warbler	0.01459	55.3	1.9
Blyt's Reed Warbler	0.01378	57.2	1.9
Black Drongo	0.01325	59	1.8
Black Headed Munia	0.013	60.7	1.7
Common Tailorbird	0.01223	62.3	1.6
Spotted Dove	0.01115	63.8	1.5
White Cheeked Barbet	0.01042	65.2	1.4
Pale-billed Flowerpecker	0.01008	66.5	1.3
Rufous Treepie	0.00887	67.7	1.2
Purple Sunbird	0.00862	68.9	1.2
Jungle Babler	0.0082	70	1.1
Jungle Myna	0.00778	71	1
Greater Racket Tailed Drongo	0.00696	72	1
Scaly-breasted Munia	0.00665	72.8	0.8

	Average dissimilarity	Percent contribution	Cumulative percentage
Ashy-wood Swallow	0.00656	73.7	0.9
Oriental Magpie Robin	0.00637	75.4	0.8
Middle reaches - Upper reaches			
Asian Palm Swift	0.06219	8.8	8.8
House Crow	0.05122	16	7.2
Yellow-billed babbler	0.03958	21.6	5.6
Common Myna	0.03349	26.3	4.7
Red-vented Bulbul	0.02474	29.8	3.5
Large Billed Crow	0.02342	33.1	3.3
Purple Rumped Sunbird	0.02077	36	2.9
Rock Pigeon	0.0188	38.7	2.7
Red-whiskered Bulbul	0.01753	41.2	2.5
Barn Swallow	0.01728	43.6	2.4
Spotted Dove	0.01634	45.9	2.3
Greenish Leaf Warbler	0.01552	48.1	2.2
Blyt's Reed Warbler	0.01539	50.3	2.2
Common Tailorbird	0.01463	52.3	2
White Cheeked Barbet	0.01333	54.2	1.9
Red-rumped Swallow	0.01276	56	1.8
Black Headed Munia	0.0127	57.8	1.8
Black Drongo	0.01269	59.6	1.8
Pale-billed Flowerpecker	0.01236	61.4	1.8
Rufous treepie	0.01105	62.9	1.5
Rose ringer Parakeet	0.0104	64.4	1.5
Little Swift	0.01032	65.8	1.4
Jungle Babbler	0.00949	67.2	1.4
Jungle Myna	0.00857	68.4	1.2

	Average dissimilarity	Percent contribution	Cumulative percentage
Plain Priniya	0.00837	69.6	1.2
Greater Racket Tailed Drongo	0.00778	70.7	1.1
Oriental Magpie Robin	0.00723	71.7	1
Purple Sunbirds	0.0072	72.7	1
Black-hooded Oriole	0.00676	74.6	0.9
Indian Peafowl	0.0066	75.6	1

Environmental factors influencing the bird commutes

Selected environmental factors were analysed using Distance-based Redundancy Analysis (Db-RDA) for water-dependent birds and water-associated birds during the migratory season and non-migratory seasons. The results are given below.

Water-dependent birds in migratory season

Distance-based Redundancy Analysis (Db-RDA) for water-associated birds during migratory season showed that the constrained axis explained the significant variation (CAP1 Eigenvalue = 1.87 Proportion explained = 78.0%, CAP2 Eigenvalue = 0.52 Proportion explained = 21.9%) (Figure 35). Forward selection of environmental variables revealed that the area of mudflats ($R^2 = 0.048$, $F = 5.86$, $p < 0.05$), area of water flow ($R^2 = 0.02$, $F = 2.82$, $p < 0.05$) and riverside vegetation ($R^2 = 0.02$, $F = 3.30$, $p < 0.05$) to be affecting species composition in sites with 9.4% variation explained in Table 13.

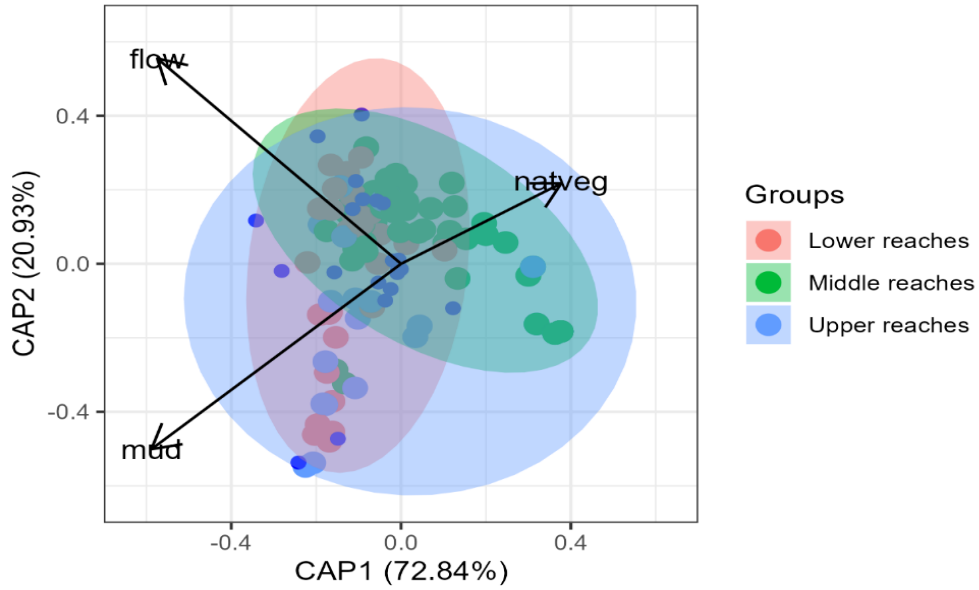


Figure 35: db-RDA water-dependent birds in the migratory season

Table 13: Forward selection of variables and Adjusted R^2 for db-RDA water-dependent birds in the migratory season

Sl.No	Variables	order	R^2	R^2 Cum	Adj R^2 Cum	F	pvalue
1	Mudflats	6	0.048893593	0.04889359	0.04055055	5.8604059	0.016*
2	Water flow	10	0.023191219	0.07208481	0.05566153	2.8241889	0.047*
3	Check Dam	11	0.0111114354	0.08319917	0.05864200	1.3577732	0.251
4	Altitude	1	0.011698160	0.09489733	0.06228101	1.4346392	0.209
5	Farmland	4	0.009676843	0.10457417	0.06387300	1.1887671	0.287
6	Open land	9	0.017266246	0.12184042	0.07350136	2.1431422	0.100
7	Natural vegetation	3	0.026095423	0.14793584	0.09270946	3.3076214	0.039*
8	Sandbanks	5	0.010357548	0.15829339	0.09536205	1.3166793	0.247
9	Temperature	16	0.006612920	0.16490631	0.09400213	0.8393903	0.391
10	Water channel	2	0.005256994	0.17016330	0.09113123	0.6651722	0.530
11	Distance from forest	13	0.004208018	0.17437132	0.08704521	0.5300614	0.660
12	Rock	7	0.003517995	0.17788931	0.08210943	0.4407600	0.641
13	Waste	15	0.003243874	0.18113319	0.07676781	0.4040647	0.646
14	Rain	17	0.003320936	0.18445412	0.07140816	0.4112761	0.740
15	Artificial Perch	8	0.002203425	0.18665755	0.06465618	0.2709098	0.863
16	Distance from settlements	12	0.002033782	0.18869133	0.05757074	0.2481724	0.776

Water-dependent birds during the non-migratory season

Distance-based Redundancy Analysis (Db-RDA) for water-associated birds during migratory season showed no constrained or unconstrained axis explaining significant variation. Forward selection of environmental variables also didn't show significant interactions between bird community and environmental variables (Table 14).

Table 14: Forward selection of variables and Adjusted R² for db-RDA water-dependent birds in the non-migratory season

SI.No	Variables	order	R ²	R ² Cum	AdjR ² Cum	F	pvalue
1	Altitude	1	0.04512	0.04512	0.02744	2.55158	0.072
2	Water channel	2	0.03282	0.07794	0.04314	1.88627	0.172
3	Distance from forest	13	0.04089	0.11883	0.06799	2.4132	0.107
4	Temperature	16	0.03344	0.15227	0.08578	2.01166	0.108
5	Waterflow	10	0.01454	0.16681	0.08349	0.87254	0.353
6	Farmland	4	0.0166	0.18341	0.08342	0.99612	0.315
7	Natural vegetation	3	0.01542	0.19882	0.08198	0.92355	0.356
8	Check Dam	11	0.01229	0.21111	0.07683	0.73204	0.459
9	Open land	9	0.00748	0.21859	0.0657	0.44006	0.572
10	Mudflats	6	0.00529	0.22388	0.0514	0.30674	0.679
11	Sandbanks	5	0.00452	0.2284	0.0355	0.25777	0.709
12	Distance from settlements	12	0.00437	0.23276	0.01865	0.24464	0.64
13	Sewage	14	0.003	0.23576	-0.0008	0.16473	0.75
14	Waste	15	0.00221	0.23796	-0.0222	0.1187	0.846
15	Rain	17	0.0026	0.24057	-0.0442	0.13703	0.855
16	Rock	7	0.00106	0.24163	-0.0695	0.05473	0.967

Water-associated birds in Migratory season

Distance-based Redundancy Analysis (Db-RDA) for water-associated birds during migratory season explained that the constrained axis showed significant variation (CAP1 Eigenvalue = 2.51 Proportion explained = 65.1%, CAP2 Eigenvalue = 0.70 Proportion explained = 18.15%) (Figure 36). Forward selection of environmental variables revealed that the area of mudflats ($R^2 = 0.05$, $F = 8.13$, $p < 0.05$) and area of water flow ($R^2 = 0.02$, $F = 3.39$, $p < 0.05$), distance from forest ($R^2 = 0.05$, $F = 8.13$, $p < 0.05$), and distance from farmland ($R^2 = 0.05$, $F = 8.13$, $p < 0.05$) are affecting (though it is weak) species composition in sites with 9.4% variation explained in Table 15.

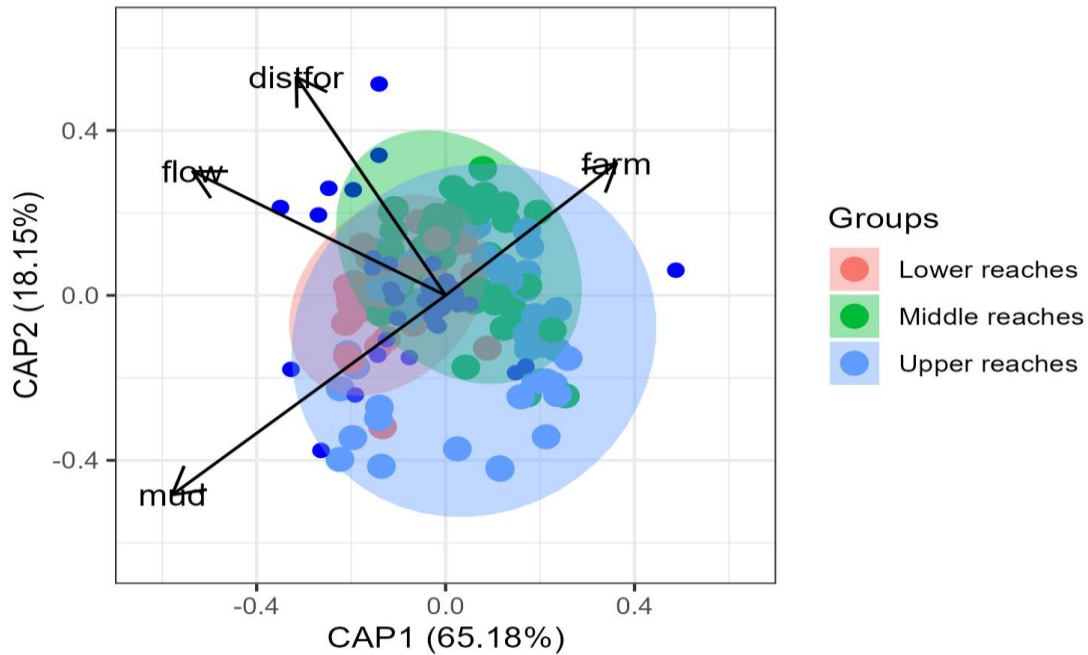


Figure 36: db-RDA water-associated birds in the migratory season

Table 15: Forward selection of variables and Adjusted R^2 for db-RDA water-associated birds in the migratory season

SI No	Variables	R^2	R^2 Cum	Adj R^2 Cum	F	pvalue
1	Mudflats	0.04575	0.04575	0.03873	6.52025	0.006*
2	Water flow	0.03512	0.08087	0.06725	5.15865	0.003*
3	Distance from forest	0.01891	0.09978	0.07963	2.81522	0.029*
4	Farmland	0.0182	0.11798	0.09145	2.74392	0.033*
5	Temperature	0.00924	0.12723	0.09417	1.39808	0.2
6	Natural vegetation	0.00831	0.13553	0.09594	1.2586	0.234
7	Rain	0.01154	0.14707	0.10114	1.75851	0.123
8	Distance from settlements	0.01035	0.15742	0.10516	1.58428	0.166
9	Artificial Perch	0.00667	0.16409	0.10531	1.02164	0.355
10	Altitude	0.00599	0.17008	0.10473	0.91724	0.379
11	Open land	0.00499	0.17508	0.10306	0.76294	0.504
12	Waste	0.00372	0.1788	0.09996	0.56611	0.644
13	Water channel	0.00345	0.18224	0.09651	0.52276	0.675
14	Sewage	0.0035	0.18574	0.09306	0.52864	0.64
15	Check Dam	0.00285	0.18859	0.08882	0.42777	0.829
16	Sandbanks	0.00258	0.19117	0.08422	0.38617	0.818

Water-associated birds in Non-migratory season

Distance-based Redundancy Analysis (Db-RDA) for water-associated birds during migratory season showed that only one constrained axis explained significant variation (CAP1 Eigenvalue = 0.46 Proportion explained = 46.7%, MDS1 Eigenvalue = 3.02 Proportion explained = 13.88%) (Figure 7). Forward selection of environmental variables revealed that the area of mudflats ($R^2 = 0.05$, $F = 8.13$, $p < 0.05$) weakly affects species composition in sites with 3.2% variation explained in Table 16.

Table 16: Forward selection of variables and Adjusted R^2 for db-RDA water-associated birds in non-migratory season

SL NO	Variables	R^2	R^2 Cum	Adj R^2 Cum	F	pvalue
1	Mudflats	0.04636	0.04636	0.03192	3.20881	0.026*
2	Sandbanks	0.03052	0.07688	0.04848	2.14872	0.09
3	Natural vegetation	0.02782	0.1047	0.06274	1.98887	0.091
4	Rock	0.0219	0.1266	0.07115	1.57952	0.168
5	Water flow	0.01709	0.14369	0.07463	1.23718	0.276
6	Open land	0.02022	0.16391	0.08167	1.47528	0.177
7	Distance from settlement	0.01327	0.17718	0.08118	0.9675	0.243
8	Distance from forest	0.01141	0.18859	0.07857	0.82981	0.537
9	Check Dam	0.01118	0.19977	0.07559	0.81019	0.538
10	Artificial perch	0.01081	0.21058	0.07209	0.7808	0.495
11	Rain	0.00853	0.21911	0.06573	0.61199	0.68
12	Water channel	0.00867	0.22778	0.0593	0.61734	0.671
13	Temperature	0.00585	0.23363	0.04913	0.41207	0.797
14	Farmland	0.00597	0.2396	0.03874	0.41588	0.828
15	Waste	0.00795	0.24754	0.03049	0.54923	0.685
16	Altitude	0.00223	0.25394	0.00028	0.1495	0.978

Discussion

Bharathapuzha river basin has 262 bird species of birds with a significant number of resident and migrant birds in all ecological zones (Raj et al. 2023). This indicates that productive and heterogeneous habitats of the Bharathapuzha river basin support birds from different niches. This shows that the ecosystem services provided by rivers are utilized by all several types of birds (Petersen et al. 2013).

This study showed that the bird species composition varied significantly between the ecological zones. This can be because of habitat differences in the ecological zones, seasonal movement patterns, population changes, availability of food and space and climatic conditions (Meyer 1992; Namgail et al. 2009; Gonz´alez-Gajardo et al. 2009; Runge et al. 2015; Yang et al. 2022). Most of the species contributing to the patterns in community and changes are flocking birds, colonial breeding birds and synanthropic birds. The high abundance of synanthropic species is considered as an indicator of anthropogenic influence (Plass & Wunderle 2013; Kurucz et al. 2021). They were found to be in high abundance in the upper reaches indicating that the habitats in the upper reaches are under pressure of urbanisation (John et al. 2019). The lower reaches are highly urbanised and the generalist species thrive in the region.

The prominence of resident birds contributed maximum to the changes in the species composition. Tolerance and adaptations of resident birds to local fragmentation and disturbance makes them thrive in the area (Rend´on et al. 2008; Donaldson et al. 2016). Areas in the lower reaches provide wintering sites for many long-distance migrant birds. Black-headed Gull, Brown-headed Gull, and Palla’s Gull were found in high abundance in the lower reaches. This indicates that these migrant birds are highly dependent on the lower reaches of this river during the migratory period.

Environmental Factors

The area of mudflats, area of water flow, riverside vegetation, distance from forest, and distance from farmland are the environmental parameters that positively influence the WDB and WAB bird communities in different seasons. Various studies indicated the importance of mudflats and the area of water flow on the water-associated bird communities (Bellio & Kingsford 2013; Aarif et al. 2014; Clemens et al. 2014; Murray & Fuller 2015; Luo et al. 2019).

Mudflats: are one of the important ecosystems which determine the characteristics of the river channel. In the Bharathapuzha river basin, from the upper reaches to the lower reaches, mudflats are seen everywhere. In some locations mudflats are natural, in some areas it is created by check dams. In the upper reaches and lower extensive mudflats are available for the WDB and WAB for foraging and resting. These mud flats are one of the most productive ecosystems and support in maintaining the food chain. The mud flats in the river basin are prone to high anthropogenic threats due to encroachment and sand mining. River-side farming is a common practice in the Bharathapuzha river basin. The farmers here use these mudflats for farming during the summers. This extensively reduces the space available for birds. The usage of chemicals in the mudflats is

contaminating the water. Destructions or disappearance of these habitats can decrease the diversity of Water-dependent birds and water-associated birds. The study strongly recommends the protection and management of mudflats.

The area of water flow represents the percentage of water in the river channel. Bharathapuzha is a perennial river. The water level reduces drastically during the summers. Though the water is less in the river channel, the flow was continuous. The anthropogenic activities in the river have drastically interrupted the water flow. The construction of dams and check dams in various places altered the natural flow. The waders and shore birds prefer the shallow flowing water in the lower reaches. The ducks and cormorants prefer the stagnant water in the dams, check dams and water bodies. This indicates that the changes in the water levels in the river channel influence the bird community. The study recommends maintaining the e-flow of the river to protect the birds and ecosystem in the river basin. Also, a systematic survey on the check dams and its effectiveness needs to be studied. A regulation on the check dam construction has to be brought into action and unwanted check dams should be removed to ensure the water flow. The recent trend in changes in rainfall patterns, floods and droughts in the river basin may affect the bird communities. Seasonal variation in river channels concerning birds and resources needs to be studied in detail.

Riverside vegetation includes the vegetation patches seen on the riverside, inside the river channel and the floating vegetation on the water. The egrets and herons are seen foraging in these habitats. The White-breasted Water Hen and Purple Moorhens were found nesting on floating vegetation. In many locations, the vegetation inside the water channel was created due to anthropogenic activities such as sand mining and check dam construction. Several bird species use this as a breeding and foraging ground. Large flocks of Cattle Egrets and Little Cormorants were observed in such vegetation. Apart from the birds, otters also use this area as their shelter which is prone to forest fires in summer.

Distance from forest and distance from farmland affected the bird structure of communities. The lower reaches of the Bharathapuzha River are dominated by paddy cultivation. Most of the WAB depends on these habitats for foraging.

No significant correlations between most variables and birds were found in our study in the non-migratory season. The non-migratory season data collection was conducted from April 2018 to September 2018, in which the Kerala flood occurred. The flood in the Bharathapuzha River

largely affected the microhabitats and riverine ecosystems, which in turn was reflected in the environmental parameters collected during the survey.

In the present study, most of the study locations fall outside the protected area network. The bird diversity in the river basin shows the importance of the non-protected areas in biodiversity conservation (Raman & Sukumar 2002; Raman & Mudappa 2003; Raman 2006; Anand 2010; Raj et al. 2022). To protect the habitats which support the bird diversity new strategies such as land-sharing with local communities are required which ensures effective biodiversity conservation over a large landscape like Bharathapuzha river basin.

CHAPTER 6

LOCATIONS OF CONSERVATION IMPORTANCE

Introduction

To preserve the threatened species and habitats, scientists have identified 36 global biodiversity hotspots in the world which require high-priority conservation attention (Olson & Dinerstein 1998; Stattersfield et al. 1998; Pimm & Raven 2000; Brooks et al. 2002; Myers 2003). Most of such hotspots are located in tropical countries and face serious threats to their natural resources. Several studies detailed the importance of these biodiversity hotspots as a global priority (Daniel 1994; Rodrigues et al. 2004).

The Western Ghats in India is one of the important biodiversity hotspots in the world. This chain of mountains runs parallel to India's western coast which spread across the states of Kerala, Tamil Nadu, Karnataka, Goa, Maharashtra and Gujarat. These mountains cover an area of 140,000 km² in a 1,600 km long stretch. The Western Ghats act as a key barrier, for monsoon winds from the south-west during late summer and create major precipitation gradients. It determines the regional climate, hydrology and the distribution of plants and animals (Gadgil & Meher-Homji 1990). Western Ghats has high levels of species richness and endemism hence recognised as the world's eight 'hottest hotspots' of biological diversity. This is a home for over 5,000 flowering plants, 139 mammals, 508 birds and 179 amphibian species and protects about 325 globally threatened species. The evergreen forests of the Western Ghats have the highest number of endemics. Several locations of the Western Ghats act as centres of endemism and speciation (Blasco 1970; Nair & Daniel 1986). The dry forests are low in endemism and diversity, but they support various wide-ranging animals (Daniels 1994). Hence, many researchers attempted to understand the conservation value of the Western Ghats, (Gadgil & Meher- Homji 1986; Daniels et al. 1991). Later, Government of India established two biosphere reserves, 13 national parks and many reserve forests for the conservation and protection of the Western Ghats biodiversity. The Nilgiri Biosphere Reserve in Tamil Nadu forms the largest contiguous protected area in the Western Ghats. The Silent Valley National Park in Kerala is one of the remaining virgin tropical evergreen forest in the country. Though the protection status was upgraded and efforts were being taken to conserve the biodiversity, Western Ghats is still under pressure. Deforestation, forest fires, mining, cattle grazing, encroachment and the spread of alien invasive species are major threats to the ecosystems. The Western Ghats has the oldest human-

modified tropical forest landscapes. This provides an opportunity to understand biodiversity patterns in response to habitat and land use changes. Bharathapuzha river originates in and flows through the biodiversity rich Western Ghats for long distance which referred in this thesis as upper reaches.

Outside Protected Area Network and its Importance

The biodiversity is not restricted only to the Protected areas. The outside protected areas play a greater role in the biodiversity conservation of the Western Ghats. Most of the forest areas in the Western Ghats are interspersed with farmlands and human settlements. These agro ecosystems outside PAs support considerable biological diversity (Garcia et al. 2010; Anand et al. 2010; Karanth et al. 2016). These ecosystems also provide connectivity between protected areas and other remnant forests (Anand et al. 2010). Human-dominated landscapes which managed biodiversity-friendly manner can facilitate the dispersal of biodiversity in a fragmented natural habitat (Perfecto & Vandermeer 2008). Hence the Protected areas and biodiversity-rich areas outside the protected area networks can be considered as ecologically interacting components of a single system (Gardner et al. 2009). However, it received very little attention in research, conservation and management. The studies on the outside protected area network show that the species persistence depends on the quality of these unprotected lands (Debinski & Holt 2000; Prugh et al. 2008; Variaret al. 2021). However, these landscapes are prone to high levels of anthropogenic threats. Local land management practices can create a local effect on the biodiversity response (Anand et al. 2010) which needs a sophisticated system for biodiversity conservation. This required a multi-disciplinary approach including social sciences, economics, and ecology. This information can be used for refining the conservation strategies and land use policies for biodiversity conservation. But such research works are in the infant stage in India (Anand et al. 2008; Anand et al. 2010; Karanth et al. 2016; Kshetry 2020). Such studies will help to understand the role and characteristics of human-modified landscapes which favour biodiversity conservation.

Conservation Importance of Bharathapuzha river basin

Bharathapuzha river basin holds various types of habitats such as high-altitude grasslands, tropical evergreen forests, moist deciduous forests, riparian forests, marshlands, wetlands, mangroves, cultivation lands, agriculture lands and urban habitats. These protected areas and river-associated habitats provide a home to various fauna and flora and become an important

repository of biodiversity. This river is very much exposed to various anthropogenic pressures. Sand mining was very prevalent in the river basin for a long time which affected the water retention in the river channel (Sridhar& Irfan 2016). The formation of large pits after sand mining created smaller islands due to the sedimentation process. This also influenced the spread of weeds and vegetation inside the river channel. The construction of dams in the upper reaches of the river destroyed the natural forests in the upper reaches and altered the water flow. The construction of check dams affected the natural flow of the river especially in the middle and lower reaches of the river. Expansion of monoculture plantations, encroachment and water pollution are the other major threats to this river basin.

Most of the study locations in the present study fall outside the protected area network. Many of such locations in the lower reaches were identified as stopover sites for migratory birds (Kumar 2001). This study recorded several threatened bird species from the river basin. Previous studies in this region reported nesting and breeding of rare and endangered bird Black-bellied Tern (Kurup 1991, 1996; Uthaman & Namassivayan 1991; Kumar 2001; Susanthkumar 2004; Arif et al. 2010). Also, 17 endemic birds were recorded from the study area. All these show that the Bharathapuzha river basin is very important for the birds in the region.

This chapter discusses the important conservation priority locations in the river basin. Protection of such conservation priority locations can provide connectivity for the birds between protected areas and other potential habitats (Raman & Sukumar 2002; Raman & Mudappa 2003; Raman 2006; Anand et al. 2010; Variar et al. 2021). Since most of the study locations fall in human-dominated areas, the study suggests adopting land-sharing strategies with local communities and birds for the protection of avian diversity in the region. Such strategies can contribute more to the community's mediated conservation actions and ensure effective biodiversity conservation over large landscapes like river basins.

Data Analysis

The 70 sampling locations in the study area are selected for analysis. Bird species richness and abundance data for each grid are used as primary data. The river basin map layers and conservation important locations were prepared and visualized using Arch GIS software. River drainage basins and watershed layers were downloaded from the Hydrology department. To identify the conservation impotent locations in the study area, conservation values were assigned

to each grid. Three species attributes were selected for determining the conservation value of each grid (Asaad et al. 2017).

1. Presence of species of conservation concern: The IUCN status of bird species reported in each grid was identified and given ranks. The grid-wise rank average was estimated for further analysis (Table 17).

Table 17: Values assigned for IUCN status of birds

SI No	IUCN status	Rank
1	Endangered	5
2	Vulnerable	4
3	Near Threatened	3
4	Least concern	2
5	Not evaluated	1

2. Occurrence of restricted-range species: Bird species endemic to the Western Ghats were identified and species richness was selected for analysis. Species richness value was normalized to 0-1 and used for the conservation value estimation.
3. Species richness/ Species diversity: Grid-wise Shannon diversity was estimated using PAST 2.8 software. This diversity was normalized to 0-1 and used for the conservation value estimation.

All values of the above-mentioned criteria were normalised to 0-1 using a formula in MS Excel

$$Z_i = (X_i - \text{minimum value}) / (\text{maximum value} - \text{minimum value}).$$

Where, Z_i = Criteria value, X_i = i^{th} number in the data set

The normalised data of the three criteria is used for estimating the conservation value of the sampling locations.

$$\text{Conservation value} = CR1 + CR2 + CR3 / \text{Total number of criteria}$$

Where, CR1 = Normalised value of criteria 1; CR2 = Normalised value of criteria 2; CR3 = Normalised value of criteria 3

Results

Species with conservation priority

Threatened Birds

The present study recorded one endangered, five vulnerable and six near-threatened bird species from the river basin (Table 18). Black-bellied Tern was the endangered bird species recorded from the river basin. Indian Spotted Eagle *Clanga hastata*, Great Hornbill *Buceros bicornis*, Nilgiri Wood Pigeon *Columba Elphinstone*, River Tern *Sterna aurantia*, and Malabar Grey Hornbill *Ocyrceros griseus* were the vulnerable species recorded in the study. Woolly-necked Stork *Ciconia episcopus*, Black-headed Ibis *Threskiornis melanocephalus*, Eurasian Curlew *Numenius Arquata*, Curlew Sandpiper *Calidris ferruginea*, Oriental Darter *Anhinga melanogaster*, and Spot-billed Pelican *Pelecanus philippensis* were the near threatened species recorded in the study.

Table 18: Globally threatened birds recorded in different ecological zones.

Species	Lower	Middle	Upper	Total
Endangered	NIL	NIL	01	01
Vulnerable	03	01	02	05
Near-threatened	06	03	05	06

Endemic Birds

Seventeen Western Ghats endemic bird species were recorded from various ecological zones of the river basin during the study period (Table 19). Most of the endemic birds were confined to the upper reaches of the river basin. Malabar Grey Hornbill *Ocyrceros griseus*, Grey-fronted Green Pigeon *Treron affinis* and Malabar Wood Shrike *Tephrodornis sylvicola* were common in all three ecological zones. Malabar Parakeet *Psittacula columboides*, Flame-throated Bulbul *Pycnonotus gularis* and Rufous Babbler *Argya subrufa* were found more abundant in the ecological zones.

Table 19: Endemic bird species recorded from different ecological zones

Order	English Name	Scientific Name	Upper reaches	Middle reaches	lower reaches
Passeriformes	Black-and-orange Flycatcher	<i>Ficedula nigrorufa</i>	*		
Passeriformes	Crimson-backed Sunbird	<i>Leptocoma minima</i>	*		
Passeriformes	Flame-throated Bulbul	<i>Pycnonotus gularis</i>	*		
Columbiformes	Grey-fronted Green Pigeon	<i>Treron affinis</i>	*	*	*
Piciformes	Malabar Barbet	<i>Psilopogon malabaricus</i>	*		
Bucerotiformes	Malabar Grey Hornbill	<i>Ocyrceros griseus</i>	*	*	*
Psittaciformes	Malabar Parakeet	<i>Psittacula columboides</i>	*	*	
Passeriformes	Malabar Starling	<i>Sturnia blythii</i>	*	*	
Passeriformes	Malabar Woodshrike	<i>Tephrodornis sylvicola</i>	*	*	*
Passeriformes	Nilgiri Flowerpecker	<i>Dicaeum concolor</i>	*		
Passeriformes	Nilgiri Flycatcher	<i>Eumyias albicaudatus</i>	*		
Passeriformes	Nilgiri Thrush	<i>Zoothera neilgherriensis</i>	*		
Columbiformes	Nilgiri Wood Pigeon	<i>Columba elphinstonii</i>	*		
Passeriformes	Rufous Babbler	<i>Argya subrufa</i>	*	*	
Passeriformes	Wayanad Laughingthrush	<i>Garrulax delesserti</i>	*		
Passeriformes	White-bellied Blue Flycatcher	<i>Cyornis pallidipes</i>	*		
Passeriformes	White-bellied Treepie	<i>Dendrocitta leucogastra</i>	*		

Conservation Importance Locations

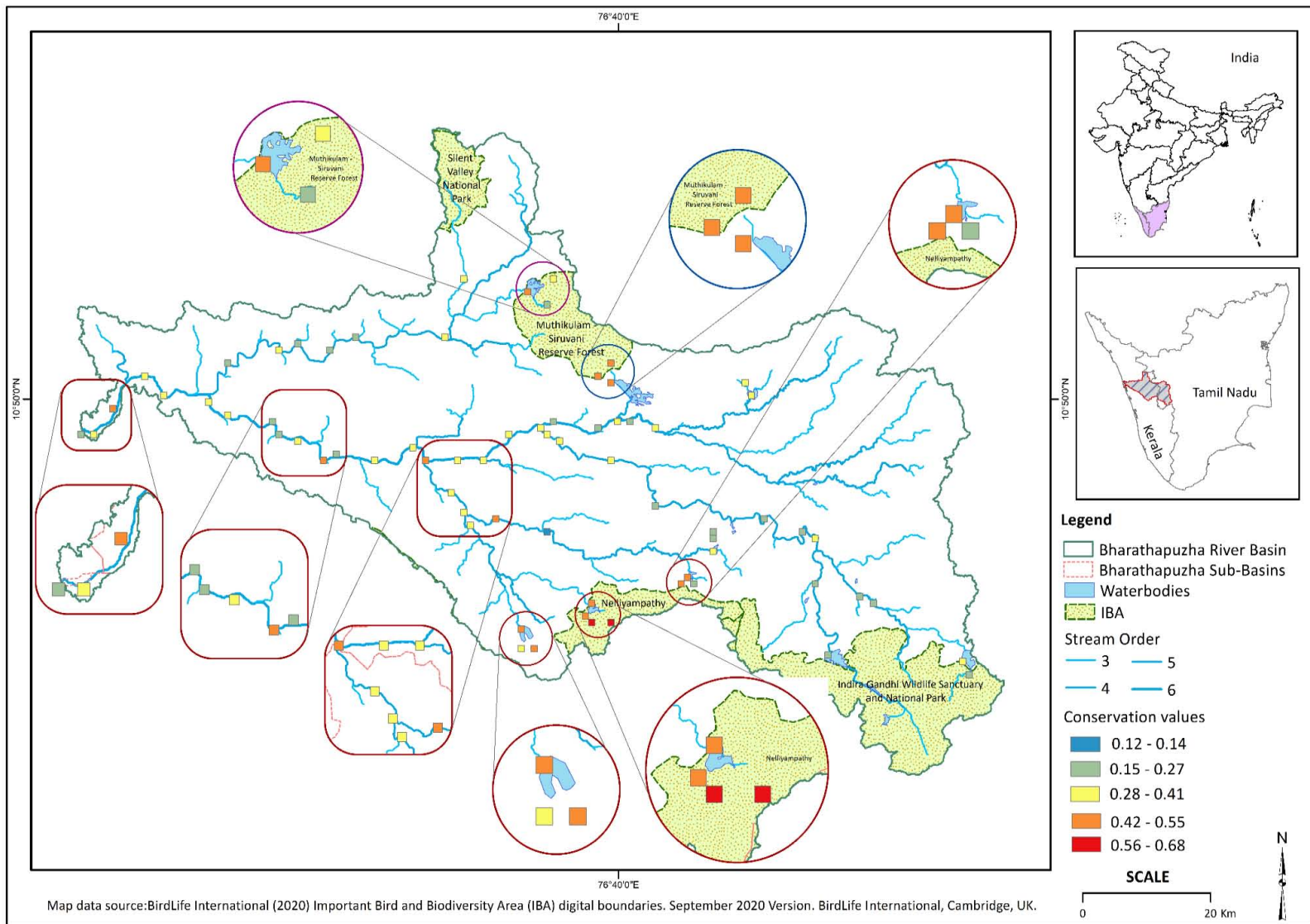
The study identified ten conservation-importance locations in the river basin (Table 20). The bird diversity, endemism, and IUCN red list categories were selected as criteria for analysis. Nelliampathi, Pothundi, Mangalam, Malampuzha, Chulliyar, and Kanjirapuzha are the most important locations for conserving avian diversity in the Upper reaches. Kuthampully and Athipotta in Middle reaches and Chamravattom and Mundaya in the lower reaches found to be

important locations for conservation (Figure 37). All these locations are outside the PAs. This indicates the importance of the protection of habitats outside the PA network. Most of the locations in the upper reaches are near dams. The presence of dams and associated forests in the area support forest birds and water birds. The locations in the middle and lower reaches are located in the human-dominated area and exposed to various anthropogenic pressures. The presence of water bodies and agricultural land influences the bird diversity in these locations.

Table 20: Conservation important location with conservation values.

Sl No	Ecological zone	Location name	Grid weightage (Range 0-1)
1	Upper reaches	Nelliyampathi	0.68
2	Upper reaches	Pothundi	0.67
3	Upper reaches	Malampuzha	0.55
4	Upper reaches	Mangalam	0.49
5	Upper reaches	Chulliyar	0.47
6	Upper reaches	Kanjirapuzha	0.46
7	Middle reaches	Kuthampully	0.44
8	Middle reaches	Athipotta	0.43
9	Lower reaches	Chamravattom	0.42
10	Lower reaches	Mundaya	0.45

Figure 37: Location of conservation importance in the Bharathapuzha river basin



Discussion

Ten conservation important locations were identified in the river basin. There were six conservation important locations identified in the upper reaches, two in the middle and lower reaches of the river basin. All these conservation priority locations are placed outside the protected area network and are highly exposed to several anthropogenic pressures. These bird-rich areas in the different ecological zones need conservation attention for the protection of bird diversity in the region.

Location of conservation importance: Upper reaches

1. **Nelliampathi:** Nelliampathi hills located in the southern Western Ghats $10^{\circ} 20' - 10^{\circ} 48' N$ and $76^{\circ} 30' - 76^{\circ} 50' E$ forming a part of the Anamalai – Palani complex. Nelliampathi borders with Palghat Gap in the north, Parambikulam Tiger Reserve on the south, and Indira Gandhi Wildlife Sanctuary on the east and west by the Chalakkudy Reserve Forest. The elevation ranges from 467 m to 1572 m. Nelliampathi attracted the attention of various researchers starting from the early 20th. The previous survey efforts recorded a total of 233 species of birds from this hill range (Praveen & Nameer 2007).

The survey locations in the present study we relocated in the lower Nelliampathi hills. Bird surveys were conducted in human-dominated forest areas. The majority of vegetation types in the surveyed locations were forest and tea plantations. This study recorded 77 bird species from the locations through systematic sampling. Nelliampathi is known for the sighting of Great Indian Hornbills. Several breeding populations were recorded from various parts of Nelliampathi. Peregrine Falcon *Falco peregrinus*, Wayanad Laughing Thrush *Pterorhinus delesserti*, Nilgiri Thrush *Zoothera neilgherriensis*, Black-capped Rock Thrush *Monticola cinclorhyncha*, Malabar Whistling Thrush (*Myophonus horsfieldii*) and Dollar Bird *Eurystomus orientalis* were some of the rare sightings from this location. Along with these rare birds, it is also home to various endemic and threatened birds.

Nelliampathi is a well-known tourist spot in Palakkad. The increasing pressure of tourism, expansion of monoculture plantations such as tea, rubber, and areca nut, infrastructural development, and landslides are the major threats to the birds. Awareness creation about the importance of Nelliampathi and its bird diversity has to be given priority. Eco-friendly tourism has to be promoted in the hills with the support of the local

people. The bird populations can be monitored through Citizen Science and e-bird platforms.



Image 7: Nelliampathi

- 2. Pothundi**($10^{\circ} 52' - 10^{\circ} 54' N$ and $76^{\circ} 62' - 76^{\circ} 63' E$): Pothundi is a village in the Palakkad district which is located in the foothills of Nelliampathi. The major habitat types of the study sites were forest, teak plantation and water bodies. There were 80 species of birds recorded from this study location. Malabar Grey Hornbill (*Ocyceus griseus*), Yellow-Footed Green Pigeon (*Treron phoenicopterus*), Yellow-Browed Bulbul (*Acritillas indica*), River Tern (*Sterna aurantia*), Asian Openbill (*Anastomus oscitans*) and Black-Headed Ibis (*Threskiornis melanocephalus*) are some of the common and rare birds recorded from the area.

The major bird habitats in the area include dam, natural forests and agricultural lands. This diversity in habitats and the presence of water bodies adjacent to the farming lands make this place as an ideal site for birds. This place is one of the known tourist locations in Palakkad. Increasing urbanization and farm tourism are prevalent in the region. Developing eco-friendly farm tourism and promotion of agriculture practices can sustain the bird diversity in the region. The study recommends conducting long-term monitoring of bird communities in this location. Understanding their seasonal changes concerning the habitats will help in planning conservation management actions.



Image 8: Pothundi

1. **Mangalam** ($10^{\circ} 29' - 10^{\circ} 30' \text{ N}$ and $76^{\circ} 32' - 76^{\circ} 33' \text{ E}$): is located in the Alathur taluk of Palakkad district in Kerala. It is located near to the Mangalam Reserve Forest, which shares the border with Parambikulam Tiger Reserve. The major habitats in the sampling locations are forests, monoculture plantations, water bodies, and human settlements. The study recorded 77 species from the Mangalam and surrounding area. It is a home for various threatened water birds such as River Terns, Painted Stork and Black-headed Ibis. There are no scientific studies available about the bird communities and their habitats in the Mangalam region. The extensive land conversion of natural forests into monoculture plantations is a major threat to the birds here. Thus, the study recommends long-term monitoring of bird communities and the land use changes in the region.

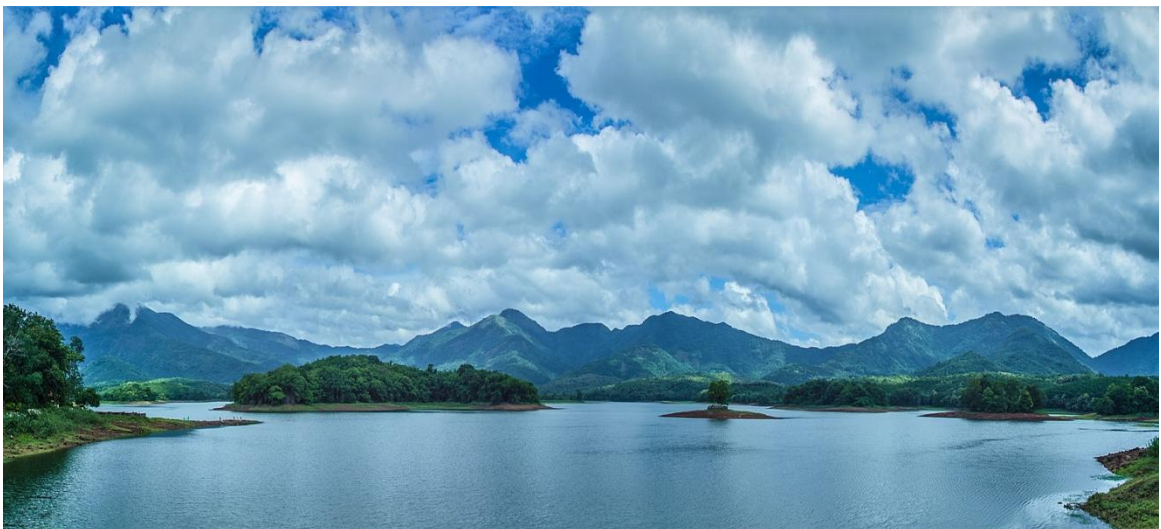


Image 9: Mangalam.

2. **Malampuzha** (10° 50' – 10° 52' N and 76° 40' – 76° 39' E): Malampuzha is located near Palakkad, in Kerala. Malampuzha Dam and the associated forest is an important location for bird community studies. The major habitats of the sampling locations are riparian forests, teak plantations, water bodies and human settlements. During the survey, 88 species of birds were recorded from the Malampuzha and associated habitats. Amur Falcon *Falco amurensis*, Bar-headed Goose *Anser indicus*, Black-bellied Tern, Malayan Night Heron *Gorsachius melanolophus*, and Chestnut-winged Cuckoo *Clamator coromandus* were the rare sightings from Malampuzha. The pair of Black-bellied Terns was sighted from Malampuzha reservoir during the survey.

The presence of several migratory birds in the Malampuzha dam shows that these birds use these locations as a stopover site during the migration. The presence of Black-bellied Tern indicates the conservation potential of this place. Tourism, sand mining, deforestation, and the expansion of monoculture plantations are the threats to this region. The study recommends long-term monitoring of bird communities in the region. Also, the study recommends monitoring the Black-bellied Tern population on the reservoir which can be considered as a potential site for conservation.



Image 10: Malampuzha reservoir and surrounding hills

3. **Chulliyar** (10° 34' – 10° 35' N and 76° 46' – 76° 45' E): Chulliyar village is located in Muthalamada Panchayath of Chittur Thaluk in Palakkad district. The area is dominated by mixed plantations of mango, coconut and areca nut. Chulliar dam is one of the most

attractive habitats for birds in this region. This dam was built across the Gayathri River. The reservoir is surrounded by human settlements and mixed plantations. The plantations, mixed forest vegetation, and water bodies are the major habitats surveyed for the birds. A total of 74 species of birds were recorded from here. The Nesting of Black-headed Ibis were recorded inside the reservoir. Nineteen nests were reported during the survey in 2019. Western Yellow Wagtail *Motacilla flava* and Little Cormorant (*Microcarbo niger*) were common in this location. Muthalamada panchayath is known for its quarry and mining which is the major threat for the breeding birds. The expansion of plantations in the forest fringing areas is the second major threat. The study recommends monitoring the breeding population of Black-headed Ibis in the region and Chulliar reservoir. The effect of mining activities on biodiversity and the breeding bird communities needs to be studied in detail.



Image 11: Chulliyar

- 4. Kanjirapuzha** ($10^{\circ} 59'$ – $10^{\circ} 57'$ N and $76^{\circ} 34'$ – $76^{\circ} 33'$ E): The Kanjirapuzha is located on the foothills of Siruvani hills. A total of 70 species of birds were recorded from Kanjirapuzha. This region was mostly dominated by plantations and human settlements. The mixed plantations and Kanjirapuzha reservoir are the major attraction for birds here. Rubber and areca nuts are major plantations in this region. The River Tern, Asian Openbill, Small Pratincole (*Glareolalactea*), and Little Cormorant (*Microcarbo niger*) were some of the most common birds in the reservoir. White-bellied Treepie (*Dendrocitta leucogastra*), Jordon's Bushlark *Mirafra affinis*, and Flame-

throated Bulbul *Rubigula gularis* were the rare sightings. The expansion of monocultural plantations in the forest fringes and the extensive tourism, urbanization and land conversion are the major threats in the region. The study recommends long-term monitoring of the forest birds in the regions. The indiscriminate land conversion can cause major loss to the biodiversity in the region.



Image 12: Kanjirapuzha and associated reservoir and forest

Location of conservation importance: Middle reaches

- 5. Kuthampully:** Kuthampully is a small village in the Thrissur district of Kerala. It is located on the banks of the Gayathri River ($10^{\circ} 59' - 10^{\circ} 57' \text{ N}$ and $76^{\circ} 34' - 76^{\circ} 33' \text{ E}$). This is the place where Gayathri River joins with Bharathapuzha. The majority of the habitats here are agriculture and human settlements. During the systematic sampling, 60 species of birds were recorded from this area. Along with synanthropic species of birds, Asian Openbill, Purple Heron *Ardea purpurea*, Cattle Egret and Woolly-Necked Stork *Ciconia episcopus* were the common birds in this region. This place is known for the handloom industry. Water pollution is the major threat in this area. Community-mediated conservation initiatives are required for the conservation of riverine birds and their habitats.



Image 13: Kuthampully river bank

- 6. Athipotta:** Athipotta is located on the bank of river Gayathri surrounded by agricultural land and human settlements ($10^{\circ} 39' N$ and $76^{\circ} 29' E$). During the systematic sampling, 56 species of birds were recorded from the location. The major habitats in the region is agricultural lands and human settlements. Black-Headed Ibis and Asian Openbill were common in this location. Extensive land conversion and developmental activities are the major threats in this location.

Location of conservation importance: Lower reaches

- 7. Chamravattom:** Chamravattom is a village located in the Malappuram district of Kerala. This location falls in the estuarine region of the Bharathapuzha River ($10^{\circ} 49' N$ and $75^{\circ} 57' E$). The river island in the Chamravattom supports a wide variety of birds. Water bodies, riverine vegetation human settlements, and agricultural lands are the major habitats here. 59 species of birds were recorded during the study period. Gulls, Terns, Storks and Egrets were very common in this location. Sand mining and seawater infusions are the major problems for this location.



Image 14: Chamravattom

- 8. *Mundaya*:** Mundaya is a village located in the lower reaches of the Bharathapuzha river basin ($10^{\circ} 46' N$ and $76^{\circ} 14' E$). Woody vegetation, agricultural lands, and water bodies are the major habitats in the area. A total of 66 species of birds were recorded from this location. Large flocks of cormorants were recorded from here. Crested Serpent Eagle *Spilornis cheela*, Red-Wattled Lapwing *Vanellus indicus*, Marsh Sandpiper *Tringa stagnatilis* and Common Sandpiper *Actitis hypoleucos* were common in this location. Sand mining and poaching are the threats in this location.

Conservation Strategies should be developed for the protection of remnant forests and agro ecosystems in the Bharathapuzha river basin to maintain landscape connectivity. Agro forests and cultivated areas are now globally recognized as important habitats for biodiversity. There is a need to increase awareness among various stakeholders including, policymakers, local administration authorities, local people, and farmers about the conservation values of these areas for the conservation of biodiversity outside the PAs particularly birds.

CHAPTER 7

SUMMARY AND CONCLUSION

Bharathapuzha river basin is one of the most important river basins in Western Ghats. This river is the second largest river in Kerala, which flows through the Palghat Gap. The Silent Valley National Park, Nelliampathi Hills and Karimbuzha Wildlife Sanctuary are the important protected areas in the river basin. This river is prone to several anthropogenic pressures such as sand mining, deforestation, pollution etc. These anthropogenic activities altered the natural flow of water and water-holding capacity. This changed the ecology of the river. In this scenario, this attempted to understand the avian community composition of this river. Also, in most of the studies in the global and national scenario, riverine studies are restricted to specific locations. This study employed a unique ridge-to-reef approach to understand the bird community and its distribution in a river basin. This is the first-ever study conducted with this approach in the Western Ghat's river basin.

The field observations were conducted from October 2017 to March 2019 in the selected riverine grids of the Bharathapuzha river basin. A total of 262 species belonging to 20 orders and 71 families were recorded. Out of 267 bird species recorded which is 49% of the total birds recorded from Kerala. So far 143 birds have been recorded and listed scientifically from the river basin. This study updated the new checklist and added 119 new species observations to the Basin. The study recorded 17 Western Ghat endemic birds. There was one endangered, five vulnerable and six near threatened birds as per the IUCN category. The mean species richness was 58.84 ± 12.53 and the mean species abundance was 527.85 ± 342.17 .

The bird species taxonomic composition shows that the most dominant group in the river basin was Passeriformes (42%) followed by Charadriiforms (13%), Pelecaniformes, and Accipitriformes (6%). Insectivore (48%) birds are found to be the most dominant feeding guild followed by semi-aquatic carnivores (14%) and carnivores (12%). Passerine birds were the most dominant group (N= 146) followed by waders (N= 33), raptors (N= 20), and shorebirds (N= 19). 80% of the birds recorded were residents and the remaining 20% were migrants.

There were 119 bird species reported from all three ecological zones. 60 bird species were reported only in the upper reaches, four in the middle reaches and 16 in the lower reaches of the river basin. House Crow, Common Myna, Cattle Egret, Little Cormorant, Yellow-billed Babbler and Red-vented Bulbul were found to be the most common and dominant birds in the river basin.

Malayan-night Heron, Chestnut-winged Cuckoo, Amur Falcon, Peregrine Falcon and Black-bellied Tern were found to be rare and important birds recorded from the river basin.

The bird species diversity and richness were found higher in the upper reaches than in the middle and lower reaches. The species abundance was higher in the lower reaches. The Migratory season was found to be more diverse in each ecological zone due to the addition of migrant birds. Rank abundance-based distribution models show that the Zipf-Mandelbrot distribution was found to be a best-fit model for upper reaches (deviance = 401.60) and lower reaches (deviance = 465.40). However, bird species in the middle reaches followed a log-normal abundance distribution (deviance = 615.83). The wetland birds were found higher in number at upper and lower reaches than the middle reaches. This shows that the larger waterbodies in the upper and lower reaches support the wetland birds in the river basin. This also highlights the unavailability of larger water bodies and the water availability in the middle reaches.

The bird communities show significant variation between the ecological zones in the seasons. However, the feeding guild composition is similar across the basin. The availability of similar foraging grounds in the upper and lower reaches affected the distribution of similar feeding guilds. Most of the species contributing to the community change are flocking birds, colonial breeding birds and synanthropic birds. The high abundance of synanthropic species is considered an indicator of anthropogenic pressure and urbanization. The presence of resident birds contributed maximum to the changes in the species composition. These highlight their tolerance and adaptations to local fragmentation and disturbance.

The areas in the lower reaches provide wintering sites for many long-distance migrant birds. Black-headed Gull, Brown-headed Gull, and Palla's Gull were found in high abundance in the lower reaches. This indicates that these migrant birds are highly dependent on the lower reaches during the migratory period. The protection of the forests in the upper reaches and all-natural habitats in the lower reaches are equally important for the conservation of birds.

The area of mudflats, area of water flow, riverside vegetation, distance from forest, and distance from farmland are the environmental parameters that positively influence the water-dependent birds and water-associated bird communities in different seasons. The study strongly recommends the protection of mudflats and riverside vegetation in the river basin. The study shows the importance of maintaining the environmental flow (e flow) in the river. The active agricultural practices need to be brought back which provide the foraging place for many of the

water-dependent birds. Also, a collective action program has to be developed to reduce the anthropogenic pressures such as sand mining, encroachment and land conversion in the basin.

The study identified ten conservation-importance locations in the river basin. Most of these locations fall under the non-protected areas. These locations are highly prone to several anthropogenic activities. The water availability due to the dams in the upper reaches supports a wide variety of birds. Maintaining the available habitats for the birds needs to be given higher priority.

Community-mediated policy interventions are much required to protect bird diversity in the human-dominated landscapes of the Bharathapuzha river basin. This study provided insight into the bird species distribution, and community assemblages in the different flow regimes of the river and the factors affecting the distribution and assemblage. The study identified potential areas for the conservation of avifauna, which can be given high priority for the conservation of avian diversity in the river basin. This information will help the policymakers to design appropriate conservation action plans for the river rejuvenation and conservation of birds in the river basin. Largely this study contributes more to the stocktaking of the state of art of the avian diversity of the land supported by Bharathapuzha river, current problems, mitigation measures and futuristic suggestions for conservation.

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PUBLICATION DETAILS

Sl No.	Name of the candidate	Date of Registration And registration number	College	No of publications	Title of the publication	Name of the Journal	Year of publication	Impact factor	Indicate first author/co-author /Corresponding author	Link to Scopus profile
1	Anoop Raj P N	Date of Registration: 12/10/2017 Registration number 179000027	Salim Ali Centre for Ornithology and Natural History (SACON), Coimbatore	2	Diversity and distribution of birds in the Bharatha puzha River Basin, Kerala	Journal of threatened taxa	2023	0.241	First & corresponding author	https://www.scopus.com/sourceid/21100806903
2	Anoop Raj P N	Date of Registration: 12/10/2017 Registration number 179000027	Salim Ali Centre for Ornithology and Natural History (SACON), Coimbatore		Avifaunal assemblage patterns in Bharatha puzha River Basin, Kerala	Journal of threatened taxa	2024	0.241	First & corresponding author	

List of publications from the PhD thesis
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1. Raj, P. A^{1,3*}, Velankar², A. D., & Pramod¹, P. (2023). Diversity and distribution of birds in the Bharathapuzha River Basin, Kerala, India. *Journal of Threatened Taxa*, 15(11), 24169-24183.

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2. Raj, P. A^{1,3*}, Velankar², A. D., & Pramod¹, P. (2024). Avifaunal assemblage patterns in Bharathapuzha River Basin, Kerala. *Journal of Threatened Taxa*, 16(2):24646–24657.

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ANNEXURE

Appendix 1: Checklist of birds

Sl No	Species	Upper reaches	Middle reaches	Lower reaches
I	Anseriformes: Anatidae			
1	Bar-headed Goose (<i>Anser indicus</i>) ‡ _{LC}	0.01 (4) ☉	0.00 (0)	0.00 (0)
2	Common Teal (<i>Anas crecca</i>) † _{LC}			*
3	Cotton Teal (<i>Nettapus coromandelianus</i>) _{LC}			*
4	Indian Spot-billed Duck (<i>Anas poecilorhyncha</i>) _{LC}	0.24 (16) ☉	0.01 (4) ☉	0.01 (17) ☉
5	Lesser Whistling Duck (<i>Dendrocygna javanica</i>) _{LC}	0.33 (20) ☉	0.01 (4) ☉	0.39 (28) ☉
II	Galliformes: Phasianidae			
6	Indian Peafowl (<i>Pavo cristatus</i>) _{LC}	0.22 (72) ●	0.21 (70) ●	0.08 (50) ●
7	Red Spurfowl (<i>Galloperdix spadicea</i>) _{LC}	0.01 (8) ☉	0.02 (11) ☉	0.00 (6) ☉
8	Jungle Bush Quail (<i>Perdica asiatica</i>) _{LC}	0.01 (4) ☉	0.00 (0)	0.00 (0)
9	Grey Francolin (<i>Francolinus pondicerianus</i>) _{LC}	0.02 (20) ☉	0.00 (0)	0.00 (0)
10	Grey Junglefowl (<i>Gallus sonneratii</i>) _{LC}	0.03 (24) ☉	0.00 (0)	0.00 (0)
III	Podicipediformes: Podicipedidae			
11	Little Grebe (<i>Tachybaptus ruficollis</i>) _{LC}	0.01 (12) ☉	0.00 (0)	0.01 (6) ☉
IV	Columbiformes: Columbidae			
12	Rock Pigeon (<i>Columba livia</i>) _{LC}	0.12 (44) ●	0.94 (93) ●	0.94 (89) ●
13	Nilgiri Wood Pigeon (<i>Columba elphinstonii</i>) _{VU}	0.01 (4) ☉	0.00 (0)	0.00 (0)
14	Spotted Dove (<i>Streptopelia chinensis</i>) _{LC}	0.39 (96) ●	0.50 (78) ●	0.21 (72) ●
15	Laughing Dove (<i>Streptopelia senegalensis</i>) _{LC}	0.02 (16) ☉	0.01 (4) ☉	0.01 (6) ☉
16	Asian Emerald Dove (<i>Chalcophaps indica</i>) _{LC}	0.01 (8) ☉	0.00 (4) ☉	0.00 (0)
17	Grey-fronted Green Pigeon (<i>Treron affinis</i>) _{LC}	0.01 (4) ☉	0.00 (0)	0.00 (0)
18	Yellow-footed Green Pigeon (<i>Treron phoenicopterus</i>) _{LC}	0.01 (4) ☉	0.00 (4) ☉	0.04 (11) ☉
19	Green Imperial Pigeon (<i>Ducula aenea</i>) _{LC}	0.02 (16) ☉	0.03 (15) ☉	0.00 (6) ☉
V	Cuculiformes: Cuculidae			
20	Greater Coucal (<i>Centropus sinensis</i>) _{LC}	0.07 (52) ●	0.08 (63) ●	0.07 (61) ●
21	Blue-faced Malkoha (<i>Phaenicophaeus viridirostris</i>) _{LC}	0.01 (20) ☉	0.00 (0)	0.00 (0)
22	Chestnut-winged Cuckoo (<i>Clamator coromandus</i>) ‡ _{LC}		*	
23	Pied Cuckoo (<i>Clamator jacobinus</i>) _{LC}	0.00 (0)	0.01 (7) ☉	>0.01 (6) ☉
24	Asian Koel (<i>Eudynamys scolopaceus</i>) _{LC}	0.15 (76) ●	0.14 (81) ●	0.07 (61) ●
25	Banded Bay Cuckoo (<i>Cacomantis sonneratii</i>) _{LC}	0.00 (4) ☉	0.00 (0)	0.00 (0)
26	Grey-bellied Cuckoo (<i>Cacomantis passerinus</i>) _{LC}	0.00 (4) ☉	0.00 (0)	>0.01 (6) ☉
27	Fork-tailed Drongo Cuckoo (<i>Surniculus dicruroides</i>) _{LC}	>0.01 (4) ☉	0.00 (0)	0.00 (0)
28	Common Hawk Cuckoo (<i>Hierococcyx varius</i>) _{LC}	0.02 (28) ●	0.01 (19) ☉	0.02 (39) ●
29	Indian Cuckoo (<i>Cuculus micropterus</i>) ‡ _{LC}	0.03 (24) ●	0.01 (15) ☉	0.01 (17) ☉
VI	Caprimulgiformes: Caprimulgidae			
30	Jerdon's Nightjar (<i>Caprimulgus atripennis</i>) _{LC}	0.01 (4) ☉	0.00 (0)	0.00 (0)
31	Indian Nightjar (<i>Caprimulgus asiaticus</i>) _{LC}	0.00 (0)	>0.01 (4) ☉	0.00 (0)
32	Savanna Nightjar (<i>Caprimulgus affinis</i>) _{LC}	0.00 (4) ☉	0.00 (0)	0.00 (0)

Caprimulgiformes: Apodidae				
33	Indian Swiftlet (<i>Aerodramus unicolor</i>) _{LC}	0.10 (20) ◉	0.25 (44) ●	0.34 (33) ◉
34	Alpine Swift (<i>Tachymarptis melba</i>) _{LC}	>0.01 (4) ◉	0.00 (0)	0.01 (11) ◉
35	Indian House Swift (<i>Apus affinis</i>) _{LC}	0.12 (16) ◉	0.23 (11) ◉	0.08 (28) ●
36	Asian Palm Swift (<i>Cypsiurus balasiensis</i>) _{LC}	1.66 (76) ●	3.23 (96) ●	2.39 (78) ●
Caprimulgiformes: Hemiprocnidae				
37	Crested Treeswift (<i>Hemiproctne coronata</i>) _{LC}	0.01 (4) ◉	0.00 (0)	0.00 (0)
VII	Gruiformes: Rallidae			
38	Common Coot (<i>Fulica atra</i>) _{LC}	0.05 (4) ◉	0.00 (4) ◉	0.00 (0)
39	Grey-headed Swamphen (<i>Porphyrio poliocephalus</i>) _{LC}	0.00 (0)	0.02 (15) ◉	0.34 (17) ◉
40	White-breasted Waterhen (<i>Amaurornis phoenicurus</i>) _{LC}	0.05 (32) ●	0.20 (78) ●	0.04 (50) ●
VIII	Charadriiformes: Recurvirostridae			
41	Black-winged Stilt (<i>Himantopus himantopus</i>) _{LC}	0.01 (4) ◉	0.00 (0)	0.01 (6) ◉
Charadriiformes: Charadriidae				
42	Pacific Golden Plover (<i>Pluvialis fulva</i>) _{†LC}	0.00 (0)	0.00 (0)	0.02 (11) ◉
43	Red-wattled Lapwing (<i>Vanellus indicus</i>) _{LC}	0.26 (56) ●	0.27 (63) ●	0.43 (83) ●
44	Kentish Plover (<i>Charadrius alexandrinus</i>) _{LC}	0.00 (0)	0.00 (0)	0.04 (6) ◉
45	Common Ringed Plover (<i>Charadrius hiaticula</i>) _{†LC}			*
46	Little Ringed Plover (<i>Charadrius dubius</i>) _{LC}	0.33 (32) ●	>0.01 (4) ◉	0.10 (44) ●
Charadriiformes:Rostratulidae				
47	Greater Painted-snipe (<i>Rostratula benghalensis</i>) _{LC}	>0.01 (4) ◉	0.00 (0)	0.01 (17) ◉
Charadriiformes:Jacanidae				
48	Pheasant-tailed Jacana (<i>Hydrophasianus chirurgus</i>) _{LC}	0.00 (0)	0.00 (0)	0.01 (6) ◉
49	Bronze-winged Jacana (<i>Metopidius indicus</i>) _{LC}	0.00 (0)	0.15 (44) ●	0.10 (33) ●
Charadriiformes:Scolopacidae				
50	Whimbrel (<i>Numenius phaeopus</i>) _{†LC}	0.00 (0)	0.00 (0)	0.01 (6) ◉
51	Eurasian Curlew (<i>Numenius arquata</i>) _{†NT}	0.00 (0)	0.00 (0)	0.01 (6) ◉
52	Ruddy Turnstone (<i>Arenaria interpres</i>) _{†LC}			*
53	Curlew Sandpiper (<i>Calidris ferruginea</i>) _{†NT}			*
54	Temminck's Stint (<i>Calidris temminckii</i>) _{†LC}			*
55	Little Stint (<i>Calidris minuta</i>) _{†LC}	0.00 (0)	0.00 (0)	0.04 (11) ◉
56	Common Snipe (<i>Gallinago gallinago</i>) _{†LC}	0.00 (4) ◉	0.00 (0)	0.00 (0)
57	Terek Sandpiper (<i>Xenus cinereus</i>) _{†LC}	0.00 (0)	0.00 (0)	0.01 (6) ◉
58	Common Sandpiper (<i>Actitis hypoleucos</i>) _{†LC}	0.28 (48) ●	0.11 (44) ●	0.37 (94) ●
59	Green Sandpiper (<i>Tringa ochropus</i>) _{†LC}	0.04 (20) ◉	0.05 (33) ●	0.13 (67) ●
60	Common Greenshank (<i>Tringa nebularia</i>) _{†LC}	0.02 (8) ◉	>0.01 (4) ◉	0.04 (11) ◉
61	Marsh Sandpiper (<i>Tringa stagnatilis</i>) _{†LC}	0.09 (20) ◉	0.01 (4) ◉	0.19 (67) ●
62	Wood Sandpiper (<i>Tringa glareola</i>) _{†LC}	0.08 (12) ◉	0.00 (4) ◉	0.08 (33) ●
63	Common Redshank (<i>Tringa totanus</i>) _{†LC}	0.00 (0)	0.01 (4) ◉	0.03 (11) ◉
Charadriiformes:Glareolidae				
64	Small Pratincole (<i>Glareolalactea</i>) _{LC}	0.03 (4) ◉	0.00 (0)	0.00 (0)
Charadriiformes:Laridae				
65	Black-headed Gull (<i>Chroicocephalus ridibundus</i>) _{†LC}	0.00 (0)	0.00 (0)	1.39 (28) ●
66	Brown-headed Gull (<i>Chroicocephalus brunnicephalus</i>) _{‡LC}	0.00 (0)	0.00 (0)	1.62 (33) ●

67	Pallas's Gull (<i>Ichthyaetus ichthyaetus</i>) † _{LC}	0.00 (0)	0.00 (0)	1.31 (22) ◐
68	Lesser Black-backed Gull (<i>Larus fuscus</i>) † _{LC}	0.00 (0)	0.00 (0)	0.52 (17) ◐
69	Little Tern (<i>Sternula albifrons</i>) _{LC}	0.02 (4) ◐	0.05 (15) ◐	0.00 (0)
70	Gull-billed Tern (<i>Gelochelidon nilotica</i>) ‡ _{LC}	0.00 (0)	0.00 (0)	0.05 (6) ◐
71	Caspian Tern (<i>Hydroprogne caspia</i>) _{LC}			*
72	Whiskered Tern (<i>Chlidonias hybrida</i>) _{LC}	0.26 (20) ◐	0.05 (19) ◐	0.39 (44) ◐
73	Black-bellied Tern (<i>Sterna acuticauda</i>) _{EN}	0.00 (4) ◐	0.00 (0)	0.00 (0)
74	River Tern (<i>Sterna aurantia</i>) _{VU}	0.15 (28) ◐	0.07 (30) ◐	0.25 (61) ●
IX	Ciconiiformes: Ciconiidae			
75	Asian Openbill (<i>Anastomus oscitans</i>) _{LC}	0.40 (52) ●	0.24 (63) ●	0.81 (94) ●
76	Woolly-necked Stork (<i>Ciconia episcopus</i>) _{NT}	0.20 (20) ◐	0.05 (15) ◐	0.17 (50) ●
77	Painted Stork (<i>Mycteria leucocephala</i>) _{LC}	0.11 (8) ◐	0.00 (0)	0.00 (0)
X	Suliformes: Anhingidae			
78	Oriental Darter (<i>Anhinga melanogaster</i>) _{NT}	0.04 (16) ◐	0.05 (41) ◐	0.08 (56) ●
	Suliformes: Phalacrocoracidae			
79	Little Cormorant (<i>Microcarboniger</i>) _{LC}	1.82 (52) ●	0.88 (93) ●	2.66 (100) ●
80	Great Cormorant (<i>Phalacrocorax carbo</i>) _{LC}	0.04 (8) ◐	0.00 (0)	0.01 (17) ◐
81	Indian Cormorant (<i>Phalacrocorax fuscicollis</i>) _{LC}	0.06 (28) ◐	0.02 (19) ◐	0.03 (28) ◐
XI	Pelecaniformes: Pelecanidae			
82	Spot-billed Pelican (<i>Pelecanus philippensis</i>) _{NT}	>0.01 (4) ◐	0.00 (0)	0.00 (0)
	Pelecaniformes: Ardeidae			
83	Yellow Bittern (<i>Ixobrychus sinensis</i>) _{LC}	>0.01 (4) ◐	>0.01 (4) ◐	0.01 (6) ◐
84	Cinnamon Bittern (<i>Ixobrychus cinnamomeus</i>) _{LC}	0.01 (4) ◐	0.00 (0)	0.00 (0)
85	Black Bittern (<i>Ixobrychus flavicollis</i>) _{LC}			*
86	Grey Heron (<i>Ardea cinerea</i>) _{LC}	0.05 (24) ◐	0.02 (30) ◐	0.08 (78) ●
87	Purple Heron (<i>Ardea purpurea</i>) _{LC}	0.04 (20) ◐	0.07 (56) ●	0.10 (67) ●
88	Great Egret (<i>Ardea alba</i>) _{LC}	0.03 (20) ◐	0.03 (19) ◐	0.17 (61) ●
89	Intermediate Egret (<i>Ardea intermedia</i>) _{LC}	0.09 (36) ◐	0.11 (59) ●	0.52 (94) ●
90	Little Egret (<i>Egretta garzetta</i>) _{LC}	0.35 (60) ●	0.43 (85) ●	1.12 (100) ●
91	Western Reef Egret (<i>Egretta gularis</i>) _{LC}	0.00 (0)	0.00 (0)	0.05 (17) ◐
92	Cattle Egret (<i>Bubulcus ibis</i>) _{LC}	1.10 (84) ●	0.93 (100) ●	1.99 (100) ●
93	Indian Pond Heron (<i>Ardeola grayii</i>) _{LC}	0.42 (88) ●	0.76 (100) ●	0.67 (100) ●
94	Striated Heron (<i>Butorides striata</i>) _{LC}	>0.01 (4) ◐	0.01 (4) ◐	0.00 (0)
95	Black-crowned Night Heron (<i>Nycticorax nycticorax</i>) _{LC}	0.01 (12) ◐	0.02 (15) ◐	0.04 (28) ◐
96	Malayan Night Heron (<i>Gorsachius melanolophus</i>) _{LC}			*
	Pelecaniformes: Threskiornithidae			
97	Glossy Ibis (<i>Plegadis falcinellus</i>) _{LC}	0.01 (4) ◐	0.00 (0)	0.04 (6) ◐
98	Black-headed Ibis (<i>Threskiornis melanocephalus</i>) _{NT}	0.52 (44) ◐	0.04 (22) ◐	0.36 (56) ●
XII	Accipitriformes: Pandionidae			
99	Osprey (<i>Pandion haliaetus</i>) † _{LC}	0.01 (8) ◐	0.00 (0)	0.00 (0)
	Accipitriformes: Accipitridae			
100	Black-winged Kite (<i>Elanus caeruleus</i>) _{LC}	0.01 (8) ◐	0.00 (0)	0.01 (11) ◐
101	Oriental Honey Buzzard (<i>Pernis ptilorhynchus</i>) _{LC}	0.03 (36) ◐	0.02 (19) ◐	0.01 (17) ◐
102	Crested Serpent Eagle (<i>Spilornis cheela</i>) _{LC}	0.09 (56) ●	0.08 (59) ●	0.06 (61) ●

103	Changeable Hawk Eagle (<i>Nisaetus cirrhatus</i>) _{LC}	0.01 (8) ☉	0.00 (0)	0.00 (0)
104	Legge's Hawk Eagle (<i>Nisaetus kelaarti</i>) _{NE}	0.00 (4) ☉	0.00 (0)	0.00 (0)
105	Black Eagle (<i>Ictinaetus malaiensis</i>) _{LC}	0.02 (16) ☉	0.00 (4) ☉	0.01 (11) ☉
106	Indian Spotted Eagle (<i>Clanga hastata</i>) _{VU}	0.00 (0)	0.00 (0)	0.00 (6) ☉
107	Booted Eagle (<i>Hieraaetus pennatus</i>) _{†LC}	0.01 (16) ☉	0.02 (22) ●	0.06 (61) ●
108	White-eyed Buzzard (<i>Butastur teesa</i>) _{LC}	0.00 (4) ☉	0.00 (0)	0.00 (0)
109	Western Marsh Harrier (<i>Circus aeruginosus</i>) _{†LC}			*
110	Crested Goshawk (<i>Accipiter trivirgatus</i>) _{LC}		*	
111	Shikra (<i>Accipiter badius</i>) _{LC}	0.05 (56) ●	0.02 (19) ☉	0.02 (39) ☉
112	Black Kite (<i>Milvus migrans</i>) _{LC}	0.12 (36) ●	0.15 (52) ●	1.15 (83) ●
113	Brahminy Kite (<i>Haliaeetus turindus</i>) _{LC}	0.35 (80) ●	0.59 (96) ●	1.73 (100) ●
114	Grey-headed Fish Eagle (<i>Haliaeetus ichthyaeetus</i>) _{NT}		*	
XIII Strigiformes: Tytonidae				
115	Common Barn Owl (<i>Tyto alba</i>) _{LC}		*	*
Strigiformes: Strigidae				
116	Oriental Scops Owl (<i>Otus sunia</i>) _{LC}	0.01 (4) ☉	0.00 (0)	0.00 (0)
117	Brown Fish Owl (<i>Ketupa zeylonensis</i>) _{LC}	0.01 (8) ☉	0.00 (0)	0.00 (0)
118	Jungle Owlet (<i>Glaucidium radiatum</i>) _{LC}	0.01 (12) ☉	0.00 (0)	0.00 (0)
119	Spotted Owlet (<i>Athene brama</i>) _{LC}	0.04 (24) ●	0.01 (11) ☉	0.01 (11) ☉
120	Mottled Wood Owl (<i>Strix ocellata</i>) _{LC}	0.00 (4) ☉	0.00 (0)	0.00 (0)
XIV Trogoniformes: Trogonidae				
121	Malabar Trogon (<i>Harpactes fasciatus</i>) _{LC}	0.02 (16) ☉	0.00 (0)	0.00 (0)
XV Bucerotiformes: Upupidae				
122	Common Hoopoe (<i>Upupa epops</i>) _{LC}	>0.01 (4) ☉	0.00 (0)	0.00 (0)
Bucerotiformes: Bucerotidae				
123	Great Hornbill (<i>Buceros bicornis</i>) _{VU}	0.01 (4) ☉	0.00 (0)	0.00 (0)
124	Malabar Grey Hornbill (<i>Ocyrceros griseus</i>) _{VU}	0.04 (28) ●	0.02 (11) ☉	0.01 (17) ☉
XVI Coraciiformes: Alcedinidae				
125	Common Kingfisher (<i>Alcedo atthis</i>) _{LC}	0.09 (68) ●	0.14 (81) ●	0.08 (72) ●
126	Stork-billed Kingfisher (<i>Pelargopsis capensis</i>) _{LC}	0.02 (24) ●	0.07 (59) ●	0.03 (39) ☉
127	White-throated Kingfisher (<i>Halcyon smyrnensis</i>) _{LC}	0.35 (92) ●	0.57 (100) ●	0.32 (100) ●
128	Pied Kingfisher (<i>Ceryle rudis</i>) _{LC}	0.04 (20) ☉	0.11 (52) ●	0.11 (72) ●
Coraciiformes: Meropidae				
129	Blue-bearded Bee-eater (<i>Nyctyornis athertoni</i>) _{LC}	0.01 (12) ☉	0.00 (0)	0.00 (0)
130	Green Bee-eater (<i>Merops orientalis</i>) _{LC}	0.48 (64) ●	0.56 (85) ●	0.67 (94) ●
131	Blue-tailed Bee-eater (<i>Merops philippinus</i>) _{LC}	0.01 (16) ☉	0.10 (33) ●	0.10 (50) ☉
132	Chestnut-headed Bee-eater (<i>Merops leschenaulti</i>) _{LC}	0.11 (28) ●	0.15 (44) ●	0.30 (72) ●
Coraciiformes: Coraciidae				
133	Indian Roller (<i>Coracias benghalensis</i>) _{LC}	0.03 (36) ●	0.05 (33) ●	0.00 (0)
134	Dollarbird (<i>Eurystomus orientalis</i>) _{LC}	0.00 (4) ☉	0.00 (0)	0.00 (0)
XVII Piciformes: Megalaimidae				
135	Malabar Barbet (<i>Psilopogon malabaricus</i>) _{LC}		*	
136	Coppersmith Barbet (<i>Psilopogon haemacephalus</i>) _{LC}	0.12 (52) ●	0.03 (30) ●	0.02 (17) ☉
137	Brown-headed Barbet (<i>Psilopogon zeylanicus</i>) _{LC}		*	

138	White-cheeked Barbet (<i>Psilopogon viridis</i>) _{LC}	0.45 (100) ●	0.34 (96) ●	0.16 (83) ●
Piciformes: Picidae				
139	Heart-spotted Woodpecker (<i>Hemicircus canente</i>) _{LC}	0.01 (8) ☉	0.01 (7) ☉	0.00 (0)
140	Brown-capped Pygmy Woodpecker (<i>Yungipicus nanus</i>) _{LC}	0.03 (32) ●	>0.01 (4) ☉	0.00 (0)
141	Rufous Woodpecker (<i>Micropternus brachyurus</i>) _{LC}	0.01 (12) ☉	0.00 (0)	0.00 (0)
142	Black-rumped Flameback (<i>Dinopium benghalense</i>) _{LC}	0.07 (52) ●	0.03 (22) ●	0.01 (11) ☉
143	Lesser Yellownappe (<i>Picus chlorolophus</i>) _{LC}	0.03 (28) ●	0.00 (4) ☉	0.00 (0)
144	Streak-throated Woodpecker (<i>Picus xanthopygaeus</i>) _{LC}	0.01 (8) ☉	0.00 (0)	0.00 (0)
XVIII Falconiformes: Falconidae				
145	Common Kestrel (<i>Falco tinnunculus</i>) _{LC}	>0.01 (4) ☉	>0.01 (4) ☉	0.01 (6) ☉
146	Amur Falcon (<i>Falco amurensis</i>) _{†LC}	0.00 (0)	0.00 (0)	0.01 (6) ☉
147	Peregrine Falcon (<i>Falco peregrinus</i>) _{LC}	*		
XIX Psittaciformes: Psittaculidae				
148	Rose-ringed Parakeet (<i>Psittacula krameri</i>) _{LC}	0.33 (84) ●	0.48 (93) ●	0.11 (78) ●
149	Plum-headed Parakeet (<i>Psittacula cyanocephala</i>) _{LC}	0.05 (20) ☉	0.05 (11) ☉	0.02 (11) ☉
150	Malabar Parakeet (<i>Psittacula columboides</i>) _{LC}	0.18 (56) ●	0.07 (19) ●	0.00 (0)
151	Vernal Hanging Parrot (<i>Loriculus vernalis</i>) _{LC}	0.14 (48) ●	0.01 (11) ☉	0.02 (22) ●
XX Passeriformes: Pittidae				
152	Indian Pitta (<i>Pitta brachyura</i>) _{‡LC}	0.01 (20) ☉	0.01 (7) ☉	0.00 (0)
Passeriformes: Campephagidae				
153	Orange Minivet (<i>Pericrocotus flammeus</i>) _{LC}	0.21 (44) L	0.02 (7) ☉	0.01 (6) ☉
154	Large Cuckooshrike (<i>Coracinamacei</i>) _{LC}	0.04 (28) ●	0.01 (15) ☉	0.01 (6) ☉
155	Black-headed Cuckooshrike (<i>Lalage melanoptera</i>) _{LC}	0.02 (20) ☉	>0.01 (4) ☉	0.02 (28) ●
Passeriformes: Oriolidae				
156	Indian Golden Oriole (<i>Oriolus kundoo</i>) _{‡LC}	0.04 (24) ●	0.04 (22) ●	0.06 (44) ●
157	Black-naped Oriole (<i>Oriolus chinensis</i>) _{†LC}	0.02 (20) ☉	0.01 (15) ☉	0.02 (28) ●
158	Black-hooded Oriole (<i>Oriolus xanthornus</i>) _{LC}	0.27 (88) ●	0.18 (74) ●	0.12 (67) ●
Passeriformes: Artamidae				
159	Ashy Woodswallow (<i>Artamus fuscus</i>) _{LC}	0.12 (44) ●	0.23 (37) ●	0.17 (72) ●
Passeriformes: Vangidae				
160	Malabar Woodshrike (<i>Tephrodornis sylvicola</i>) _{LC}	0.02 (16) ☉	>0.01 (4) ☉	0.01 (11) ☉
161	Common Woodshrike (<i>Tephrodornis pondicerianus</i>) _{LC}	*	*	
Passeriformes: Aegithinidae				
162	Common Iora (<i>Aegithina tiphia</i>) _{LC}	0.19 (68) ●	0.09 (70) ●	0.08 (67) ●
Passeriformes: Dicruridae				
163	Black Drongo (<i>Dicrurus macrocercus</i>) _{LC}	0.51 (96) ●	0.50 (100) ●	0.43 (94) ●
164	Ashy Drongo (<i>Dicrurus leucophaeus</i>) _{‡LC}	0.02 (20) ☉	0.00 (0)	>0.01 (6) ☉
165	Bronzed Drongo (<i>Dicrurus aeneus</i>) _{LC}	>0.01 (4) ☉	0.00 (0)	0.01 (11) ☉
166	Greater Racket-tailed Drongo (<i>Dicrurus paradiseus</i>) _{LC}	0.27 (64) ●	0.08 (37) ●	0.10 (44) ●
Passeriformes: Monarchidae				
167	Black-naped Monarch (<i>Hypothymis azurea</i>) _{LC}	0.04 (28) ●	0.01 (4) ☉	0.00 (0)
168	Indian Paradise-flycatcher (<i>Terpsiphone paradisi</i>) _{‡LC}	0.07 (48) ●	0.02 (19) ☉	0.01 (11) ☉
Passeriformes: Laniidae				
169	Brown Shrike (<i>Lanius cristatus</i>) _{†LC}	0.03 (20) ☉	>0.01 (4) ☉	0.03 (22) ●

170	Bay-backed Shrike (<i>Lanius vittatus</i>) _{LC}	>0.01 (4) ☉	0.00 (0)	>0.01 (6) ☉
171	Long-tailed Shrike (<i>Lanius schach</i>) _{LC}	0.01 (8) ☉	0.02 (30) ☉	>0.01 (6) ☉
Passeriformes: Corvidae				
172	Rufous Treepie (<i>Dendrocitta vagabunda</i>) _{LC}	0.30 (84) ●	0.30 (85) ●	0.14 (89) ●
173	White-bellied Treepie (<i>Dendrocitta leucogastra</i>) _{LC}	0.02 (12) ☉	0.00 (0)	0.00 (0)
174	House Crow (<i>Corvus splendens</i>) _{LC}	1.34 (100) ●	2.77 (100) ●	4.46 (100) ●
175	Large-billed Crow (<i>Corvus macrorhynchos</i>) _{LC}	0.57 (84) ●	0.67 (85) ●	0.57 (78) ●
Passeriformes: Stenostiridae				
176	Grey-headed Canary-flycatcher (<i>Culicicapa ceylonensis</i>) ‡ _{LC}		*	
Passeriformes: Paridae				
177	Cinereous Tit (<i>Parus cinereus</i>) _{LC}	0.03 (8) ☉	0.00 (0)	0.00 (0)
Passeriformes: Alaudidae				
178	Jerdon's Bushlark (<i>Mirafra affinis</i>) _{LC}	0.07 (24) ☉	0.01 (7) ☉	0.01 (11) ☉
179	Oriental Skylark (<i>Alauda gulgula</i>) _{LC}		*	
180	Malabar Lark (<i>Galerida malabarica</i>) _{LC}		*	*
Passeriformes: Cisticolidae				
181	Common Tailorbird (<i>Orthotomus sutorius</i>) _{LC}	0.39 (96) ●	0.61 (100) ●	0.31 (94) ●
182	Jungle Prinia (<i>Prinia sylvatica</i>) _{LC}	0.03 (16) ☉	0.00 (0)	>0.01 (6) ☉
183	Ashy Prinia (<i>Prinia socialis</i>) _{LC}	0.01 (12) ☉	0.08 (48) ☉	0.12 (67) ●
184	Plain Prinia (<i>Prinia inornata</i>) _{LC}	0.07 (40) ☉	0.21 (70) ●	0.14 (72) ●
185	Zitting Cisticola (<i>Cisticola juncidis</i>) _{LC}	0.01 (4) ☉	>0.01 (4) ☉	0.02 (28) ☉
Passeriformes: Acrocephalidae				
186	Thick-billed Warbler (<i>Arundinaxaedon</i>) † _{LC}	0.01 (4) ☉	0.00 (0)	0.00 (0)
187	Booted Warbler (<i>Iduna caligata</i>) † _{LC}	>0.01 (4) ☉	0.00 (0)	0.00 (0)
188	Blyth's Reed Warbler (<i>Acrocephalus dumetorum</i>) † _{LC}	0.45 (96) ●	0.48 (93) ●	0.34 (89) ●
189	Clamorous Reed Warbler (<i>Acrocephalus stentoreus</i>) _{LC}	0.05 (32) ☉	0.01 (11) ☉	0.01 (11) ☉
Passeriformes: Hirundinidae				
190	Barn Swallow (<i>Hirundo rustica</i>) ‡ _{LC}	0.44 (48) ☉	0.51 (63) ●	0.81 (67) ●
191	Wire-tailed Swallow (<i>Hirundo smithii</i>) _{LC}	0.00 (0)	0.00 (0)	0.11 (17) ☉
192	Red-rumped Swallow (<i>Cecropis daurica</i>) _{LC}	0.30 (28) ☉	0.48 (52) ●	1.11 (72) ●
193	Streak-throated Swallow (<i>Petrochelidon fluvicola</i>) _{LC}	0.00 (0)	0.02 (4) ☉	0.00 (0)
Passeriformes: Pycnonotidae				
194	Flame-throated Bulbul (<i>Rubigula gularis</i>) _{LC}	0.14 (24) ☉	0.00 (0)	0.00 (0)
195	Red-vented Bulbul (<i>Pycnonotus cafer</i>) _{LC}	1.00 (100) ●	0.86 (96) ●	0.57 (100) ●
196	Red-whiskered Bulbul (<i>Pycnonotus jocosus</i>) _{LC}	0.63 (88) ●	0.62 (89) ●	0.46 (89) ●
197	White-browed Bulbul (<i>Pycnonotus luteolus</i>) _{LC}	0.15 (52) ●	0.03 (19) ☉	0.06 (28) ☉
198	Yellow-browed Bulbul (<i>Acritillas indica</i>) _{LC}	0.21 (64) ●	>0.01 (4) ☉	0.01 (11) ☉
Passeriformes: Phylloscopidae				
199	Green Leaf Warbler (<i>Phylloscopus nitidus</i>) † _{LC}	0.05 (44) ☉	0.02 (15) ☉	0.02 (22) ☉
200	Greenish Leaf Warbler (<i>Phylloscopus trochiloides</i>) ‡ _{LC}	0.42 (84) ●	0.14 (67) ●	0.10 (72) ●
201	Large-billed Leaf Warbler (<i>Phylloscopus magnirostris</i>) ‡ _{LC}	0.01 (4) ☉	>0.01 (4) ☉	0.00 (0)
Passeriformes: Zosteropidae				
202	Indian White-eye (<i>Zosterops palpebrosus</i>) _{LC}	0.17 (20) ☉	0.00 (0)	>0.01 (6) ☉

Passeriformes: Timaliidae				
203	Tawny-bellied Babbler (<i>Dumetia hyperythra</i>) _{LC}	0.04 (16) ☉	0.00 (0)	0.00 (0)
204	Dark-fronted Babbler (<i>Rhopocichla atriceps</i>) _{LC}	0.03 (4) ☉	0.00 (0)	0.00 (0)
205	Indian Scimitar Babbler (<i>Pomatorhinus horsfieldii</i>) _{LC}	0.04 (20) ☉	0.00 (0)	0.00 (0)
Passeriformes: Pellorneidae				
206	Puff-throated Babbler (<i>Pellorneum ruficeps</i>) _{LC}	0.04 (16) ☉	0.00 (0)	0.00 (0)
Passeriformes: Leiothrichidae				
207	Jungle Babbler (<i>Argya striata</i>) _{LC}	0.61 (60) ●	0.05 (11) ☉	0.03 (11) ☉
208	Yellow-billed Babbler (<i>Argya affinis</i>) _{LC}	1.43 (100) ●	1.40 (93) ●	0.54 (72) ●
209	Common Babbler (<i>Argya caudata</i>) _{LC}	0.02 (4) ☉	0.00 (0)	0.00 (0)
210	Rufous Babbler (<i>Argya subrufa</i>) _{LC}	0.09 (16) ☉	0.01 (4) ☉	0.00 (0)
211	Wayanad Laughingthrush (<i>Pterorhinus delesserti</i>) _{LC}	0.07 (4) ☉	0.00 (0)	0.00 (0)
Passeriformes: Sittidae				
212	Velvet-fronted Nuthatch (<i>Sitta frontalis</i>) _{LC}	0.07 (24) ☉	0.00 (0)	0.00 (0)
Passeriformes: Sturnidae				
213	Common Hill Myna (<i>Gracula religiosa</i>) _{LC}	0.33 (24) ☉	0.00 (0)	0.00 (0)
214	Rosy Starling (<i>Pastor roseus</i>) _{†LC}	0.08 (12) ☉	0.02 (4) ☉	0.17 (17) ☉
215	Brahminy Starling (<i>Sturnia pagodarum</i>) _{LC}	0.01 (4) ☉	0.04 (11) ☉	0.00 (0)
216	Chestnut-tailed Starling (<i>Sturnia malabarica</i>) _{LC}	0.01 (8) ☉	0.00 (0)	0.06 (11) ☉
217	Malabar Starling (<i>Sturnia blythii</i>) _{NE}	0.04 (12) ☉	0.01 (4) ☉	0.02 (6) ☉
218	Common Myna (<i>Acridotheres tristis</i>) _{LC}	1.12 (100) ●	1.45 (100) ●	1.14 (100) ●
219	Jungle Myna (<i>Acridotheres fuscus</i>) _{LC}	0.33 (64) ●	0.04 (15) ☉	0.02 (6) ☉
Passeriformes: Turdidae				
220	Nilgiri Thrush (<i>Zootheraneilgherriensis</i>) _{NE}	0.01 (8) ☉	0.00 (0)	0.00 (0)
221	Orange-headed Thrush (<i>Geokichlacitrina</i>) _{LC}	0.05 (28) ☉	0.01 (19) ☉	0.02 (28) ☉
Passeriformes: Muscicapidae				
222	Asian Brown Flycatcher (<i>Muscicapa dauurica</i>) _{LC}	0.01 (8) ☉	0.00 (0)	0.00 (0)
223	Brown-breasted Flycatcher (<i>Muscicapa muttui</i>) _{†LC}	0.10 (52) ●	0.01 (11) ☉	0.02 (28) ☉
224	Indian Robin (<i>Copsychus fulicatus</i>) _{LC}	0.06 (28) ☉	0.02 (11) ☉	0.01 (11) ☉
225	Oriental Magpie Robin (<i>Copsychus saularis</i>) _{LC}	0.26 (84) ●	0.19 (78) ●	0.07 (61) ●
226	White-rumped Shama (<i>Copsychus malabaricus</i>) _{LC}	*		
227	White-bellied Blue Flycatcher (<i>Cyornis pallidipes</i>) _{LC}	0.03 (16) ☉	0.00 (0)	0.00 (0)
228	Tickell's Blue Flycatcher (<i>Cyornis tickelliae</i>) _{LC}	0.03 (24) ☉	0.00 (0)	0.00 (0)
229	Nilgiri Flycatcher (<i>Eumyias albicaudatus</i>) _{LC}	*		
230	Verditer Flycatcher (<i>Eumyias thalassinus</i>) _{‡LC}	>0.01 (4) ☉	0.00 (0)	0.00 (0)
231	Malabar Whistling Thrush (<i>Myophonus horsfieldii</i>) _{LC}	0.18 (44) ☉	0.01 (7) ☉	0.00 (0)
232	Black-and-orange Flycatcher (<i>Ficedula nigrorufa</i>) _{LC}	*		
233	Rusty-tailed Flycatcher (<i>Ficedula ruficauda</i>) _{†LC}	0.01 (12) ☉	0.00 (0)	0.00 (0)
234	Taiga Flycatcher (<i>Ficedula albicilla</i>) _{†LC}	*		
235	Blue-capped Rock Thrush (<i>Monticola cinclorhyncha</i>) _{‡LC}	0.02 (8) ☉	0.00 (0)	0.00 (0)
236	Pied Bushchat (<i>Saxicola caprata</i>) _{LC}	0.11 (48) ☉	0.05 (30) ☉	0.05 (33) ☉
Passeriformes: Dicaeidae				
237	Thick-billed Flowerpecker (<i>Dicaeum agile</i>) _{LC}	0.02 (12) ☉	0.00 (0)	0.00 (0)
238	Pale-billed Flowerpecker (<i>Dicaeum erythrorhynchos</i>) _{LC}	0.35 (92) ●	0.29 (85) ●	0.17 (83) ●

239	Nilgiri Flowerpecker (<i>Dicaeum concolor</i>) _{LC}	0.01 (4) ☉	0.00 (0)	0.00 (0)
Passeriformes:Nectariniidae				
240	Purple-rumped Sunbird (<i>Leptocoma zeylonica</i>) _{LC}	0.93 (100) ●	0.83 (100) ●	0.44 (100) ●
241	Crimson-backed Sunbird (<i>Leptocoma minima</i>) _{LC}	0.08 (32) ☉	0.00 (0)	0.00 (0)
242	Purple Sunbird (<i>Cinnyris asiaticus</i>) _{LC}	0.23 (84) ●	0.22 (74) ●	0.17 (72) ●
243	Loten's Sunbird (<i>Cinnyris lotenius</i>) _{LC}	0.18 (76) ●	0.06 (41) ☉	0.05 (39) ☉
244	Little Spiderhunter (<i>Arachnothera longirostra</i>) _{LC}	0.05 (20) ☉	>0.01 (4) ☉	0.00 (0)
Passeriformes:Irenidae				
245	Asian Fairy-bluebird (<i>Irena puella</i>) _{LC}	0.05 (16) ☉	0.00 (0)	0.00 (0)
Passeriformes:Chloropseidae				
246	Jerdon's Leafbird (<i>Chloropsis jerdoni</i>) _{LC}	0.13 (56) ●	0.05 (37) ☉	0.04 (39) ☉
247	Golden-fronted Leafbird (<i>Chloropsis aurifrons</i>) _{LC}	0.04 (20) ☉	0.02 (19) ☉	0.01 (11) ☉
Passeriformes:Ploceidae				
248	Streaked Weaver (<i>Ploceus manyar</i>) _{LC}	0.00 (0)	0.01 (4) ☉	0.00 (0)
249	Baya Weaver (<i>Ploceus philippinus</i>) _{LC}	0.00 (0)	0.23 (7) ☉	0.00 (0)
Passeriformes:Estrildidae				
250	Red Munia (<i>Amandava amandava</i>) _{LC}			*
251	Indian Silverbill (<i>Euodice malabarica</i>) _{LC}	0.01 (4) ☉	0.00 (0)	0.00 (0)
252	White-rumped Munia (<i>Lonchura striata</i>) _{LC}	0.00 (0)	0.01 (4) ☉	0.01 (11) ☉
253	Scaly-breasted Munia (<i>Lonchura punctulata</i>) _{LC}	0.06 (8) ☉	0.08 (19) ☉	0.27 (33) ☉
254	Tricoloured Munia (<i>Lonchura malacca</i>) _{LC}	0.15 (24) ☉	0.24 (30) ☉	0.34 (39) ☉
Passeriformes:Passeridae				
255	House Sparrow (<i>Passer domesticus</i>) _{LC}	0.00 (0)	0.04 (19) ☉	0.01 (6) ☉
256	Yellow-throated Sparrow (<i>Gymnoris xanthocollis</i>) _{LC}	0.01 (4) ☉	0.00 (0)	0.00 (0)
Passeriformes:Motacillidae				
257	Forest Wagtail (<i>Dendronanthus indicus</i>) [†] _{LC}	0.02 (16) ☉	0.00 (0)	0.00 (0)
258	Grey Wagtail (<i>Motacilla cinerea</i>) [‡] _{LC}	0.10 (52) ●	0.04 (33) ☉	0.01 (17) ☉
259	Western Yellow Wagtail (<i>Motacilla flava</i>) [†] _{LC}	0.04 (24) ☉	0.01 (7) ☉	0.01 (22) ☉
260	White-browed Wagtail (<i>Motacilla maderaspatensis</i>) _{LC}	0.16 (56) ●	0.33 (78) ●	0.29 (83) ●
261	Paddyfield Pipit (<i>Anthusrufulus</i>) _{LC}	0.05 (36) ☉	0.02 (15) ☉	0.01 (28) ☉
Passeriformes:Fringillidae				
262	Common Rosefinch (<i>Carpodacus erythrinus</i>) [‡] _{LC}			*

Appendix 2: Details of the sampling locations

Grid No	Ecological zone	Latitude	Longitude	Grid Name
1	Lower reaches	75.91097	10.78534	Ponnani
1	Lower reaches	75.91305	10.78652	Ponnani
1	Lower reaches	75.91266	10.7845	Ponnani
1	Lower reaches	75.91055	10.78812	Ponnani
2	Lower reaches	76.3751	10.7685	Ottappalam
2	Lower reaches	76.37929	10.76908	Ottappalam
2	Lower reaches	76.38135	10.76597	Ottappalam
2	Lower reaches	76.37503	10.76513	Ottappalam
3	Lower reaches	76.43669	10.75206	Thiruvilwamala
3	Lower reaches	76.44345	10.75085	Thiruvilwamala
3	Lower reaches	76.43912	10.74922	Thiruvilwamala
3	Lower reaches	76.43577	10.75019	Thiruvilwamala
4	Lower reaches	76.32261	10.74822	Mannannur
4	Lower reaches	76.32719	10.74612	Mannannur
4	Lower reaches	76.32111	10.74473	Mannannur
4	Lower reaches	76.31885	10.748	Mannannur
5	Lower reaches	76.51546	10.78059	Mankara
5	Lower reaches	76.51384	10.78157	Mankara
5	Lower reaches	76.51254	10.78007	Mankara
5	Lower reaches	76.51614	10.78262	Mankara
6	Upper reaches	76.54034	10.97863	Kanjirapuzha
6	Upper reaches	76.53962	10.9833	Kanjirapuzha
6	Upper reaches	76.53744	10.98595	Kanjirapuzha
6	Upper reaches	76.53541	10.98581	Kanjirapuzha
7	Lower reaches	76.26617	10.75504	Cheruthuruthi
7	Lower reaches	76.26483	10.7534	Cheruthuruthi
7	Lower reaches	76.26991	10.75563	Cheruthuruthi
7	Lower reaches	76.271	10.75331	Cheruthuruthi
8	Lower reaches	76.55888	10.79763	Parali
8	Lower reaches	76.5563	10.79722	Parali
8	Lower reaches	76.5563	10.79378	Parali
8	Lower reaches	76.5567	10.79631	Parali
9	Middle reaches	76.42468	10.91499	Karimpuzha
9	Middle reaches	76.42267	10.91698	Karimpuzha
9	Middle reaches	76.42072	10.91771	Karimpuzha
9	Middle reaches	76.41865	10.91697	Karimpuzha
10	Middle reaches	76.29972	10.91653	Thootha
10	Middle reaches	76.29271	10.91598	Thootha

10	Middle reaches	76.2962	10.92071	Thootha
10	Middle reaches	76.29316	10.91896	Thootha
11	Middle reaches	76.26178	10.89886	Mavundirikadavu
11	Middle reaches	76.25799	10.89712	Mavundirikadavu
11	Middle reaches	76.26121	10.90193	Mavundirikadavu
11	Middle reaches	76.26374	10.90492	Mavundirikadavu
12	Middle reaches	76.39866	10.74521	Kuthampully
12	Middle reaches	76.39575	10.74786	Kuthampully
12	Middle reaches	76.39159	10.75175	Kuthampully
12	Middle reaches	76.39378	10.7455	Kuthampully
13	Middle reaches	76.45247	10.99758	Mannarkkad
13	Middle reaches	76.45294	10.99636	Mannarkkad
13	Middle reaches	76.44884	10.9963	Mannarkkad
13	Middle reaches	76.45242	11.00365	Mannarkkad
14	Lower reaches	76.24961	10.74823	Mundaya
14	Lower reaches	76.24725	10.75081	Mundaya
14	Lower reaches	76.2508	10.74596	Mundaya
14	Lower reaches	76.2547	10.7497	Mundaya
15	Middle reaches	76.67887	10.80427	Kottekkadu
15	Middle reaches	76.68071	10.80581	Kottekkadu
15	Middle reaches	76.67909	10.80558	Kottekkadu
15	Middle reaches	76.67991	10.80559	Kottekkadu
16	Middle reaches	76.43214	10.7028	Cheerakuzhi
16	Middle reaches	76.43393	10.70119	Cheerakuzhi
16	Middle reaches	76.431	10.70076	Cheerakuzhi
16	Middle reaches	76.42839	10.70243	Cheerakuzhi
17	Middle reaches	76.56697	10.78223	Anikodu
17	Middle reaches	76.56252	10.78597	Anikodu
17	Middle reaches	76.5662	10.78496	Anikodu
17	Middle reaches	76.56993	10.78168	Anikodu
18	Lower reaches	76.47538	10.74807	Thottumukk
18	Lower reaches	76.47635	10.75018	Thottumukk
18	Lower reaches	76.4801	10.75154	Thottumukk
18	Lower reaches	76.47228	10.74827	Thottumukk
19	Lower reaches	76.18258	10.79822	Pattambi
19	Lower reaches	76.18028	10.80061	Pattambi
19	Lower reaches	76.17517	10.80106	Pattambi
19	Lower reaches	76.17494	10.79809	Pattambi
20	Lower reaches	76.21756	10.77971	Arangotukara
20	Lower reaches	76.21392	10.77734	Arangotukara
20	Lower reaches	76.21143	10.7794	Arangotukara
20	Lower reaches	76.21137	10.77671	Arangotukara
21	Lower reaches	76.18907	10.78092	Thirumittakkodu

21	Lower reaches	76.18507	10.7826	Thirumittakkodu
21	Lower reaches	76.19173	10.78434	Thirumittakkodu
21	Lower reaches	76.18544	10.78597	Thirumittakkodu
22	Middle reaches	76.45931	10.66072	Padur
22	Middle reaches	76.45455	10.66146	Padur
22	Middle reaches	76.45734	10.66032	Padur
22	Middle reaches	76.46201	10.65887	Padur
23	Middle reaches	76.45042	10.67284	Pazhampalakkodu
23	Middle reaches	76.45246	10.67609	Pazhampalakkodu
23	Middle reaches	76.45038	10.68023	Pazhampalakkodu
23	Middle reaches	76.45028	10.67781	Pazhampalakkodu
24	Upper reaches	76.84216	10.85287	Walayar1
24	Upper reaches	76.84099	10.85315	Walayar1
24	Upper reaches	76.84421	10.85238	Walayar1
24	Upper reaches	76.84041	10.85429	Walayar1
25	Upper reaches	76.71726	10.79092	Narakampallipuzha
25	Upper reaches	76.71695	10.78966	Narakampallipuzha
25	Upper reaches	76.71842	10.79269	Narakampallipuzha
25	Upper reaches	76.7184	10.78915	Narakampallipuzha
26	Upper reaches	76.85	10.83867	Walayar
26	Upper reaches	76.85275	10.83617	Walayar
26	Upper reaches	76.8578	10.83773	Walayar
26	Upper reaches	76.85405	10.83808	Walayar
27	Lower reaches	76.11482	10.81257	Velliyamkallu
27	Lower reaches	76.11844	10.80707	Velliyamkallu
27	Lower reaches	76.11419	10.80734	Velliyamkallu
27	Lower reaches	76.1173	10.80958	Velliyamkallu
28	Lower reaches	76.09045	10.82563	Kudallur
28	Lower reaches	76.09017	10.82889	Kudallur
28	Lower reaches	76.09291	10.83291	Kudallur
28	Lower reaches	76.08939	10.8327	Kudallur
29	Lower reaches	76.02886	10.83531	Kuttipuram
29	Lower reaches	76.02222	10.83511	Kuttipuram
29	Lower reaches	76.02211	10.84003	Kuttipuram
29	Lower reaches	76.02502	10.84067	Kuttipuram
30	Middle reaches	76.2167	10.90852	Kattupara
30	Middle reaches	76.21238	10.91473	Kattupara
30	Middle reaches	76.21096	10.91284	Kattupara
30	Middle reaches	76.21663	10.91404	Kattupara
31	Middle reaches	76.18905	10.89903	Pulamanthol
31	Middle reaches	76.19124	10.8989	Pulamanthol
31	Middle reaches	76.18785	10.90425	Pulamanthol
31	Middle reaches	76.18821	10.90133	Pulamanthol

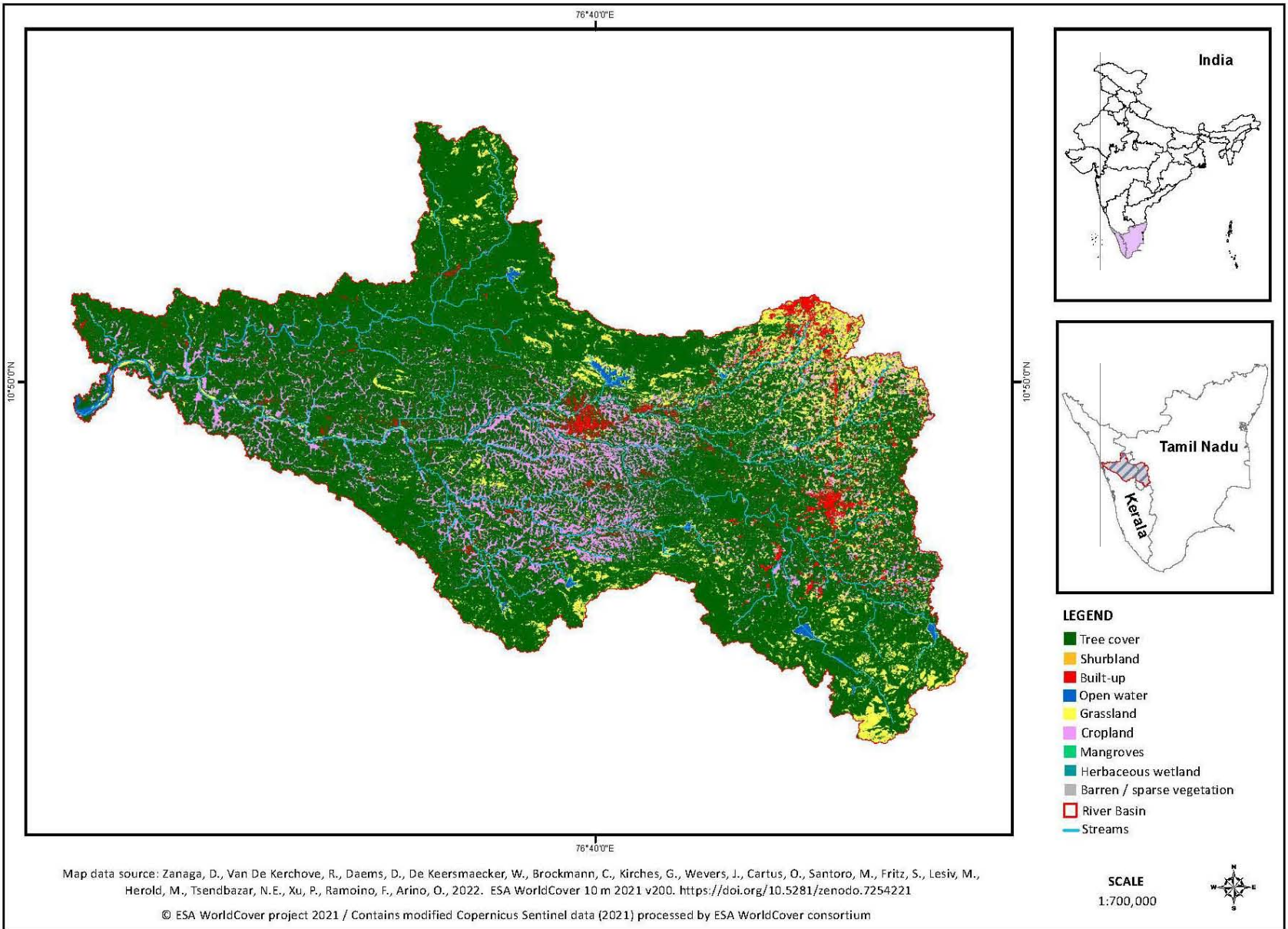
32	Middle reaches	76.66431	10.80606	Kadukamkunnam
32	Middle reaches	76.66249	10.80615	Kadukamkunnam
32	Middle reaches	76.66276	10.80446	Kadukamkunnam
32	Middle reaches	76.66079	10.8044	Kadukamkunnam
33	Middle reaches	76.57855	10.80097	Edathara
33	Middle reaches	76.57543	10.80164	Edathara
33	Middle reaches	76.57483	10.79908	Edathara
33	Middle reaches	76.57095	10.79907	Edathara
34	Middle reaches	76.58529	10.7784	Pirayiri
34	Middle reaches	76.58485	10.77698	Pirayiri
34	Middle reaches	76.58416	10.77511	Pirayiri
34	Middle reaches	76.58283	10.77329	Pirayiri
35	Middle reaches	76.64029	10.79066	Melamuri
35	Middle reaches	76.63913	10.78955	Melamuri
35	Middle reaches	76.64164	10.79185	Melamuri
35	Middle reaches	76.64194	10.79431	Melamuri
36	Middle reaches	76.65437	10.74723	Yakkara
36	Middle reaches	76.65303	10.74882	Yakkara
36	Middle reaches	76.65848	10.74909	Yakkara
36	Middle reaches	76.65968	10.74643	Yakkara
37	Upper reaches	76.65465	10.85869	Malambuzha
37	Upper reaches	76.65695	10.85908	Malambuzha
37	Upper reaches	76.65166	10.86047	Malambuzha
37	Upper reaches	76.6599	10.85613	Malambuzha
38	Upper reaches	76.6405	10.86458	Malambuzha 1
38	Upper reaches	76.63919	10.86513	Malambuzha 1
38	Upper reaches	76.63778	10.86561	Malambuzha 1
38	Upper reaches	76.63894	10.86896	Malambuzha 1
39	Upper reaches	76.65569	10.87916	Malambuzha2
39	Upper reaches	76.6579	10.88387	Malambuzha2
39	Upper reaches	76.65674	10.88049	Malambuzha2
39	Upper reaches	76.65699	10.88255	Malambuzha2
40	Middle reaches	76.71901	10.68718	Chitoor
40	Middle reaches	76.72108	10.68475	Chitoor
40	Middle reaches	76.71847	10.68883	Chitoor
40	Middle reaches	76.72038	10.68649	Chitoor
41	Upper reaches	76.57886	11.00295	Erumbakachola 1km
41	Upper reaches	76.57871	11.0001	Erumbakachola 1km
41	Upper reaches	76.57756	10.99784	Erumbakachola 1km
41	Upper reaches	76.57644	10.99592	Erumbakachola 1km
42	Upper reaches	76.56489	10.966	Palakkayam 1/2 km
42	Upper reaches	76.56544	10.96406	Palakkayam 1/2 km
42	Upper reaches	76.5623	10.96177	Palakkayam 1/2 km

42	Upper reaches	76.56546	10.96825	Palakkayam 1/2 km
43	Upper reaches	76.77357	10.57656	Chulliyar1
43	Upper reaches	76.76874	10.57861	Chulliyar1
43	Upper reaches	76.77696	10.57752	Chulliyar1
43	Upper reaches	76.77121	10.57669	Chulliyar1
44	Upper reaches	76.75084	10.57756	Chulliyar2
44	Upper reaches	76.75412	10.57914	Chulliyar2
44	Upper reaches	76.75629	10.57947	Chulliyar2
44	Upper reaches	76.75869	10.57972	Chulliyar2
45	Upper reaches	76.76257	10.58753	Chulliyar
45	Upper reaches	76.76356	10.585	Chulliyar
45	Upper reaches	76.76525	10.58329	Chulliyar
45	Upper reaches	76.76747	10.58346	Chulliyar
46	Upper reaches	76.79976	10.63908	Meenkara 1
46	Upper reaches	76.79928	10.63753	Meenkara1
46	Upper reaches	76.7993	10.63629	Meenkara1
46	Upper reaches	76.7996	10.63812	Meenkara1
47	Upper reaches	76.79655	10.64742	Meenkara2
47	Upper reaches	76.79808	10.64835	Meenkara2
47	Upper reaches	76.80026	10.6482	Meenkara2
47	Upper reaches	76.80138	10.64849	Meenkara2
48	Upper reaches	76.79702	10.62279	Meenkara
48	Upper reaches	76.79932	10.62632	Meenkara
48	Upper reaches	76.79806	10.62586	Meenkara
48	Upper reaches	76.79905	10.61856	Meenkara
49	Upper reaches	76.52891	10.51217	Mangalam
49	Upper reaches	76.53396	10.51537	Mangalam
49	Upper reaches	76.52992	10.51476	Mangalam
49	Upper reaches	76.53182	10.51495	Mangalam
50	Upper reaches	76.53104	10.48455	Mangalam 2
50	Upper reaches	76.52833	10.48419	Mangalam 2
50	Upper reaches	76.52666	10.48329	Mangalam 2
50	Upper reaches	76.52666	10.48523	Mangalam 2
51	Upper reaches	76.55072	10.4879	Mangalam 1
51	Upper reaches	76.5506	10.48947	Mangalam 1
51	Upper reaches	76.55202	10.48675	Mangalam 1
51	Upper reaches	76.55163	10.48396	Mangalam 1
52	Upper reaches	76.62559	10.54795	Pothundy
52	Upper reaches	76.62791	10.55006	Pothundy
52	Upper reaches	76.62887	10.55165	Pothundy
52	Upper reaches	76.62735	10.54878	Pothundy
53	Upper reaches	76.62073	10.53245	Pothundi 1
53	Upper reaches	76.62315	10.52981	Pothundi 1

53	Upper reaches	76.61809	10.53445	Pothundi1
53	Upper reaches	76.616	10.53632	Pothundi1
54	Upper reaches	76.62904	10.51959	Pothundi2
54	Upper reaches	76.62999	10.52278	Pothundi2
54	Upper reaches	76.63087	10.52495	Pothundi2
54	Upper reaches	76.63284	10.52108	Pothundi2
55	Lower reaches	75.9309	10.78663	Karma road
55	Lower reaches	75.92329	10.78384	Karma road
55	Lower reaches	75.92608	10.7845	Karma road
55	Lower reaches	75.92869	10.78569	Karma road
56	Lower reaches	75.95523	10.8201	Chamravattom Bridge
56	Lower reaches	75.9583	10.82007	Chamravattom Bridge
56	Lower reaches	75.95772	10.81687	Chamravattom Bridge
56	Lower reaches	75.95477	10.81788	Chamravattom Bridge
57	Lower reaches	75.9966	10.86318	Thirunavaya
57	Lower reaches	76.00099	10.86652	Thirunavaya
57	Lower reaches	75.99647	10.8674	Thirunavaya
57	Lower reaches	76.00197	10.86203	Thirunavaya
58	Upper reaches	76.6532	10.52142	Nelliyampathi
58	Upper reaches	76.65288	10.52394	Nelliyampathi
58	Upper reaches	76.65548	10.52709	Nelliyampathi
58	Upper reaches	76.65336	10.52667	Nelliyampathi
59	Middle reaches	76.56285	10.64824	Thrippalur
59	Middle reaches	76.56191	10.64876	Thrippalur
59	Middle reaches	76.56342	10.64681	Thrippalur
59	Middle reaches	76.56355	10.64551	Thrippalur
60	Middle reaches	76.48996	10.66497	Athipotta
60	Middle reaches	76.49791	10.6671	Athipotta
60	Middle reaches	76.49131	10.66385	Athipotta
60	Middle reaches	76.49475	10.66579	Athipotta
61	Upper reaches	77.15072	10.47351	Thirumurthy
61	Upper reaches	77.15283	10.47237	Thirumurthy
61	Upper reaches	77.15367	10.47043	Thirumurthy
61	Upper reaches	77.15335	10.46829	Thirumurthy
62	Upper reaches	77.1577	10.45212	Thirumoorthi1
62	Upper reaches	77.15884	10.45211	Thirumoorthi1
62	Upper reaches	77.1577	10.45273	Thirumoorthi1
62	Upper reaches	77.15948	10.45405	Thirumoorthi1
63	Middle reaches	76.11895	10.88058	Thiruvegappura
63	Middle reaches	76.1148	10.88019	Thiruvegappura
63	Middle reaches	76.11515	10.88168	Thiruvegappura
63	Middle reaches	76.118	10.88253	Thiruvegappura
64	Middle reaches	76.87404	10.66337	State boarder

64	Middle reaches	76.8752	10.67015	State boarder
64	Middle reaches	76.87138	10.66533	State boarder
64	Middle reaches	76.87339	10.66815	State boarder
65	Middle reaches	76.94782	10.64217	Ambrampalayam
65	Middle reaches	76.94697	10.63741	Ambrampalayam
65	Middle reaches	76.94595	10.64368	Ambrampalayam
65	Middle reaches	76.94746	10.63966	Ambrampalayam
66	Middle reaches	76.94067	10.57349	Anamalai
66	Middle reaches	76.93951	10.57608	Anamalai
66	Middle reaches	76.93984	10.58151	Anamalai
66	Middle reaches	76.93958	10.57813	Anamalai
67	Middle reaches	77.00415	10.55865	Palanttrangarai Bridge
67	Middle reaches	77.00225	10.55732	Palanttrangarai Bridge
67	Middle reaches	77.00717	10.56137	Palanttrangarai Bridge
67	Middle reaches	77.00991	10.56316	Palanttrangarai Bridge
68	Middle reaches	77.02658	10.54665	Manjanaikkanur Bridge
68	Middle reaches	77.02161	10.55273	Manjanaikkanur Bridge
68	Middle reaches	77.02265	10.55051	Manjanaikkanur Bridge
68	Middle reaches	77.02501	10.54855	Manjanaikkanur Bridge
69	Upper reaches	76.95734	10.47548	Aliayar
69	Upper reaches	76.95918	10.47856	Aliayar
69	Upper reaches	76.96237	10.48003	Aliayar
69	Upper reaches	76.96559	10.48202	Aliayar
70	Middle reaches	76.92484	10.65219	Athupollachi
70	Middle reaches	76.92339	10.65072	Athupollachi
70	Middle reaches	76.9225	10.64872	Athupollachi
70	Middle reaches	76.92248	10.64535	Athupollachi

Appendix 3: Land use and Land cover map of Bharathapuzha river basin (Secondary sources)



Appendix 4: Data sheet (Birds)

Season: Location name: Grid No: Count no: Date: Weather:

Observation time	Species	No	Activity	Remarks

Appendix 5: Data sheet (Environmental parameters)

Season: Location name : Grid No: Count no: Date: Weather:

Altitude (m)	Accuracy	Water channel (%)	Natural vegetation (%)	Farm land (%)	Sand banks (%)	Mud flats (%)	Rocks (%)	Artificial perches (%)	Land area (%)	Canopy cover (%)

Appendix 6: **Personal Details**

Name : Anoop Raj P N
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 E mail id : anupnarayanan1@gmail.com
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Awards and achievements : 1. Doctoral research fellowship by Kerala State Biodiversity Board in 2017-2020 (Fellowship No: 783/A1/2017/KSBB).
 2. Third Prize on oral presentation at the National Conference on Environment and Ecology at Bharathiar University, on 4th & 5th October 2023



Diversity and distribution of birds in the Bharathapuzha River Basin, Kerala, India

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Abstract: Bharathapuzha River is the second largest, west-flowing river in Kerala, Western Ghats. This river is exposed to high levels of anthropogenic and natural pressures. This study attempts to understand the diversity and distribution of birds in this river basin. The observations were made from October 2017 to July 2019 in 70*1 km² grids distributed in three strata (i.e., upper, middle, and lower reaches). A total of 262 bird species were recorded from the river basin. The diversity and richness of birds were found high in the upper reaches of the river and the species abundance was found more in the lower reaches. Due to the high turnover of migratory species, the rank abundance model for upper and lower reaches showed a high degree of dominance while middle reaches showed a relatively even distribution of abundances. Deforestation, sand mining, and water pollution were found to be the major threats in the river basin. Hence the results show the importance of the protection and rejuvenation of the ecosystems associated with the river for the conservation of avian diversity in the region.

Keywords: Bird community, ecological indicators, ecological zones, migrant birds, Nila river, rank abundance models, resident birds, riverine biodiversity, riverine birds, Western Ghats.

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Author contributions: ARPN—study design, field surveys, data analysis and preparation of manuscript, PP—study design, review, preparation of manuscript, ADV—data analysis, preparation of manuscript.

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INTRODUCTION

Rivers are considered an important ecological entity that supports rich biodiversity. The water flow, geography, interaction between the terrestrial and aquatic ecosystems, and the dynamic nature make the rivers one of Earth's most complex biophysical systems (Naiman et al. 1993). Though the rivers harbour rich biodiversity, they are also prone to many natural and anthropogenic challenges. Therefore, understanding the biological communities of the river system is essential for its management and conservation prioritization. The diverse habitats on the river corridors support many birds (Stevens et al. 1977; Stauffer & Best 1980; Knopf 1985). Since birds are considered as ecological indicators, habitat quality can be assessed through long-term avifauna monitoring. Understanding the bird communities and habitat association of different species (including migratory species) in different seasons is important for planning conservation strategies (Rice et al. 1980; Naiman et al. 1993; Gergel et al. 2002).

Kerala is one of the important places for avian research. The high level of habitat heterogeneity and its mosaic nature supports a wide range of birds (Neelakantan 1969, 1970, 1981, 1982; Neelakantan & Sureshkumar 1980; Neelakantan et al. 1980; Ali & Ripley 1983; Pramod 1995). The wetlands in Kerala enhance avian diversity by hosting migratory birds, hence many of the larger wetlands in Kerala were announced as Ramsar sites (Jayson 2002; Nameer 2005)

Bharathapuzha River (10.416–11.25 N and 75.833–76.916 E) in Kerala is known for its cultural and ecological significance. This river is considered as the cradle of civilization in Kerala. The major portion of the Bharathapuzha River flows through a human-dominated and agricultural landscape. The diverse habitat in the fluvial channel of the river supports great bird diversity. Many researchers have attempted to document the bird diversity in the river basin (Namassivayam & Venugopal 1989; Namassivayam et al. 1989; Kurup 1991; Uthaman & Namassivayam 1991; Neelakantan et al. 1993; Pramod 1995; Kurup 1996; Bijukumar 2006; Arif et al. 2010). However, the information available about the bird diversity of this river basin is sporadic.

In this investigation, we considered the river basin as a single ecological entity. We employed a ridge-to-reef approach to document the bird diversity from headwaters, main tributaries, mainstream and estuary. This study aims to establish baseline information about the avifauna of the Bharathapuzha River Basin and as a potential survey design for other river basins.

MATERIALS AND METHOD

Study area

The river Bharathapuzha originates from the southern part of the Palakkad Gap, in the Anamalai hills in the state of Tamil Nadu. It flows through the Palakkad gap covering Pollachi in Tamil Nadu; Palakkad, Thrissur, and Malappuram districts in Kerala and debouches into the Arabian Sea at Ponnani on the Malabar coast. The total length of the river is 250 km, of which 209 km flows through Kerala and 41 km through Tamil Nadu (Figure 1). The total extent of the river drainage basin is 6,186 km² between an elevation gradient of 2,461–0 m with an annual discharge of 3.94 km³ water. The study divided the river drainage basin into three different ecological zones based on the stream orders as per Strahler (1957). Streams of order one to three were denoted as upper reaches (Image 1), order four to five as middle reaches (Image 2) and sixth-order streams were denoted as lower reaches (Image 3) (Abel et al. 2008).

The major tributaries of the river are Chitrapuzha, Gayathripuzha, Kunthipuzha, and Kalpathipuzha. All these tributaries originate from the northern and southern tips of the Palakkad Gap, which are the permanent and important water sources for the river. There are 11 dams constructed on this river for drinking water supply and irrigation to serve millions of people in the region.

Study design

The hydrology layer for the river basin was extracted using ASTER GDEM V2 and stream orders were established using the Strahler (1957) method. Field surveys were conducted along 453 km stretches at these ecological zones (Figure 1). These stretches were divided into 70 grid cells of 1 X 1 km. These selected locations were sampled from October 2017 to July 2019 in three replications which include two migratory (November–March) and one non-migratory season (April–October). In each cell bird observations were made for a 15 min period using point count with the fixed-width method (Reynolds et al. 1980). A total of 840 point counts were conducted in the sampling area. Over-flying birds, bird detections >50 m, and uncertain bird identifications were truncated from the data to improve the robustness of the study. Direct and indirect signs of birds were observed at 0600–1100 h and 1530–1900 h in each location. Direct observations were made using binoculars and spotting scopes. Bird identification was done using field guides (Ali & Ripley 1983; Ali 1999; Grimmett et al. 1999; Kazmierczak 2000) and photographs. The bird checklist was prepared using Praveen et al. (2020).

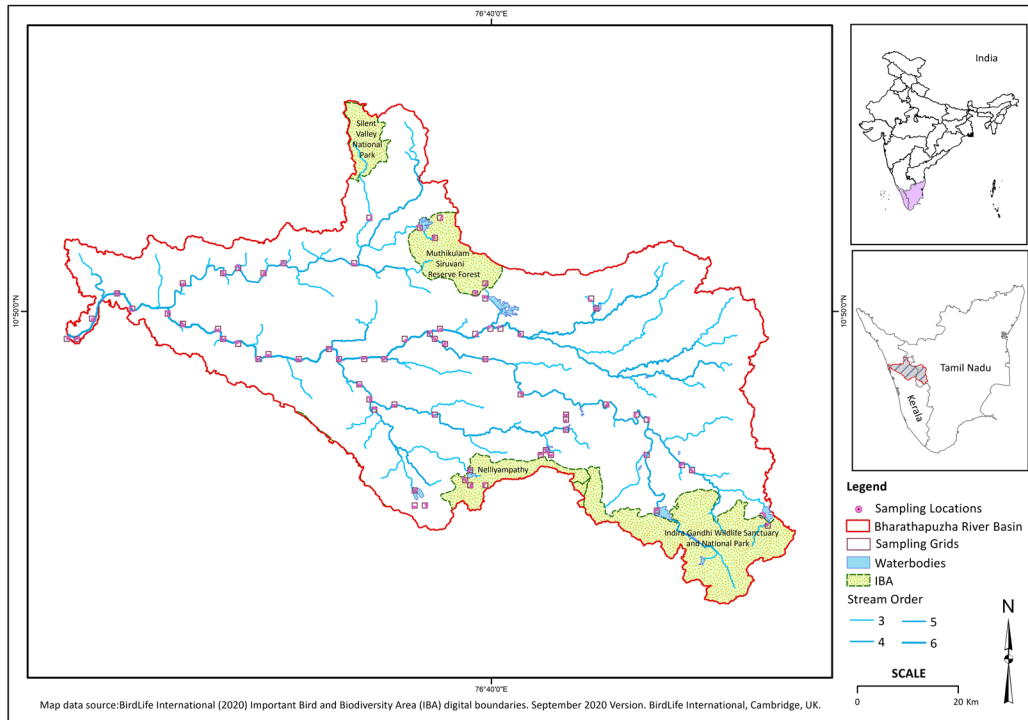


Figure 1. Location map of Bharathapuzha River Basin showing streams and sampling locations.



Image 1. Habitat in the upper reaches of Bharathapuzha River Basin. © P.N. Anoop Raj.



Image 2. Habitat in the middle reaches of Bharathapuzha River Basin. © P.N. Anoop Raj.

Opportunistic bird observations, i.e., the birds observed in the study areas after the predesigned observation period were recorded as ad libitum. The time of observation, date and number of individuals sighted, and habitat were noted.

Data analysis: Bird abundance data was arranged in the species vs sites contingency table. Absolute species richness for each region was tabulated. To check sampling adequacy, species richness was also estimated using Chao 1TM index. To compare diversity, dominance and evenness Shannon-Weiner (H') and Simpson index were estimated

(Magurran 1988). Relative abundance for all species was calculated in each ecological zone (Sutherland et al. 2004) using the formula.

$$RA_i = \left(\frac{N_i}{P} \right) \times 100$$

Where RA = relative abundance of species i , N_i = Abundance of species i in ecological zone, P = Population of all species in river basin.

Relative abundance was calculated with the whole population of birds in the river basin to make it comparable



Image 3. Habitat in the lower reaches of Bharathapuzha River Basin.
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between ecological zones. The relative frequency of occurrence (RF) of birds in grids was used to understand the commonality/rarity of birds in each ecological zone. Hence the birds with RF more than 50% are considered as common, 20% to 50% as less common and >20% as rare.

To understand the migratory species of birds, bird species observed were classified into three categories such as resident, local migrant or long-distance migrant (SolB 2023). To assess species distribution patterns, rank abundance distribution patterns were examined. All statistical analyses were performed using R statistical language V4.3.0 with R Studio IDE for R V2023.03.01. Diversity indices and rank abundance distributions were estimated using 'vegan': Community Ecology Package 2.6-4 (Oksanen et al. 2013).

RESULTS

Diversity

The bird observations were conducted from October 2017 to July 2019. A total of 262 species of birds were recorded belonging to 20 orders and 71 families (Table 1). Out of 262 bird species recorded in the study area 235 species of birds were recorded while employing the bird survey method; 27 bird species were observed in the opportunistic observations. Ecological zone-wise sampling efforts, bird species observed and the number of individual birds sighted are shown in Table 2. A total of 36,811 individuals were recorded from the river basin in migratory ($n = 27,242$) and non-migratory ($n = 9,569$) seasons during the survey. Passeriformes were the most dominant group in the river basin (42%) followed by Charadriiformes (13%), Falconiformes (8%),

and Ciconiformes (6%). Passerine birds were the most dominant group ($N = 146$) followed by waders ($N = 33$), raptors ($N = 20$), and shorebirds ($N = 19$). Absolute species richness and estimated species richness using Chao-1 was similar (Table 3) indicating sampling was adequate. While the Shannon-Weiner index (H') shows higher species diversity in upper reaches (Table 3) than in middle and lower reaches. However, Simpsons' index for evenness and dominance was found to be similar across all ecological zones.

Bird species occurrence in different ecological zones

Rare birds were more compared to common and less common birds in all ecological zones. The upper reaches of the river basin reported 45 species of resident, two species of local migrants and four species of long-distance migrant birds as common, while 91 residents, 10 local migrants and eight long-distance migrants were rare. In the middle reaches, 43 residents, two species of local migrants and one species of long-distance migrant birds were common. 58 residents, six local migrants and three long-distance migrants were rare. In lower reaches, 48 residents, two local migrants and five migrant species were common and 48 residents, two local migrants and 10 migrant species were rare (Table 4).

Zipf-Mandlebrot distribution was found to be the best-fit model for upper reaches (deviance = 401.60) and lower reaches (deviance = 465.40). However, bird species in the middle reaches followed a log-normal abundance distribution (deviance = 615.83) (Table 5). Lower reaches had a steeper distribution than upper reaches and middle reaches indicating a high species turnover rate. While upper and lower reaches show shallow slopes, Middle reaches have more even abundances with species ranked with log-normal distribution.

DISCUSSION

Being a human-dominated landscape, some synanthropic birds such as the Common Myna *Acridotheres tristis*, House Crow *Corvus splendens*, and Black Drongo *Dicrurus macrocercus*, were dominant in the three ecological zones of the river basin region. However, Purple-rumped Sunbird *Leptocoma zeylonica*, Red-vented Bulbul *Pycnonotus cafer*, Common Tailorbird *Orthotomus sutorius*, Asian Palm Swift *Cypsiurus balasiensis*, Yellow-billed Babbler *Turdoides affinis*, and White-cheeked Barbet *Psilopogon viridis* were the other common resident birds in the river basin. The wetland associated birds such as Cattle Egret *Bubulcus ibis*, Little Cormorant

Microcarbo niger, Indian Pond Heron *Ardeola grayii*, and White-throated Kingfisher *Halcyon smyrnensis* were also found commonly in the river basin. Most of these birds are generalist feeders and adapt themselves to survive in any condition. Black-bellied Tern *Sterna acuticauda*, Dark-fronted Babbler *Rhopocichla atriceps*, Asian Emerald Dove *Chalcophaps indica*, Indian Spotted Eagle *Clanga hastata*, Cinnamon Bittern *Ixobrychus cinnamomeus*, Striated Heron *Butorides striata*, Yellow Bittern *Ixobrychus sinensis*, Spot-billed Pelican *Pelecanus philippensis*, and Pheasant-tailed Jacana *Hydrophasianus chirurgus* found as rare resident birds in the river basin in which a few of these birds were specific to ecological zones.

Greenish Warbler *Phylloscopus trochiloides*, Grey Wagtail *Motacilla cinerea*, and Barn Swallow *Hirundo rustica* were found to be the common local migrant birds in the river basin. Chestnut-tailed Starling *Sturnia malabarica*, Bar-headed Goose *Anser indicus*, and Gull-billed Tern *Gelochelidon nilotica* were the rare local migrant birds.

Blyth's Reed Warbler *Acrocephalus dumetorum*, Common Sandpiper *Actitis hypoleucos*, and Booted Eagle *Hieraetus pennatus* were the common long-distance migrants. Booted Warbler *Iduna caligata*, Eurasian Curlew *Numenius arquata*, Whimbrel *Numenius phaeopus*, and Amur Falcon *Falco amurensis* were the rare long-distance migrants.

Malayan Night-heron *Gorsachius melanolophus*, Chestnut-winged Cuckoo *Clamator coromandus*, Black-bellied Tern *Sterna acuticauda*, and Indian Spotted Eagle *Clanga hastata* were some of the important sightings during the study period. The maximum flock size is seen in Little Cormorants with <300 individuals in a single location at Walayar dam. Gull species such as Black-headed Gull *Chroicocephalus ridibundus* and Pallas's Gull *Ichthyaetus ichthyaetus* congregated highly in the estuarine region. Totally, 2,200 individual birds were encountered in a single grid at Ponnani.

The study identified 60 species that are specific to the upper reaches, four to middle reaches and 16 to the lower reaches. 119 birds were common to all regions (Figure 2). Out of these, 17 birds were endemic to Western Ghats including one 'Endangered', seven 'Near Threatened', and four 'Vulnerable' birds as per the IUCN Red List of Threatened Species. This indicates that productive and heterogeneous habitats of the Bharathapuzha River Basin support birds from different niches and foraging guilds from forest to wetland-dependent birds as well as synanthropic species.

Upper reaches show higher species richness than middle and lower reaches because of the presence of

primary forests, human habitations, and dams. Hence this region supports different foraging and feeding guilds (Ali & Ripley 1983; Wiens 1989). Also, the presence of dams in the upper reaches and the presence of estuary and check dams in the lower reaches enables to host a large number of migratory birds such as Little-ringed Plover *Charadrius dubius*, Marsh Sandpiper *Tringa stagnatilis* and Barn Swallows *Hirundo rustica*. However, due to the lesser availability of the wintering grounds in the middle reaches, fewer migratory birds were observed.

Ziph-Mandlebrot distribution of rank abundances in upper reaches and lower reaches has steep concave slope indicating that few species occur in high abundances (Figure 3). Species with high abundance ranks in these regions are migratory species like Black-headed Gull *Chroicocephalus ridibundus* and Pallas's Gull *Ichthyaetus ichthyaetus* with flock sizes of <5,000 individuals which dwarf the abundances of resident species. However, in the middle reaches, flock sizes of migratory birds are smaller which shows a more even distribution of rank abundances.

Status of migratory birds in the Bharathapuzha River

Purathur in the Bharathapuzha River basin was identified as one of the major stop-over sites for many migratory birds (Kurup 1991; Kumar 2001). Large flocks of Black-headed Gull, Pallas's Gull, & Brown-headed Gull (<5,000), Whiskered Tern (<100), and resident egrets such as Cattle Egret and Little Egret (<100) were recorded from the Purathur region during the study period. Smaller migratory bird flocks of Little-ringed Plover and Common Sandpipers were reported from the dams and several other parts of the main course. Solitary and passage migrant birds such as the Amur Falcon were reported from the headwater region. There were consecutive sightings of these passage migrants in the river basin from 2017 (Malampuzha Dam), 2018 (Thirunavaya), and 2019 (Malampuzha Dam). This indicates the importance of the river Bharathapuzha and associated habitats for the conservation of migratory and resident birds.

Major Threats

During the study period, natural vegetation near the sampling locations in upper reaches was cleared for expansion of agriculture especially for cash crops like rubber, teak, coffee and coconut. Such deforestation activities for the construction of dams, human settlements and infrastructure development were also reported in various studies (Nossiter 1982; Eapen 1999; Kumar 2005; John et al. 2019).

Bharathapuzha River is one of the most affected river systems due to the predominant sand mining. Legal and

Table 1. Relative abundances and relative frequency of occurrence of bird species in different ecological zones in Bharathapuzha River Basin.

	Species	Upper reaches	Middle reaches	Lower reaches
I	Anseriformes: Anatidae			
1	Bar-headed Goose <i>Anser indicus</i> † _{LC}	0.01 (4) [⊕]	0.00 (0)	0.00 (0)
2	Common Teal <i>Anas crecca</i> † _{LC}			*
3	Cotton Teal <i>Nettapus coromandelianus</i> _{LC}			*
4	Indian Spot-billed Duck <i>Anas poecilorhyncha</i> _{LC}	0.24 (16) [⊕]	0.01 (4) [⊕]	0.01 (17) [⊕]
5	Lesser Whistling Duck <i>Dendrocygna javanica</i> _{LC}	0.33 (20) [⊕]	0.01 (4) [⊕]	0.39 (28) [⊗]
II	Galliformes: Phasianidae			
6	Indian Peafowl <i>Pavo cristatus</i> _{LC}	0.22 (72) [●]	0.21 (70) [●]	0.08 (50) [●]
7	Red Spurfowl <i>Galloperdix spadicea</i> _{LC}	0.01 (8) [⊕]	0.02 (11) [⊕]	0.00 (6) [⊕]
8	Jungle Bush Quail <i>Perdica asiatica</i> _{LC}	0.01 (4) [⊕]	0.00 (0)	0.00 (0)
9	Grey Francolin <i>Francolinus pondicerianus</i> _{LC}	0.02 (20) [⊕]	0.00 (0)	0.00 (0)
10	Grey Junglefowl <i>Gallus sonneratii</i> _{LC}	0.03 (24) [⊗]	0.00 (0)	0.00 (0)
III	Podicipediformes: Podicipedidae			
11	Little Grebe <i>Tachybaptus ruficollis</i> _{LC}	0.01 (12) [⊕]	0.00 (0)	0.01 (6) [⊕]
IV	Columbiformes: Columbidae			
12	Rock Pigeon <i>Columba livia</i> _{LC}	0.12 (44) [⊗]	0.94 (93) [●]	0.94 (89) [●]
13	Nilgiri Wood Pigeon <i>Columba elphinstonii</i> _{VU}	0.01 (4) [⊕]	0.00 (0)	0.00 (0)
14	Spotted Dove <i>Streptopelia chinensis</i> _{LC}	0.39 (96) [●]	0.50 (78) [●]	0.21 (72) [●]
15	Laughing Dove <i>Streptopelia senegalensis</i> _{LC}	0.02 (16) [⊕]	0.01 (4) [⊕]	0.01 (6) [⊕]
16	Asian Emerald Dove <i>Chalcophaps indica</i> _{LC}	0.01 (8) [⊕]	0.00 (4) [⊕]	0.00 (0)
17	Grey-fronted Green Pigeon <i>Treron affinis</i> _{LC}	0.01 (4) [⊕]	0.00 (0)	0.00 (0)
18	Yellow-footed Green Pigeon <i>Treron phoenicopterus</i> _{LC}	0.01 (4) [⊕]	0.00 (4) [⊕]	0.04 (11) [⊕]
19	Green Imperial Pigeon <i>Ducula aenea</i> _{LC}	0.02 (16) [⊕]	0.03 (15) [⊕]	0.00 (6) [⊕]
V	Cuculiformes: Cuculidae			
20	Greater Coucal <i>Centropus sinensis</i> _{LC}	0.07 (52) [●]	0.08 (63) [●]	0.07 (61) [●]
21	Blue-faced Malkoha <i>Phaenicophaeus viridirostris</i> _{LC}	0.01 (20) [⊕]	0.00 (0)	0.00 (0)
22	Chestnut-winged Cuckoo <i>Clamator coromandus</i> † _{LC}	*		
23	Pied Cuckoo <i>Clamator jacobinus</i> _{LC}	0.00 (0)	0.01 (7) [⊕]	>0.01 (6) [⊕]
24	Asian Koel <i>Eudynamis scolopaceus</i> _{LC}	0.15 (76) [●]	0.14 (81) [●]	0.07 (61) [●]
25	Banded Bay Cuckoo <i>Cacomantis sonneratii</i> _{LC}	0.00 (4) [⊕]	0.00 (0)	0.00 (0)
26	Grey-bellied Cuckoo <i>Cacomantis passerinus</i> _{LC}	0.00 (4) [⊕]	0.00 (0)	>0.01 (6) [⊕]
27	Fork-tailed Drongo Cuckoo <i>Surniculus dicruroides</i> _{LC}	>0.01 (4) [⊕]	0.00 (0)	0.00 (0)
28	Common Hawk Cuckoo <i>Hierococcyx varius</i> _{LC}	0.02 (28) [⊗]	0.01 (19) [⊕]	0.02 (39) [⊗]
29	Indian Cuckoo <i>Cuculus micropterus</i> † _{LC}	0.03 (24) [⊗]	0.01 (15) [⊕]	0.01 (17) [⊕]
VI	Caprimulgiformes: Caprimulgidae			
30	Jerdon's Nightjar <i>Caprimulgus atripennis</i> _{LC}	0.01 (4) [⊕]	0.00 (0)	0.00 (0)
31	Indian Nightjar <i>Caprimulgus asiaticus</i> _{LC}	0.00 (0)	>0.01 (4) [⊕]	0.00 (0)
32	Savanna Nightjar <i>Caprimulgus affinis</i> _{LC}	0.00 (4) [⊕]	0.00 (0)	0.00 (0)
	Caprimulgiformes: Apodidae			
33	Indian Swiftlet <i>Aerodramus unicolor</i> _{LC}	0.10 (20) [⊕]	0.25 (44) [⊗]	0.34 (33) [⊗]
34	Alpine Swift <i>Tachymarptis melba</i> _{LC}	>0.01 (4) [⊕]	0.00 (0)	0.01 (11) [⊕]
35	Indian House Swift <i>Apus affinis</i> _{LC}	0.12 (16) [⊕]	0.23 (11) [⊕]	0.08 (28) [⊗]
36	Asian Palm Swift <i>Cypsiurus balasensis</i> _{LC}	1.66 (76) [●]	3.23 (96) [●]	2.39 (78) [●]
	Caprimulgiformes: Hemiprocnidae			
37	Crested Treeswift <i>Hemiproctus coronata</i> _{LC}	0.01 (4) [⊕]	0.00 (0)	0.00 (0)
VII	Gruiformes: Rallidae			
38	Common Coot <i>Fulica atra</i> _{LC}	0.05 (4) [⊕]	0.00 (4) [⊕]	0.00 (0)

	Species	Upper reaches	Middle reaches	Lower reaches
39	Grey-headed Swamphen <i>Porphyrio poliocephalus</i> _{LC}	0.00 (0)	0.02 (15) [⊗]	0.34 (17) [⊗]
40	White-breasted Waterhen <i>Amaurornis phoenicurus</i> _{LC}	0.05 (32) [⊗]	0.20 (78) ●	0.04 (50) ●
VIII	Charadriiformes: Recurvirostridae			
41	Black-winged Stilt <i>Himantopus himantopus</i> _{LC}	0.01 (4) [⊗]	0.00 (0)	0.01 (6) [⊗]
	Charadriiformes: Charadriidae			
42	Pacific Golden Plover <i>Pluvialis fulva</i> † _{LC}	0.00 (0)	0.00 (0)	0.02 (11) [⊗]
43	Red-wattled Lapwing <i>Vanellus indicus</i> _{LC}	0.26 (56) ●	0.27 (63) ●	0.43 (83) ●
44	Kentish Plover <i>Charadrius alexandrinus</i> _{LC}	0.00 (0)	0.00 (0)	0.04 (6) [⊗]
45	Common Ringed Plover <i>Charadrius hiaticula</i> † _{LC}			*
46	Little Ringed Plover <i>Charadrius dubius</i> _{LC}	0.33 (32) [⊗]	>0.01 (4) [⊗]	0.10 (44) [⊗]
	Charadriiformes: Rostratulidae			
47	Greater Painted-snipe <i>Rostratula benghalensis</i> _{LC}	>0.01 (4) [⊗]	0.00 (0)	0.01 (17) [⊗]
	Charadriiformes: Jacanidae			
48	Pheasant-tailed Jacana <i>Hydrophasianus chirurgus</i> _{LC}	0.00 (0)	0.00 (0)	0.01 (6) [⊗]
49	Bronze-winged Jacana <i>Metopidius indicus</i> _{LC}	0.00 (0)	0.15 (44) [⊗]	0.10 (33) [⊗]
	Charadriiformes: Scolopacidae			
50	Whimbrel <i>Numenius phaeopus</i> † _{LC}	0.00 (0)	0.00 (0)	0.01 (6) [⊗]
51	Eurasian Curlew <i>Numenius arquata</i> † _{NT}	0.00 (0)	0.00 (0)	0.01 (6) [⊗]
52	Ruddy Turnstone <i>Arenaria interpres</i> † _{LC}			*
53	Curlew Sandpiper <i>Calidris ferruginea</i> † _{NT}			*
54	Temminck's Stint <i>Calidris temminckii</i> † _{LC}			*
55	Little Stint <i>Calidris minuta</i> † _{LC}	0.00 (0)	0.00 (0)	0.04 (11) [⊗]
56	Common Snipe <i>Gallinago gallinago</i> † _{LC}	0.00 (4) [⊗]	0.00 (0)	0.00 (0)
57	Terek Sandpiper <i>Xenus cinereus</i> † _{LC}	0.00 (0)	0.00 (0)	0.01 (6) [⊗]
58	Common Sandpiper <i>Actitis hypoleucos</i> † _{LC}	0.28 (48) [⊗]	0.11 (44) [⊗]	0.37 (94) ●
59	Green Sandpiper <i>Tringa ochropus</i> † _{LC}	0.04 (20) [⊗]	0.05 (33) [⊗]	0.13 (67) ●
60	Common Greenshank <i>Tringa nebularia</i> † _{LC}	0.02 (8) [⊗]	>0.01 (4) [⊗]	0.04 (11) [⊗]
61	Marsh Sandpiper <i>Tringa stagnatilis</i> † _{LC}	0.09 (20) [⊗]	0.01 (4) [⊗]	0.19 (67) ●
62	Wood Sandpiper <i>Tringa glareola</i> † _{LC}	0.08 (12) [⊗]	0.00 (4) [⊗]	0.08 (33) [⊗]
63	Common Redshank <i>Tringa totanus</i> † _{LC}	0.00 (0)	0.01 (4) [⊗]	0.03 (11) [⊗]
	Charadriiformes: Glareolidae			
64	Small Pratincole <i>Glareola lactea</i> _{LC}	0.03 (4) [⊗]	0.00 (0)	0.00 (0)
	Charadriiformes: Laridae			
65	Black-headed Gull <i>Chroicocephalus ridibundus</i> † _{LC}	0.00 (0)	0.00 (0)	1.39 (28) [⊗]
66	Brown-headed Gull <i>Chroicocephalus brunnicephalus</i> † _{LC}	0.00 (0)	0.00 (0)	1.62 (33) [⊗]
67	Pallas's Gull <i>Ichthyaetus ichthyaetus</i> † _{LC}	0.00 (0)	0.00 (0)	1.31 (22) [⊗]
68	Lesser Black-backed Gull <i>Larus fuscus</i> † _{LC}	0.00 (0)	0.00 (0)	0.52 (17) [⊗]
69	Little Tern <i>Sternula albifrons</i> _{LC}	0.02 (4) [⊗]	0.05 (15) [⊗]	0.00 (0)
70	Gull-billed Tern <i>Gelochelidon nilotica</i> † _{LC}	0.00 (0)	0.00 (0)	0.05 (6) [⊗]
71	Caspian Tern <i>Hydroprogne caspia</i> _{LC}			*
72	Whiskered Tern <i>Chlidonias hybrida</i> _{LC}	0.26 (20) [⊗]	0.05 (19) [⊗]	0.39 (44) [⊗]
73	Black-bellied Tern <i>Sterna acuticauda</i> _{EN}	0.00 (4) [⊗]	0.00 (0)	0.00 (0)
74	River Tern <i>Sterna aurantia</i> _{NT}	0.15 (28) [⊗]	0.07 (30) [⊗]	0.25 (61) ●
IX	Ciconiiformes: Ciconiidae			
75	Asian Openbill <i>Anastomus oscitans</i> _{LC}	0.40 (52) ●	0.24 (63) ●	0.81 (94) ●
76	Woolly-necked Stork <i>Ciconia episcopus</i> _{VU}	0.20 (20) [⊗]	0.05 (15) [⊗]	0.17 (50) ●
77	Painted Stork <i>Mycteria leucocephala</i> _{NT}	0.11 (8) [⊗]	0.00 (0)	0.00 (0)
X	Suliformes: Anhingidae			

	Species	Upper reaches	Middle reaches	Lower reaches
78	Oriental Darter (<i>Anhinga melanogaster</i>) _{NT}	0.04 (16) [⊕]	0.05 (41) [⊗]	0.08 (56) [●]
	Suliformes: Phalacrocoracidae			
79	Little Cormorant <i>Microcarbo niger</i> _{LC}	1.82 (52) [●]	0.88 (93) [●]	2.66 (100) [●]
80	Great Cormorant <i>Phalacrocorax carbo</i> _{LC}	0.04 (8) [⊕]	0.00 (0)	0.01 (17) [⊕]
81	Indian Cormorant <i>Phalacrocorax fuscicollis</i> _{LC}	0.06 (28) [⊗]	0.02 (19) [⊕]	0.03 (28) [⊗]
XI	Pelecaniformes: Pelecanidae			
82	Spot-billed Pelican <i>Pelecanus philippensis</i> _{NT}	>0.01 (4) [⊕]	0.00 (0)	0.00 (0)
	Pelecaniformes: Ardeidae			
83	Yellow Bittern <i>Ixobrychus sinensis</i> _{LC}	>0.01 (4) [⊕]	>0.01 (4) [⊕]	0.01 (6) [⊕]
84	Cinnamon Bittern <i>Ixobrychus cinnamomeus</i> _{LC}	0.01 (4) [⊕]	0.00 (0)	0.00 (0)
85	Black Bittern <i>Ixobrychus flavicollis</i> _{LC}	*		
86	Grey Heron <i>Ardea cinerea</i> _{LC}	0.05 (24) [⊗]	0.02 (30) [⊗]	0.08 (78) [●]
87	Purple Heron <i>Ardea purpurea</i> _{LC}	0.04 (20) [⊕]	0.07 (56) [●]	0.10 (67) [●]
88	Great Egret <i>Ardea alba</i> _{LC}	0.03 (20) [⊕]	0.03 (19) [⊕]	0.17 (61) [●]
89	Intermediate Egret <i>Ardea intermedia</i> _{LC}	0.09 (36) [⊗]	0.11 (59) [●]	0.52 (94) [●]
90	Little Egret <i>Egretta garzetta</i> _{LC}	0.35 (60) [●]	0.43 (85) [●]	1.12 (100) [●]
91	Western Reef Egret <i>Egretta gularis</i> _{LC}	0.00 (0)	0.00 (0)	0.05 (17) [⊕]
92	Cattle Egret <i>Bubulcus ibis</i> _{LC}	1.10 (84) [●]	0.93 (100) [●]	1.99 (100) [●]
93	Indian Pond Heron <i>Ardeola grayii</i> _{LC}	0.42 (88) [●]	0.76 (100) [●]	0.67 (100) [●]
94	Striated Heron <i>Butorides striata</i> _{LC}	>0.01 (4) [⊕]	0.01 (4) [⊕]	0.00 (0)
95	Black-crowned Night Heron <i>Nycticorax nycticorax</i> _{LC}	0.01 (12) [⊕]	0.02 (15) [⊕]	0.04 (28) [⊗]
96	Malayan Night Heron <i>Gorsachius melanolophus</i> _{LC}	*		
	Pelecaniformes: Threskiornithidae			
97	Glossy Ibis <i>Plegadis falcinellus</i> _{LC}	0.01 (4) [⊕]	0.00 (0)	0.04 (6) [⊕]
98	Black-headed Ibis <i>Threskiornis melanocephalus</i> _{NT}	0.52 (44) [⊗]	0.04 (22) [⊗]	0.36 (56) [●]
XII	Accipitriformes: Pandionidae			
99	Osprey <i>Pandion haliaetus</i> _{LC} [†]	0.01 (8) [⊕]	0.00 (0)	0.00 (0)
	Accipitriformes: Accipitridae			
100	Black-winged Kite <i>Elanus caeruleus</i> _{LC}	0.01 (8) [⊕]	0.00 (0)	0.01 (11) [⊕]
101	Oriental Honey Buzzard <i>Pernis ptilorhynchus</i> _{LC}	0.03 (36) [⊗]	0.02 (19) [⊕]	0.01 (17) [⊕]
102	Crested Serpent Eagle <i>Spilornis cheela</i> _{LC}	0.09 (56) [●]	0.08 (59) [●]	0.06 (61) [●]
103	Changeable Hawk Eagle <i>Nisaetus cirrhatus</i> _{LC}	0.01 (8) [⊕]	0.00 (0)	0.00 (0)
104	Legge's Hawk Eagle <i>Nisaetus kelaarti</i> _{NE}	0.00 (4) [⊕]	0.00 (0)	0.00 (0)
105	Black Eagle <i>Ictinaetus malaiensis</i> _{LC}	0.02 (16) [⊕]	0.00 (4) [⊕]	0.01 (11) [⊕]
106	Indian Spotted Eagle <i>Clanga hastata</i> _{VU}	0.00 (0)	0.00 (0)	0.00 (6) [⊕]
107	Booted Eagle <i>Hieraetus pennatus</i> _{LC} [†]	0.01 (16) [⊕]	0.02 (22) [⊗]	0.06 (61) [●]
108	White-eyed Buzzard <i>Butastur teesa</i> _{LC}	0.00 (4) [⊕]	0.00 (0)	0.00 (0)
109	Western Marsh Harrier <i>Circus aeruginosus</i> _{LC} [†]			*
110	Crested Goshawk <i>Accipiter trivirgatus</i> _{LC}	*		
111	Shikra <i>Accipiter badius</i> _{LC}	0.05 (56) [●]	0.02 (19) [⊕]	0.02 (39) [⊗]
112	Black Kite <i>Milvus migrans</i> _{LC}	0.12 (36) [⊗]	0.15 (52) [●]	1.15 (83) [●]
113	Brahminy Kite <i>Haliastur indus</i> _{LC}	0.35 (80) [●]	0.59 (96) [●]	1.73 (100) [●]
114	Grey-headed Fish Eagle <i>Haliaeetus ichthyaetus</i> _{NT}	*		
XIII	Strigiformes: Tytonidae			
115	Common Barn Owl <i>Tyto alba</i> _{LC}		*	*
	Strigiformes: Strigidae			
116	Oriental Scops Owl <i>Otus sunia</i> _{LC}	0.01 (4) [⊕]	0.00 (0)	0.00 (0)
117	Brown Fish Owl <i>Ketupa zeylonensis</i> _{LC}	0.01 (8) [⊕]	0.00 (0)	0.00 (0)

	Species	Upper reaches	Middle reaches	Lower reaches
118	Jungle Owlet <i>Glaucidium radiatum</i> _{LC}	0.01 (12) [⊗]	0.00 (0)	0.00 (0)
119	Spotted Owlet <i>Athene brama</i> _{LC}	0.04 (24) [⊗]	0.01 (11) [⊗]	0.01 (11) [⊗]
120	Mottled Wood Owl <i>Strix ocellata</i> _{LC}	0.00 (4) [⊗]	0.00 (0)	0.00 (0)
XIV	Trogoniformes: Trogonidae			
121	Malabar Trogon <i>Harpactes fasciatus</i> _{LC}	0.02 (16) [⊗]	0.00 (0)	0.00 (0)
XV	Bucerotiformes: Upupidae			
122	Common Hoopoe <i>Upupa epops</i> _{LC}	>0.01 (4) [⊗]	0.00 (0)	0.00 (0)
	Bucerotiformes: Bucerotidae			
123	Great Hornbill <i>Buceros bicornis</i> _{VU}	0.01 (4) [⊗]	0.00 (0)	0.00 (0)
124	Malabar Grey Hornbill <i>Ocyrceros griseus</i> _{LC}	0.04 (28) [⊗]	0.02 (11) [⊗]	0.01 (17) [⊗]
XVI	Coraciiformes: Alcedinidae			
125	Common Kingfisher <i>Alcedo atthis</i> _{LC}	0.09 (68) ●	0.14 (81) ●	0.08 (72) ●
126	Stork-billed Kingfisher <i>Pelargopsis capensis</i> _{LC}	0.02 (24) [⊗]	0.07 (59) ●	0.03 (39) [⊗]
127	White-throated Kingfisher <i>Halcyon smyrnensis</i> _{LC}	0.35 (92) ●	0.57 (100) ●	0.32 (100) ●
128	Pied Kingfisher <i>Ceryle rudis</i> _{LC}	0.04 (20) [⊗]	0.11 (52) ●	0.11 (72) ●
	Coraciiformes: Meropidae			
129	Blue-bearded Bee-eater <i>Nyctornis athertoni</i> _{LC}	0.01 (12) [⊗]	0.00 (0)	0.00 (0)
130	Green Bee-eater <i>Merops orientalis</i> _{LC}	0.48 (64) ●	0.56 (85) ●	0.67 (94) ●
131	Blue-tailed Bee-eater <i>Merops philippinus</i> _{LC}	0.01 (16) [⊗]	0.10 (33) [⊗]	0.10 (50) [⊗]
132	Chestnut-headed Bee-eater <i>Merops leschenaulti</i> _{LC}	0.11 (28) [⊗]	0.15 (44) [⊗]	0.30 (72) ●
	Coraciiformes: Coraciidae			
133	Indian Roller <i>Coracias benghalensis</i> _{LC}	0.03 (36) [⊗]	0.05 (33) [⊗]	0.00 (0)
134	Dollarbird <i>Eurystomus orientalis</i> _{LC}	0.00 (4) [⊗]	0.00 (0)	0.00 (0)
XVII	Piciformes: Megalaimidae			
135	Malabar Barbet <i>Psilopogon malabaricus</i> _{LC}	*		
136	Coppersmith Barbet <i>Psilopogon haemacephalus</i> _{LC}	0.12 (52) ●	0.03 (30) [⊗]	0.02 (17) [⊗]
137	Brown-headed Barbet <i>Psilopogon zeylanicus</i> _{LC}	*		
138	White-cheeked Barbet <i>Psilopogon viridis</i> _{LC}	0.45 (100) ●	0.34 (96) ●	0.16 (83) ●
	Piciformes: Picidae			
139	Heart-spotted Woodpecker <i>Hemicircus canente</i> _{LC}	0.01 (8) [⊗]	0.01 (7) [⊗]	0.00 (0)
140	Brown-capped Pygmy Woodpecker <i>Yungipicus nanus</i> _{LC}	0.03 (32) [⊗]	>0.01 (4) [⊗]	0.00 (0)
141	Rufous Woodpecker <i>Micropternus brachyurus</i> _{LC}	0.01 (12) [⊗]	0.00 (0)	0.00 (0)
142	Black-rumped Flameback <i>Dinopium benghalense</i> _{LC}	0.07 (52) ●	0.03 (22) [⊗]	0.01 (11) [⊗]
143	Lesser Yellownape <i>Picus chlorolophus</i> _{LC}	0.03 (28) [⊗]	0.00 (4) [⊗]	0.00 (0)
144	Streak-throated Woodpecker <i>Picus xanthopygaeus</i> _{LC}	0.01 (8) [⊗]	0.00 (0)	0.00 (0)
XVIII	Falconiformes: Falconidae			
145	Common Kestrel <i>Falco tinnunculus</i> _{LC}	>0.01 (4) [⊗]	>0.01 (4) [⊗]	0.01 (6) [⊗]
146	Amur Falcon <i>Falco amurensis</i> [†] _{LC}	0.00 (0)	0.00 (0)	0.01 (6) [⊗]
147	Peregrine Falcon <i>Falco peregrinus</i> _{LC}	*		
XIX	Psittaciformes: Psittaculidae			
148	Rose-ringed Parakeet <i>Psittacula krameri</i> _{LC}	0.33 (84) ●	0.48 (93) ●	0.11 (78) ●
149	Plum-headed Parakeet <i>Psittacula cyanocephala</i> _{LC}	0.05 (20) [⊗]	0.05 (11) [⊗]	0.02 (11) [⊗]
150	Malabar Parakeet <i>Psittacula columboides</i> _{LC}	0.18 (56) ●	0.07 (19) [⊗]	0.00 (0)
151	Vernal Hanging Parrot <i>Loriculus vernalis</i> _{LC}	0.14 (48) [⊗]	0.01 (11) [⊗]	0.02 (22) [⊗]
XX	Passeriformes: Pittidae			
152	Indian Pitta <i>Pitta brachyura</i> [‡] _{LC}	0.01 (20) [⊗]	0.01 (7) [⊗]	0.00 (0)
	Passeriformes: Campephagidae			
153	Orange Minivet <i>Pericrocotus flammeus</i> _{LC}	0.21 (44) [⊗]	0.02 (7) [⊗]	0.01 (6) [⊗]

	Species	Upper reaches	Middle reaches	Lower reaches
154	Large Cuckooshrike <i>Coracina macei</i> _{LC}	0.04 (28) [§]	0.01 (15) [®]	0.01 (6) [®]
155	Black-headed Cuckooshrike <i>Lalage melanoptera</i> _{LC}	0.02 (20) [®]	>0.01 (4) [®]	0.02 (28) [§]
	Passeriformes: Oriolidae			
156	Indian Golden Oriole <i>Oriolus kundoo</i> † _{LC}	0.04 (24) [§]	0.04 (22) [§]	0.06 (44) [§]
157	Black-naped Oriole <i>Oriolus chinensis</i> † _{LC}	0.02 (20) [®]	0.01 (15) [®]	0.02 (28) [§]
158	Black-hooded Oriole <i>Oriolus xanthornus</i> _{LC}	0.27 (88) ●	0.18 (74) ●	0.12 (67) ●
	Passeriformes: Artamidae			
159	Ashy Woodswallow <i>Artamus fuscus</i> _{LC}	0.12 (44) [§]	0.23 (37) [§]	0.17 (72) ●
	Passeriformes: Vangidae			
160	Malabar Woodshrike <i>Tephrodornis sylvicola</i> _{LC}	0.02 (16) [®]	>0.01 (4) [®]	0.01 (11) [®]
161	Common Woodshrike <i>Tephrodornis pondicerianus</i> _{LC}	*	*	
	Passeriformes: Aegithinidae			
162	Common Iora <i>Aegithina tiphia</i> _{LC}	0.19 (68) ●	0.09 (70) ●	0.08 (67) ●
	Passeriformes: Dicruridae			
163	Black Drongo <i>Dicrurus macrocercus</i> _{LC}	0.51 (96) ●	0.50 (100) ●	0.43 (94) ●
164	Ashy Drongo <i>Dicrurus leucophaeus</i> † _{LC}	0.02 (20) [®]	0.00 (0)	>0.01 (6) [®]
165	Bronzed Drongo <i>Dicrurus aeneus</i> _{LC}	>0.01 (4) [®]	0.00 (0)	0.01 (11) [®]
166	Greater Racket-tailed Drongo <i>Dicrurus paradiseus</i> _{LC}	0.27 (64) ●	0.08 (37) [§]	0.10 (44) [§]
	Passeriformes: Monarchidae			
167	Black-naped Monarch <i>Hypothymis azurea</i> _{LC}	0.04 (28) [§]	0.01 (4) [®]	0.00 (0)
168	Indian Paradise-flycatcher <i>Terpsiphone paradisi</i> † _{LC}	0.07 (48) [§]	0.02 (19) [®]	0.01 (11) [®]
	Passeriformes: Laniidae			
169	Brown Shrike <i>Lanius cristatus</i> † _{LC}	0.03 (20) [®]	>0.01 (4) [®]	0.03 (22) [§]
170	Bay-backed Shrike <i>Lanius vittatus</i> _{LC}	>0.01 (4) [®]	0.00 (0)	>0.01 (6) [®]
171	Long-tailed Shrike <i>Lanius schach</i> _{LC}	0.01 (8) [®]	0.02 (30) [§]	>0.01 (6) [®]
	Passeriformes: Corvidae			
172	Rufous Treepie <i>Dendrocitta vagabunda</i> _{LC}	0.30 (84) ●	0.30 (85) ●	0.14 (89) ●
173	White-bellied Treepie <i>Dendrocitta leucogastra</i> _{LC}	0.02 (12) [®]	0.00 (0)	0.00 (0)
174	House Crow <i>Corvus splendens</i> _{LC}	1.34 (100) ●	2.77 (100) ●	4.46 (100) ●
175	Large-billed Crow <i>Corvus macrorhynchos</i> _{LC}	0.57 (84) ●	0.67 (85) ●	0.57 (78) ●
	Passeriformes: Stenostiridae			
176	Grey-headed Canary-flycatcher <i>Culicicapa ceylonensis</i> † _{LC}	*		
	Passeriformes: Paridae			
177	Cinereous Tit <i>Parus cinereus</i> _{LC}	0.03 (8) [®]	0.00 (0)	0.00 (0)
	Passeriformes: Alaudidae			
178	Jerdon's Bushlark <i>Mirafra affinis</i> _{LC}	0.07 (24) [§]	0.01 (7) [®]	0.01 (11) [®]
179	Oriental Skylark <i>Alauda gulgula</i> _{LC}	*		
180	Malabar Lark <i>Galerida malabarica</i> _{LC}		*	*
	Passeriformes: Cisticolidae			
181	Common Tailorbird <i>Orthotomus sutorius</i> _{LC}	0.39 (96) ●	0.61 (100) ●	0.31 (94) ●
182	Jungle Prinia <i>Prinia sylvatica</i> _{LC}	0.03 (16) [®]	0.00 (0)	>0.01 (6) [®]
183	Ashy Prinia <i>Prinia socialis</i> _{LC}	0.01 (12) [®]	0.08 (48) [§]	0.12 (67) ●
184	Plain Prinia <i>Prinia inornata</i> _{LC}	0.07 (40) [§]	0.21 (70) ●	0.14 (72) ●
185	Zitting Cisticola <i>Cisticola juncidis</i> _{LC}	0.01 (4) [®]	>0.01 (4) [®]	0.02 (28) [§]
	Passeriformes: Acrocephalidae			
186	Thick-billed Warbler <i>Arundinax aedon</i> † _{LC}	0.01 (4) [®]	0.00 (0)	0.00 (0)
187	Booted Warbler <i>Iduna caligata</i> † _{LC}	>0.01 (4) [®]	0.00 (0)	0.00 (0)
188	Blyth's Reed Warbler <i>Acrocephalus dumetorum</i> † _{LC}	0.45 (96) ●	0.48 (93) ●	0.34 (89) ●

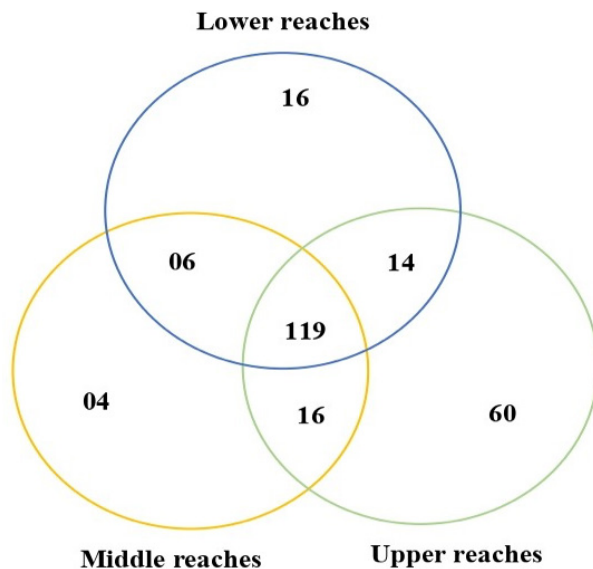
	Species	Upper reaches	Middle reaches	Lower reaches
189	Clamorous Reed Warbler <i>Acrocephalus stentoreus</i> _{LC}	0.05 (32) [§]	0.01 (11) [®]	0.01 (11) [®]
	Passeriformes: Hirundinidae			
190	Barn Swallow <i>Hirundo rustica</i> [‡] _{LC}	0.44 (48) [§]	0.51 (63) ●	0.81 (67) ●
191	Wire-tailed Swallow <i>Hirundo smithii</i> _{LC}	0.00 (0)	0.00 (0)	0.11 (17) [®]
192	Red-rumped Swallow <i>Cecropis daurica</i> _{LC}	0.30 (28) [§]	0.48 (52) ●	1.11 (72) ●
193	Streak-throated Swallow <i>Petrochelidon fluvicola</i> _{LC}	0.00 (0)	0.02 (4) [®]	0.00 (0)
	Passeriformes: Pycnonotidae			
194	Flame-throated Bulbul <i>Rubigula gularis</i> _{LC}	0.14 (24) [§]	0.00 (0)	0.00 (0)
195	Red-vented Bulbul <i>Pycnonotus cafer</i> _{LC}	1.00 (100) ●	0.86 (96) ●	0.57 (100) ●
196	Red-whiskered Bulbul <i>Pycnonotus jocosus</i> _{LC}	0.63 (88) ●	0.62 (89) ●	0.46 (89) ●
197	White-browed Bulbul <i>Pycnonotus luteolus</i> _{LC}	0.15 (52) ●	0.03 (19) [®]	0.06 (28) [§]
198	Yellow-browed Bulbul <i>Acritillas indica</i> _{LC}	0.21 (64) ●	>0.01 (4) [®]	0.01 (11) [®]
	Passeriformes: Phylloscopidae			
199	Green Leaf Warbler <i>Phylloscopus nitidus</i> [†] _{LC}	0.05 (44) [§]	0.02 (15) [®]	0.02 (22) [§]
200	Greenish Leaf Warbler <i>Phylloscopus trochiloides</i> [‡] _{LC}	0.42 (84) ●	0.14 (67) ●	0.10 (72) ●
201	Large-billed Leaf Warbler <i>Phylloscopus magnirostris</i> [‡] _{LC}	0.01 (4) [®]	>0.01 (4) [®]	0.00 (0)
	Passeriformes: Zosteropidae			
202	Indian White-eye <i>Zosterops palpebrosus</i> _{LC}	0.17 (20) [®]	0.00 (0)	>0.01 (6) [®]
	Passeriformes: Timaliidae			
203	Tawny-bellied Babbler <i>Dumetia hyperythra</i> _{LC}	0.04 (16) [®]	0.00 (0)	0.00 (0)
204	Dark-fronted Babbler <i>Rhopocichla atriceps</i> _{LC}	0.03 (4) [®]	0.00 (0)	0.00 (0)
205	Indian Scimitar Babbler <i>Pomatorhinus horsfieldii</i> _{LC}	0.04 (20) [®]	0.00 (0)	0.00 (0)
	Passeriformes: Pellorneidae			
206	Puff-throated Babbler <i>Pellorneum ruficeps</i> _{LC}	0.04 (16) [®]	0.00 (0)	0.00 (0)
	Passeriformes: Leiothrichidae			
207	Jungle Babbler <i>Argya striata</i> _{LC}	0.61 (60) ●	0.05 (11) [®]	0.03 (11) [®]
208	Yellow-billed Babbler <i>Argya affinis</i> _{LC}	1.43 (100) ●	1.40 (93) ●	0.54 (72) ●
209	Common Babbler <i>Argya caudata</i> _{LC}	0.02 (4) [®]	0.00 (0)	0.00 (0)
210	Rufous Babbler <i>Argya subrufa</i> _{LC}	0.09 (16) [®]	0.01 (4) [®]	0.00 (0)
211	Wayanad Laughingthrush <i>Pterorhinus delesserti</i> _{LC}	0.07 (4) [®]	0.00 (0)	0.00 (0)
	Passeriformes: Sittidae			
212	Velvet-fronted Nuthatch <i>Sitta frontalis</i> _{LC}	0.07 (24) [§]	0.00 (0)	0.00 (0)
	Passeriformes: Sturnidae			
213	Common Hill Myna <i>Gracula religiosa</i> _{LC}	0.33 (24) [§]	0.00 (0)	0.00 (0)
214	Rosy Starling <i>Pastor roseus</i> [†] _{LC}	0.08 (12) [®]	0.02 (4) [®]	0.17 (17) [®]
215	Brahminy Starling <i>Sturnia pagodarum</i> _{LC}	0.01 (4) [®]	0.04 (11) [®]	0.00 (0)
216	Chestnut-tailed Starling <i>Sturnia malabarica</i> _{LC}	0.01 (8) [®]	0.00 (0)	0.06 (11) [®]
217	Malabar Starling <i>Sturnia blythii</i> _{NE}	0.04 (12) [®]	0.01 (4) [®]	0.02 (6) [®]
218	Common Myna <i>Acridotheres tristis</i> _{LC}	1.12 (100) ●	1.45 (100) ●	1.14 (100) ●
219	Jungle Myna <i>Acridotheres fuscus</i> _{LC}	0.33 (64) ●	0.04 (15) [®]	0.02 (6) [®]
	Passeriformes: Turdidae			
220	Nilgiri Thrush <i>Zoothera neilgherriensis</i> _{NE}	0.01 (8) [®]	0.00 (0)	0.00 (0)
221	Orange-headed Thrush <i>Geokichla citrina</i> _{LC}	0.05 (28) [§]	0.01 (19) [®]	0.02 (28) [§]
	Passeriformes: Muscipidae			
222	Asian Brown Flycatcher <i>Muscicapa dauurica</i> _{LC}	0.01 (8) [®]	0.00 (0)	0.00 (0)
223	Brown-breasted Flycatcher <i>Muscicapa muttui</i> [†] _{LC}	0.10 (52) ●	0.01 (11) [®]	0.02 (28) [§]
224	Indian Robin <i>Copsychus fulicatus</i> _{LC}	0.06 (28) [§]	0.02 (11) [®]	0.01 (11) [®]
225	Oriental Magpie Robin <i>Copsychus saularis</i> _{LC}	0.26 (84) ●	0.19 (78) ●	0.07 (61) ●

	Species	Upper reaches	Middle reaches	Lower reaches
226	White-rumped Shama <i>Copsychus malabaricus</i> _{LC}	*		
227	White-bellied Blue Flycatcher <i>Cyornis pallidipes</i> _{LC}	0.03 (16) [®]	0.00 (0)	0.00 (0)
228	Tickell's Blue Flycatcher <i>Cyornis tickelliae</i> _{LC}	0.03 (24) [§]	0.00 (0)	0.00 (0)
229	Nilgiri Flycatcher <i>Eumyias albicaudatus</i> _{LC}	*		
230	Verditer Flycatcher <i>Eumyias thalassinus</i> ‡ _{LC}	>0.01 (4) [®]	0.00 (0)	0.00 (0)
231	Malabar Whistling Thrush <i>Myophonus horsfieldii</i> _{LC}	0.18 (44) [§]	0.01 (7) [®]	0.00 (0)
232	Black-and-orange Flycatcher <i>Ficedula nigrorufa</i> _{LC}	*		
233	Rusty-tailed Flycatcher <i>Ficedula rufigaucha</i> † _{LC}	0.01 (12) [®]	0.00 (0)	0.00 (0)
234	Taiga Flycatcher <i>Ficedula albicilla</i> † _{LC}	*		
235	Blue-capped Rock Thrush <i>Monticola cinclorhyncha</i> ‡ _{LC}	0.02 (8) [®]	0.00 (0)	0.00 (0)
236	Pied Bushchat <i>Saxicola caprata</i> _{LC}	0.11 (48) [§]	0.05 (30) [§]	0.05 (33) [§]
	Passeriformes: Dicaeidae			
237	Thick-billed Flowerpecker <i>Dicaeum agile</i> _{LC}	0.02 (12) [®]	0.00 (0)	0.00 (0)
238	Pale-billed Flowerpecker <i>Dicaeum erythrorhynchos</i> _{LC}	0.35 (92) ●	0.29 (85) ●	0.17 (83) ●
239	Nilgiri Flowerpecker <i>Dicaeum concolor</i> _{LC}	0.01 (4) [®]	0.00 (0)	0.00 (0)
	Passeriformes: Nectariniidae			
240	Purple-rumped Sunbird <i>Leptocoma zeylonica</i> _{LC}	0.93 (100) ●	0.83 (100) ●	0.44 (100) ●
241	Crimson-backed Sunbird <i>Leptocoma minima</i> _{LC}	0.08 (32) [§]	0.00 (0)	0.00 (0)
242	Purple Sunbird <i>Cinnyris asiaticus</i> _{LC}	0.23 (84) ●	0.22 (74) ●	0.17 (72) ●
243	Loten's Sunbird <i>Cinnyris lotenius</i> _{LC}	0.18 (76) ●	0.06 (41) [§]	0.05 (39) [§]
244	Little Spiderhunter <i>Arachnothera longirostra</i> _{LC}	0.05 (20) [§]	>0.01 (4) [®]	0.00 (0)
	Passeriformes: Irenidae			
245	Asian Fairy-bluebird <i>Irena puella</i> _{LC}	0.05 (16) [®]	0.00 (0)	0.00 (0)
	Passeriformes: Chloropseidae			
246	Jerdon's Leafbird <i>Chloropsis jerdoni</i> _{LC}	0.13 (56) ●	0.05 (37) [§]	0.04 (39) [§]
247	Golden-fronted Leafbird <i>Chloropsis aurifrons</i> _{LC}	0.04 (20) [®]	0.02 (19) [®]	0.01 (11) [®]
	Passeriformes: Ploceidae			
248	Streaked Weaver <i>Ploceus manyar</i> _{LC}	0.00 (0)	0.01 (4) [®]	0.00 (0)
249	Baya Weaver <i>Ploceus philippinus</i> _{LC}	0.00 (0)	0.23 (7) [®]	0.00 (0)
	Passeriformes: Estrildidae			
250	Red Munia <i>Amandava amandava</i> _{LC}			*
251	Indian Silverbill <i>Euodice malabarica</i> _{LC}	0.01 (4) [®]	0.00 (0)	0.00 (0)
252	White-rumped Munia <i>Lonchura striata</i> _{LC}	0.00 (0)	0.01 (4) [®]	0.01 (11) [®]
253	Scaly-breasted Munia <i>Lonchura punctulata</i> _{LC}	0.06 (8) [®]	0.08 (19) [®]	0.27 (33) [§]
254	Tricoloured Munia <i>Lonchura malacca</i> _{LC}	0.15 (24) [§]	0.24 (30) [§]	0.34 (39) [§]
	Passeriformes: Passeridae			
255	House Sparrow <i>Passer domesticus</i> _{LC}	0.00 (0)	0.04 (19) [®]	0.01 (6) [®]
256	Yellow-throated Sparrow <i>Gymnoris xanthocollis</i> _{LC}	0.01 (4) [®]	0.00 (0)	0.00 (0)
	Passeriformes: Motacillidae			
257	Forest Wagtail <i>Dendronanthus indicus</i> † _{LC}	0.02 (16) [®]	0.00 (0)	0.00 (0)
258	Grey Wagtail <i>Motacilla cinerea</i> ‡ _{LC}	0.10 (52) ●	0.04 (33) [§]	0.01 (17) [®]
259	Western Yellow Wagtail <i>Motacilla flava</i> † _{LC}	0.04 (24) [§]	0.01 (7) [®]	0.01 (22) [§]
260	White-browed Wagtail <i>Motacilla maderaspatensis</i> _{LC}	0.16 (56) ●	0.33 (78) ●	0.29 (83) ●
261	Paddyfield Pipit <i>Anthus rufulus</i> _{LC}	0.05 (36) [§]	0.02 (15) [®]	0.01 (28) [§]
	Passeriformes: Fringillidae			
262	Common Rosefinch <i>Carpodacus erythrinus</i> ‡ _{LC}			*

Migratory status: †—long distance migrant | ‡—local migrant | IUCN Status: LC—Least Concern | NT—Near Threatened | VU—Vulnerable | EN—Endangered | NE—Not Evaluated. *—Opportunistic sightings. Rarity: ●—Common | §—Less common | ®—Rare.

Table 2. Ecological zone-wise sampling effort for avifauna diversity survey in Bharathapuzha River Basin.

Ecological zone	Grids (n)	Point counts (n)	Total effort (Hours)	Species observed (n)	Individuals encountered (n)
Upper reaches	25	300	75	209	11,280
Middle reaches	27	324	81	145	10,602
Lower reaches	18	216	54	155	14,929
Overall	70	840	210	235	36,811

**Figure 2. Occurrence of various bird species in different ecological zones.**

illegal sand mining altered the river ecosystem, especially in the mainstream. The illegal sand mining and over-exploitation of sand destroyed the river ecosystem (Sreedhar & Irfan 2016). There were several sighting reports and nesting records of 'Endangered' Black-bellied Tern in the river basin (Susanthkumar 2004; Aarif et al. 2010). However, in this study, we couldn't find nesting of these birds in the river basin. Sand mining is still prevalent in the lower reaches of the Bharathapuzha River Basin. It can be detrimental to the benthic ecosystem on which many bird species are dependent. Hence sand mining may have cascading effects on the biodiversity of the entire river basin.

Due to the strong opposition by the local people, nature enthusiasts and NGOs, there have been various regulations and restrictions imposed on sand mining activities. Even though, illegal sand mining is prevalent in several locations in the river basin. Interestingly, legal sand mining in the estuary region, at Ponnani is also observed (Image 4).

Table 3. Diversity indices calculated for various ecological zones.

	Upper reaches	Middle reaches	Lower reaches
Dominance (D)	0.021	0.038	0.035
Simpson (1-D)	0.98	0.96	0.96
Shannon (H')	4.35	3.82	3.88
Chao-1	220.70	158.20	158.50
Observed species richness	209	145	155

CONCLUSION

The study covered 48% of the total bird species recorded from Kerala (Chandran et al. 2020). The last published checklist of birds of the region by Bijukumar (2006) has reported 143 bird species from the river basin. This study updates the checklist and increases the number of bird species on the list to 262.

The holistic approach of the river as a single ecological entity helps to understand the changes in the avian diversity in different regions of the river over time. The headwater region of the river basin supports the resident birds. The main course and estuary regions play a pivotal role in the conservation of migratory birds. Hence protection of the forests in the upper reaches and all-natural habitats in the lower reaches are equally important for the conservation of birds. Bringing back the natural ecosystem of the river is everyone's responsibility. Hence community-mediated policy interventions are very much required to reduce sand mining and rebuild the riverine ecosystem, which ultimately protects the biodiversity.

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Table 4. Common and rare birds reported in each ecological zone.

Migratory status	Upper reaches			Middle reaches			Lower reaches		
	Common	Less common	Rare	Common	Less common	Rare	Common	Less common	Rare
Resident	45	39	91	43	18	58	48	25	48
Local migrant	2	5	10	2	3	6	2	5	7
Long distance migrant	4	1	8	1	3	9	5	7	10

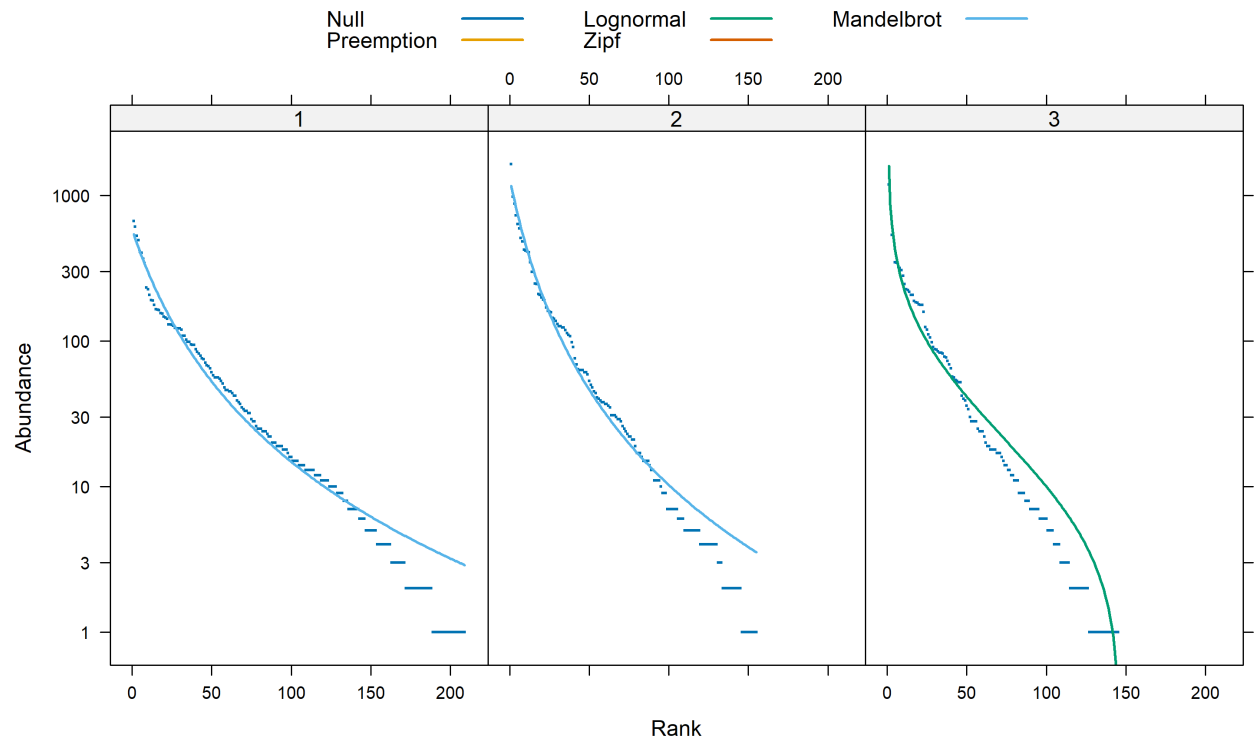


Figure 3. Best fit rank abundance model for birds observed in different regions of Bharathapuzha River Basin: 1—Upper reaches | 2—Lower reaches | 3—Middle reaches.

Table 5. Estimated RAD of bird species from distinct ecozones based on stream order in Bharathapuzha River Basin.

		Null	Log-normal	Pre-emption	Zipf	Zipf-Mandlebrot
Upper reaches	Deviance	3698.84	622.88	1028.77	2780.50	401.60*
	AIC	4660.40	1588.44	1992.32	3746.05	1369.15
	ΔAIC	3291.25	219.29	623.17	2376.9	0
Middle reaches	Deviance	5204.45	615.83*	1280.85	2491.06	1280.85
	AIC	5876.61	1291.99	1955.01	3167.22	1959.01
	ΔAIC	4584.62	0	663.02	1875.23	667.02
Lower reaches	Deviance	7401.81	742.92	1571.21	3466.99	465.40*
	AIC	8163.55	1508.65	2334.94	4232.73	1233.14
	ΔAIC	6930.41	275.51	1101.80	2999.59	0

AIC—Akaike information criterion



Image 4. Sand dredging along the coast of Ponnani estuary in lower reaches of Bharathapuzha River Basin. © P.N. Anoop Raj.

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Avifaunal assemblage patterns in Bharathapuzha River Basin, Kerala, India

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Abstract: Bharathapuzha, the second largest west-flowing river in the Western Ghats, originates from the northern and southern parts of the Palghat gap and debouches into the Arabian Sea at Ponnani. This river is exposed to high levels of anthropogenic pressures. This study looks into avifaunal assemblage patterns and the factors influencing the structure of bird communities in different ecological zones of the Bharathapuzha River Basin. The syntropic birds and flocking birds contribute variations in the bird community assemblage in the river basin. For the water-dependent and water-associated birds, mudflats, water flow, riverside vegetation, and distance from the forest were found to be the influencing factors in the migratory season. The study also emphasized the importance of protecting these river-associated habitats for the conservation of birds.

Keywords: Anthropogenic pressures, bird community, environmental factors, mudflats, Nila River, riverine birds, riverside vegetation, water flow, water-associated birds, water-dependent birds.

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INTRODUCTION

Bird species respond rapidly to any changes in the environment (Bühning-Gaese 1997; Waide et al. 1999; Donald et al. 2001; Suárez-Seoane et al. 2002; Benton et al. 2003; McCracken & Tallowin 2004; Batáry et al. 2007). The avian species diversity, richness, and abundance are determined by various factors such as migration, natality, mortality, and availability of food and niches (Fitzherbert et al. 2008; Jayapal et al. 2009). Many researchers have attempted to study bird communities in the different habitats in the Western Ghats (Daniels 1989; Pramod 1995, Karanth et al. 2016) which provided useful information about the distribution trends. Most of these studies focused on forest ecosystems in the protected area network. Understanding the pattern of distribution of birds and their drivers in highly disturbed ecosystems outside the protected area network is less attempted (Garcia et al. 2010; Anand et al. 2010; Chandran & Vishnudas 2018; Variar et al. 2021).

From the origin to the mouth, the Bharathapuzha River passes through various landscapes and topographic conditions. Most ecosystems in the river basin are located outside the protected area network and are vulnerable to anthropogenic pressures. Deforestation in the hill region, construction of check dams, indiscriminate sand mining, the spread of weeds and invasive plants inside the river channel, expansion of monoculture plantations, encroachment and water pollution are the major threats to the river (John et al. 2019). In this study, we attempted to understand the pattern of avifaunal assemblage in the Bharathapuzha river basin which is highly disturbed due to anthropogenic pressures which destroyed the riverine habitats, water quality, and natural water flow.

MATERIAL AND METHODS

Study area

Bharathapuzha is a 6th-order river (Strahler 1964) having a large extent of production landscape in the basin (Jacob & Narayanaswami 1954; John et al. 2019). The total area of the river drainage basin is 6186 km², which includes 50 watersheds and 290 mini watersheds. Twenty-five percent of the river drainage basin comes under various protected areas (Raj & Azeez 2010; John et al. 2019). Silent Valley National Park, one of the important biodiversity hotspots in the country falls in this river basin. This river originates from the Thirumurthi hills of Anamalai and flows towards the west through the Palghat Gap until it drains into the Arabian

Sea. Chitturpuzha, Kalpathipuzha, Gayathripuzha, and Thoothapuzha are major tributaries of this river which originates from the Western Ghats. These rivers play a crucial role in maintaining the water flow in the river.

Study design

Field surveys were conducted in 453 km stretches of the river between the elevation gradient of 621–0 m. The intensive sampling area was selected using stratified sampling techniques. The area was stratified into three ecological zones based on the river flow, geomorphology, and ecological setting of the river. Thus, the sampling locations were classified into the upper reaches (headwaters), middle reaches (tributary), and lower reaches (main course and estuary) of the river which are henceforth termed ecological zones (Abell et al. 2008). Considering the extent of area available in these zones, the sampling locations and sampling efforts were distributed. Sampling was done in one non-migratory (April to October 2018) and two migratory seasons (November 2017–February 2018, and November 2018–February 2019). The riverine area in the basin was gridded into 1 km² grids. From these, 70 grids along the river channel were selected through random sampling for intensive study (Figure 1). In each grid, data on birds and associated environmental parameters were collected through 4-point counts (each 15-minute long) using the fixed width point count method (Reynolds et al. 1980). Thus, for the three seasons together, a total of 840-point counts of bird data collection were conducted from the sampling area. Observations were done 0600–1100 h and 1530–1900 h. Bird identification was done using field guides and photographs (Ali & Ripley 1983; Ali 1999; Karmierczak 2000; Grimmett et al. 2014).

Data preparation

Data collected from 70 grids in three seasons (two migratory, one non-migratory) were tabulated and organized as 210 samples. Contingency tables were created as samples vs. species with abundance values as scores using the pivot table function in the spreadsheet package. Samples with no detection were removed from the tables.

Bird group categories

The bird species recorded during the study period were classified into three groups as water-dependent birds (WDB), water-associated birds (WAB), and non-water-associated birds (NWAB).

Water-dependent birds (WDB) are the birds that use water as their most preferred habitat. This includes the

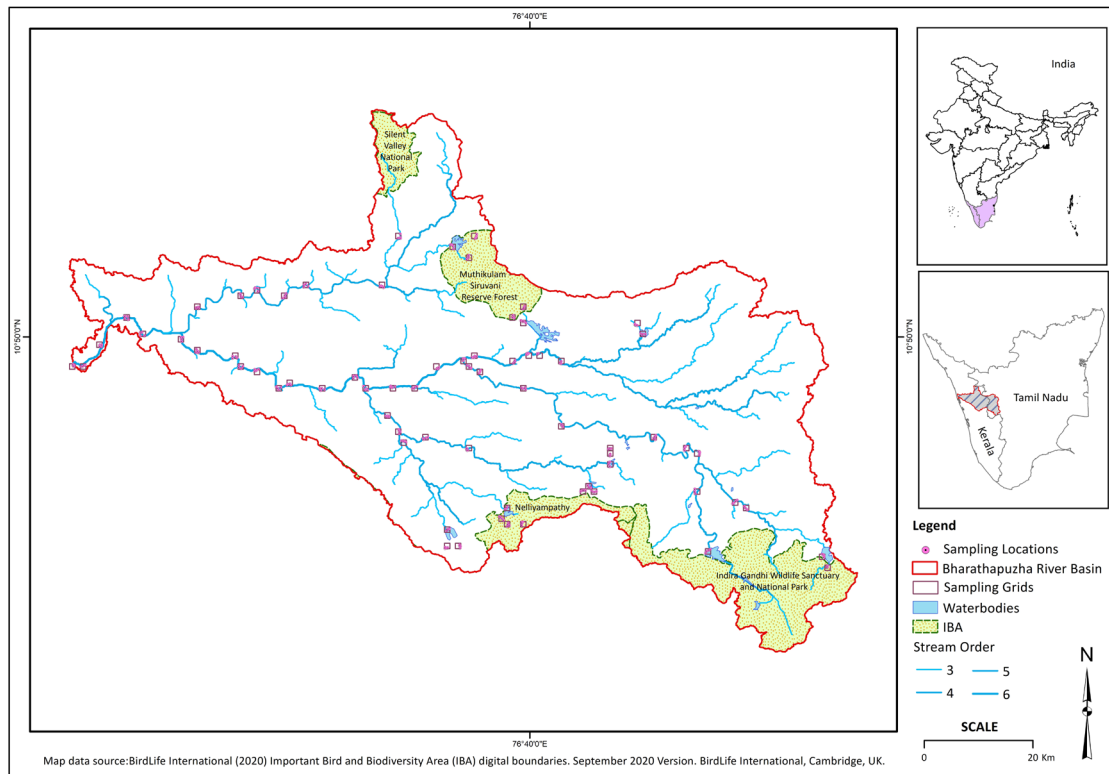


Figure 1. Location map of Bharathapuzha River Basin showing streams and sampling locations.

taxonomic groups such as Anseriformes, Suliformes, and a few members of Charadriiformes.

Water-associated birds (WAB) include the taxonomic groups such as Pelecaniformes, Ciconiformes, Gruiformes, Charadriiformes, and a few members of Coraciiformes, Passeriformes, and Accipitriformes.

Non-water-associated birds (NWAB) are the birds that don't use riverine habitats as primary habitats. Galliformes, Podicipediformes, Cuculiformes, Caprimulgiformes, Accipitriformes, Strigiformes, Trogoniformes, Bucerotiformes, Coraciiformes, Piciformes, Falconiformes, Psittaciformes, and Passeriformes come under this category.

Environmental parameters

Data on 17 environmental parameters were collected. The parameters such as check dams, waste dumping, and artificial perches were recorded as presence and absence. Area of water channel, water flow, riverside vegetation, mudflats, sandbanks, rocks and barren land recorded in percentage (%) in a unit area by visual estimation. The canopy cover was recorded using the *Canopeo* (Patrignani et al. 2015). The distance from the nearest forest, agricultural land, and human settlements was collected on a km scale using the Google Earth Pro

application. The temperature and rainfall data were collected from the Worldclim database for the study period.

Analysis

To assess the community structure and its variation across ecological zones and seasons, non-metric multidimensional scaling (nMDS) was performed (Kruskal 1964; Borcard et al. 2011). For nMDS, the contingency table was prepared using one nonmigratory and migratory season data. Analysis was performed separately for WDB, WAB, and NWAB. Bray-Curtis dissimilarity index being sensitive to differences in abundances and does not rely on absences has been used extensively in community ecology (Schroeder & Jenkins 2018; Lorenzón et al. 2019). Hence, a distance matrix with Bray-Curtis dissimilarities was used for nMDS ordination. To determine if the clusters shown in nMDS ordination are statistically significant, ANOSIM was also performed using the Bray-Curtis dissimilarity matrix (Anderson & Walsh 2013). ANOSIM was performed using ecological zone and season as grouping variables.

Similarity Percentage (SIMPER) analysis was employed to further assess the contribution of the species to the dissimilarities between the grouping

variables (Clarke 1993; White et al. 2005; Asefa et al. 2017).

To test the impact of environmental parameters on the community structure of WDB and WAB in migratory and non-migratory seasons, distance-based redundancy analysis was used (Legendre & Anderson 1999). First, a global model was performed by incorporating all non-auto-correlated environmental variables. Linear dependencies for all environmental variables were checked by computing variance inflation factors (VIF) for each variable. The variable reduction was performed using the forward selection method (Boccard et al. 2011) by including variables with VIF below 10. A most parsimonious model was computed using the environmental variables within $\alpha = 0.05$ during the forward selection method. The proportion of variation explained by each variable was calculated by adjusting the R^2 value with the R^2 value of the global model as the threshold.

All statistical analysis was performed in R statistical language (v4.3.2) with R Studio IDE (v2023.06.0). Vegan, a community ecology package was used to perform ordination and significance testing (Oksanen et al. 2013). Ordination graphs were generated using the package ggplot2 (Wickham 2016).

RESULTS

Bird assemblage patterns across ecozones and season

The study recorded 235 species of birds while employing the sampling protocols. There were 23 species of WDB, 49 species of WAB, and 163 NWAB recorded from the river basin.

Water dependent birds

Ordination shows that the avifaunal community in the middle reaches is not distinct and completely overlaps within the upper and middle reaches (Figure 2). Some WDBs distinctly favored sites from either upper or lower reaches (nMDS: stress = 0.15, non-metric $R^2 = 0.97$). The variation between ecological zones was more significant than within ecological zones (ANOSIM: $R = 0.132$, $p < 0.05$). However, the bird community variation observed between migratory and non-migratory seasons was not significant (ANOSIM: $R = 0.007$, $p < 0.7$).

Little Cormorants *Microcarbo niger*, Black-headed Gull *Chroicocephalus ridibundus*, Brown-headed Gull *Chroicocephalus brunnicephalus*, White-breasted Waterhen *Amaurornis phoenicurus*, Palla's Gull *Ichthyiaetus ichthyiaetus*, and Oriental Darter *Anhinga melanogaster* contributed to the community variation in the lower and middle reaches. Along with the above-mentioned bird species, the presence of River Tern *Sterna aurantia* and Lesser Whistling Duck *Dendrocygna javanica* contributed to the community variation in

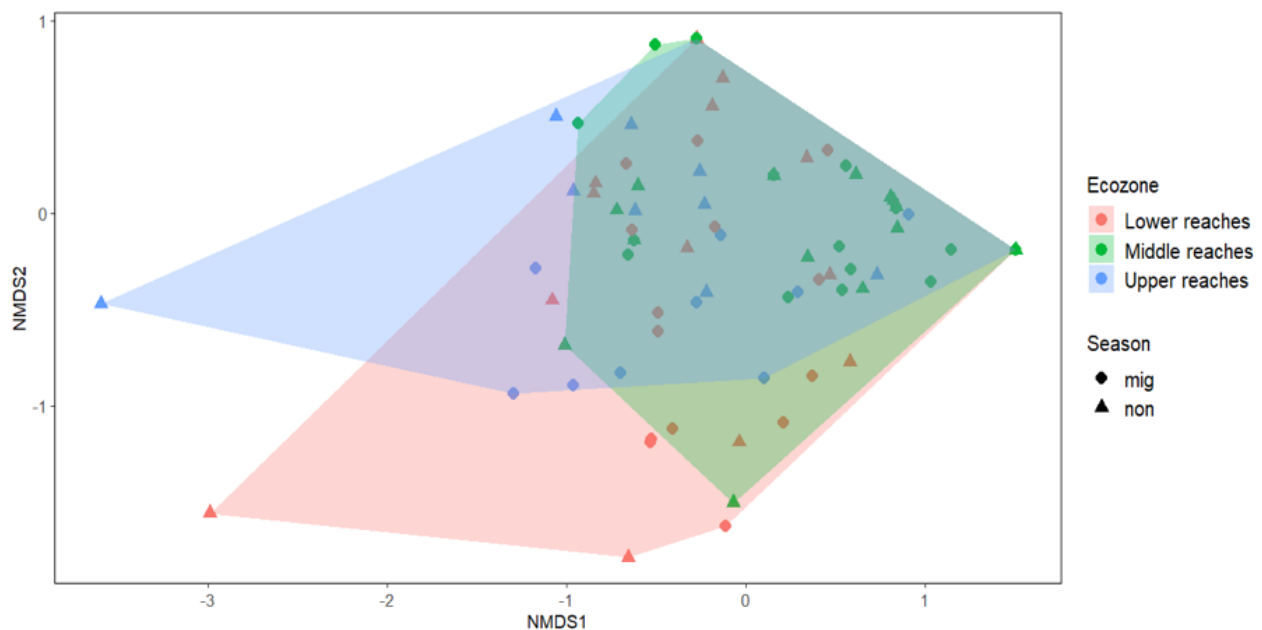


Figure 2. Non-metric multidimensional scaling (nMDS) for water-dependent birds (mig: migratory season; non: non migratory season).

the lower and upper reaches. Little Cormorant, White-breasted Waterhen, River Tern, and Lesser Whistling Duck contributed to the community variation between the middle and upper reaches.

Water associated birds

The lower reaches and middle reaches have many sites with similar species composition, however, many sites recorded very distinct composition (nMDS: Stress = 0.219, Non-metric R² = 0.94) (Figure 3). Similarly, several sites in the middle and lower reaches were similar in composition to the upper reaches. Also, lower and upper reaches have sites with unique compositions specific to the respective ecological zones. The variation between ecological zones is more significant than within ecological zones (ANOSIM: R = 0.159, p <0.05). While considering the lower reaches and upper reaches separately, the sites with unique compositions are more. Due to this, species composition between seasons is significantly different (ANOSIM: R = 0.039, p <0.05).

Cattle Egret *Bubulcus ibis*, Brahmini Kite *Haliastur indus*, Little Egret *Egretta garzetta*, Green Bee-eater

Merops orientalis, Indian Pond Heron *Ardeola grayii*, Asian Openbill *Anastomus oscitans* contributed maximum to the bird community variation between lower and middle reaches. A similar pattern was seen in the lower and upper reaches. Along with the other bird species White-throated Kingfisher *Halcyon smyrnensis* also contributed to the variation between middle and upper reaches. The presence of other species like Red-wattled Lapwing *Vanellus indicus*, Black-headed Ibis *Threskiornis melanocephalus*, Large Pied Wagtail *Motacilla maderaspatensis*, Common Sandpiper *Actitis hypoleucos*, Intermediate Egret *Ardea intermedia*, Chestnut-headed Bee-eater *Merops leschenaulti*, and Marsh Sandpiper *Tringa stagnatilis* had different abundances between ecological zones which resulted in dissimilarities evident in nMDS and ANOSIM.

Non-water associated birds

The lower reaches, middle reaches, and upper reaches are distinct in species compositions (nMDS: Stress = 0.19, Non-metric R² = 0.96) (Figure 4). However, most of the sites in the middle are similar in composition

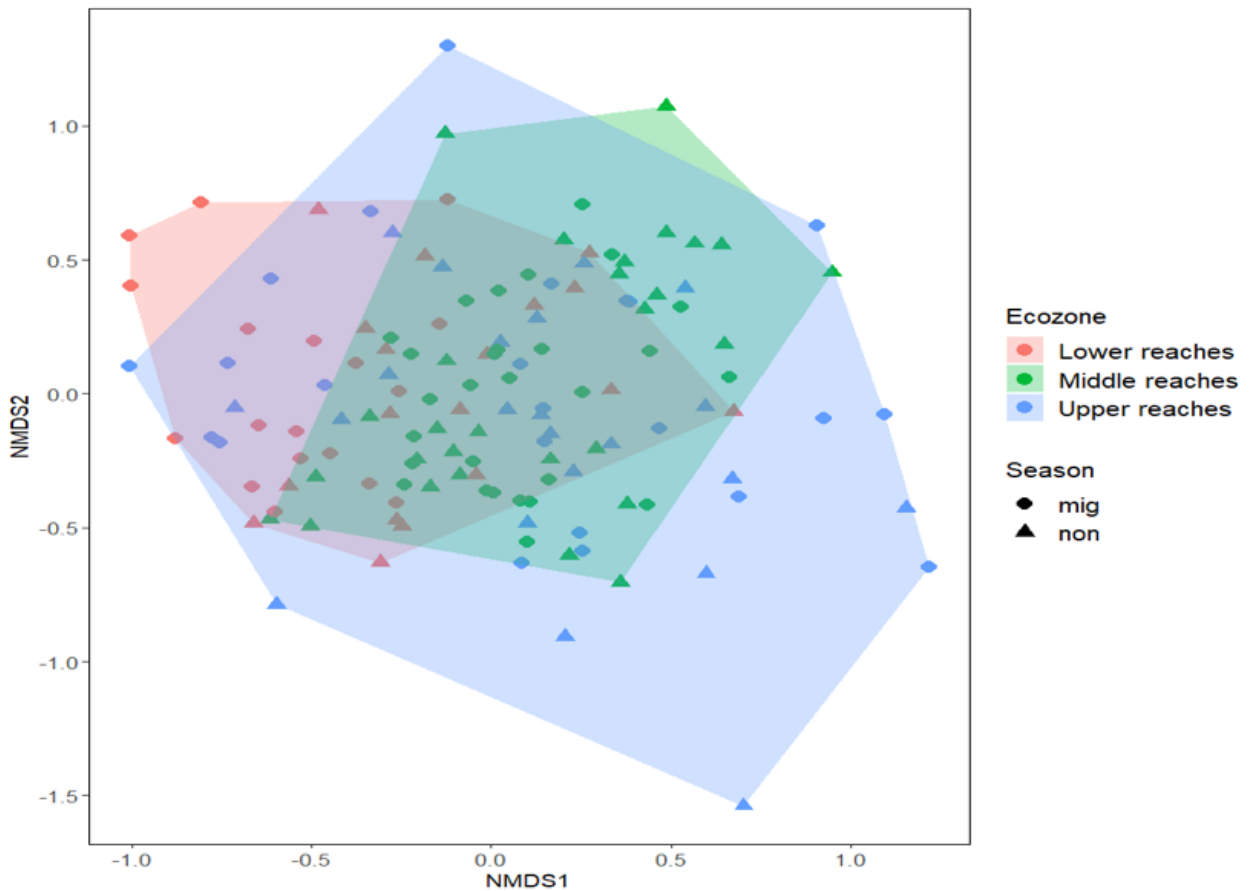


Figure 3. Non-metric multidimensional scaling (nMDS) for water-associated birds (mig: migratory season; non: non migratory season).

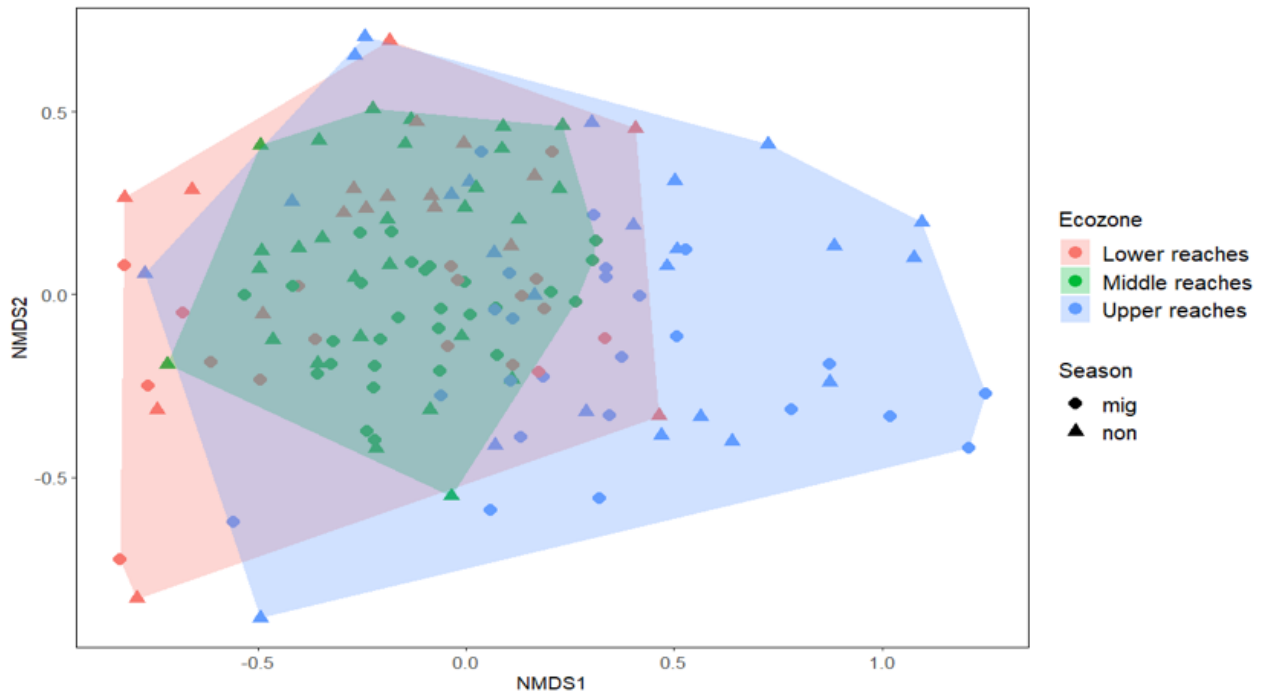


Figure 4. Non-metric multidimensional scaling (nMDS) for non-water associated birds (mig: migratory season; non: non migratory season).

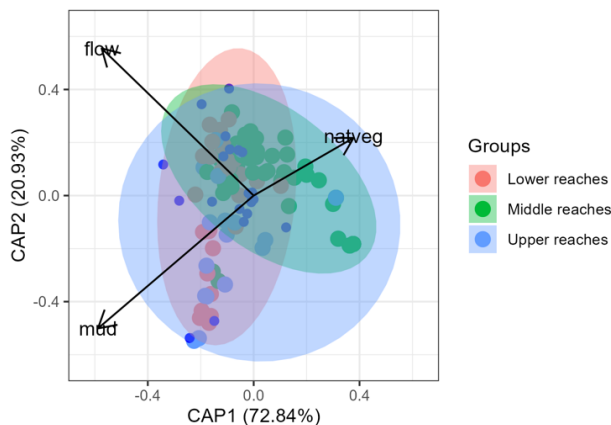


Figure 5. Distance-based redundancy analysis (db-RDA) for water-dependent birds in the migratory season.

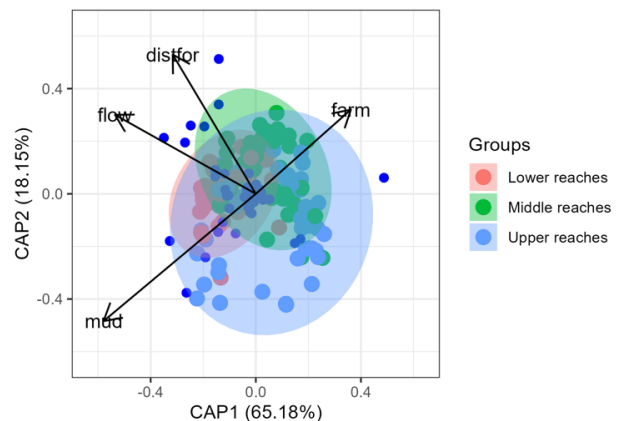


Figure 6. Distance-based redundancy analysis (db-RDA) for water-associated birds in the migratory season.

with upper and lower reaches. Lower and upper reaches have more unique sites with NWABs than with WDBs and WABs. The variation between ecological zones is higher than within ecological zones (ANOSIM: $R = 0.154$, $p < 0.05$). Some sites have unique seasonal assemblages of birds. This made composition in the migratory seasons, and seasonal variation significant (ANOSIM: $R = 0.053$, $p < 0.05$).

In non-river-associated birds, differential abundances of synanthropic species were found to be contributing factors to dissimilarity between ecozones. House Crow *Corvus splendens*, Asian Palm Swift *Cypsiurus balasensis*,

Rock Pigeon *Columba livia*, Common Myna *Acridotheres tristis*, Yellow-billed Babbler *Turdoides affinis*, Large-billed Crow *Corvus macrorhynchos* and Barn Swallow *Hirundo rustica* contributed to the bird community variation between the lower and middle reaches; middle and upper reaches; and lower and upper reaches. The abundance variation of Black Kite *Milvus migrans* and Purple-rumped Sunbird *Leptocoma zeylonica*, also contributed much to these variations.

Factors Influencing Bird Community structure in Bharathapuzha river basin

Selected environmental parameters were analyzed using distance-based redundancy analysis (Db-RDA) for WDBs and WABs during the migratory season and non-migratory seasons. The results are given below.

Water-dependent birds in migratory season

Db-RDA for WABs during migratory season showed that the constrained axis explained the significant variation (CAP1 Eigenvalue = 1.87 Proportion explained = 78.0%, CAP2 Eigenvalue = 0.52 Proportion explained = 21.9%) (Figure 5). Forward selection of environmental

Table 1. Table 1. Forward selection of variables and adjusted R² for distance-based redundancy analysis (db-RDA) of water-dependent birds in the migratory season.

	Variables	R ²	R ² Cum	AdjR ² Cum	F	p value
1	Mudflats	0.048893593	0.04889359	0.04055055	5.8604059	0.016*
2	Water flow	0.023191219	0.07208481	0.05566153	2.8241889	0.047*
3	Check dams	0.011114354	0.08319917	0.05864200	1.3577732	0.251
4	Altitude	0.011698160	0.09489733	0.06228101	1.4346392	0.209
5	Farmland	0.009676843	0.10457417	0.06387300	1.1887671	0.287
6	Barren land	0.017266246	0.12184042	0.07350136	2.1431422	0.100
7	Riverside vegetation	0.026095423	0.14793584	0.09270946	3.3076214	0.039*
8	Sandbank	0.010357548	0.15829339	0.09536205	1.3166793	0.247
9	Temperature	0.006612920	0.16490631	0.09400213	0.8393903	0.391
10	Area of water channel	0.005256994	0.17016330	0.09113123	0.6651722	0.530
11	Distance from forest	0.004208018	0.17437132	0.08704521	0.5300614	0.660
12	Rocks	0.003517995	0.17788931	0.08210943	0.4407600	0.641
13	Waste dumping	0.003243874	0.18113319	0.07676781	0.4040647	0.646
14	Rainfall	0.003320936	0.18445412	0.07140816	0.4112761	0.740
15	Perches	0.002203425	0.18665755	0.06465618	0.2709098	0.863
16	Distance from human settlements	0.002033782	0.18869133	0.05757074	0.2481724	0.776

Table 2. Forward selection of variables and adjusted R² for distance-based redundancy analysis (db-RDA) of water-dependent birds in the non-migratory season.

	Variables	R ²	R ² Cum	AdjR ² Cum	F	p value
1	Altitude	0.04512	0.04512	0.02744	2.55158	0.072
2	Area of Water channel	0.03282	0.07794	0.04314	1.88627	0.172
3	Distance from forest	0.04089	0.11883	0.06799	2.4132	0.107
4	Temperature	0.03344	0.15227	0.08578	2.01166	0.108
5	Water flow	0.01454	0.16681	0.08349	0.87254	0.353
6	Farmland	0.0166	0.18341	0.08342	0.99612	0.315
7	Riverside vegetation	0.01542	0.19882	0.08198	0.92355	0.356
8	Check dam	0.01229	0.21111	0.07683	0.73204	0.459
9	Barren land	0.00748	0.21859	0.0657	0.44006	0.572
10	Mudflats	0.00529	0.22388	0.0514	0.30674	0.679
11	Sandbanks	0.00452	0.2284	0.0355	0.25777	0.709
12	Distance from human settlement	0.00437	0.23276	0.01865	0.24464	0.64
13	Sewage	0.003	0.23576	-0.0008	0.16473	0.75
14	Waste dumping	0.00221	0.23796	-0.0222	0.1187	0.846
15	Rain fall	0.0026	0.24057	-0.0442	0.13703	0.855
16	Rocks	0.00106	0.24163	-0.0695	0.05473	0.967

variables revealed that the Area of mudflats ($R^2 = 0.048$, $F = 5.86$, $p < 0.05$), area of water flow ($R^2 = 0.02$, $F = 2.82$, $p < 0.05$) and riverside vegetation ($R^2 = 0.02$, $F = 3.30$, $p < 0.05$) to be affecting species composition in sites with 9.4% variation explained in Table 1.

Water-depended birds during the non-migratory season

Db-RDA for WDBs during migratory season showed no constrained or unconstrained axis explaining significant variation. Forward selection of environmental variables also didn't show significant variation between bird community and environmental variables (Table 2).

Water-associated birds in Migratory season

Db-RDA for water-associated birds during migratory explained that the constrained axis showed significant variation (CAP1 Eigenvalue = 2.51 Proportion explained = 65.1%, CAP2 Eigenvalue = 0.70, Proportion explained = 18.15%) (Figure 6). Forward selection of environmental variables revealed that the area of mudflats ($R^2 = 0.05$, $F = 8.13$, $p < 0.05$) and area of water flow ($R^2 = 0.02$, $F = 3.39$, $p < 0.05$), distance from forest ($R^2 = 0.05$, $F = 8.13$, $p < 0.05$), and distance from farm ($R^2 = 0.05$, $F = 8.13$, $p < 0.05$) weakly affected species composition in ecological zones with 9.4% variation explained in Table 3.

Water-associated birds in Non-migratory season

Db-RDA for WABs during migratory season showed that only one constrained axis explained significant variation (CAP1 Eigenvalue = 0.46 Proportion explained = 46.7%, MDS1 Eigenvalue = 3.02 Proportion explained = 13.88%) (Figure 7). Forward selection of environmental variables revealed that the area of mudflats ($R^2 = 0.05$, $F = 8.13$, $p < 0.05$) weakly affects species composition in ecological zones with 3.2% variation explained in Table 4.

DISCUSSION

Bharathapuzha river basin has 262 species of birds with a significant number of residents and migrants which are distributed throughout the basin (Raj et al. 2023). This indicates the diversity of productive and heterogeneous habitats in the river basin.

This study showed that the bird species composition varied significantly between the ecological zones. This could be because of habitat heterogeneity, seasonal movement patterns, population changes, availability of food and space and climatic conditions in the ecological zones. Similar observations on bird communities were explained earlier by many (Meyer & Turner 1992; Namgail et al. 2017; Gonz'alez-Gajardo et al. 2009;

Table 3. Forward selection of variables and adjusted R² for distance-based redundancy analysis (db-RDA) of water-associated birds in the migratory season.

	Variables	R ²	R ² Cum	AdjR ² Cum	F	p value
1	Mudflats	0.04575	0.04575	0.03873	6.52025	0.006*
2	Water flow	0.03512	0.08087	0.06725	5.15865	0.003*
3	Distance from forest	0.01891	0.09978	0.07963	2.81522	0.029*
4	Farmland	0.0182	0.11798	0.09145	2.74392	0.033*
5	Temperature	0.00924	0.12723	0.09417	1.39808	0.2
6	Riverside vegetation	0.00831	0.13553	0.09594	1.2586	0.234
7	Rainfall	0.01154	0.14707	0.10114	1.75851	0.123
8	Distance from human settlement	0.01035	0.15742	0.10516	1.58428	0.166
9	Perch	0.00667	0.16409	0.10531	1.02164	0.355
10	Altitude	0.00599	0.17008	0.10473	0.91724	0.379
11	Barren land	0.00499	0.17508	0.10306	0.76294	0.504
12	Waste dumping	0.00372	0.1788	0.09996	0.56611	0.644
13	Area of Water channel	0.00345	0.18224	0.09651	0.52276	0.675
14	Sewage	0.0035	0.18574	0.09306	0.52864	0.64
15	Check dam	0.00285	0.18859	0.08882	0.42777	0.829
16	Sandbanks	0.00258	0.19117	0.08422	0.38617	0.818
17	Rocks	0.00119	0.19236	0.07794	0.17628	0.981

Table 4. Forward selection of variables and adjusted R² for distance-based redundancy analysis (db-RDA) of river-associated birds in non-migratory season.

	variables	R ²	R ² Cum	AdjR ² Cum	F	p value
1	Mudflats	0.04636	0.04636	0.03192	3.20881	0.026*
2	Sandbanks	0.03052	0.07688	0.04848	2.14872	0.09
3	Riverside vegetation	0.02782	0.1047	0.06274	1.98887	0.091
4	Rock	0.0219	0.1266	0.07115	1.57952	0.168
5	Water flow	0.01709	0.14369	0.07463	1.23718	0.276
6	Barren land	0.02022	0.16391	0.08167	1.47528	0.177
7	Distance from human settlement	0.01327	0.17718	0.08118	0.9675	0.243
8	Distance from forest	0.01141	0.18859	0.07857	0.82981	0.537
9	Check dam	0.01118	0.19977	0.07559	0.81019	0.538
10	Perch	0.01081	0.21058	0.07209	0.7808	0.495
11	Rainfall	0.00853	0.21911	0.06573	0.61199	0.68
12	Area of water channel	0.00867	0.22778	0.0593	0.61734	0.671
13	Temperature	0.00585	0.23363	0.04913	0.41207	0.797
14	Farmland	0.00597	0.2396	0.03874	0.41588	0.828
15	Waste dumping	0.00795	0.24754	0.03049	0.54923	0.685
16	Sewage	0.00417	0.25171	0.01695	0.28391	0.892
17	Altitude	0.00223	0.25394	0.00028	0.1495	0.978

Runge et al. 2015; Yang et al. 2022).

The bird community includes various species of flocking birds, colonial breeding birds and synanthropic birds. Their contribution to the variation was more visible due to the relatively high abundance. The high abundance of synanthropic species such as Red-vented Bulbul, Red-whiskered Bulbul, House Crow, and Black Drongo is considered as an indicator of human influence or urbanization (Plass & Wunderle 2013; Kurucz et al. 2021). They were found to be in high abundance in the upper reaches indicating that the habitats in the upper reaches are under anthropogenic pressure (John et al. 2019). Black Kite, Brahmini Kite, Cattle Egret, Rock Pigeon and House Crow were found in large numbers in the lower reaches. This indicates that the lower reaches of the river is highly urbanised and the generalist species thrive in the region.

The resident birds also contributed to the changes in the species composition. This could be because of their tolerance and adaptation to local fragmentation and disturbance (Rendón et al. 2008; Donaldson et al. 2016). Areas in the lower reaches provide wintering sites for many long-distance migrant birds. Black-headed Gull, Brown-headed Gull, and Pallas' Gull were found in high abundance in the lower reaches. This indicates that these migrant birds are highly dependent on the large waterbodies of the lower reaches.

Environmental factors influencing the water-dependent and water-associated birds in the Bharathapuzha river basin.

The area of mudflats, area of water flow, riverside vegetation, distance from forest, and distance from farmland are the environmental parameters that have positively influenced the WDB and WAB bird communities' distribution. Various studies indicate the importance of mudflats and the area of water flow on the WAB communities (Bellio & Kingsford 2013; Aarif et al. 2014; Clemens et al. 2014; Murray & Fuller 2015; Luo et al. 2019).

Mudflats are one of the important ecosystems which determine the characteristics of the river channel. In the Bharathapuzha river basin, from the upper reaches to the lower reaches, mudflats are seen everywhere in various degrees. In some locations, mudflats form due to the natural flow of water, whereas in some areas it is created due to the check dams. In the upper and lower reaches, relatively more extensive mudflats are available for the WDB and WAB for foraging and resting. These mud flats are one of the most productive ecosystems and are reported to have high levels of benthic and soil biota (Dittmann 2008; Dissanayake 2019). The mud flats in the river basin are prone to high anthropogenic threats due to encroachment and sand mining. River-side farming is a common practice in the Bharathapuzha river basin.

The farmers here use these mudflats for farming during the summers. This extensively reduces the space and food availability of birds. Destruction or disappearance of these habitats can decrease the diversity of WDB and WAB. The study strongly recommends the protection and management of existing mudflats in the riverine area.

The area of water flow represents the percentage of water in the river channel. Bharathapuzha is a perennial river. The water level reduces drastically during the summers. Though the water is less in the river channel, the flow is continuous. The anthropogenic activities in the river have drastically interrupted the water flow. The construction of dams and check dams in various places has altered the natural flow. The large waders (herons, egrets, and storks) and shorebirds (plovers and sandpipers) prefer the shallow flowing water in the lower reaches. But the deep divers like kingfishers are seen mostly in the middle reaches. The ducks and cormorants prefer the stagnant water in the dams and check dams. This indicates that the changes in the water levels in the river channel influence the bird community. The study highlights the importance of maintaining the flow of the river to protect the birds and ecosystem in the river basin.

Riverside vegetation includes the vegetation patches seen on the riverside, inside the river channel, and the floating vegetation on the water. The egrets and herons are seen foraging in these habitats. The White-breasted Waterhen and Purple Moorhen were found nesting on floating vegetation. In many locations, the vegetation inside the water channel was created due to anthropogenic activities such as sand mining and check dam construction. Several bird species use this as a breeding and foraging ground. Large flocks of Cattle Egrets and little cormorants are seen in such vegetation. Apart from the birds, otters also are observed to use this area as their shelter which is prone to periodical fires in summer.

Distance from forest and distance from farmland shows a weak statistical significance in its effect on the bird communities. The lower reaches of the Bharathapuzha River are dominated by paddy cultivation. Most of the WAB depend on these habitats for foraging.

CONCLUSION

The present study, recommends a systematic survey of the check dams and their effectiveness in the river basin. A regulation on check dam construction has to be

brought into action and unwanted check dams should be removed to ensure the water flow. No significant correlations between most variables and birds were found in our study in the non-migratory season. The non-migratory season data collection was conducted from April 2018 to September 2018, in which the Kerala flood occurred. The flood in the Bharathapuzha River affected largely on the microhabitats and riverine ecosystems which in turn reflected on the environmental parameters collected during the survey. The recent trend in changes in rainfall patterns, floods and droughts in the river basin may affect the bird communities. Seasonal variation in river channels and resource availability needs to be studied in detail. In the present study, most of the study locations fell outside the protected area network. The bird diversity in the river basin shows the importance of the non-protected areas in biodiversity conservation (Raman & Sukumar 2002; Raman & Mudappa 2003; Raman 2006; Anand 2010; Raj et al. 2023). To protect these habitats which support bird diversity new strategies such as land-sharing with local communities are required which ensure effective biodiversity conservation over a large landscape like the Bharathapuzha river basin.

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