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**Cover: Common Keeled Skink *Eutropis carinata* in oil pastels, colour pencils, & micron pen adapted from photograph by H. Byju © Pooja Ramdas Patil.**

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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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**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

Bird species respond rapidly to any changes in the environment (Būhning-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 km$^2$, 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 km$^2$ 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

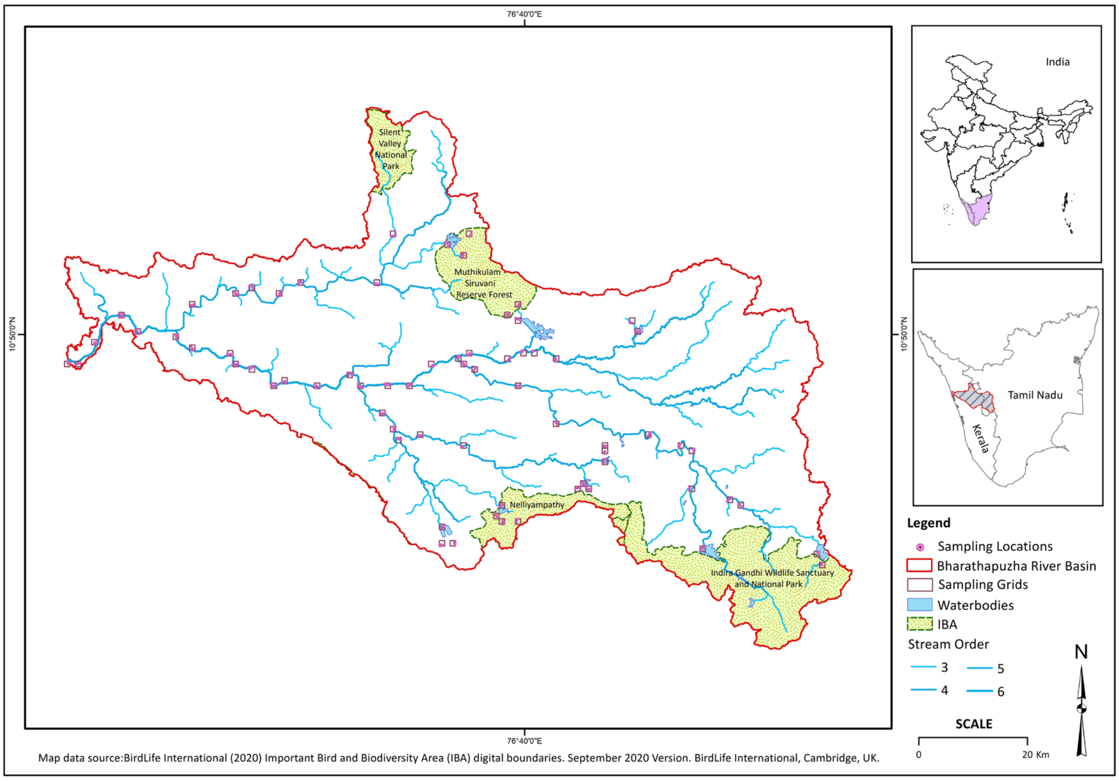


**Figure 1. Location map of Bharathapuzha River Basin showing streams and sampling locations.**

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

Water-associated birds (WAB) include the taxonomic groups such as Pelecaniformes, Ciconiformes, Gruiformes, Charadriiformes, and a few members of Coraciiforms, 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, Coraciiforms, 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 α = 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 *Ichthyaetus ichthyaetus*, 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

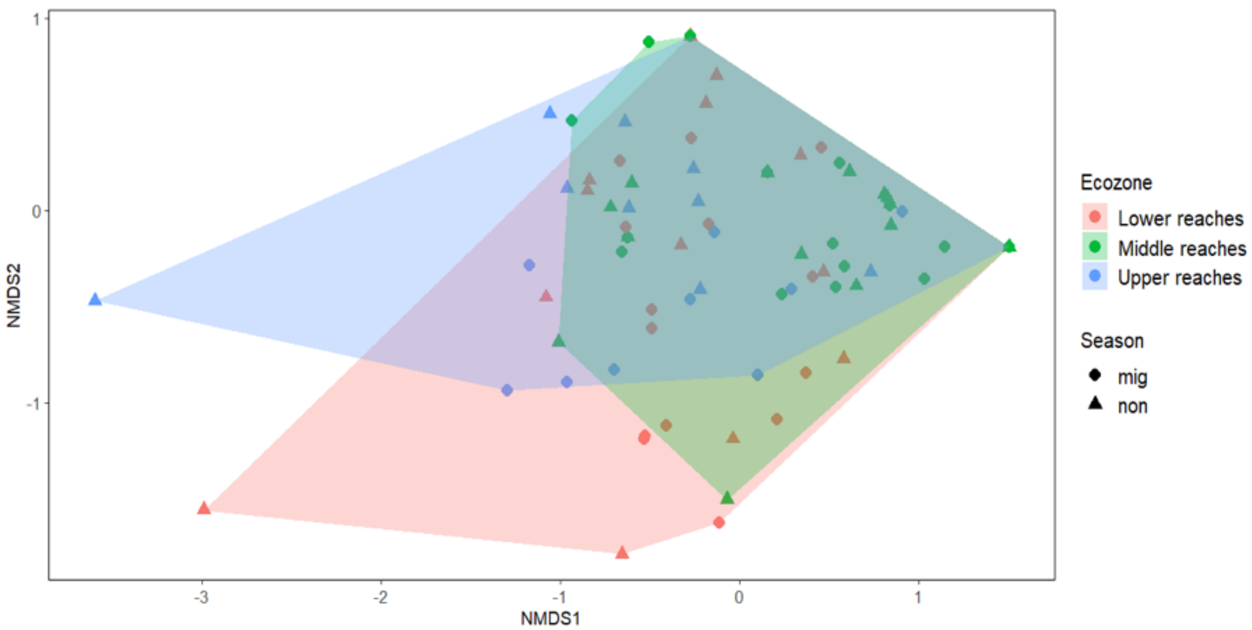


**Figure 2. Non-metric multidimensional scaling (nMDS) for water-dependent birds (mig: migratory season; non: non migratory season).**

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 $R^2$ = 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 $R^2$ = 0.96 ) (Figure 4). However, most of the sites in the middle are similar in composition

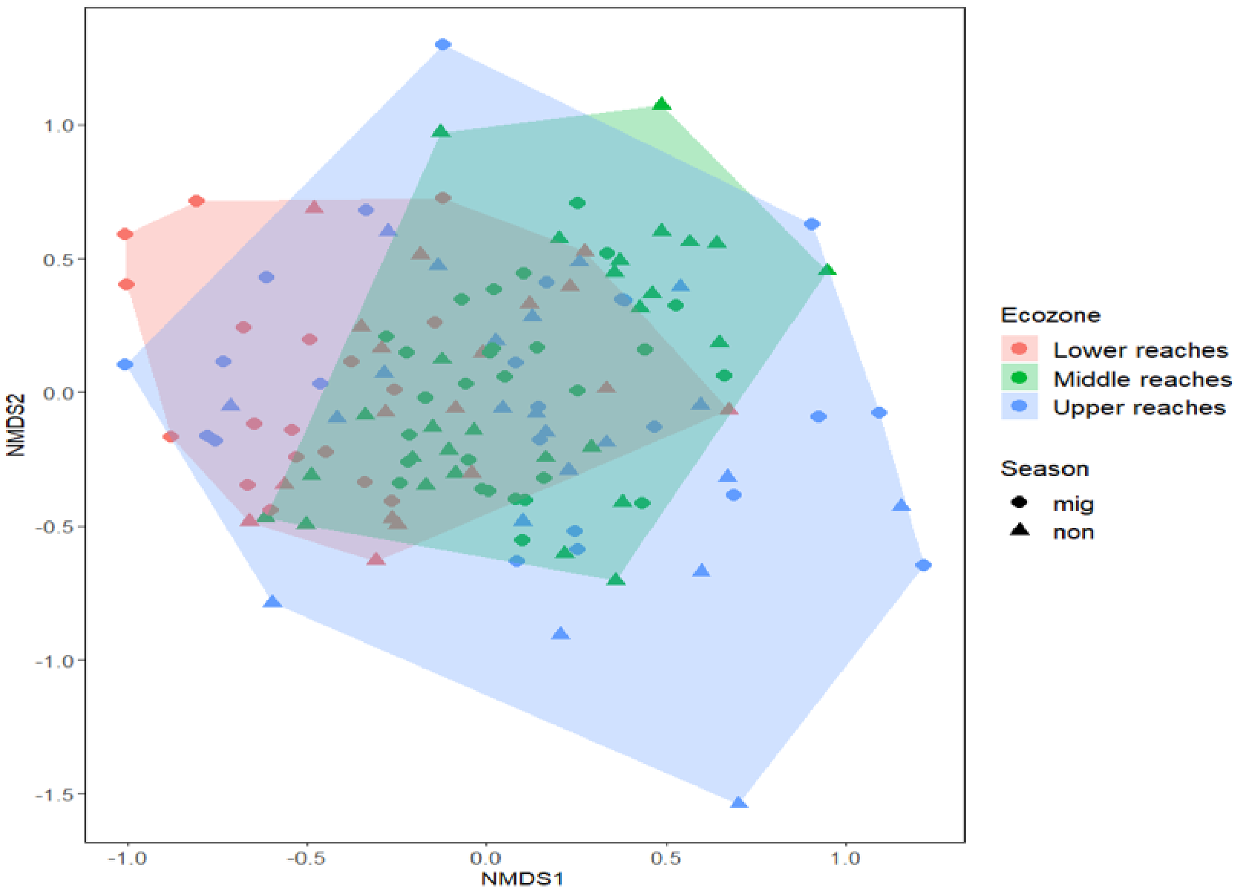


**Figure 3. Non-metric multidimensional scaling (nMDS) for water-associated birds (mig: migratory season; non: non migratory season).**

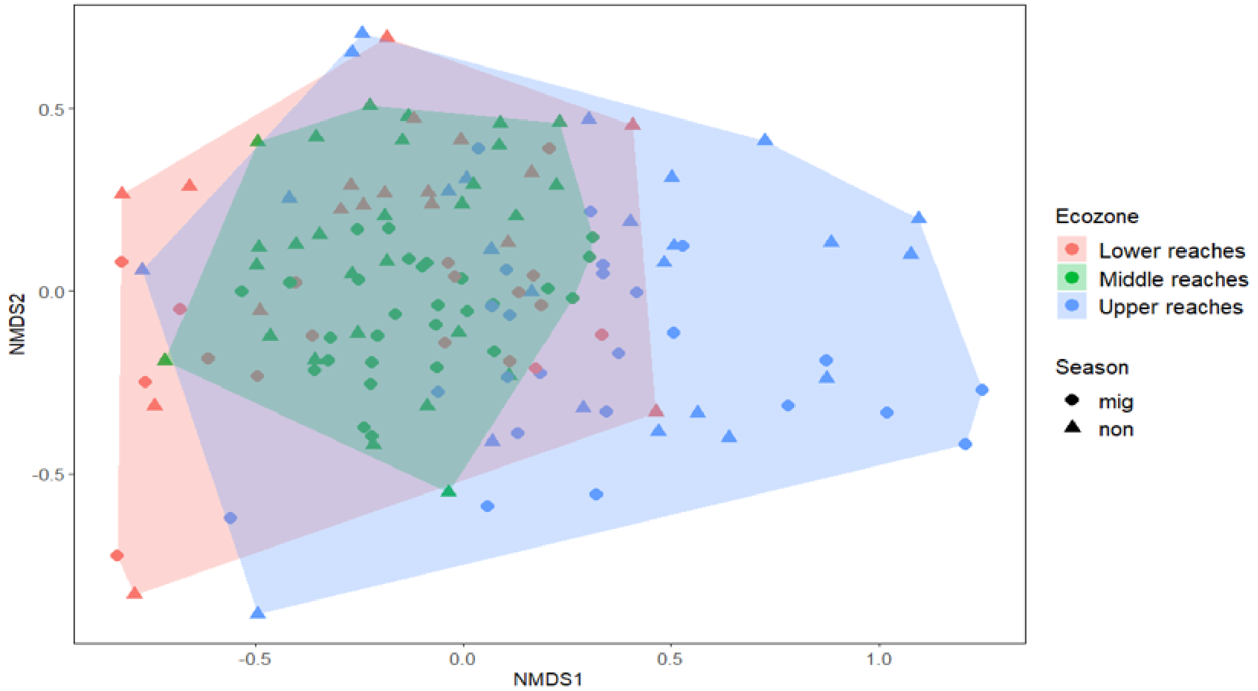


Figure 4. Non-metric multidimensional scaling (nMDS) for non-water associated birds (mig: migratory season; non: non migratory season).

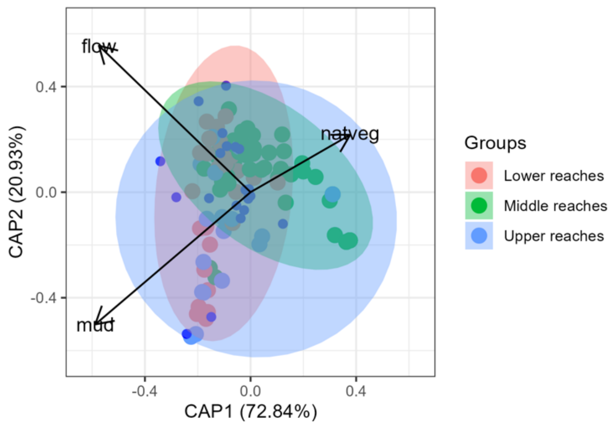


Figure 5. Distance-based redundancy analysis (db-RDA) for water-dependent birds in the migratory season.

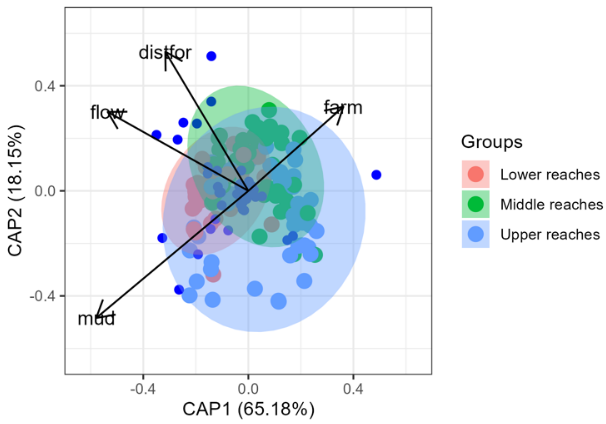


Figure 6. Distance-based redundancy analysis (db-RDA) for water-associated birds in the migratory season.

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 balasiensis*, 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-depended 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 $R^2$ for distance-based redundancy analysis (db-RDA) of water-dependent birds in the migratory season.

| | Variables | $R^2$ | $R^2$Cum | Adj$R^2$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 $R^2$ for distance-based redundancy analysis (db-RDA) of water-dependent birds in the non-migratory season.

| | Variables | $R^2$ | $R^2$Cum | Adj$R^2$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 $R^2$ for distance-based redundancy analysis (db-RDA) of water-associated birds in the migratory season.**

| | Variables | $R^2$ | $R^2$Cum | Adj$R^2$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 $R^2$ for distance-based redundancy analysis (db-RDA) of river-associated birds in non-migratory season.**

| | variables | $R^2$ | $R^2$Cum | Adj$R^2$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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