PATTERNS OF DISTRIBUTION AND MULTISCALE-HABITAT CORRELATES OF RIVERINE BIRDS IN THE UPPER GANGES, WESTERN HIMALAYA

A THESIS
Submitted by

ANKITA SINHA

for the award of the Degree of

**DOCTOR OF PHILOSOPHY
IN
WILDLIFE SCIENCE**

Under the guidance of

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Declaration by the Candidate

I declare that the thesis entitled **Patterns of distribution and multiscale-habitat correlates of riverine birds in the Upper Ganges, Western Himalaya** submitted by me for the degree of Doctor of Philosophy is the record of research work carried out by me during the period from **2014 to 2019** under the guidance of **Dr. K. Ramesh, Dr. B.S. Adhikari and Prof. S.J. Ormerod** and has not formed the basis for the award of any degree, diploma, associate ship, fellowship, titles in this or any other University or other institution of higher learning. I further declare that the material obtained from other sources has been duly acknowledged in the thesis. I shall be solely responsible for any plagiarism or other irregularities, if noticed in the thesis.

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Ms. Ankita Sinha has put in more than six terms of research work embedded in this thesis under our guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

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Mysterious and little-known organisms live along the whitewaters of the Himalaya. In the end, I hope that the time spent on the banks of the mountain streams will help me evolve as a researcher and unravel answers to many questions which remain unanswered as yet.

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Summary

1. Fauna associated with riverine ecosystems vary considerably at the global scale ranging from obligate terrestrial to obligate aquatic. Birds constitute key components of wildlife along running water systems.
2. The global river bird community is diverse with 66 species, spanning across 19 families with 37 non-passerines and 29 passerines. Asia has the maximum number of species followed by South America and Africa.
3. The global distribution ranges of specialist river birds show that large areas of the world hold few or no specialist riverine birds. Richness peaks in the eastern Himalaya and the Myanmar-China border, around the Kakabo Raazi mountains where more than 15 species of specialist river birds overlap in range.
4. Species richness reflects considerable radiation in particular groups; Muscicapidae (small passerine insectivorous birds mostly belonging to the old world) in Asia, ovenbirds (Funariidae) and tyrant flycatchers (Tyrannidae)in South America, and the Pratincoles (Glareolidae) in Africa.
5. Ecological understanding and conservation efforts of specialist river birds remain rudimentary especially in the tropics where rivers are faced with a host of threats.
6. In this particular study, field surveys were undertaken to understand bird community composition and river habitat characteristics across summer (breeding) and autumn (wintering/non-breeding) seasons in the Bhagirathi basin, a major headstream of the Upper Ganges in the state of Uttarakhand in the western Indian Himalaya between years 2014 and 2018.

7. The Bhagirathi river runs for 217 km along an elevational gradient, between 3100m and 330m a.s.l. This basin was chosen as it provides a huge elevational gradient and variations in both natural and anthropogenic land-use.
8. A total of 32 bird species from 12 families were found using riparian resources. Birds were grouped into river obligates and non-obligates based on their dependence on river production.
9. Breeding records of most of the passerine birds (river chats, Grey and White Wagtail, Brown Dipper, Little Forktail), and others like the Ibisbill and Common Sandpiper were recorded along higher elevation river reaches; species richness thus increasing with elevation in summer. All the passerines wintered to lower elevation river reaches in autumn elevating species richness thus increasing in these sites. Crested Kingfisher, White-browed Wagtail and River Lapwing were recorded to be breeding along lower elevation river reaches, also these species did not show altitudinal migration
10. River bird distribution reflected channel character, bank morphology, aspects of river flow and land use patterns. Results from field surveys showed there were two distinct assemblages shaped by variable habitat preferences of bird species along the Bhagirathi river. Riverine specialists were associated significantly with the least modified river reaches characterised by faster flows, exposed bedrocks, banks with pebbles, boulders with more intact riverine forests against non-obligate bird species that apparently preferred wider channels with slow flow and more urban land-use.
11. The functional dispersion in river specialist birds in the Bhagirathi basin varied according to different environmental variables in the riverine habitat, indicating that trait dispersion in the functional space of species are uncoupled in these communities. Birds showed strong phylogenetic signal in body size, bill size and tarsus length.

12. Population trends of the global river bird assemblage shows that larger body-sized birds are more threatened and birds with a smaller global geographical range (often endemic to islands) are the most threatened.
13. Over 15 species of specialist river birds are endemic to islands or are restricted to very small geographic distributions on the mainland. Three species, the Brazilian Merganser, White-bellied Heron and Javan Blue-banded Kingfisher are Critically Endangered, while five, six and eleven species have been categorised as Endangered, Vulnerable and Near Threatened respectively by the IUCN with multiple factors leading to their declining populations.
14. According to the IUCN database dams and other water management schemes impact populations of more than fifteen species globally notably the White-bellied Heron (Critically Endangered), Brazilian Merganser (Critically Endangered), Blue Duck (Endangered), Wrybill (Vulnerable) and Indian Skimmer (Vulnerable). Disturbance created by recreational activities, other human works in riparian zones like annual and perennial non-timber cropping, removal of riparian forests are other major factors affecting threatened specialist river bird species of the world.
15. Some species which require immediate attention in the Indian context are the White-bellied Heron, Black-bellied Tern and the Indian Skimmer. The decline of many of these species is attributable to widespread increases in human disturbance, exploitation and degradation of rivers and associated wetlands through fishing, transportation, domestic use, irrigation schemes and pollution from agricultural and industrial chemicals.
16. Variability in flow conditions, especially large fluctuations in water velocity and depth caused by hydroelectric projects and impoundments, modification of natural

banks to concrete embankments, removal of natural riverine forest to enhance opportunities for agriculture

17. Biodiversity assessments which form crucial components of Environmental Impact Assessments conducted prior to developmental projects along rivers exclusively target charismatic species. Ecosystem specific taxa which are more sensitive to minute changes in the riverine environment and adequate consideration in future.

Chapter 1

INTRODUCTION

Freshwater fauna are exceptionally biodiverse (Revenga and Kura, 2003; Naiman *et al.*, 2006) contributing to almost a quarter of the total vertebrate diversity on earth (Strayer and Dudgeon, 2010; Molur *et al.*, 2011), while they constitute about 10 % of all animal species on earth (Revenga and Kura, 2003; Naiman *et al.,* 2006; Dudgeon *et al.,* 2006; Ballian *et al*., 2008), Many vertebrates are associated in some way with running waters and some are clearly ecologically important owing to their critical roles in aquatic food webs (He *et al.*, 2018). Apart from fishes, very little is known about their roles and importance in the running water ecosystem. Information on other megafauna remains localised and patchy despite the fact that the rate of decline of vertebrate populations is much higher (81%) in freshwater systems than in terrestrial (38%) and marine (36%) realms (WWF, 2016; He *et al.,* 2018; Reid *et al.,* 2018).

Rivers and streams constitute significant components of freshwater habitats. Riverine ecosystems are transition habitats between aquatic and terrestrial zones and undergo exchange of matter and energy (Ward, 1998; Ward *et al.,* 2002a; Helfield and Naiman, 2001; Nakano and Murakami, 2001;Woodward and Hildrew, 2002); harbouring biota which are characteristic of terrestrial-aquatic continuum habitats. The species pool residing in these habitats characteristically possess life history traits that enable them to operate between these interface zones (Murakami and Nakano, 2000; Nakano and Murakami, 2001). Riverine fauna form significant components of inland waters comprising of a mixture of terrestrial and aquatic communities inhabiting diverse lotic, lentic, riparian and groundwater habitats (Ward *et al.,* 2002). These biodiverse communities which range from being obligate terrestrial to obligate aquatic are uniquely adapted to exploit the high turnover of habitat patches characteristic of riverine ecosystems (Robinson *et al.,* 2002).

Birds are a part of almost all ecosystems across the globe and variably function as predators, pollinators, scavengers, seed dispersers and ecosystem engineers (Whelan *et al.,* 2008). Birds are relatively well known as they have been studied for a very long time now, with distinctively adaptive traits evolved to live in certain environments (Schulze *et al.,* 2004; Hausner *et al.,* 2003; Gregory *et al.,* 2003; Mistry *et al.,* 2008). Birds have been efficiently used to design a series of metrics based on assemblage structure (Bradford *et al.,* 1998; Canterbury *et al.,* 2000; Gregory *et al.,* 2005; Siriwardena *et al.,* 2019) and functional diversity (Suri *et al.,* 2017) to reflect the ecological health of the ecosystems they inhabit. Globally, river birds constitute an abundant, diverse and conspicuous element of the vertebrate fauna inhabiting riverine areas (Ormerod and Tyler, 1993; Buckton and Ormerod, 2002). River birds are riparian consumers that benefit from aquatic transfers gained from insects emerging from streams (Sullivan *et al.,* 2007; Nakano and Murakami, 2001; Buckton and Ormerod, 2008). They depend on riverine resources for their feeding, breeding and roosting (Sullivan *et al.,* 2007; Buckton and Ormerod, 2008). Their association with the riverine environment has been overlooked, research has been restricted to few species hitherto and insights on global patterns is restricted (but see Buckton and Ormerod, 2002).

Specialist river birds often occupy higher trophic positions than fishes and hence can potentially reflect impairments in lower trophic levels successfully (Petersson *et al.,* 1995; Steinmetz *et al.,* 2003; Sullivan *et al.,* 2006). Within the stream corridor, riparian-obligate birds might often be expected to respond to changes in surrounding habitats before aquatic organisms (Bryce *et al.,* 2002) as they are more mobile than other taxa and can shift to better sites seeking resources. While avian species have not received significant attention in the bioassessment of streams and rivers, they may complement the traditional use of benthic macroinvertebrates and fish (Feck and Hall, 2004; Ormerod and Tyler, 1995). The role of specialist river birds in the food webs of running water systems have seldom been appreciated although they can often be quite crucial. Owing to their enhanced mobility, birds can respond to irruptive or pulsed resources in ways generally not possible for other vertebrates (Sullivan *et al.,* 2007). Moreover, migratory species link ecosystem processes and fluxes across great distances and times.

The highest mountain range in the world, the Himalaya spans a large latitudinal, longitudinal and elevational gradient. The mountain range is a global biodiversity hotspot (Myers *et al.,* 2000) and hosts an exceptionally rich avian biodiversity (Price *et al.,* 2014). The Himalayan mountains simultaneous to being biologically diverse, are among the most dynamic regions of the world characterized by high levels of erosion and hydraulic vigour (Brewin *et al.,* 2000). A wide range of global change effects now impact the Himalayan rivers, including glacial retreat, increasing modification of catchments and riparian zones, diffuse pollution, urban encroachment, impoundment, and abstraction (Manel *et al.,* 2000). These changes are so extensive that the Ganges is now listed among the world’s top ten rivers at risk from over-exploitation (Wong *et al.,* 2007). So far, however, the ecological consequences of these modifications, are poorly known.

The Himalayan mountain range is home to the most speciose community of specialist river birds at latitudes between 20–40° N with more than 13 species overlapping in range (Buckton and Ormerod, 2002). It remains yet unravelled what drives these patterns at regional and local scales. Specialist river bird assemblages have never been studied before to understand processes which drive co-occurrence patterns across space and time. The high species diversity despite the temperate climate makes the western Himalayas a powerful system to test the general importance of several mechanisms driving the elevational distribution of species and their ecological adaptations. Biogeographically situated in one of the most populous countries of the world, the western Himalaya, faces significant anthropogenic pressures largely through hydropower development, tourism and rampant land-conversions from forest to agriculture or urban dwellings (Elsen *et al.*, 2017a). Hence, provides an ideal setting to study the effects of habitat loss on the ecology of montane birds which are specialized to live in riverine environments. However, a dearth of baseline data for most taxa of this region is a serious challenge for ecological research on distribution regimes.

This research aims to fill the void, with the following objectives:

1. To quantify species diversity and abundance of riverine avifauna and species co-occurrence pattern and species turnover across elevational and fluvial gradients and to study community nestedness.
    - To quantify species richness and abundance patterns of riverine avifauna in the Western Himalaya across elevational and seasonal gradients.
    - To investigate species co-occurrence patterns in specialist riverine birds and understand underlying driving mechanisms.

2. To determine relationships between bird assemblage characteristics and habitat heterogeneity along elevational zones across seasons.

- To determine relationships between bird assemblage characteristics and river habitat structure.

3. To assess the effects of landscape configuration and anthropogenic parameters on the habitat of riverine birds.

- To develop the utility of riverine birds as potential indicators of monitoring riverine landscape health.

By developing a basic understanding of the ecology of riverine birds, there are major opportunities to understand better their significance to nature conservation, river management and in monitoring river ecosystem change, including for climate change research and management.

Chapter 2

RIVER BIRDS OF THE WORLD

2.1 Global patterns of species richness

Analyzing broad biogeographical patterns in species assemblages constitutes a critical step towards elucidating the factors shaping them (MacArthur, 1972; Rosenzweig, 1995). Broad-scale patterns of spatial variation in species distribution are central to many fundamental questions in macroecology and conservation biology. Birds occupy riverine habitats almost in every part of the world except the North and South poles (Bukton and Ormerod, 2002). A phylogenetic tree for the study species was constructed using published phylotree (Jetz *et al.*, 2012) to understand phylogenetic relationships between the species and their biogeographic affinities.

Table 2.1. Specialist riverine birds of the world. 'C' indicates the continents on which the species occurs: 1 = Asia, 2 = Australasia,3 = Europe, 4 = North America, 5 = South America, 6 = Africa. Preferences for stream size. 'Diet' indicates the basic diet of each species, as invertebrates, fish, or plants. The IUCN status is coded as Least Concerned~0; Near Threatened~1; Vulnerable~2; Endangered~3; Critically Endangered~4.

Common name	Scientific name	Family	IUCN status	C	Diet
African Skimmer	*Rhynchops flavirostris*	*Laridae*	1	6	Fish
Indian Skimmer	*Rhynchops albicollis*	*Laridae*	2	1	Fish, crustacea and inverts
River Tern	*Sterna aurentia*	*Laridae*	1	1	Fish, crustacea, tadpole and inverts
Black-bellied Tern	*Sterna acuticauda*	*Laridae*	3	1	Fish, crustacea and inverts
White-bellied Heron	*Ardea insignis*	Ardeidae	4	1	Omnivorous
Fasciated Tiger Heron	*Tigrisoma fasciatum*	Ardeidae	0	5	Fish
Forest Bittern	*Zonerodius heliosylus*	Ardeidae	1	1	Fish
Great Stone Curlew	*Esacus recurvirostris*	Burhinidae	1	1	Inverts
Blue Duck	*Hymenolaimus malacorhynchus*	Anatidae	3	6	Inverts, plant parts
Torrent Duck	*Meganetta armata*	Anatidae	0	5	Inverts
Salvadori's Teal	*Salvadorina waigiuensis*	Anatidae	2	1	Fish, inverts and plants
African black Duck	*Anas sparsa*	Anatidae	0	3	Omnivore
Bronze-winged Duck	*Anas specularis*	Anatidae	1	5	Omnivore
Harlequin Duck	*Histrionicus histrionicus*	Anatidae	0	1, 2, 4	Inverts
Brazilian Merganser	*Mergus octosetaceus*	Anatidae	4	3	Inverts
Scaly-sided Merganser	*Mergus squamatus*	Anatidae	3	1	Fish and inverts
Ibisbill	*Ibidorhyncha struthersii*	Ibidorynchidae	0	1	Inverts
Little pratincole	*Glareola lactea*	Glareolidae	0	1,3	Inverts
Madagascar Pratincole	*Glareola ocularis*	Glareolidae	2	3	Inverts
Rock Pratincole	*Glareola nuchalis*	Glareolidae	0	3	Inverts
Grey Pratincole	*Glareola cinerea*	Glareolidae	0	3	Inverts

White-headed Lapwing	*Vanellus albiceps*	Charadriidae	0	3	Omnivorous
River Lapwing	*Vanellus duvaucelli*	Charadriidae	1	1	Inverts
Wrybill	*Anarchynychus frontalis*	Charadriidae	2	6	Fish and inverts
Wandering Tattler	*Hetreoscelus incanus*	Scolopacidae	0	1,4,5,6	Inverts
Grey-tailed Tattler	*Hetreoscelus brevips*	Scolopacidae	1	1,2,6	Inverts
Blakinston's Eagle Owl	*Ketupa blakistoni*	Strigidae	3	1	Omnivorous
Pel's Eagle Owl	*Ketupa peli*	Strigidae	0	3	Omnivorous
Southern Silvery Kingfisher	*Alcedo argentata*	Alcedinidae	1	1	Fish
Javan Blue-banded Kingfisher	*Alcedo euryzona*	Alcedinidae	4	1	Fish
Malay blue-banded Kingfisher	*Alcedo peninsulae*	Alcedinidae	1	1	Fish
Common Kingfisher	*Alcedo atthis*	Alcedinidae	0	1,2	Fish
Half-collared Kingfisher	*Alcedo semitorquata*	Alcedinidae	0	3	Fish
Blyth's Kingfisher	*Alcedo hercules*	Alcedinidae	1	1	Fish
Green and Rufous Kingfisher	*Chloroceryle inda*	Alcedinidae	0	5	Fish
Crested Kingfisher	*Megaceryle lugubris*	Alcedinidae	0	1	Fish
Pied Kingfisher	*Ceryle rudis*	Alcedinidae	0	1,2,3,5	Fish and inverts
Sharp-tailed Streamcreeper	*Lochmias oustaleti*	Furnariidae	0	5	Inverts
Grey-flanked Cinclodes	*Cinclodes oustaleti*	Furnariidae	0	5	Inverts
Orlog's Cinclodes	*Cinclodes orlogi*	Furnariidae	0	5	Inverts
Torrent Tyrannulet	*Serpophaga cinerea*	Tyrannidae	0	5	Inverts
Black Phoebe	*Sayornis nigricans*	Tyrannidae	0	5	Inverts
Drab Water Tyrant	*Ochthoeca littoralis*	Tyrannidae	0	5	Inverts
Mountain Wagtail	*Motacilla clara*	Motacillidae	0	3	Inverts
Japanese Wagtail	*Motacilla grandis*	Motacillidae	0	1	Inverts

Grey Wagtail	*Motacilla cinerea*	Motacillidae	0	1,2,3	Inverts
Brown Dipper	*Cinclus pallassi*	Cinclidae	0	1,2	Fish and inverts
White-throated Dipper	*Cinclus cinclus*	Cinclidae	0	1,2,3	Fish and inverts
American Dipper	*Cinclus mexicanus*	Cinclidae	0	4	Fish and inverts
Rufous-throated Dipper	*Cinclus schulzi*	Cinclidae	2	5	Fish and inverts
White-capped Dipper	*Cinclus leucocephalus*	Cinclidae	0	5	Fish and inverts
Little Forktail	*Enicurus scouleri*	Muscicapidae	0	1	Inverts
Spotted Forktail	*Enicurus maculatus*	Muscicapidae	0	1	Inverts
Slaty-backed Forktail	*Enicurus schistaceus*	Muscicapidae	0	1	Inverts
Black-backed Forktail	*Enicurus immaculatus*	Muscicapidae	0	1	Inverts
Sunda Forktail	*Enicurus velatus*	Muscicapidae	0	1	Inverts
White-crowned Forktail	*Enicurus leschenaulti*	Muscicapidae	0	1	Inverts
Chestnut-naped Forktail	*Enicurus ruficapillus*	Muscicapidae	0	1	Inverts
Plumbeous water Redstart	*Rhyacornis fuliginosus*	Muscicapidae	0	1	Inverts
Luzon Redstart	*Rhyacornis bicolor*	Muscicapidae	2	1	Inverts
White-capped Redstart	*Phoenicurus leucocephalous*	Muscicapidae	0	1	Inverts
Blue Whistling Thrush	*Myophonous caelerous*	Muscicapidae	0	1	Inverts
Sri Lanka Whistling Thrush	*Myophonous blighi*	Muscicapidae	3	1	Inverts
Torrent Flyrobin	*Monachella muelleriana*	Petrocidae	0	1	Inverts
Louisiana Waterthrush	*Seirus motacilla*	Parulidae	0	4,5	Inverts
Torrent Lark	*Grallina bruijn*	Monarchidae	0	1	Inverts

The global river bird community is diverse with 66 species, spanning across 19 families with 37 non-passerines and 29 passerines (songbirds). The 66 species described here are dependent on streams and river systems for major parts of their life cycle, feed majorly from riverine production and breed along riverine tracts. Some species have been phylogenetically reclassified while some like the Skimmers were not included in the previous list (Buckton and Ormerod, 2002). Species which live in estuaries, marshland or lakes were excluded to ensure focus only on riparian species. I also excluded terrestrial species that sometimes occur in the river corridor, but equally occur in suitable habitats in other environments. For example, Prothonotary Warbler, a wood warbler found in North America, White Wagtail, many ducks and geese which use river habitats more seasonally and are not dependent entirely on riverine resources have been excluded from this list (Table 2.1).

Among the non-passerines, families broadly represent aquatic bird groups like ducks, terns, herons, pratincoles and kingfishers, with the exception of the eagle owls (Strigidae). Two species, the Blackinston's Eagle Owl (*Ketupa blakinstoni*) and Pel' Eagle Owl (*Ketupa peli*) have specialized to live in riverine habitats. Both the species are endemics with very specilaised habits of feeding. Kingfishers (Alcedinidae) followed by ducks (Anatidae) are the most represented groups (Figure 2.1). Whereas in the passerines, (songbirds) all the families are essentially terrestrial birds of which some species have exclusively adapted to live in riparian conditions, with the exception of the family Cinclidae, (dippers) which includes five species described globally (Figure2.2, Table 2.1). White-throated Dipper has the largest distribution range across Europe and Asia and parts of northern Africa, Brown Dipper which is endemic to Asia distributed across the Himalaya, Taiwan, Thailand, the American Dipper which is recorded from North America, White-capped Dipper and the Rufous-throated Dippers, the rarest of all which are passerine birds with an extraordinary capacity of to dive and swim underwater; they live exclusively along rivers and waterfalls all throughout the world and feed on aquatic prey (Tyler and Ormerod, 1994). There is a great variation in body size in the non-passerine group with the world's second largest heron, the White-bellied

Heron being a river specialist to kingfishers like the Eurasian Kingfisher measuring to only 18 cms.

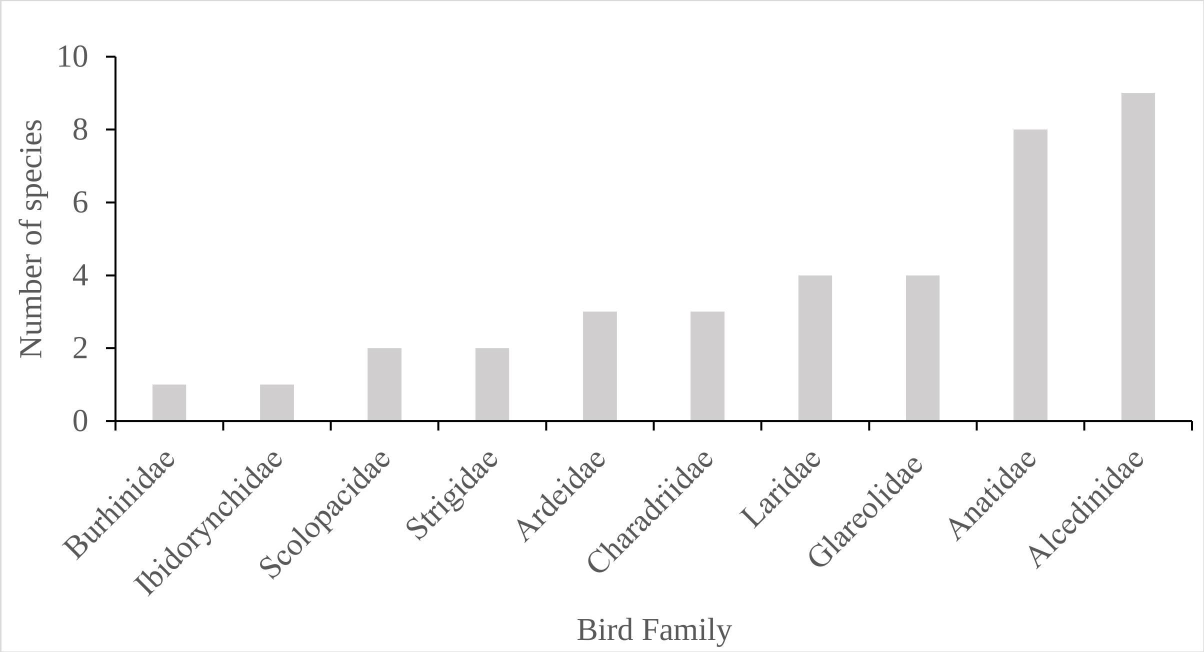


Figure 2.1. Species richness of non-passerine specialist river birds in the world (N=37)

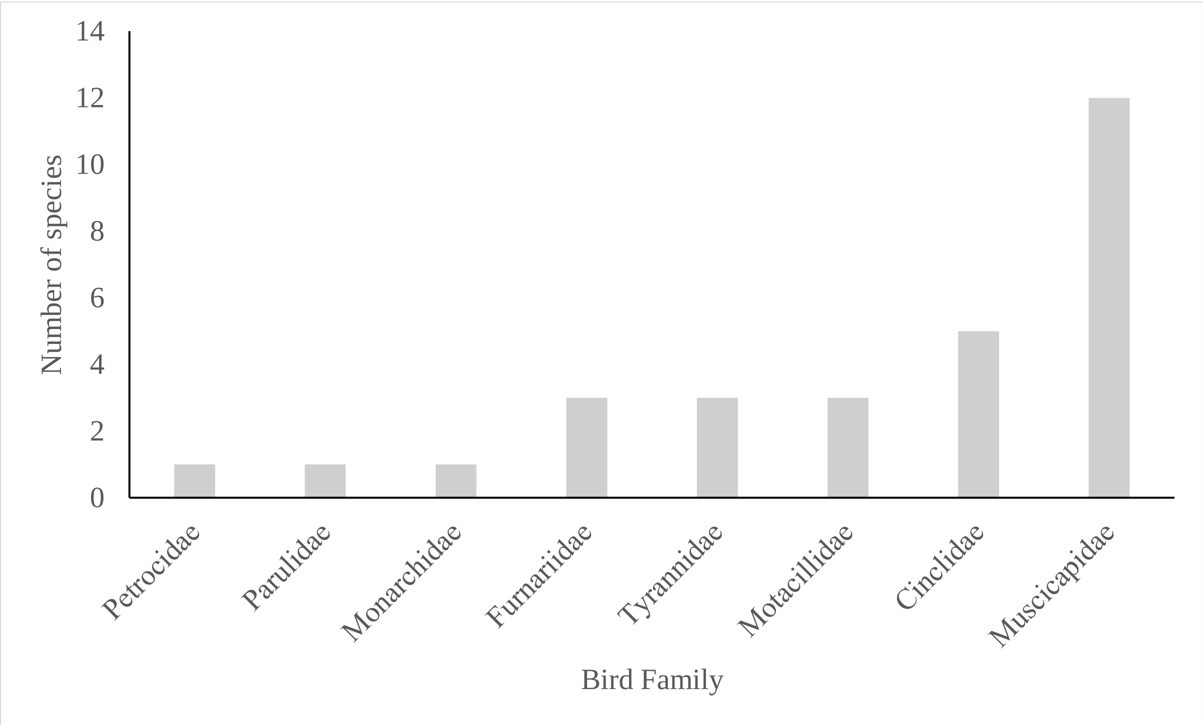


Figure 2.2. Species richness of passerine specialist river birds in the world (N=29)

Four species of specialist riverine birds are single genus (Figure 2.3); all of these are island inhabitants barring the Ibisbill. The bird lives on high elevation shingle riverbanks of the Himalaya and Central Asia and has a shiny bill that is long and curved downwards in the front (Sibley and Monroe, 1990). The Torrent Flyrobin is recorded from New Guinea and the Bismarck Archipelago. Salvadori's teal is reported from New Guinea while the Wrybill is endemic to parts of New Zealand. The Wrybill is unique being the only bird species reported to have its beak always curved towards the right side.

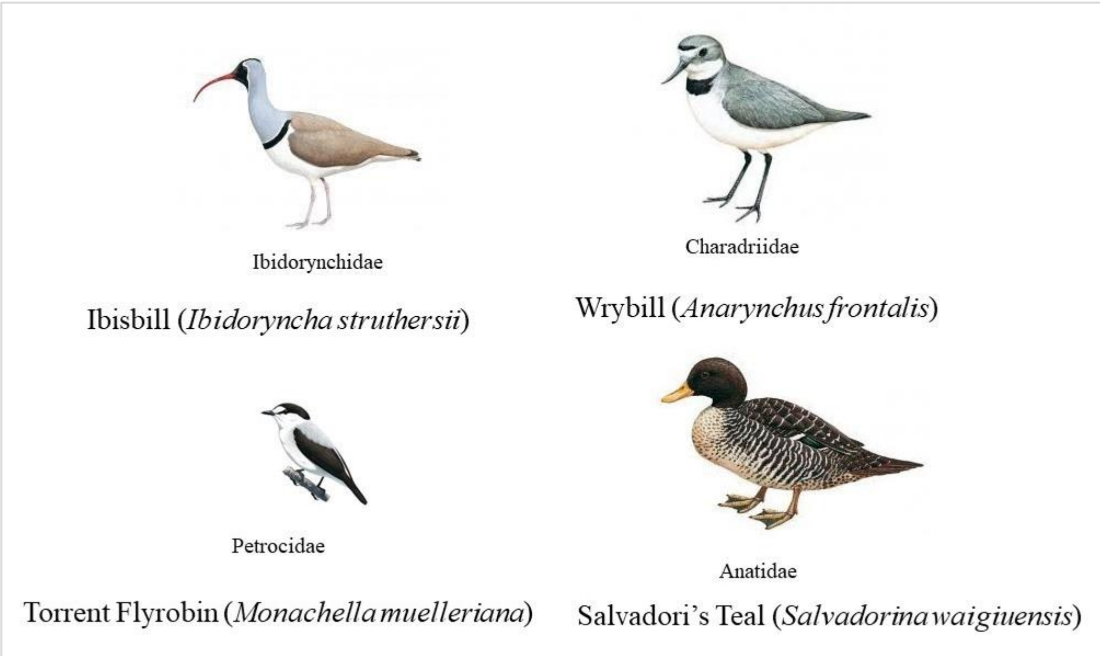


Figure 2.3. Single genus river specialist birds of the world (Picture courtesy: www.hbw.com)

A map depicting richness patterns of specialist river birds of the world was prepared by plotting the individual species range maps downloaded from IUCN (www.iucnredlist.com). Birds have specialized into riparian habitats in all continents except Antarctica (Figure 2.4, Table 2.2). Asia has the maximum number of species followed by South America and Africa. Endemicity also follows the same pattern with maximum endemic species in Asia followed by South America and Africa (Table 2.2). Europe has the minimum number of species and also no endemic species. North America has one species, the Louisiana Waterthrush (*Seirus motacilla*). Interestingly, the mainland of Australia has no species (Figure 2.4), Papua New Guinea has 4 endemic species and two are endemic to New Zealand (Table 2.2).

Table 2.2. Continental species richness and endemicity in specialist river birds

Continent	Number of species	Number of endemic species
Asia	36	28
Africa	12	9
Europe	4	0
North America	4	1
South America	15	13
Oceania	8	6

The global distribution ranges of specialist river birds show that large areas of the world hold few or no specialist riverine birds. Most of North Africa and eastern North America has no bird species which have specialized to live in riverine habitats. Although parts of central and southern Africa have five co-occurring species or more (Figure 2.4); specialist river birds peak in richness around latitudes between 20 -30 degrees North (Figure 2.5) with maximum number of species overlap in range in the eastern Himalayan and Malayan mountain ranges (Figure 2.4). A large proportion of specialist river birds are found in mountainous ecosystems with characteristic adaptations unique to montane microclimates, with 40% of river bird species found between 1000m and 3000m a.s.l., below and above which richness declines (Buckton and Ormerod, 2002). At the global scale more than 15 species of specialist river birds overlap in range in the eastern Himalayan mountains range and the Myanmar-China border, around the Kakabo Raazi mountains, the highest mountains in Myanmar.

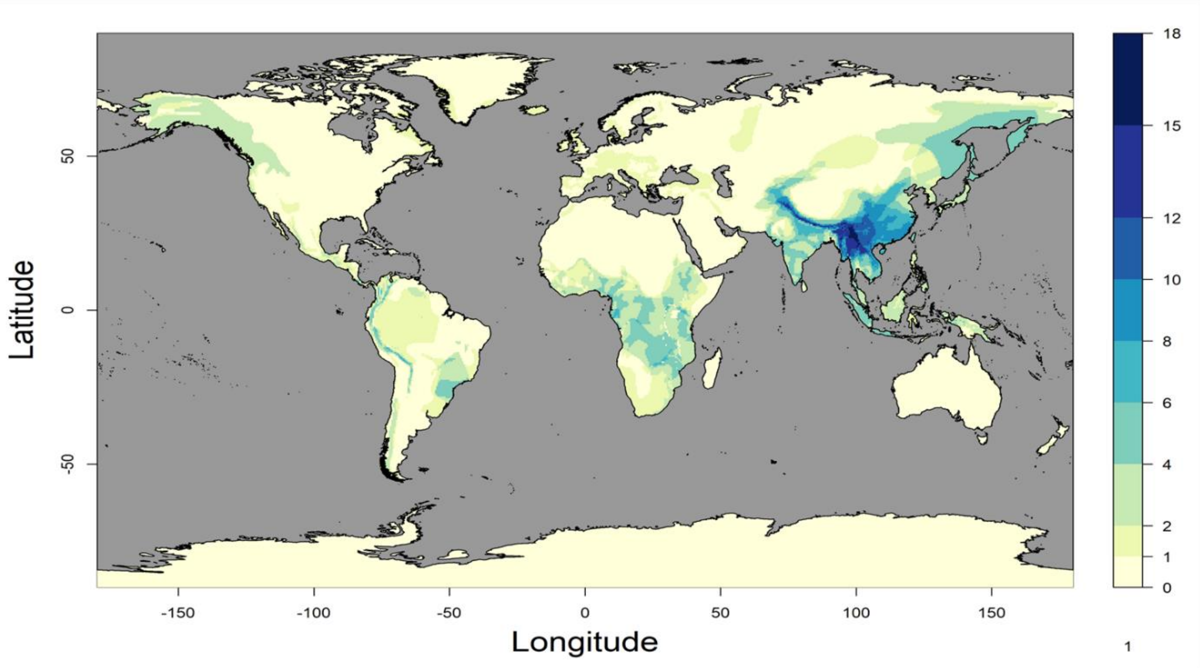


Figure 2.4. Global patterns of species richness of specialist riverine birds

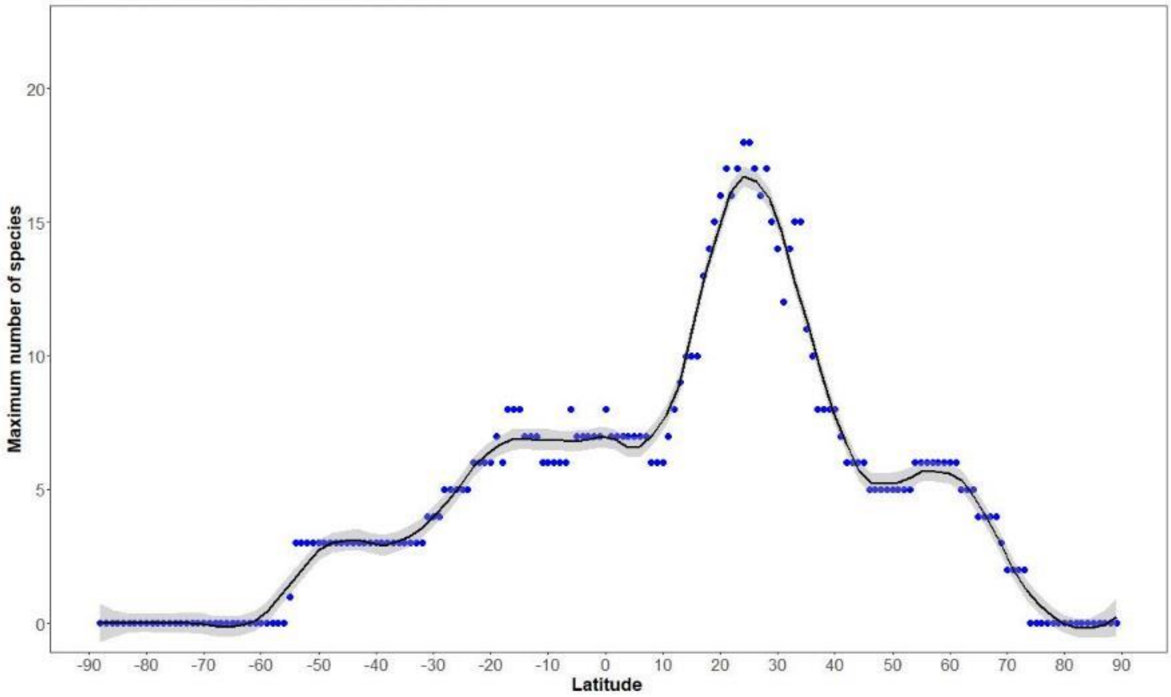


Figure 2.5. Latitudinal trend in species richness of specialist riverine birds

Past research looked at the geographical features and richness pattern relationships, and found that most species occur typically on small, fast flowing rivers (Buckton and Ormerod, 2002). The relationship of species richness with continent area showed a linear although insignificant relationship, trend being largely contributed by the effect of Asia, the largest continent (Buckton and Ormerod, 2002). Species richness increased significantly with productivity and surface configuration (i.e. relief) which is probably owing to the fact that complex terrain gives rise to higher densities of stream networks, providing more habitat for birds (Buckton and Ormerod, 2002). I checked for the same by calculating the total river length per continent from remotely sensed Hydrosheds data (USGS) and found that river bird richness increases linearly with the total river length (Figure 2.6).

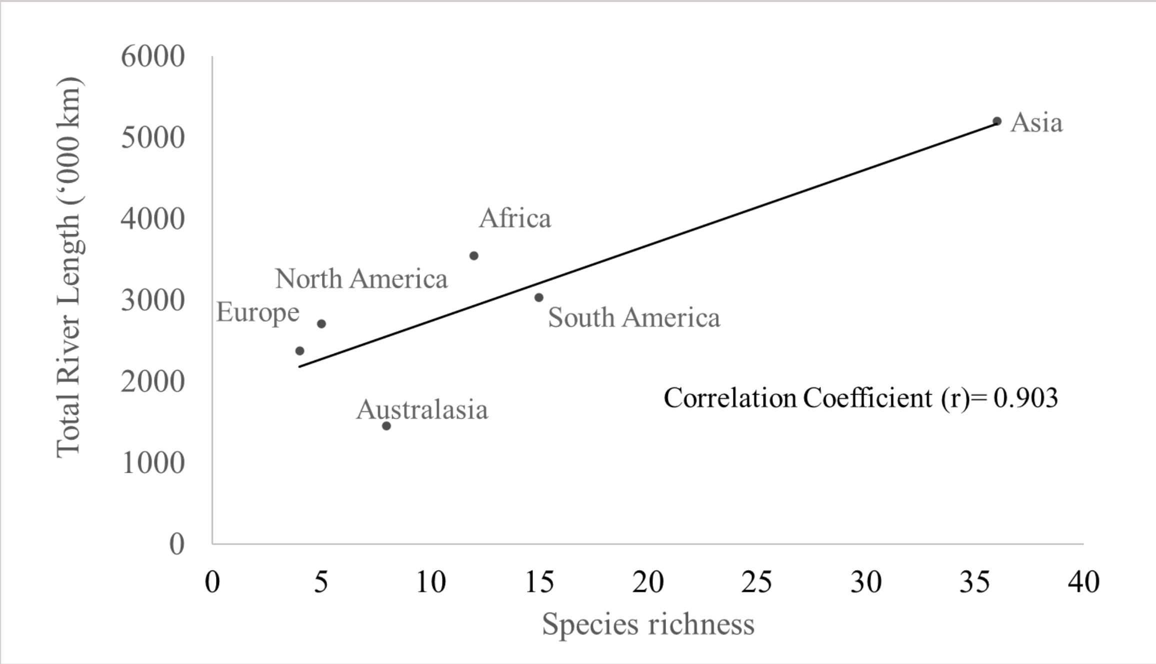


Figure 2.6. Total river length in continents and species richness of specialist river birds

2.2 Adaptations to the riverine environment

While waterbirds like ducks, geese, rails, cranes, flamingos and other wader species use a wide range of habitat types for feeding, breeding and nesting, specialist river birds are crucially dependent on both the water channel and the riparian land and hence are often found to choose mosaic of habitats in which both the land and the water are undisturbed or in the native condition (Sinha *et al.,* 2019a). Specialist river birds have affinities for particular landforms of riverscapes (Figure 2.7). Birds use the water channel, the river bank and the riparian vegetation in multiple ways for their life activities directly and indirectly. Food is acquired from the water channel in the form of fishes, larvae and adults of macro-invertebrates, crustacea, molluscs and submerged vegetation. Apart from supplying food the water channel regulates the local temperature and the microhabitat moisture regime. The river bank provides rock crevices and caves for nest building, resting, moulting or hiding and bushes which provide protective riverbank vegetation (William and McKinney, 1996) apart from providing food subsidies. The riverine vegetation is the major source of allochthonous input to the stream system; riverine birds use twigs and moss for nest building while some birds such as the Brazilian Merganser and Scaly-sided Merganser use tree holes for nest building (Bruno *et al.,* 2010; Cornelius *et al.,* 2008). Mid-channel habitat features like exposed bedrocks, mature islands etc, and riverbank vegetation provide significant foraging perches apart from resting places. Little Forkail in the Himalaya and Torrent Tyrannulet in the Andes extensively use these mid-channel features for active foraging (Sinha *et al.,* 2019a; George and Master, 2008). Grey wagtails and Ibisbills feed and breed in shingle riverbeds which are rare elements in upland river system. Globally, passerines show affinities for river stretches lined by broadleaf forests (Master *et al.,* 2005; Sinha *et al.*, 2019a). Breeding events in Grey Wagtails have been reported comparatively more from natural stretches in UK; birds preferring rural habitats, along running waters close to waterfalls and weirs (Tyler, 1972; Ormerod and Tyler, 1987). Banks of streams and rivers with overhanging roots are common nest sites; birds often making use of holes, ledges created by vegetation on riverbanks.

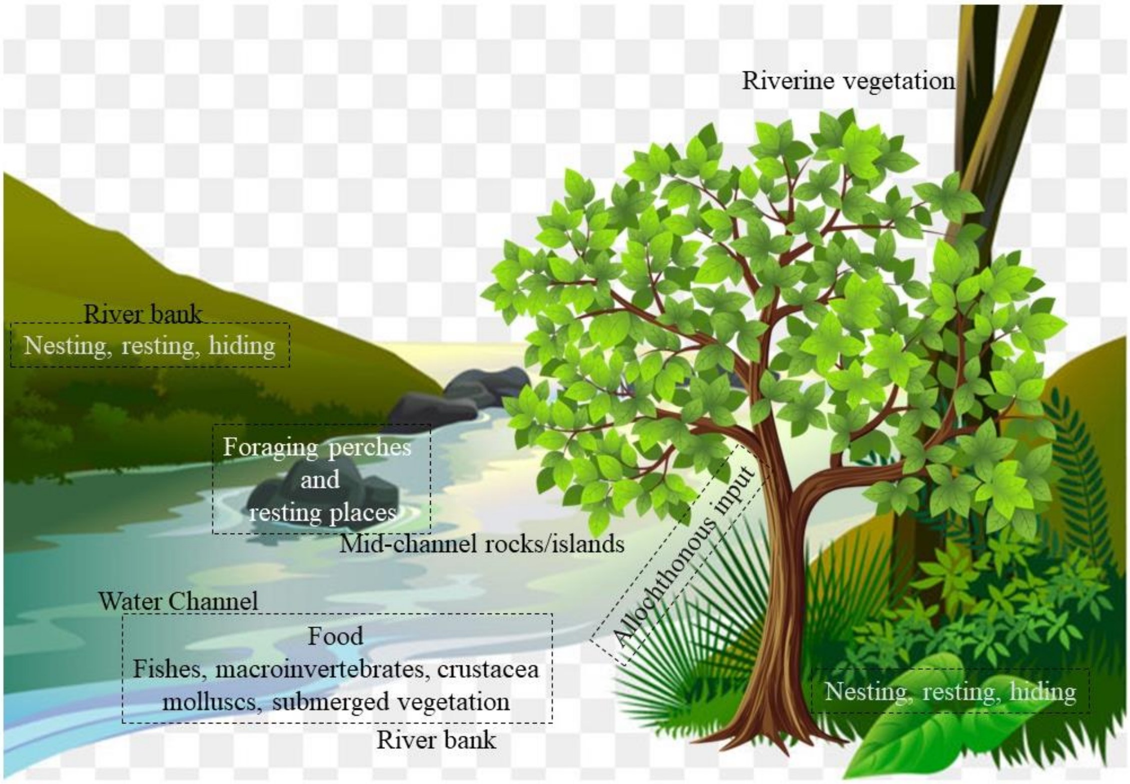


Figure 2.7. The river habitat template showing habitat features used by riverine birds, the water channel and mid-channel rocks and islands, river bank and riverine vegetation.

Riverine forests provide crucial resources to riparian birds like pathways for migrating birds in the form of edge cover (Gergel *et al.,* 2002; Naiman *et al.*,1993). In North America, Louisiana Waterthrush are recorded at higher densities along hemlock dominated headwater streams (Barnes *et al.,* 2018) while Half-collared Kingfishers live along forested mountain streams in Ethiopia. In a study in Costa Rica, maximum number of overwintering water thrushes and other riparian songbirds were recorded along river reaches with medium to high gradient streams with extensive forest canopy and lack of sedimentation (Master *et al.,* 2005). In the family Anatidae, Blue Ducks are truly riverine ducks, their distribution now restricted to upland forested catchments in the central North Island and west coast of the South Island in New Zealand (Fordyce, 1976). Birds have been reported to establish territories along river stretches with greater physical stability, channel gradient and elevation, narrower widths, coarser bed substrata (more boulders), and more riparian native forests (Collier *et al.*, 1993). Similar patterns were reflected in passerines in the Himalayan mountains (Sinha *et al.,* 2019a).

A range of adaptations are common across members of different families which include camouflage with the stony bed of riverbanks and bills adapted to exploit riverine resources indicating that birds have undergone adaptation to exploit riverine environments. Examples include the major overlap in ecological parameters of the four species of river obligate ducks, Torrent Duck (South America), African Black Duck (eastern and southern Africa), Salvadori's Teal (New Guinea) and the Blue Duck (New Zealand). The Torrent Duck is found across the Andean river systems while the African Black Duck has a broad distribution across Africa. The Salvadori's Teal and Blue Duck are only restricted to Guinea and New Zealand respectively. All the ducks lack an eclipse plumage and are anatomically adapted to live in fast flowing rivers with an insectivorous and piscivorous diet. Both sexes usually pair for life and participate in parental activities and are highly territorial (Kear, 1975). Another similarity lies in the vocalisations of river birds, adapted to stream environment with species having characteristically high-pitched calls to compensate for the noise generated by torrential rivers.

Other examples include the Ibsibill (*Ibidorynchus struthersii*) and the Wrybill (*Anarynchus frontalis*) with highly specialized foraging traits. The Wrybill which is restricted to New Zealand is the only bird in the world with a laterally curved bill, which it uses to procure insect larvae from beneath rounded riverbed stones. Wrybills are completely dependent on large braided rivers for breeding. The bird looks predominantly grey all through their life stages and perfectly camouflages with shingle riverbeds. Ibisbills have a beak curved in the front which aids in probing from underneath shingle beds and rounded pebbles, characteristic of high altitude river beds in Central Asia and the Himalayas. Among the passerines the foraging tactics span a larger spectrum owing to their evolved evolutionary history which includes flycatching, gleaning, sallying and picking. In case of river endemics like the dippers, birds dive underwater for larger aquatic prey which often include fishes (Tyler and Ormerod, 1995).This can be owing to phylogenetic relatedness among species (Figure 2.7). An alternative explanation could be the universally harsh/unique conditions in river systems which drove convergent evolution across different biogeographic regions. Environmental filters being consistent globally led to similar trait-environment relationships across evolutionarily distinct assemblages (Bower and Winemiller. 2019). Aiming to understand the phylogenetic relatedness of the 66 species of specialist river birds, a phylotree was constructed based on Jetz *et al.,* (2012) with a consensus tree made from 100 trees of the study species (birdtree.org). Analysis was carried out in packages “ape” (Paradis *et al.*, 2004) and “phytools” (Revell, 2012) in R.

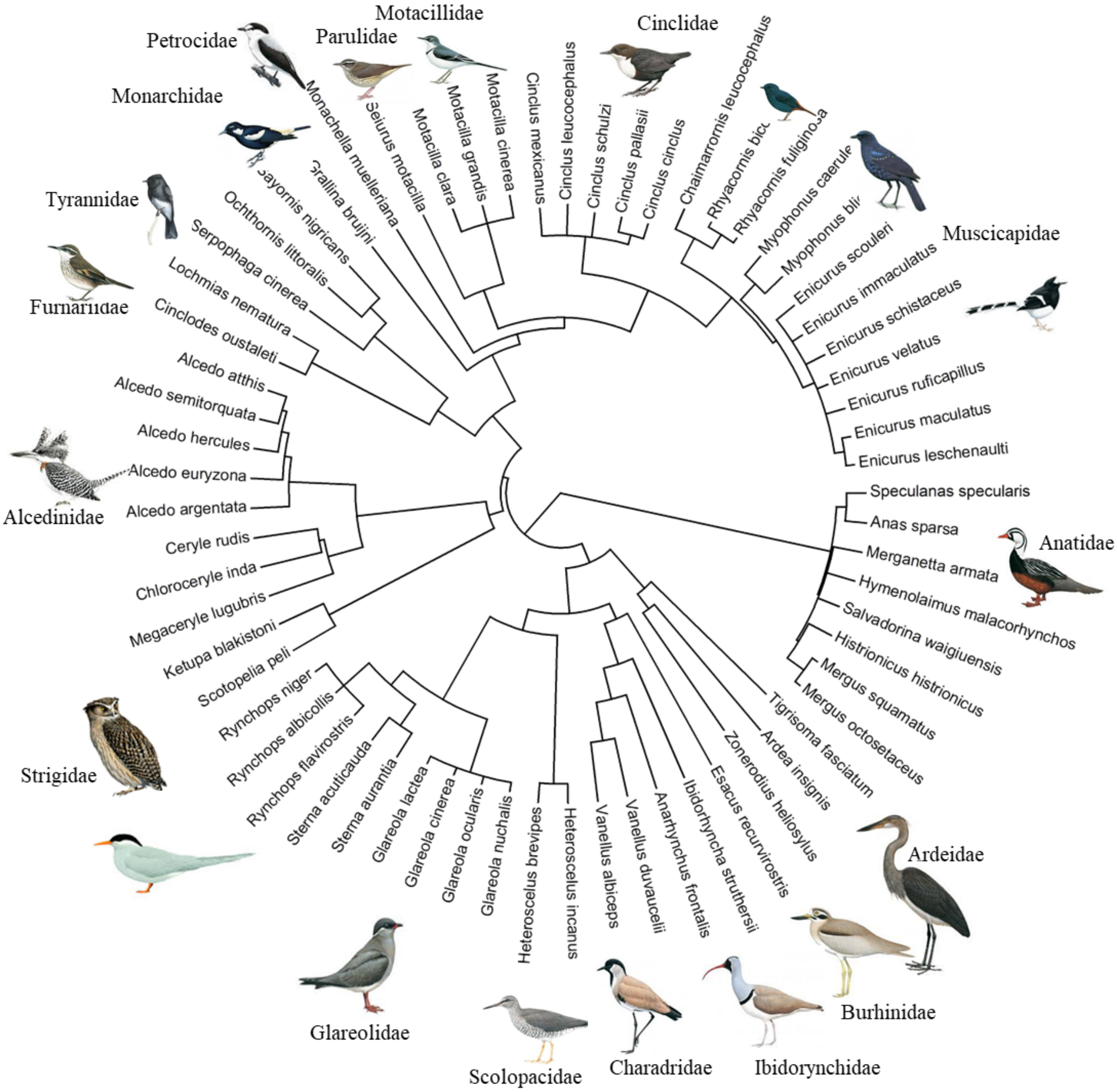


Figure 2.8. Phylogenetic tree showing 62 species of specialist river across the globe

The variations in species richness can be partly explained as a result of radiation in different taxonomic groups across different continents (Figure 2.8). Thus, in Asia, species richness reflects considerable radiation in the Muscicapidae, small passerine insectivorous birds mostly belonging to the old world. Greatest radiation in South America is in the ovenbirds (Funariidae) and tyrant flycatchers (Tyrannidae), and the Pratincoles (Glareolidae) in Africa.

In the Australasian group of islands, the river bird community consists of members from multiple families from both the passerines and non-passerines.

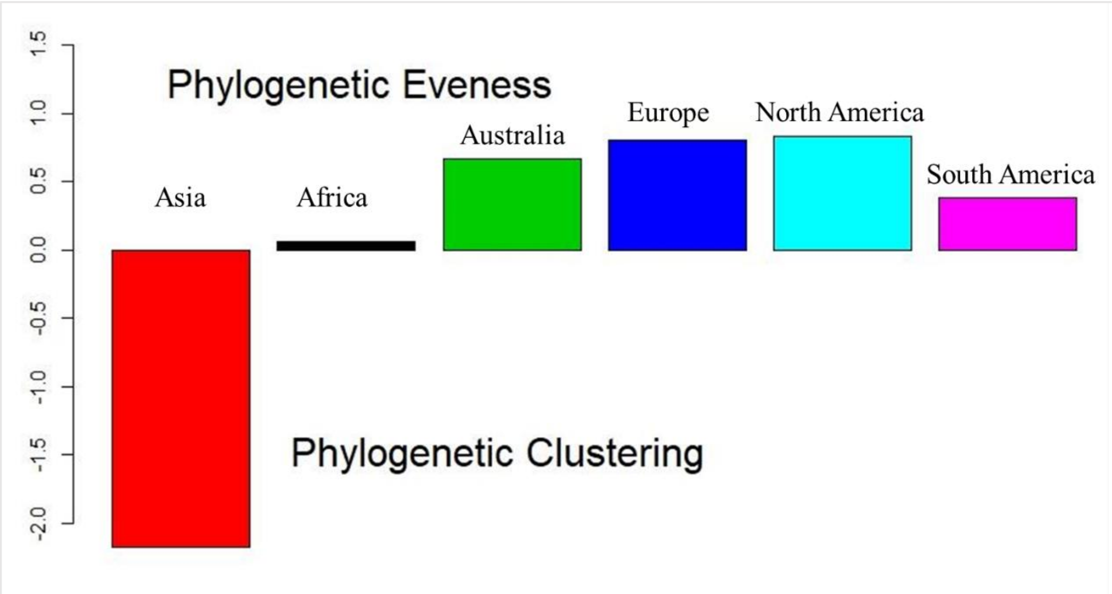


Figure 2.9. Phylogenetic relatedness of specialist riverine birds across different continents

To understand phylogenetic relationships among species, Mean Pairwise Distance for species assemblages for each of the continents was calculated. The analysis was done in package 'picante' in R (Kembel *et al.*, 2010). MPD is a measure of the phylogenetic distance among species within a community and is independent of the species richness (Webb *et al.*, 2002). It is considered a basal measure (i.e. which is more sensitive to distant taxa) because it calculates the pairwise distance between each species in the community. Increase in values indicate that birds are phylogenetically dispersed which also hints towards assemblages being functionally over-dispersed (i.e. coexisting species tend to be less similar in their ecological traits). Europe and North America although have lesser number of species show phylogenetic evenness, i.e. species belong to diverse families (Figure 2.9). Whereas in Asia which has the maximum number of species shows considerable clustering in phylogenetic groups, i.e.

species are more closely related to each other than expected hinting towards radiation events in particular families as expected.

2.3 Key gaps in the study of river birds

The ecology of specialist river birds remains poorly understood, with disproportionate research efforts focusing on a few species. Previous research extensively focussed on few species, the White-throated dipper (*Cinclus cinclus*) in Europe and the Louisiana Waterthrush *(Parkesia motacilla*) and American Dipper (*Cinclus mexicanus*) in North America respectively probably due to their broad distribution ranges across accessible terrains.. Studies in Asia hail from the Himalayas (Buckton and Ormerod, 2002; 2008; Manel *et al.,* 2000) and Taiwan where Brown Dipper is the only species which has been extensively researched (Chiu *et al.,* 2009; Chen and Wang, 2010; Chiu *et al.,* 2013; Hong *et al.,* 2018). There is a dearth of work from Africa and South America. Research on specialist river birds from South America remains limited although it has many endemic species which thrive exclusively along river systems like the Torrent Tyrannulet (*Serpophaga cinereal),* Shar-tailed Streamcreeper (*Lochmias oustaleti),* Torrent Duck (*Merganetta armata)* and the Rufous-throated Dipper (*Cinclus schulzii*).

Following are some key gaps in the study of river birds:

- There is little ecological knowledge on obligate river birds from the tropics.
- Most of the past studies on riverine birds were autecological in nature. Species often facilitate each other’s survival and community studies might unravel solutions to conservation issues for speciose communities apart from facilitating understanding of co-existence mechanisms unique to dynamic riverine ecosystems.

- Although there exists some evidence about the role of other terrestrial taxa on stream communities (Sanzone *et al.,* 2003), the functional role of river birds in exploiting riparian prey remains largely unknown.
- A better understanding of their role in exploiting resources from riparian habitats can aid in understanding nutrient-energy processes across trans-boundary systems (Nakano and Murakami, 2001).
- Except for White-throated Dippers and Louisiana Waterthrush, the potential of this group as indicators of running water systems have not been explored thoroughly.
- The effect of flow modification has emerged as a major driver of impairment to running waters and dependent flora and fauna (Bunn and Arthington, 2002). Rivers globally have been dammed for generation of hydroelectric power for decades now. Not many studies have addressed the effect of dams and the probable pathways they might impact these riparian consumers (but see Chiu *et al.*, 2013; Silverthorn *et al.*, 2018).
- There is little work on natural and human-induced threats (like exploitation of riparian resources, introduction of alien species, pollution etc.) to the survival of this group which thrive in aquatic-terrestrial continuum habitats and thus prone to modifications to both the river channel and the riparian land.
- The impacts of climate change on obligate river birds remains unknown. Advances in understanding the impacts of flow modifications on river birds species in the UK hints towards unavoidable impacts on sensitive species (Royan *et al.,* 2013; Royan *et al.,* 2014) with a direct bearing on their foraging and nesting ecology. A large fraction of the birds described in section 2.1 are dependent on snow-fed streams, their life cycle being tied to the cycle of snowmelt and water runoff processes. Pathways through which birds shall get affected to altered temperature and precipitation regimes remains unknown.

- There are not any <u>phylogenetic studies</u> trying to address the convergence in foraging tactics, body size, breeding behaviour etc., of species with geographic ranges in different continents.

Similar aspects have been briefly discussed in forthcoming chapters, but detailed research might shed light on processes like environmental filtering or other drivers which structure riverine faunal assemblages.

Chapter 3

STUDY AREA AND STUDY DESIGN

3.1 Geographical location

Encompassing elevations of around 60m and 8000m a.s.l. within 150-200km the highest mountains of the world also represent the longest altitudinal gradient (Grytnes and Vetaas, 2002). This gives rise to multiple climatic zones, tropical/subtropical, temperate, subalpine, and alpine which provide breeding grounds for nearly 8% of the world's bird species (Price *et al.*, 2003; Rasmussen and Anderton, 2005). Most of the rivers of the northern Indian sub-continent have their sources in the snow and glacier melt runoff of the Himalaya. Field studies were conducted in the Bhagirathi basin, a major headstream of the Upper Ganges in the state of Uttarakhand in the western Indian Himalaya, and six other first order streams. The Bhagirathi river runs for 217 km along an elevational gradient, between 3100m a.s.l. (30°59′39.1″N, 78°56′38.7″E) and 330m a.s.l. (30°07′03.9″ N, 78°18′26.0″ E ; Figure 3.1). This basin was chosen as it provides a huge elevational gradient and variations in both natural and anthropogenic land-use. The river flows through deep gorges and narrow valleys, and where forests remain (the vegetation of the study area has been discussed in detailed in section 3.2), the major tree species include broadleaves, conifers and some riverine specialists.

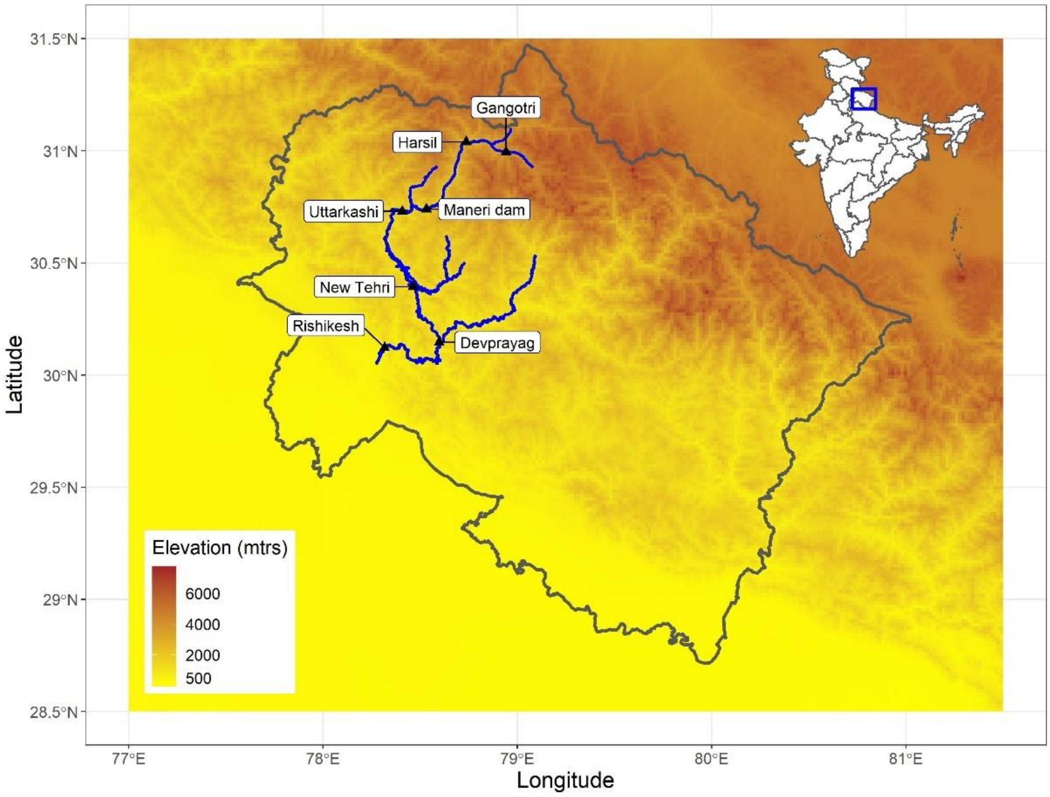


Figure 3.1. Map showing the studied section of the Upper Ganges (the Bhagirathi river) with major settlements. Inset: location of study area in India.

Given the large altitudinal relief, the study area is characterized by diverse biomes. Water in the river and smaller streams comes from different sources, glacial melt, rainwater and underground springs. During the sampling years, summer months were pleasant and lasted for a short duration in the higher elevations (above 2000m a.s.l.), April to June, whereas winters were long spanning from end of October to February, major snowfall being in late December till mid-February. Summer months experienced clear days with light showers in the evenings at higher elevations (above 2500m a.s.l.), whereas major rainfall from the monsoon was restricted from July to September. Multiple episodes of cloud bursts, flash floods and flooding of the river banks during the monsoon months often led to incidental road closures and temporary hinderance to accessibility. Summer months were warm at elevations below 700m a.s.l. with temperatures soaring above 40 °C around Rishikesh in the month of

May. Owing to the huge elevation gradient there were vast differences in the temperature regime between the highest and lowest points of the study area.

3.2 Land-use /Land cover

Based on remote sensing approaches supported by field validation, the land-use/land-cover types were documented for the study area. The Bhagirathi basin is composed of dense forest (24.1%), open forest (24.3%), shrubland (3.1%), grassland (5.6%), agriculture land (4.5%), barren land (7.1%), river (0.6%) and snow cover (30.6%) (Figures correspond to the year 2015; Gaur *et al.,* 2019). Landscape study through remote sensing and field validation provides evidence that forest cover occupies 42 % of the entire landscape, suggesting that the entire area still holds substantial vegetation cover (Gaur *et al.*, 2019). The dense forest markedly declined (18.3 %) across a time span of 22 years (1993 to 2015), although the overall area under forests has relatively not undergone much change. The open forest class showed an increase (18.3 %) in the entire river basin. Agriculture class (increase of 2.5 %) was found uniformly distributed in the entire landscape barring higher altitudes with a significant concentration along the rivers (Figure 3.2).

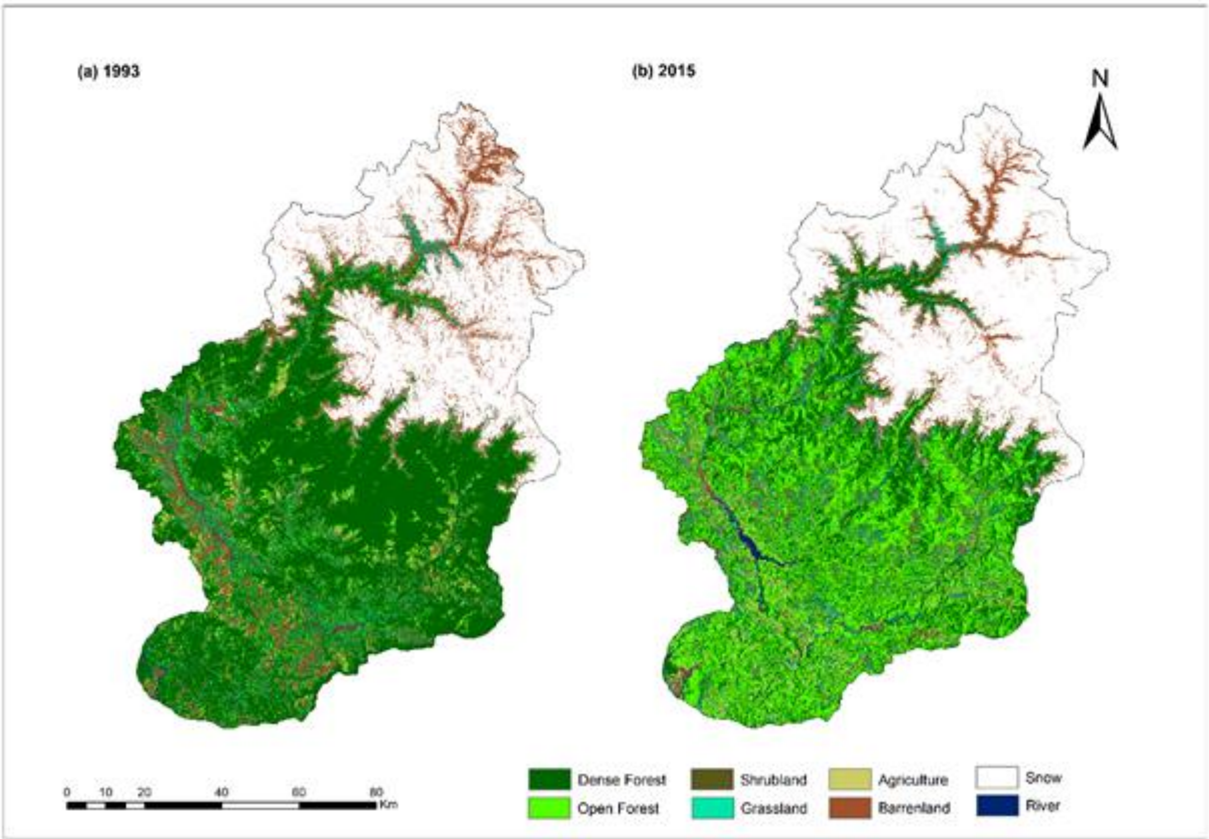


Figure 3.2. Land cover maps depicting temporal change (a: 1993 and b: 2015) in the eight land cover types namely, dense forest, open forest, shrubland, grassland, agriculture, barren land, snow and river) of the Bhagirathi basin.

Deforestation, building of roads, human encroachment, and development of dams for hydropower could be some of the reasons for degradation of the areas under forest cover (Roy and Rathore, 2019). The Tehri and Koteshwar dams, which became operational around the year 2008 led to land submergence thereby flooding the river perimeter and increasing the area under river class, conspicuous in the map (Figure 3.2).

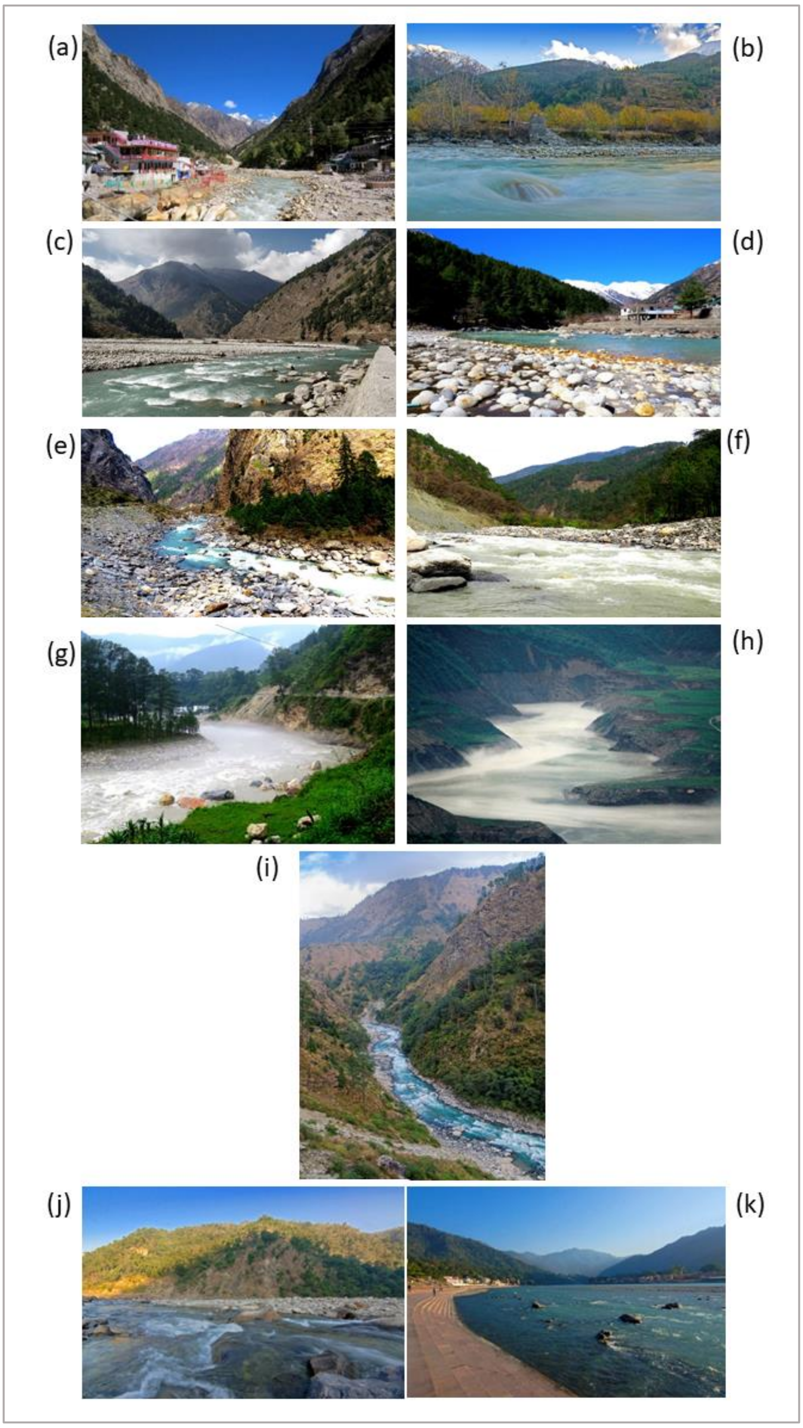


Figure 3.3. Pictures of field study sites to illustrate the variety of riverine habitats: Higher elevation reaches: (a) Gangotri~3100 m (b) Dharali~2740 m (picture courtesy: Nilanjan Chatterjee) (c)Bogory ~2500 m (d) Harsil~2500 m; middle elevation sites : (e) Gangnani (f) Naluna~1450 m (g) Netala ~1300m (h) New Tehri~ 800m (picture courtesy: Nilanjan Chatterjee); lower elevation sites: (i) Devprayag ~533 m (picture courtesy: Nilanjan Chatterjee) (j) Phoolchatti~ 380 m (picture courtesy: Nilanjan Chatterjee) (k) Rhisikesh~330 m (picture courtesy: Nilanjan Chatterjee)

3.3 Riverine Vegetation

River corridors are linear features in the landscape; upland river systems characteristically being single-thread channels bordered by a narrow band of native riparian vegetation (Naiman *et al.,* 1993; Ward *et al.,* 2002a). Riverine systems being non-equilibrium systems provide high environmental heterogeneity making riverine plant communities the most productive and diverse in the world, with plant associations of larger complexity than surrounding landscapes (Tockner and Stanford, 2002). A pilot assessment of riverine tree species diversity was conducted in a buffer zone of 1 km along the Bhagirathi river walking on trails (this covered all the sites in which bird surveys and river habitat surveys were conducted) and the dominant trees were recorded at 1200 points within a sampling effort of 152 kms in the non-monsoon months. The Bhagirathi catchment consists of four forest types (Sub-Group level-16) according to Champion and Seth Classification of Forests (1968; Table 3.1). These include Tropical moist deciduous forests, Tropical dry deciduous forests, Himalayan sub-tropical Pine forests and Himalayan moist temperate forests. A total of 15 dominant tree species were identified which include broadleaves, conifers and some riverine specialists with significant elevational segregation. True riverine species which can be best described as early successional species were *Populus ciliata*, *Alnus nepalensis*, *Dalbergia sisoo, Toona ciliata, Bombax ceiba, Adina cordifolia* and *Holoptelea integrefolia.* Lower elevation river reaches had the highest number of tree species. Riverine stands above 2000m a.s.l. majorly comprised of conifers like *Picea smithiana* and *Cedrus deodara* and few stands of *Populus ciliata.* True riverine species in the mid-elevations (between 800m- 2000m) consisted of patches of *Alnus nepalensis,* and *Toona ciliata. Pinus roxburghii* forms riverine stands around the Tehri dam backwaters with patches of *Dalbergia sisoo* and *Acacia catechu* at few places. *Adina cordifolia, Syzigium cumini* and *Holoptelea integrefolia* are dominant riverine tree species in an elevational zone between 800m and 300m with *Shorea robusta, Bauhinia variegata, Celtis australis, Mallotus philippensis, Linnea coromondolica* and *Sapium insigne* as significant associate species.

3.4 Biodiversity values

The Bhagirathi basin supports high biodiversity, including multiple threatened and endangered species (Rajvanshi *et al.,* 2012; Sinha *et al.*, 2019b). Terrestrial mammalian fauna includes Himalayan brown bear (*Ursus arctos issabellinus*), snow leopard (*Panthera uncia*), Himalayan musk deer (*Moschus leucogaster*), Asiatic black bear (*Ursus thibenatus),* Common leopard (*Panthera pardus*) and Himalayan yellow throated marten (*Martes flavigula*) etc. The river basin is rich in avifaunal diversity with around 280 species recorded from riverine areas which includes many rare and endangered species like the Egyptian Vulture (*Neophron percnopterus*), Steppe Eagle (*Aquila nipalensis*) and Cheer Pheasant (*Catreus wallichii*). Some like the Common Pochard (*Aythya farina*) and Ferruginous Duck (*Aythya nyroca*) use the riverine corridor for stopover for winter migration (Sinha *et al.,* 2019 b). Aquatic species include the endemic snow trout (*Schizothorax* species) and Golden Mahsheer (*Tor putitora*) which is Endangered. Consequently, any dramatic changes in habitat can have irreversible effects on the population dynamics and possible cross-seasonal or carry-over effects that can influence demographics and functioning of native species.

Table 3.1. List of the different Champion and Seth forest classes in the Bhagirathi basin, each class depicting the dominant tree and shrub assemblage in each group.

S.No	Group	Sub-Group	Species Found
1.	**Moist Tropical Forests**	**Tropical moist deciduous Forests**	Dominant Trees- *Albizia procera, Adina cordifolia, Mallotus philippensis, Bauhinia variegata* Dominant Shrubs- *Adhatoda vasica, Colebrookea oppositifoli*a
2.	**Dry Tropical Forests**	**Tropical dry deciduous Forests**	Dominant Trees - *Anogeissus latifolia, Acacia catechu, Bauhinia variegata, Mallotus philippensis, Lannea coromandelica, Dalbergia sissoo.* Dominant Shrubs - *Murraya koenigii, Woodfordia fructicosa, Colebrookea oppositifolia, Adhatoda vasica*
3.	**Montane Subtropical Forests**	**Himalayan Subtropical Pine Forests**	Dominant Trees - *Pinus roxburghii* (80-90%), *Quercus leucotrichophora, Rhododendron arboreum, Engelhardtia spicata* Dominant Shrubs - *Debregeasia hypoleuca*
4.	**Montane Temperate Forests**	**Himalayan moist temperate Forests**	Dominant Trees - *Quercus leucotrichophora, Cedrus deodara, Pinus wallichiana, Cupressus torulosa, Abies pindrow, Picea smithiana, Acer caesium, Celtis australis, Alnus nepalensis, Populus ciliata* Dominant Shrubs - *Prinsepia utilis, Salix denticulata, Sorbaria tomentosa, Debregeasia hypoleuca*

3.5 Population structure

The Bhagirathi basin spreads across three administrative districts of Garhwal region viz., Tehri, Pauri, and Uttarkashi encompassing the river stretch between the Gangotri and Rishikesh. It has small to medium sub-urban locales and many villages, the major settlements enroute the river are Rishikesh (300m a.s.l.), Devprayag (700m a.s.l.), New Tehri (2,100m a.s.l.), Uttarkashi (1,300m a.s.l.), Harsil (2,500m a.s.l.) and Gangotri (3,200m a.s.l.). According to the Census of India, 2011 Uttarkashi and Rishikesh have population figures of 3,30,086 and 1,02,138, respectively making them some of the most populated places in the state of Uttarakhand. Rishikesh, Devprayag, Uttarkashi and Gangotri are pilgrim towns and experience a huge influx of tourists during the months of May to September.

3.6 Hydropower Development

Himalayan rivers are mostly perennial, but discharge patterns are strongly seasonal as a result of monsoonal precipitation and snow-melt (Brewin *et al.,* 2000). While large discharge volumes from the Himalaya provide major potential for hydroelectric power development (Rees and Collins, 2006), such seasonality implies that power can only be harnessed reliably using impoundments. The river Bhagirathi has enormous hydropower potential owing to its terrain complexity and large volumes of water. The functional dams enroute the Bhagiarthi river are Maneri, Joshiyara (Bhali), Koteshwar and the Tehri. There are more than five other dams on the same river which have been commissioned but are not yet functional. The overall impacts of these are altered flow regime, diverted river length and submergence of forested areas and human habitation lands (Rajvanshi *et al.*, 2012).

The above discussion clearly highlights the importance of this particular river stretch and also the scope that they naturally provide to understand the complex interactions between organisms residing in these habitats and impacts of anthropogenic developments.

3.7 Field sampling design

Reconnaissance surveys were planned to survey maximum number river reaches to understand the river habitat structure and undermine maximum heterogeneity in the landscape. In order to cover the entire riverine stretch between Rishikesh and Gangotri (the mountainous section of the river) which provides a huge elevational gradient, field work was planned from suitable strategic halts. These were planned keeping in mind the availability of basic amenities and easy accessibility to all the river reaches. Surveys were based from Rishikesh, Devprayag, New Tehri, Chinyali Saur, Uttarkashi and Harsil. Monsoon months were avoided owing to logistic constraints of reaching to the survey sites and to dodge natural hazards like landslides and floods.

3.8 Bird surveys

River reaches (500m each) were surveyed along an altitudinal gradient (300–3100m a.s.l.) following a widely used model for assessing river bird distribution (Buckton, 1998) for the years 2014-2018 (Figure 3.5). Surveys were carried out in the pre-monsoon (April–June, breeding season) and post-monsoon periods (October–December, wintering season), with timings sufficient to detect altitudinal migrant species that move between elevations in winter.

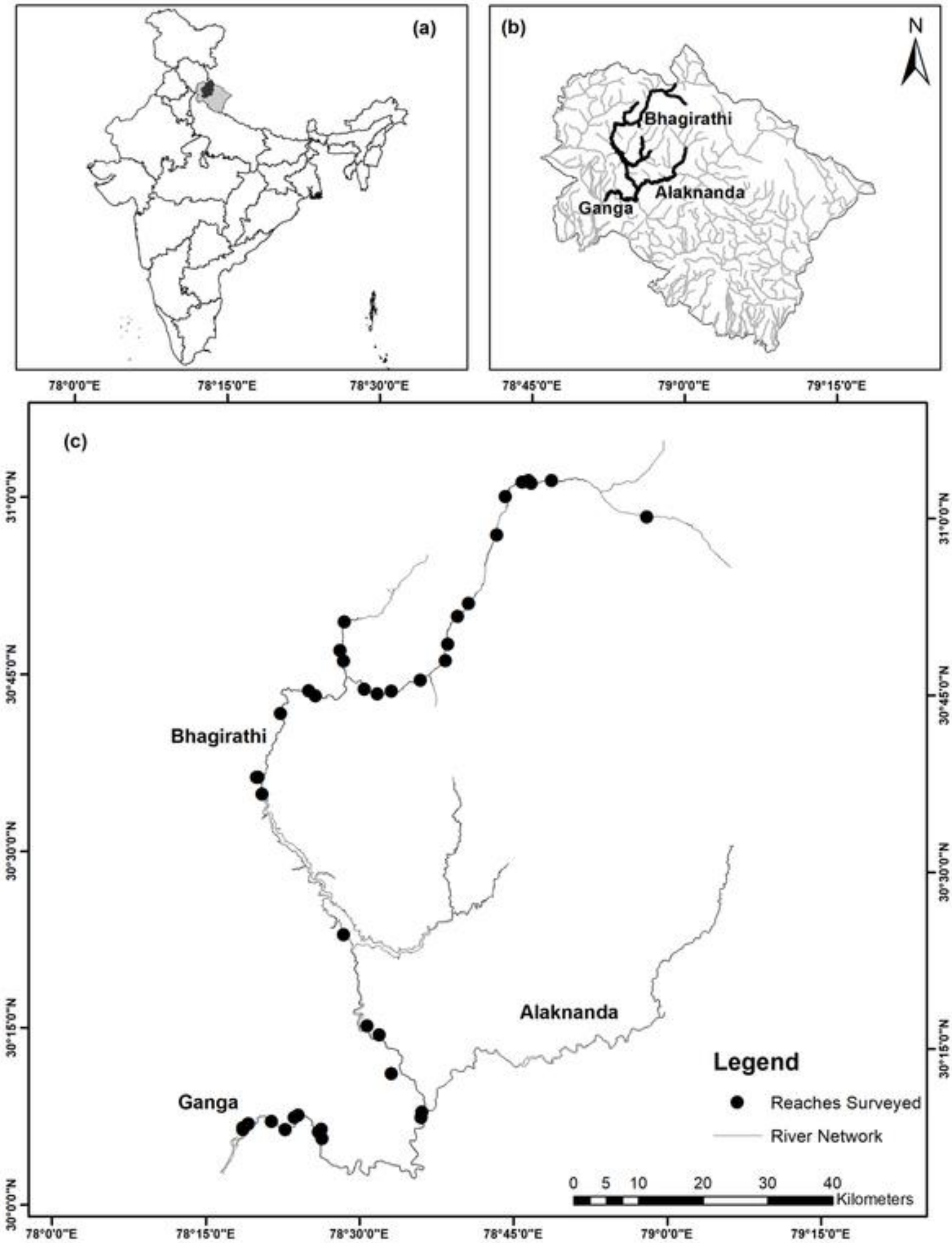


Figure 3.4. Map showing the (a) Bhagirathi basin (shaded black) in the state of Uttarakhand (shaded grey) India (b) the river network in the state of Uttarakhand and (c) the intensive study site showing the 43 river reaches surveyed.

In each of the two seasons, three visits were made to each river segment (500m) to increase the detection probability of all species (McCarthy *et al.,* 2013). This visit frequency is considered appropriate for species that occupy linear territories along rivers (D'Amico and Hemery, 2003). The pattern of visits to each region was randomized as far as logistically possible to avoid spatio-temporal auto-correlation in the resulting data.I walked the banks during early morning (06.00 to ± 10.00) and late afternoon (15.00 to ± 18.00) and recorded birds using 8 × 42 binoculars. All birds seen or heard were identified by sound or sight and recorded by distance category from the channel: 0–25 m, 25–100 m, >100 m or 'inflight' (Marchant *et al.,* 2002). A species was recorded as present if it was observed during surveys on any occasion (out of the three visits) and considered absent otherwise. Riverine systems being dynamic River Habitat Surveys were undertaken simultaneously with every bird survey.

Birds were grouped into two categories (river obligates and non-obligates) based on their dependence on river production. River obligates were defined as species that (i) occur exclusively along streams or river channels during a significant part of their breeding or nonbreeding life cycle; and (ii) depend on production wholly or partly originating from the river channel (Buckton and Ormerod, 2002). Species feeding and roosting on habitats such as wet woodlands, inland waters, ponds and lakes besides inhabiting river banks were described as non-obligate species.

Chapter 4

SPATIO-TEMPORAL COMPOSITION OF THE RIVER BIRD COMMUNITY IN WESTERN HIMALAYA

4.1 Introduction

Understanding the organization of species assemblages has intrigued many; from field ecologists who aim at understanding the relative influence of different factors in shaping communities to mathematicians who have modelled these phenomena giving them perceptible dimensions (Schoener, 1974; Levin, 1992; ter Braak and Juggins, 1993; Weiher and Keddy, 2001; Gotelli and McCabe, 2002; Okansen *et al.,* 2007; Wisz *et al.,* 2013). Fundamental to the study of communities is the description of the species they include, abundances of these species, variations in commonness and rarity over space and time. That some have a wide distribution while some are restricted to few locations is a well-documented fact (Preston, 1948; Magurran and Henderson, 2003; Magurran and Henderson, 2011). The number of species forms the basis of many ecological models in understanding community structure (MacArthur and Wilson, 1967; Connell, 1978). Estimating the species richness is the simplest way to describe regional diversity (Gotelli and Chao, 2013) and quantifying it has remained imperative for assessments based on field observations.

Changes in the local environmental conditions play fundamental roles in community dynamics (Dent and Wright, 2009). Studies on elevational gradients have been especially useful owing to changes in various environmental factors over relatively small distances (McCoy, 1990; McCain, 2005). The huge elevational gradient across small distances in the Himalayan mountain range has led to a series of studies documenting variation in species richness in multiple taxa like vascular plants (Oommen and Shankar, 2005; Grytnes and

Vetaas, 2002; Rana *et al.,* 2019), ferns (Bhattarai *et al.,* 2004) and birds (Acharya *et al.,* 2011; Price *et al.,* 2011; Pan *et al.,* 2016; Elsen *et al.,* 2017 b). Riverine biodiversity patterns, although, have not received adequate attention yet, especially organisms which thrive in riparian habitats.

Rivers are hierarchical systems with a characteristic unidirectional flow and multiple gradients (longitudinal, lateral, vertical and temporal) along which the composition of communities change as rivers progress from headwaters to floodplains (Ward *et al.,* 2002b). Riparian zones provide essential habitats for many species of birds (Knopf, 1985, Stauffer and Best, 1980, Stevens *et al*., 1977); riparian avian communities often being more diverse with a higher abundance of species than surrounding uplands (Gates and Giffen, 1991, Stauffer and , 1980). Bird species use riparian areas differentially throughout the season (Rice and Anderson, 1980; Sinha *et al*., 2019b); hence, habitat associations of different species need to be monitored across seasons to thoroughly appraise riparian zones for conservation.

Birds inhabiting the Western Himalaya, an Endemic Bird Area show a large variety of distributional patterns with some species being restricted to narrow elevational bands while others are relatively broadly distributed (Elsen *et al.,* 2017 b; Sinha *et al.,* 2019 b). Amongst these, a large number undertake short migration from higher elevation breeding grounds to warmer lower elevations for wintering (Grimmett *et al.,* 2013; Elsen *et al.,* 2017b; Sinha *et al*., 2019b). Thus, the avifaunal assemblage of any particular location remains dynamic. In this chapter I looked at the composition of the river bird community in the Bhagirathi basin across the elevation gradient aiming to understand the spatio-temporal community dynamics of this assemblage.

4.2 Methodology

Bird surveys were undertaken during reconnaissance surveys in riparian areas to understand habitat use by birds. Henceforth, birds exclusively dependent on riparian resources were identified and surveys were repeated for multiple years for the forty-two river reaches to ensure that none of the river bird species using the riverine habitat were missed. Field data from replicate surveys spanning multiple years (summer~2014-2018; winter ~2014-2017) were used to understand species richness patterns across seasons and elevational gradient in the Bhagirathi basin. Any species occurring in less than two river reaches were not considered for further analysis. Encounter rate was calculated as number of individuals of each species recorded per river reach (500m). The data for bird species was averaged for every site (for the three repeats) and also for the number of years for estimating figures the summer (n=5) and autumn (n=4) seasons. Patterns for obligate and non-obligate riverine species were discerned separately.

The co-occurrence measure was calculated as,

Cooc(sp1, sp2) = 2*Number of sites both sp1 and sp2 occurs/ (Number of sites sp1 occurs +Number of sites sp2 occurs)

This measure is akin to the Sorensen's Index. Species with no overlap between sampling sites would have zero co-occurrence whereas a complete overlap would result in a value of 1. I calculated pairwise species cooccurrence for the sixteen species for the summer and winter. I hypothesized average species cooccurrence would be lower in summer which is the breeding season compared to autumn (the non-breeding season). A pairwise t-test was performed to validate the hypothesis.

To check for nestedness patterns in the river bird community across different seasons I calculated "nestedtemp" and "nestedNODF" function in the "vegan" package in R (Oksanen *et al*., 2016). Function "nestednodf" implements a nestedness metric based on overlap and decreasing fill (Almeida-Neto *et al.*, 2008). I calculated nestedness for both the seasons and hypothesized that the nestedness would be higher in autumn (non-breeding season).

4.3 Results

A total of 280 species of birds spanning 64 families were recorded in field surveys along the Bhagirathi river (Sinha *et al*., 2019b). A total of 32 bird species from 12 families were found using riparian resources (Table 4.1). Eight species of ducks (family Anatidae) were recorded with most sightings during winter months. Individuals or small flocks were encountered mostly in the vicinity of reservoirs around the Tehri and Maneri dams. Two species of Thick-Knees were reported from the banks of the Ganga in Rishikesh in winters. The major contribution to the river bird community along the river Bhagirathi was from the family Musicapidae (songbirds), many being obligate riverine. Other obligate river birds belonged to the families Cinclidae (dippers), Alcedinidae (kingfishers), Ibidorynchidae (Ibisbill) and Charadriidae (waders) (Table 4.1). Four species of kingfishers were recorded in field surveys along the Bhagirathi, only one among them being a river obligate, the Crested Kingfisher (*Megaceryle lugubris*) (Table 4.1). Breeding grounds of Ibisbill were recorded at an elevation of 2500m a.s.l. in Harsil. Birds of different age structure were recorded all year round hinting that this population might be resident in these river beds (Sinha *et al*., 2014). River Lapwings were found breeding in the lower reaches of the Bhagirathi river and larger flocks were recorded in winter around same areas.

Table 4.1. Bird species encountered during field surveys along the Bhagirathi river (not all the species were recorded every year). Species recorded at least once on all occasions of sampling between years 2014-2018 have been marked with a *.

Non-obligate	
Bird species	**Family**
Ruddy Shelduck (*Tadorna ferruginea*)	Anatidae
Gadwall (*Mareca strepera*)	Anatidae
Mallard (*Anas platyrynchos*)	Anatidae
Indian Spot-billed Duck (*Anas poecilorhyncha*)	Anatidae
Northern Shoveler (*Anas clypeata*)	Anatidae
Common Teal (*Anas crecca*)	Anatidae
Red-crested Pochard (*Netta rufina*)	Anatidae
Tufted Duck (*Aythya fuligula*)	Anatidae
Striated Heron (*Butorides striata*)	Ardeidae
Indian Pond Heron (*Ardeola grayii*)	Ardeidae
Gray Heron (*Ardea cinerea*)	Ardeidae
Little Cormorant (*Microcarbo niger*) *	Phalacrocoracidae
Great Cormorant (*Phalacrocorax fuscicollis*) *	Phalacrocoracidae
Indian Thick-knee (*Burhinus oedicnemus*)	Burhinidae
Great Thick-knee (*Esacus recurvirostris*)	Burhinidae
River Lapwing (*Vanellus duvaucelii*) *****	Charadriidae
Common Sandpiper (*Actitis hypoleucos*) *	Scolopacidae
Pallas's Gull (*Ichthyaetus ichthyaetus*)	Laridae
White-throated Kingfisher (*Halcyon smyrnensis*) *	Alcedinidae
Common Kingfisher (*Alcedo atthis*) *	Alcedinidae
Pied Kingfisher (*Ceryle rudis*)	Alcedinidae
Blue Whistling Thrush (*Myophonus caelereus*) *	Muscicapidae

Grey Wagtail (*Motacilla cinerea*) *	Muscicapidae
White Wagtail (*Motacilla alba*) *	Motacillidae
White-browed Wagtail (*Motacilla maderaspatensis*) *	Motacillidae

Obligate	
Bird species	**Family**
Ibisbill (*Ibidoryncha struthersii*)	Ibidorynchidae
Crested Kingfisher (*Megaceryle lugubris*)*	Alcedinidae
Brown Dipper (*Cinclus pallassi*) *	Cinclidae
Plumbeous Water Redstart (*Phoenicurus fuliginosus*) *	Muscicapidae
White-capped Redstart (*Phoenicurus leucocephalus*) *	Muscicapidae
Little Forktail (*Enicurus scouleri*) *	Muscicapidae
Spotted Forktail (*Enicurus macultus*) *	Muscicapidae

For further analysis, species (N=16) which were recorded at least once on all occasions of field sampling between years 2014-2018 were used. Species richness patterns showed clear trends with elevation for both the seasons (Figure 4.1). Overall species richness increased with elevation in the summer months and showed an opposite trend in autumn (Figure 4.1). The trend is not continuous, with species richness peaking around elevations between 2300-2700m a.s.l. in summer where on an average 6 species were receorded (Figure 4.1). In autumn, species richness declined with increasing elevation with is a peak around 2300-2700m a.s.l.

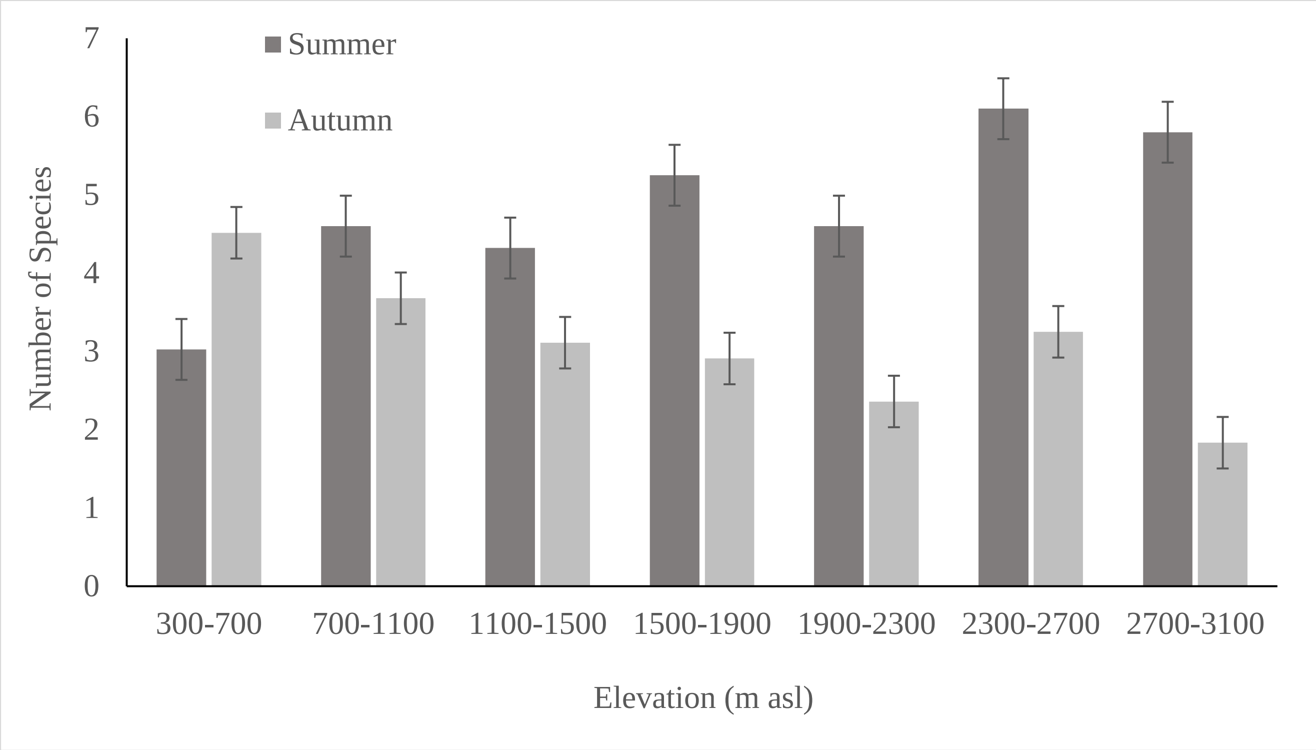


Figure 4.1. Species richness (number of species recorded) across the river reaches sampled in field surveys across the multiple years (2014-18) in the Bhagirathi river basin in spring and autumn.

The obligate species were mostly passerines, with Plumbeous Water Redstart and Brown Dipper being the most encountered species followed by White-capped Water Redstart and Crested Kingfisher (Figure 4.2 (a)), while Ibisbills were recorded only from two river reaches (Sinha *et al.*, 2015). Both species of Forktails were encountered in low numbers along the Bhagirathi river (Figure 4.2 (a)). Among the non-obligate river species, Blue Whistling Thrush and White-browed Wagtail were the most encountered species (Figure 4.2 (b)). River Lapwings occurred in four river reaches (Table 4.1) in flocks sometimes exceeding fifty individuals during communal winter roosts.

There was much difference in the encounter rate of different species across spring and autumn (Figure 4.2 (a) and (b)). Among obligates both the water redstarts had higher encounter rates in autumn as compared to spring. All the other species (Brown Dipper, Crested Kingfisher, Spotted Forktail, Little Forktail and Ibisbill) showed higher encountered rates in autumn as compared to spring (Figure 4.2 (a)). In case of the non-obligates, which use the riverine habitats more opportunistically or seasonally, only two species (Little Cormorant and River Lapwing) were recorded more in the autumn months (Figure 4.2 (b)). Little Cormorants were recorded singly/ in pairs or in small flocks in pool habitats around dams and lower elevation river islands. Encounter rates for Blue Whistling Thrush did not vary much across summer and winter (Figure 4.2 (b)). River Lapwings were recorded in medium to large flocks in lower elevation river sites in winter. All three species of wagtails (Grey Wagtail, White Wagtail, White-browed Wagtail), two species of kingfishers (Common Kingfisher and White-throated Kingfisher) and the Common kingfisher were encountered more in spring.

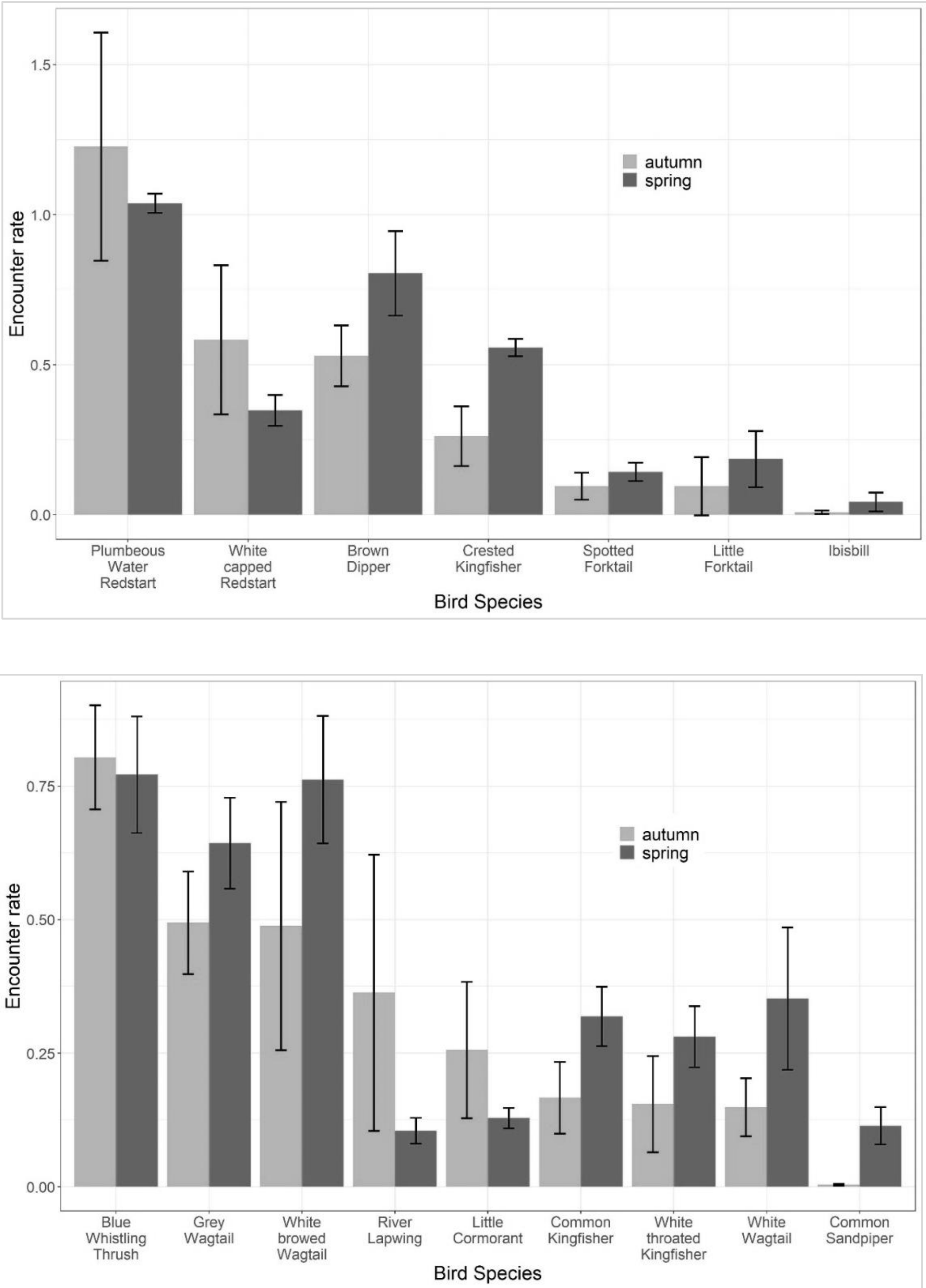
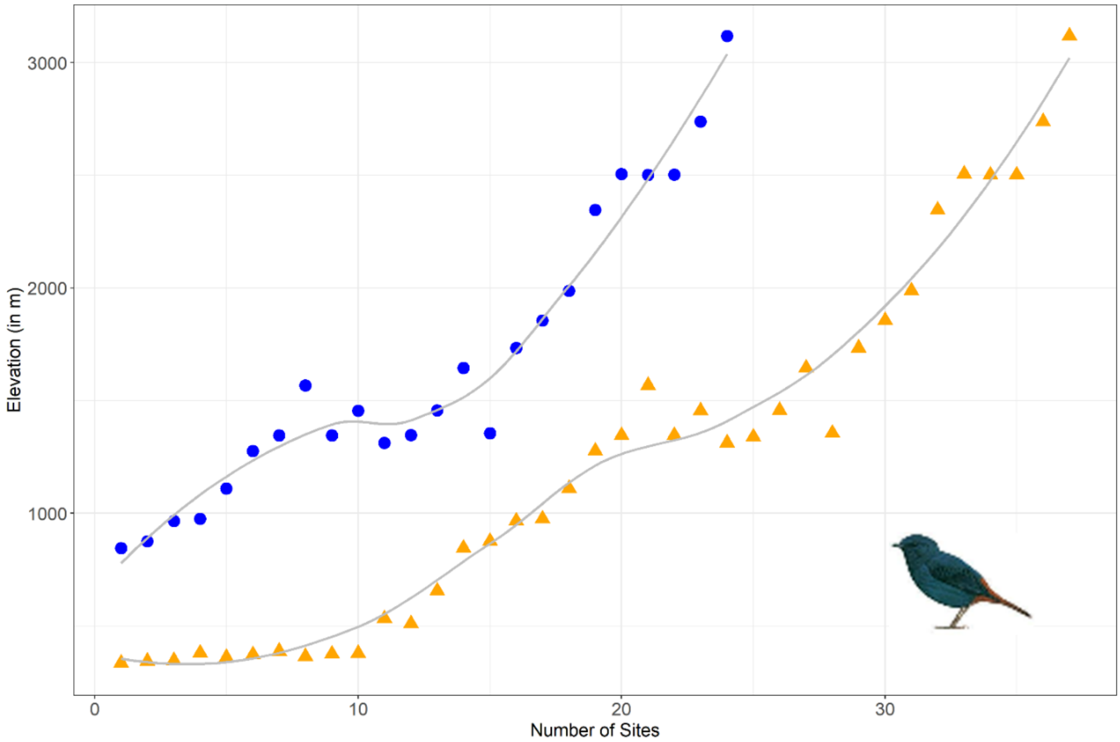
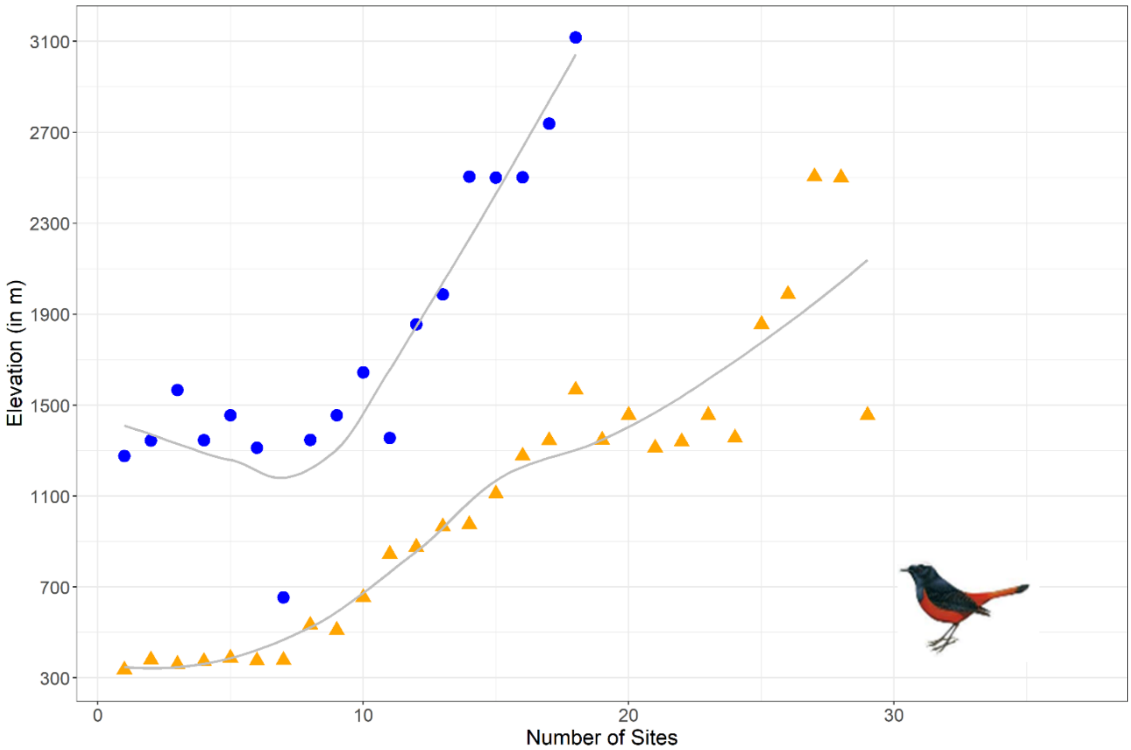
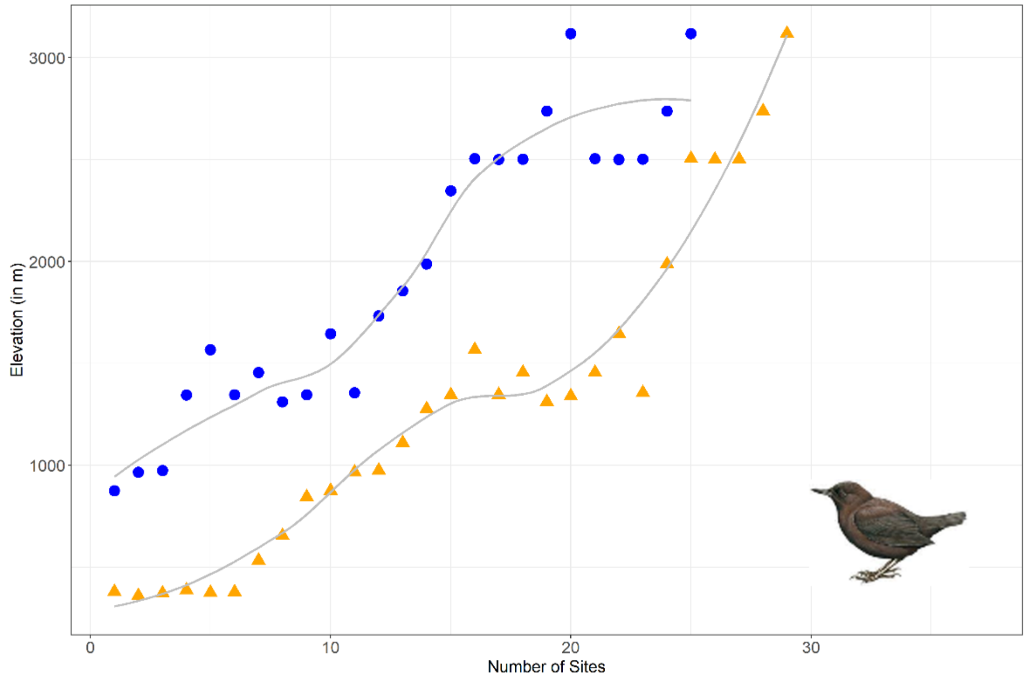


Figure 4.2. Encounter rate/ 500m of river bird (a) obligate riverine species and (b) non-obligate riverine species across the multiple years (2014-18). Error bars were plotted with the standard error values which were calculated for temporal replicates of the forty-one river reaches (of 500 m length) sampled along the Bhagirathi river. Note the scales are different for both figures.

The occupancy of sites (surveyed in field) by the most encountered obligate and non-obligate species were plotted to understand elevational distribution patterns. Species that were recorded in less than 10 sites were not plotted. Many of the river bird species showed distinct elevational distribution in summer and winter, especially the passerines. While White-capped Redstarts were recorded in mid-elevation and low elevation sites in winter, Plumbeous Water Redstart were recorded throughout the elevational gradient sampled, much like the Brown Dipper (Figure 4.3). Crested Kingfishers were not recorded above an elevation of 1500 m asl and did not show any difference in occupancy across elevation in different seasons (Figure 4.3). Summer distribution of both the Redstarts and Brown Dipper were above 1000m a.s.l., birds being encountered upto the highest sampling point at 3100m a.s.l.


Elevation (in m)
3000
2000
1000
0
10
20
30
Number of Sites


Elevation (in m)
3100
2700
2300
1900
1500
1100
700
300
0
10
20
30
Number of Sites



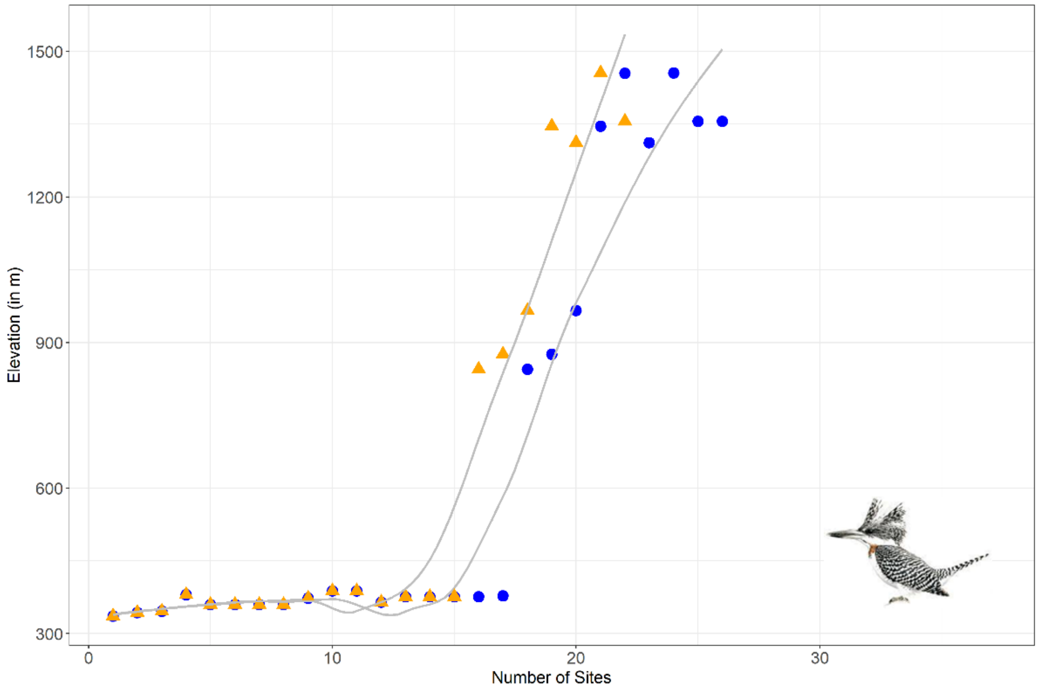
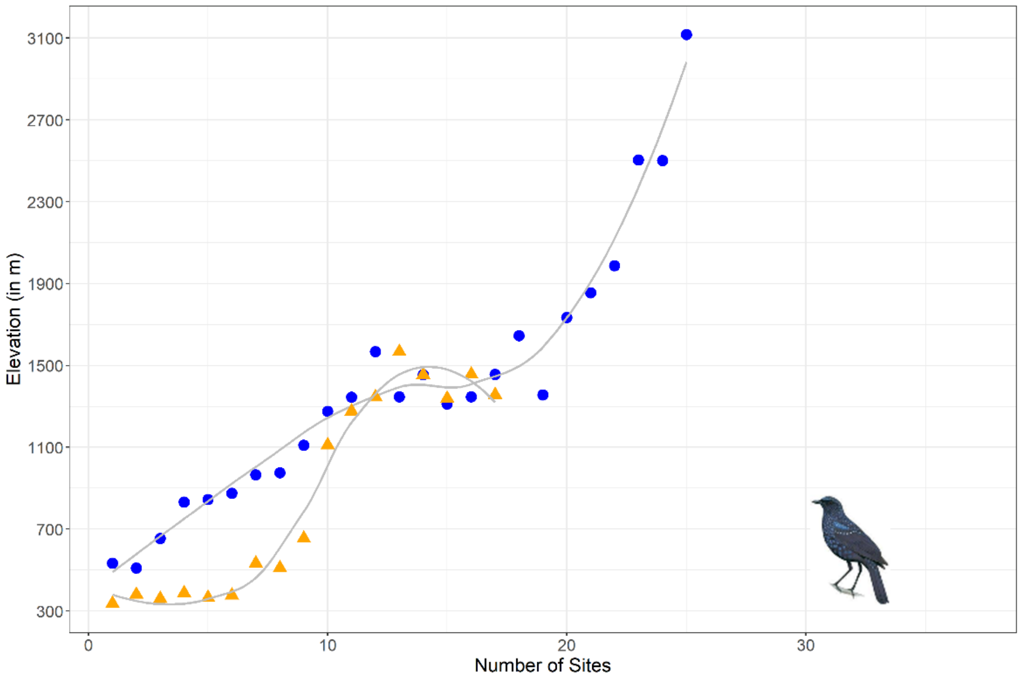


Figure 4.3. Trend of elevational distribution of the four most encountered obligate river bird species along the Bhagirathi river based on field surveys in 2014. Note: The scale for the y-axis depicting elevation at which bird was recorded is different for some species.

Among the non-obligate species, trends of elevational distribution varied for different species. Grey Wagtails showed a similar pattern of seasonal distribution (Figure 4.4) like the Plumbeous water Redstart and Brown Dipper. Blue Whistling Thrush showed a very different distribution regime, with birds were recorded well below mid-elevation river reaches at 1500 m asl in autumn. White-browed Wagtails were recorded until mid-elevation river sites at around 1300m a.s.l. in summer but remained mostly below 500m a.s.l by the onset of winter months (Figure 4.4).



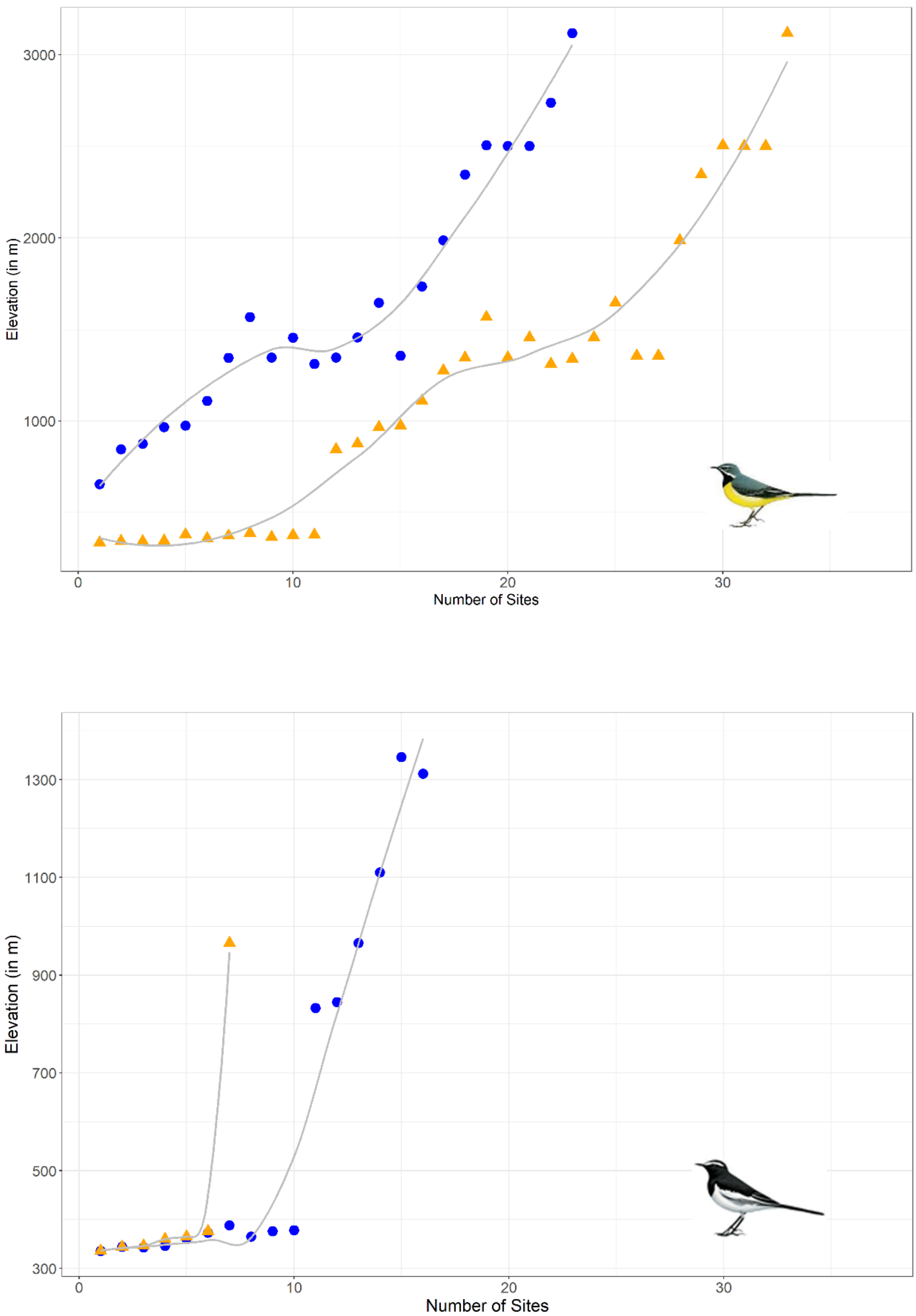


Figure 4.4. Trend of elevational distribution of the three most encountered non-obligate river bird species along the Bhagirathi basin based on field surveys in 2014. The scale for the y-axis depicting elevation at which bird was recorded is different for different species.

We looked at species pair co-occurrences separately for summer (Figure 4.5) and winter (Figure 4.6). The results for only the year 2014 have been shown here. Least co-occurrence is shown by pink (signifying these species always co-occurred) and highest values by blue (signifying these species never co-occurred), while intermediate values are depicted by lighter shades of both. The overall trend was more pair-wise co-occurrences in autumn (onset of winter) compared to summer (the breeding season). Some species pairs were found both in summer and winter. Five species of passerines formed the maximum number of pair-wise combinations in summer; Plumbeous water Redstart, Blue Whistling Thrush, Brown Dipper, White-capped Redstart and Brown Dipper (Figure 4.5). Other species pairs that co-occurred in summer are the White-browed Wagtail, White-throated Kingfisher and the Crested Kingfisher (Figure 4.5).

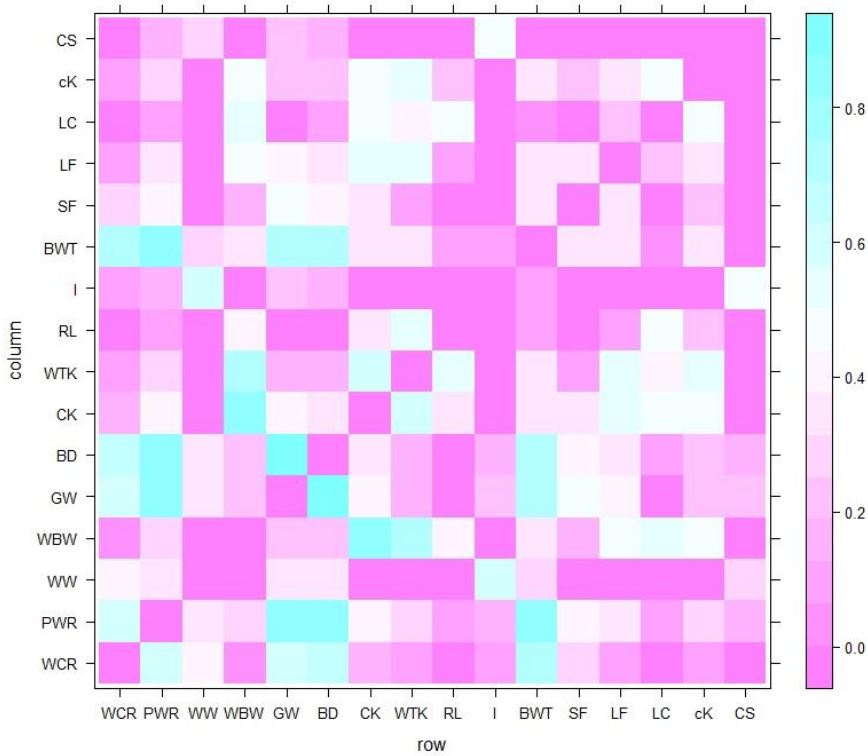


Figure 4.5. Species pair co-occurrence patterns of sixteen bird species recorded in riverine areas in summer for the year 2014 calculated from presence-absence matrix.

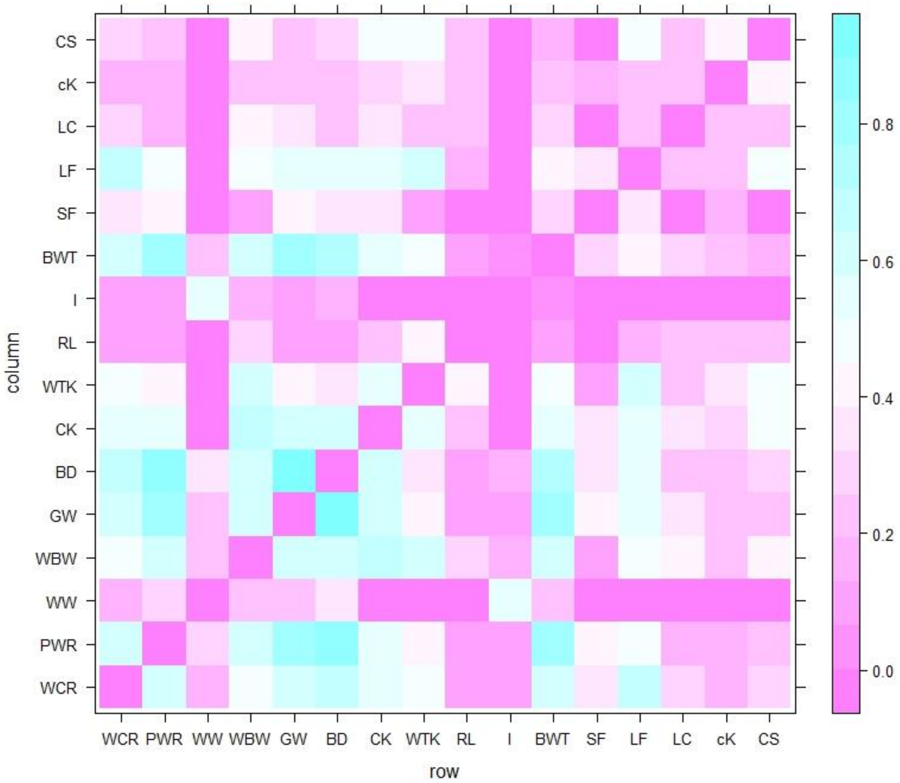


Figure 4.6. Species pair co-occurrence patterns of sixteen bird species recorded in riverine areas in autumn for the year 2014 calculated from presence-absence matrix.

A co-occurrence matrix was created to explore the pair-wise combination of bird species that co-existed in summer and autumn separately. With the 16 species described in section 4.3, there were 120 such combinations possible. In summer, around 80 combinations out of the 120 did not occur (Figure 4.7) whereas in autumn there were only around 40 such combinations which did not occur (Figure 4.8). The number of bird species pairs that always co-occurred remained same for both summer and autumn.

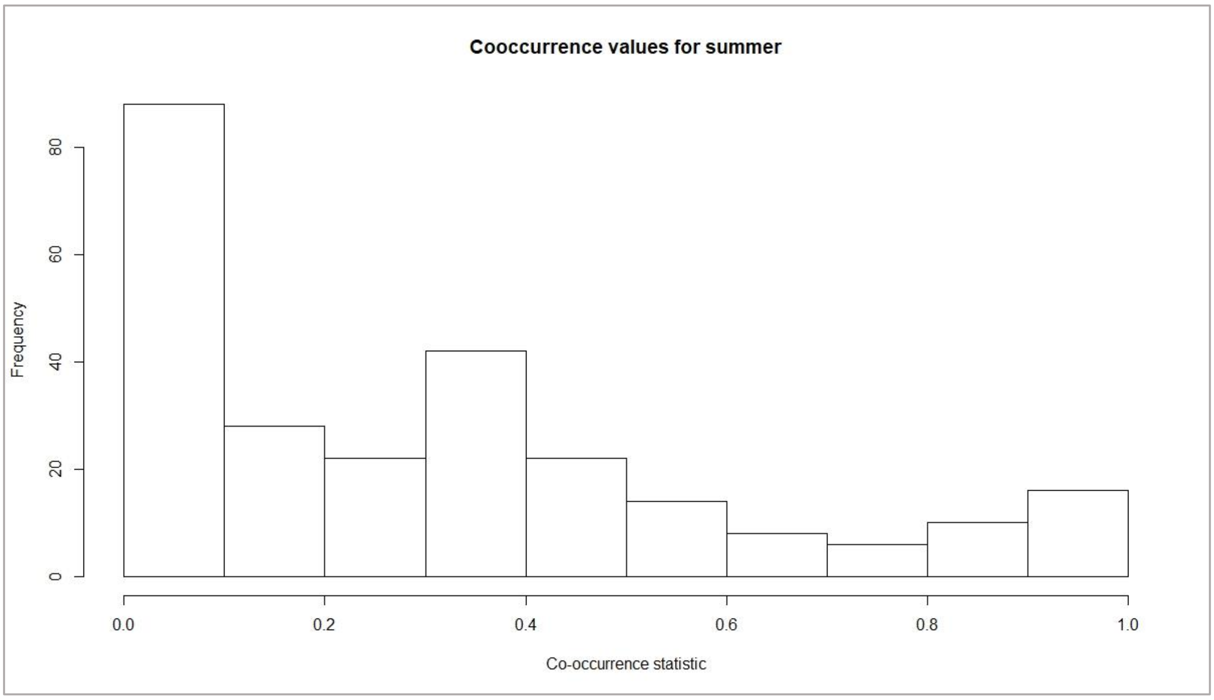


Figure 4.7. Histogram depicting co-occurrence values of sixteen bird species recorded in riverine areas in summer for the year 2014.

During summer and autumn the number of pair-wise combinations that never co-occurred were almost the same (around 15%) (Figures 4.7 and 4.8). Although in autumn the number of species pairs that always co-occurred was lower as compared to the summer time. The number of species pairs which co-occurred partially were slightly higher in autumn than summer.

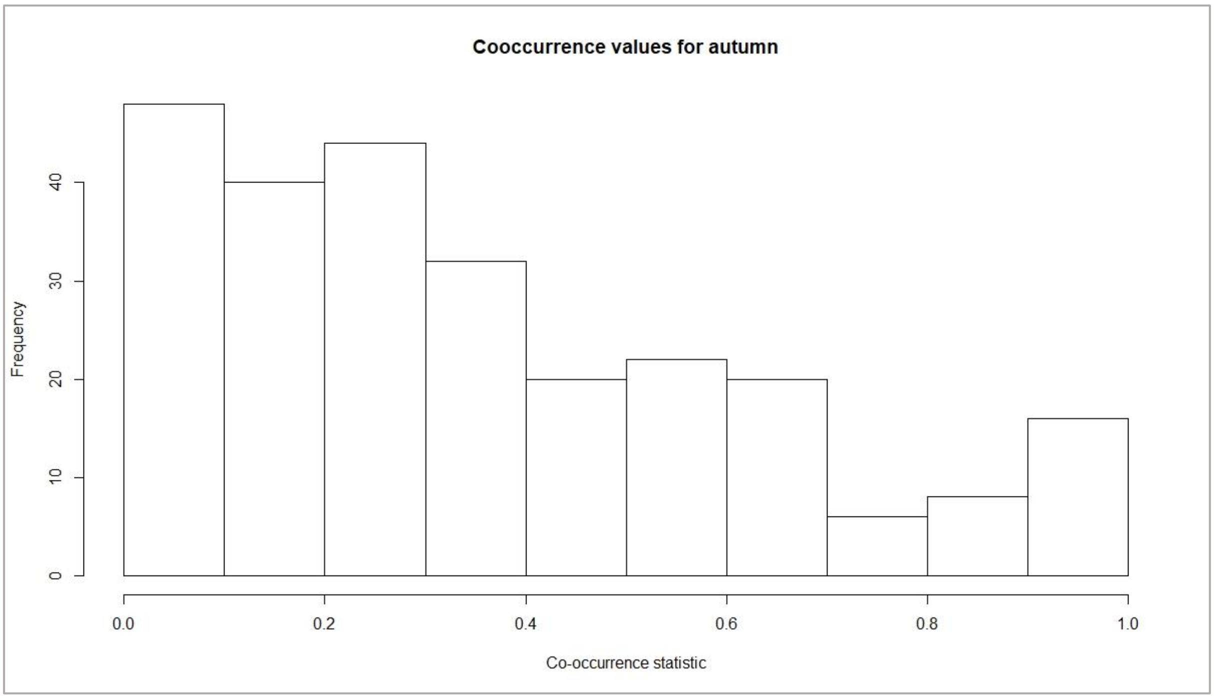
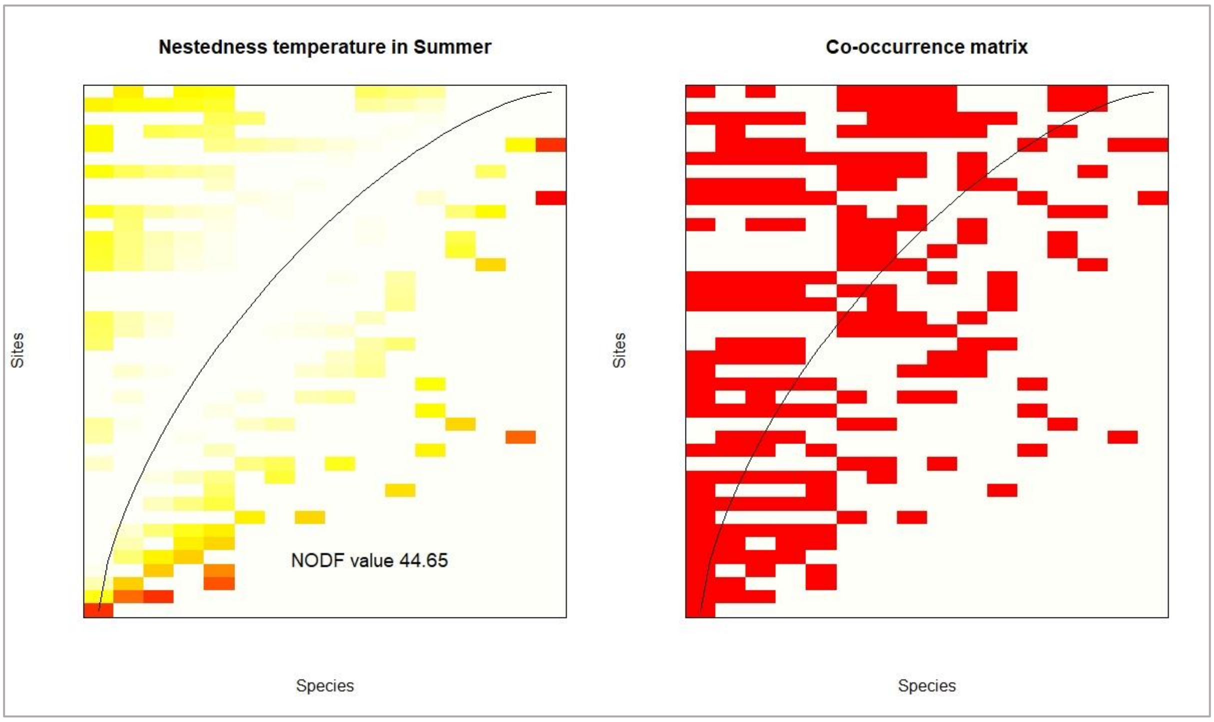


Figure 4.8. Histogram depicting co-occurrence values of sixteen bird species recorded in riverine areas in autumn for the year 2014.

The “nestedtemp” function calculates temperature of arranged sites x species matrix. This is an iterative algorithm where species are filled from the upper left corner of the matrix and deviations of both presence and absence from the diagonal are computed as the matrix temperature (Figure 4.8). Increase in matrix temperature denotes increase in nestedness in the community. The nestedness temperature calculated using NODF for autumn (62.71) was higher compared to summer (44.65) season. Two basic properties are required for a matrix to have the maximum degree of nestedness according to this metric: (a) complete overlap of 1's from right to left columns and from down to up rows, and (b) decreasing marginal totals between all pairs of columns and all pairs of rows.



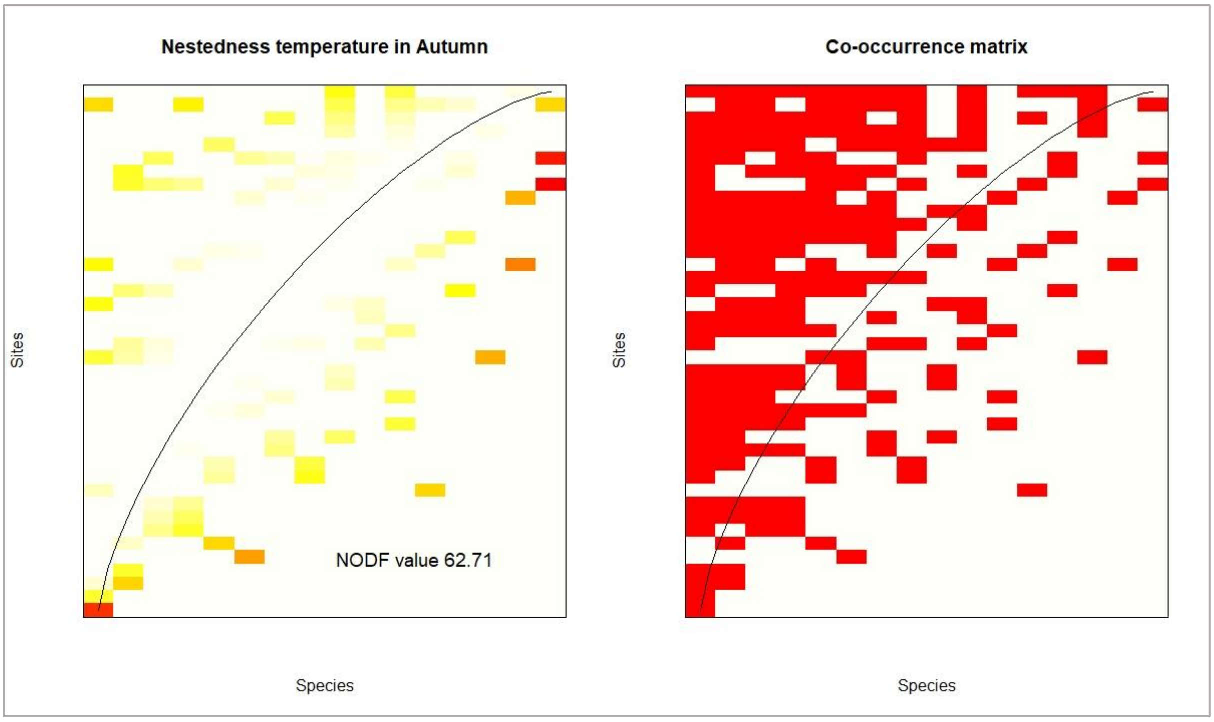


Figure 4.9. Nestedness patterns with NODF values in river bird community in summer (a) and autumn (b) in the Bhagirathi basin

4.4 Discussion

The occurrence of species from different families (Table 4.1), varying markedly in their basic ecology, results from the large species richness of Himalayan river birds in turn reflecting high primary production and the physiographic complexity associated with marked altitudinal relief in this near-tropical region (Buckton and Ormerod, 2002). The most encountered species in this study were same as studies (Manel *et al.,* 1999) conducted in Nepal two decades ago. The importance of the pronounced altitudinal range of the Himalaya was illustrated in the specific altitudinal distributions of species (Figures 4.3 and 4.4). Co-existence of different species reflect evolutionary processes and ecological adaptations at different spatial and temporal scales. Observed distribution patterns can be related to the spatial structure of the riverine environment and the habitat requirements of individual species (see Chapter 5), or to spatial aspects of population dynamics which needs further insights.

The summer sampling window spanned between March until the onset of monsoon in June which encompasses the breeding season of all the species that were studied (Ali and Ripley 1968). Breeding activities during these months encompass breeding display, egg laying, nest building and raising a clutch which are high on energy requirements. Breeding was recorded for more than ten species in field surveys. Breeding records of most of the passerine birds (both the river chats, Grey and White Wagtail, Brown Dipper, Little Forktail), and others like the Ibisbill and Common Sandpiper were recorded along higher elevation river reaches; species richness thus increasing with elevation in summer (Figure 4.1). Blue Whistling Thrush and Spotted Forktails were recorded nesting around mid-elevation river stretches. All the passerines wintered to lower elevation river reaches (some examples in Figure 4.3); species richness thus increasing in autumn in these sites. Breeding records of Crested

Kingfisher, White-browed Wagtail and River Lapwing were recorded along lower elevation river reaches, also these species did not show altitudinal migration (Figure 4.4).

More number of pairwise combinations of species cooccurrences were recorded in autumn than summer. Some species never co-occurred in the breeding season owing to strict preferences of elevation for breeding grounds (Figures 4.3 and 4.4). These patterns are typical of processes characteristic of mountain environments; being sensitive to seasonal variation in climate, which might lead to resource bottlenecks for food and other resources owing to temperature regulated physiological processes (Barve, 2017).

There were lower levels of nestedness and higher levels of co-occurrences in summer against the onset of winter when many of the bird species winter down to lower elevations. Nested patterns often emerge in the presence of ecological gradients promoting the co-existence which is the case in autumn where there is a pronounced effect of temperature difference across the highest and lowest elevation sampling sites in the study area. High habitat heterogeneity and strong interspecific competition both act against the formation of nested subsets (Wright et al., 1998). Although, it is difficult to comment on the intensity of competition in this case in the absence of experimental evidence.

Both species co-occurrence patterns and body-size distributions can depend on the spatial scale of analysis and disturbance history (Gotelli and Ellison, 2002; Jenkins, 2006). At local scales, where the aim was to understand co-occurrences of bird species dependent of river ecosystems, behavioural modifications and fine-scale resource partitioning (Albrecht and Gotelli, 2001) might act to promote coexistence among species with comparable body sizes. For example, ways of resource acquisition might differ among closely related species (Bohning-Gaese and Oberrath, 1999; Johnson *et al*., 2008), thus reducing competition via habitat segregation. Thus, seasonal patterns of distribution of the river bird community along a large altitudinal gradient can shed light on processes structuring these dynamic communities. The next chapters try to understand the same by looking at habitat use patterns in birds and understanding trait functionality and habitat selection relationships aided by phylogenetic relatedness among co-occurring species.

Chapter 5

HABITAT ASSOCIATION OF RIVER BIRD COMMUNITY IN THE WESTERN HIMALAYA

The sections 4.2 and 4.3 have been modified from the following published manuscript:

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5.1 Introduction

The cumulative response of individual organisms to ecological and environmental variation plays a critical role in shaping biological communities. Investigating patterns pertaining to the interactions between organisms and their environment have remained the soul of ecological studies for more than a century now and birds remain one of the most studied groups (Cody, 1974; Rotenberry and Weins, 1980; Rotenberry, 1985; Terborgh, 1985; Weins, 1992; Gotelli and Cowell, 2001; Grant, 1999; Grant and Grant, 2006; Ghosh *et al.,* 2014; Price *et al.,* 2014; White *et al.,* 2019). Functional attributes of communities often enable a better and more holistic assessment of the effects of fluctuations in their climatic and anthropomorphic environment (Weins, 1989; Suding *et al.*, 2008; Giordani *et al.*, 2012). As the field of conservation planning evolves, strategies have broadened from targeting single species and biological communities are increasingly gaining popularity as useful foci for conservation action (Olden, 2003; Li *et al.*, 2013; Srinivasan *et al.*, 2019).

Natural riverine landscapes form linear habitats with complex land-water coupling mediated by exchange of matter and energy (Ward *et al.,* 2002a). These support biodiverse communities which are uniquely adapted to exploit the high turnover of habitat types characteristic of riverine ecosystems (Robinson *et al.,* 2002; He *et al.,* 2018). Globally, river birds constitute an abundant, diverse and conspicuous element of vertebrate fauna inhabiting riverine areas (Ormerod and Tyler, 1993; Buckton and Ormerod, 2002; Sullivan *et al.,* 2007). They depend on riverine resources for their feeding, breeding and roosting (Buckton and Ormerod, 2008). Assessing habitat requirements of river birds are central to understanding their distribution and abundance and can potentially enhance their roles in understanding changes in the riverine structure and underlying processes (Buckton and Ormerod, 1997). So far, however, despite previous broad-scale work (Manel *et al.,* 2000; Buckton and Ormerod, 2008), no previous study has used detailed standardized habitat data from river systems in the Himalayan region to understand the distribution of specialist river birds in relation to natural and anthropogenic aspects of the riverine environment. This is despite the Himalayan mountains having more specialist river birds than anywhere on earth (Buckton and Ormerod, 2002). This chapter deals with a detailed assessment of natural and anthropogenic factors potentially affecting this group based on field surveys along the Bhagirathi river, an important headwater of the Ganges in the state of Uttarakhand, western Indian Himalaya.

5.2 Methodology

5.2.1 River Habitat Survey

Variables describing the river channel (the central element of the river corridor), flow character, bank structural composition were recorded along with information on adjacent land use following the methodology detailed in Raven *et al.* (1998) and subsequently applied to Himalayan rivers (Manel *et al.,* 2000). Observations were conducted at two different scales: (i) perpendicular transects or ‘spot checks’ at 10 points every 50m along the 500m reach and

(ii) ‘sweep up’ assessments of features over the whole 500m survey site following Raven *et al.* (1997, 1998) (Table 5.1). Spot checks recorded features over given bank widths on either side of the observer while sweep-up variables recorded the extent of features over the entire 500 m reach, describing them either as absent, present (<33% of the survey reach) or extensive (>33%).

The physical structure of the river and its bank was recorded on a six-point scale ranging across absent or rare (1–20% cover); occasional (21–40% cover); frequent (41–60% cover); abundant (61–80% cover); and dominant (81–100% cover). The bank substratum composition was recorded according to the previously defined scale with respect to percentage of boulders, cobbles, pebbles, gravel and sand. The lotic zone of the river was classified as cascades, riffles, runs, glides and dam backwaters. Cascades were defined as white waters falling from a height of more than 1m, riffles as shallow, fast flowing discrete sections and runs as reaches more than 30m of shallow fast flowing sections. Riverine vegetation was recorded as extent of grasses, shrubs and trees in the 500m section. Trees were recorded as absent, isolated and scattered, occasional clumps or semi-continuous and continuous. Canopy structure of the adjacent riverine vegetation was measured using a densiometer and was ranked as 0, 1 or 2 based on the percentage of the canopy cover for <20%, 20–50% and >50%, respectively. Bank profile was described as natural/unmodified, steep (>45° slope). Presence and absence of settlements along the banks were recorded alongside dominant human activities, such as fishing, sand-mining, road construction, water extraction for domestic use, recreational camping that were noted separately as categorical or ordinal variables. This array of habitat variables is intended to capture the complex structure of rivers that arises from local geomorphology, natural variations in vegetation and river management. This exercise aimed at capturing significant and ecologically meaningful correlates with the distribution of river birds (Buckton and Ormerod, 1997; Ormerod *et al.*, 1997).

Table 5.1. Habitat features recorded during the river habitat survey and further used for establishing relationships with the riverine bird assemblage

Spot-checks (presence recorded at 10 points)	**Sweep-up (recorded as present or extensive, >33 % of reach unless otherwise stated)**
River Flow type: Slow/ Moderate/ Fast	Riparian land use within 50m of bank, e.g. urban, broad-leaved woodland, rough pasture
Presence absence of cascades	Extent of channel features. e.g. waterfalls, cascades, riffle-pools, runs, exposed boulders, channel bars, side bars
Channel width: < 10m, 10-30m, >30m	Riverine forest patch vegetation structure based on presence of open/dense canopy
Channel depth Bank width	Presence of dams /reservoirs upstream Presence of predominant human activities like fishing, sand mining, road cutting, dredging, re-sectioning of bank etc.
Artificial structures on bank like flood control embankments and other concrete structures for water extraction and daily use by humans	Presence of recreational water sports activities and camps
Presence of pebble islands and exposed bedrock in mid-channel Bank height Artificial structures on bank	Distance to riverine forest patch
Bank material, e.g. bedrock, boulder, cobble, sand, pebble	
Channel modification, e.g. culverted, re-sectioned, reinforced	
Presence of human settlements on the banks	

Quantitative relationships between river bird species, assemblage composition and habitat features were modelled empirically using multivariate techniques in which assemblages and habitat characteristics were reduced to simplified axes using ordination- type methods (Rotenberry and Weins, 1980; Hill *et al.*, 1990, 1991). Ordination is an exploratory analytical method of ordering of species along some ecological gradients.

Habitat variables from river habitat survey that included categorical (n = 14), ordinal (n = 4) and continuous (n = 5) variables were reduced by principal components analysis (PCA) (Abdi and Williams 2010). The principal components (PCs) were used further to understand the possible importance of habitat structure to different bird species. Variables that expressed the habitat character of the site location; channel properties (e.g. river flow type, channel width and presence of characteristic features like cascades and riffles), bank features (e.g. width of the bank), bank material (e.g. pebbles, boulders, sand), riverine vegetation canopy structure and distance of vegetation from the bank were used. Canonical correspondence analysis (CCA) was used to examine bird assemblage composition in relation to habitat characters using the R 3.1 (R Core development team 2014) package 'vegan' (Oksanen *et al.*, 2016). CCA is a multivariate extension of weighted averaging ordination, which effectively arranges species occurrence and co-occurrence along putative predictor vectors that are a combination of best-fitting environmental variables (Ter Braak, 1987). The presence/ absence of 14 bird species figured in this analysis, and the untransformed PCs were used as potential predictors. This analysis was not weighed by abundance, using only presence–absence data. To assess which variables best explained the presence of each species, logistic regression was used to relate the presence/absence of the six most widespread river bird species to the highest-ranking PCs that described river habitat character. Intercept terms were ignored as the incremental effect of habitat change was the focus of interest. Using the sign of the coefficient term in the regression model, we identified the most significant habitat variables in the PC separately for presence and absence of the bird species.

5.3 Results

Four principal components explained over 60% of the variance in habitat character in the 41 river reaches sampled (Table 5.2), and there was marked heterogeneity in the riverine habitat structure. Inter-correlation between variables prevented clear identification of natural versus human influences on habitat features, but PC1 (26.5% of explained variance) described a trend from narrower, faster, tree-lined river reaches at higher elevation to lower reaches with modified banks lined by urban settlements. PC2 (15.4%) largely reflected trends in substratum character from river reaches with boulders and pools to those with pebble islands and bars in the river channel. PC3 (10.5%) increased where mid-sized river reaches had boulder-strewn banks, while PC4 (9.0%) increased in wider, lower reaches with pools, mid-channel bars, agriculture and trees along the banks.

Table 5.2. Trends in habitat characters shown by PCA from river habitat surveys of 41 sites in Upper Ganges (Bhagirathi river) in 2014-18. The percentage of variance explained by each PC (principal component) is shown in parentheses.

PC1 (26.1%)	PC2 (15.5%)	PC3 (9.8%)	PC4 (8.8%)
Altitude (+) Riffles (+) Cascades (+) Logs in river channel (+) Shrubs (+) Trees (+) Channel width <10 meters (+) Urban settlements (-) Modified river banks (-) Channel width more than 30 meters (-)	Boulders (+) Trees (+) Shrubs (+) Pool (+) Agriculture (-) Pebble island in river channel (-) Log in river channel (-) Mid-channel bars (-) Altitude (-)	Channel width 10-30 meters (+) Boulders (+) Channel width <10 meters (-) Cascades (-) Trees (-) Channel width more than 30 meters (-) Log in river channel (-)	Pool (+) Agriculture (+) Mid channel bars (+) Trees (+) Cascades (-) Boulders (-) Pebble island in river channel (-)

5.3.1 Bird distribution and habitat structure

In ordination, four constrained habitat axes explained 32% of the total inertia in the bird species data, with CCA1 (17.7%) and CCA2 (9.6%) explaining most variation (Figure 5.1).Taken individually, habitat PC1 ($F_{1,36}$=5.11, p=0.001), PC2 ($F_{1,36}$=3.84, p=0.002), and PC4 ($F_{1,36}$=2.89, p=0.006) all explained significant aspects of assemblage composition and reflected the habitat requirements of each species.

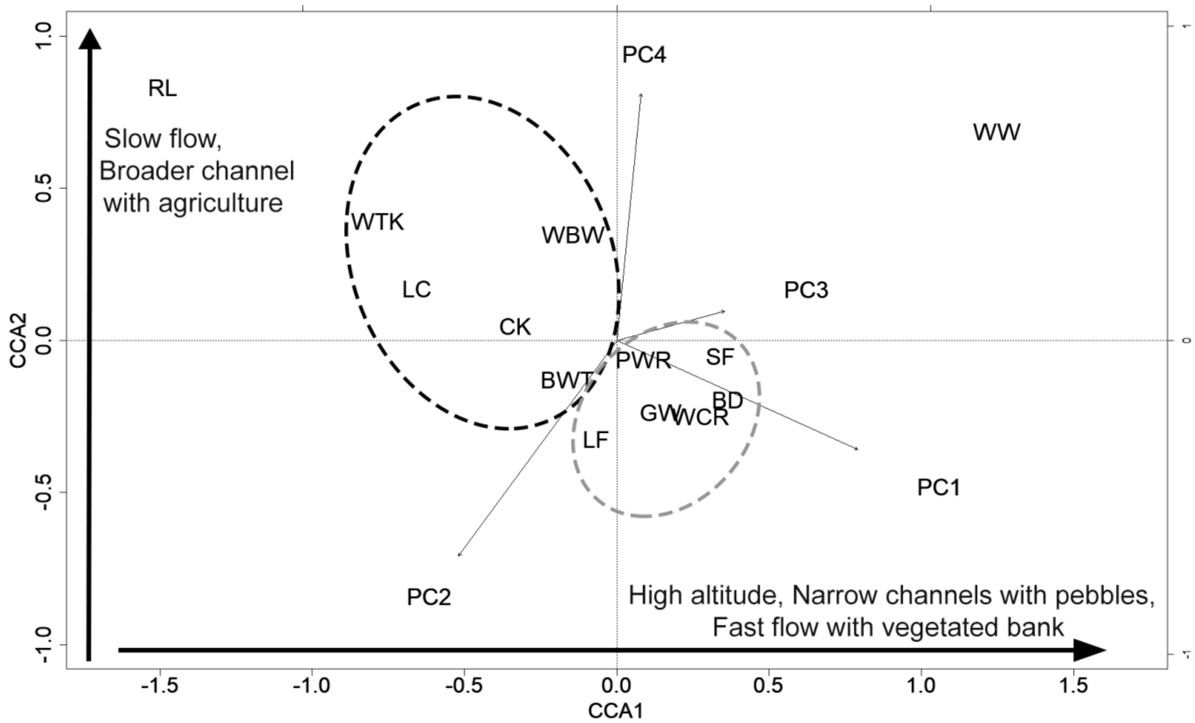


Figure 5.1. Biplot of the first two CCA axes showing the positions of 14 river bird species and the associated principal components describing river habitats in the upper Ganges; riverine obligates are encircled by grey dotted lines and non-obligates by black dotted lines. PWR-Plumbeous Water Redstart WCR- White-capped Redstart BD- Brown Dipper GW- Grey Wagtail WBW- White-browed Wagtail WW- White Wagtail CK- Crested Kingfisher WTK- White-throated Kingfisher BWT- Blue Whistling Thrush SF- Spotted Forktail LF- Little Forktail LC-Little Cormorant RL-River Lapwing.

Among bird species, Spotted Forktail, Brown Dipper, Plumbeous Water Redstart, Grey Wagtail and White-capped Redstart all had higher scores on CCA1 reflecting affinities for higher altitude, narrower channels, faster flows and more intact riparian vegetation. In contrast, River Lapwing, Blue Whistling Thrush, White-throated Kingfisher, White-browed Wagtail and Little Cormorant scored negatively on CCA1, reflecting their downstream distribution and tolerance of human activities. On CCA2, White Wagtail, White-browed Wagtail and Little Cormorant scored positively, reflecting their occurrence at slower flow, broader channels and banks with agriculture, while Spotted Forktail, White-throated

Kingfisher and Blue-whistling Thrush scored negatively. In combination, these effects meant that the ordination (Figure 5.1) broadly separated two species groups respectively, riverine obligates (grey circle) and non-obligates (Figure 5.1, black circle), with a large part of this division occurring on habitat PC1 ($F_{1,36}$=5.11, p=0.001). Preference for higher altitude reaches was stronger among passerines than non-passerines as reflected by their positive values on CCA axis 1.

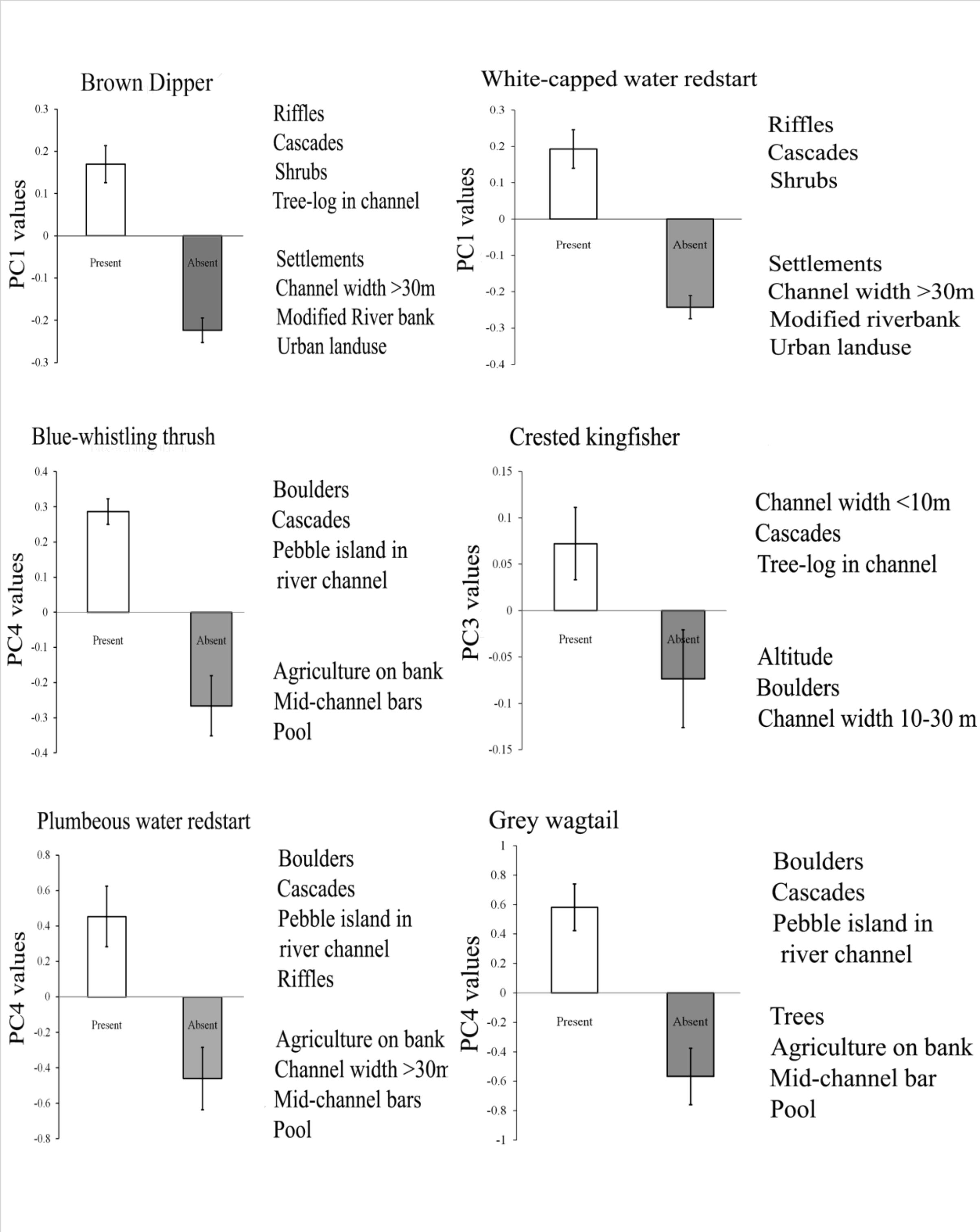


Figure 5.2. Plots depicting correlation between the principal components of the river-habitat variables across the sampled (43) river reaches along the Upper Ganges and the presence/

absence of six species of river birds. The most significant variables of the PC are shown in the vertical axis of individual plots. Error bars indicate ±1 SE.

Table 5.3. Results of logistic regression representing the presence/absence of six most widespread river bird species in relation to the highest ranking principal components describing habitat character. PCs with a significance value above 0.001 are listed.

Bird Species	Significant PCs	Regression Coefficient	Pr (>|z|)
Plumbeous Water Redstart	PC4	1.87	0.004
	PC2	-1.06	0.006
White-capped Redstart	PC1	0.79	0.003
Brown Dipper	PC1	0.70	0.003
Blue Whistling Thrush	PC4	0.72	0.041
Crested Kingfisher	PC2	0.14	0.475
Grey Wagtail	PC4	2.01	0.006

Logistic regression confirmed relationships between the presence/absence of each of the six most widespread river birds and river habitat character (Table 5.3; Figure 5.2). Specifically, the regressions confirmed how Plumbeous Water Redstart occurred mostly on moderately wide (10-30m) river segments with pebble banks, faster flow and pebble island; Brown Dipper and White-capped Redstart preferred narrower, tree-lined river reaches at higher elevations with cascades while avoiding wider river segments with settlements, urban land-use and modified river banks. Blue Whistling Thrush and Grey Wagtail were positively associated with boulder-strewn banks, cascades and pebble islands, while being absent from river reaches with slow flow and agricultural land use (Table 5.3, Figure 5.2).

5.4 Discussion

Our study identifies the habitat heterogeneity of Himalayan rivers and confirms the highly diverse community of riverine bird species that occur in these systems. Results demonstrate that the occurrence of river birds is apparently influenced strongly by natural elements of river flow variability, riverine vegetation structure, river channel and bank morphology alongside potential human influences (Figure5.1; Table 5.3). Unlike past studies where many variables were used to model bird-habitat relationship we chose to use river habitat data cautiously based on previously published literature to reduce the risk of spurious correlations (Ormerod *et al.*, 1985; Ormerod *et al.*, 1986; Ormerod and Tyler, 1991; Buckton and Ormerod, 2008; Vaughan *et al.*, 2007).

The separation of habitat space along major variates in different species describing habitat character (Figure 5.1) revealed how smaller, passerine and river-obligate species preferred high altitude river reaches with faster flows as distinct from larger, non-obligate bird species that apparently preferred wider channels with slow flow and more urban land-use. Within the obligate group, there was separation in the utilization of the water channel and banksides by individual species, ranging from predominantly aquatic habitat use in the Brown Dipper and Little Forktail, ground-gleaning or fly-catching over the channel or riparian zone in the Plumbeous and White-capped Water Redstart, and foraging near the riparian margin in the Spotted Forktail (Ormerod and Buckton, 2008). Even with similar body sizes, Plumbeous water Redstart and Little Forktail have different foraging techniques in which the former feeds more frequently by aerial fly-catching, while the latter feeds from spray-drenched exposed boulders and wetted bankside pebbles and rocks. These contrasting patterns of microhabitat use illustrate how different species can partition physical habitat space and foraging niches in riverine environments. Consistent patterns are reflected also in the adaptation of the larger non-passerines to larger water bodies and less hydraulically dynamic water bodies where they occur more frequently.

The riverine obligates avoided urban land-use habitats which are characterized by paved banks and river banks clear of riverine vegetation, a pattern observed in other parts of the world (Larsen *et al*., 2010; McClure *et al*., 2015). These observations suggest that the river obligate species offer the best potential indicators of human impact, and we expand this theme below. This separation between obligate and non-obligate species concur with well-known ecological principles where sympatric species at the risk of overlapping resources differ along key dimensions that ensure either niche complementarity or resource partitioning (Schoener, 1974; Royan *et al.*, 2016). In bird communities, niche separation reflects differences in feeding behaviour (Buckton and Ormerod, 2002; Cody, 1968), dietary specialization (Nudds and Bowlby, 1984), habitat use and morphology (Miles and Ricklefs, 1984). Passeriformes are morphologically pre-adapted to diverse foraging techniques, which include fly catching, ground gleaning and aquatic foraging in stream or bankside habitats. In turn, these behaviours provide scope for different members to exploit the three main sections of the riverine environment, i.e. the channel, the bankside and the riparian zone.

While altitude per se can affect bird distribution, other factors such as temperature, atmospheric oxygen concentrations, nutrients and physical features such as slope or flow velocity are also important. Changes in the spatio-temporal heterogeneity of river flows can alter the distribution and abundance of certain fish and aquatic invertebrates (Bunn and Arthington, 2002) which are important dietary components for several of the bird species studied. Variability in flow conditions, especially large fluctuations in water velocity and depth caused by impoundment, affects the availability of foraging habitats which is liable to disrupt river-bird community structure (Cumming *et al.*, 2012).

Owing to remoteness of these areas, quantitative studies aimed at understanding the effects of changes to the riverine environment on river biodiversity are few, and robust hypothesis testing is scarce (Ormerod *et al*., 1994, 1997; Juttner *et al.*, 1996; Suren and Ormerod, 1998). Himalayan streams form headwater systems contributing significantly to the river network of important river systems of the country, the Ganga, Yamuna and Brahmaputra. Disturbances that are now widespread across multiple headwater watersheds resulting from agricultural intensification, road networks, air pollution, and diffuse patchworks of logging sites or residential development are likely to be more detrimental than disturbances that are confined to few or to individual watersheds. Wherever possible, minimizing the spatial extent of human disturbance in headwater areas may guard against the widespread degradation of physical and chemical conditions in these up-land stream networks and the subsequent transmittal of impacts downstream and associated biota.

Chapter 6

DISCERNING PROCESSSES DRIVING THE ASSEMBLY OF RIVER BIRD COMMUNITIES IN WESTERN HIMALAYA

6.1 Introduction

Multiple ecological processes interact to determine the structure of communities. 'Habitat filtering' which highlights processes controlled by the abiotic environment in shaping the distribution of species has remained one of the most enduring concepts in the study of community assembly and dynamics (Weiher and Keddy, 1998; Webb, 2000; Kraft *et al.*, 2015). However, the understanding that environmental factors do not operate independently in structuring communities, and both abiotic and biotic factors may operate as filters at multiple, potentially nested scales goes back to two decades from now (Poff, 1997). Recent studies have criticised inferences based on observational studies and their inability to discern patterns created by competition and environmental filtering (Mayfield and Levine, 2010; Cadotte and Tucker, 2017). Hence there is a growing consensus on supplementing field observational studies with an understanding of species trait–environment links (McGill *et al.,* 2006; Winemiller *et al.*, 2015).

Two major approaches that quantify species ecological differences are functional (or trait based) and phylogenetic (or the amount of evolutionary divergence). As determinants of functions, individual traits can reveal the mechanisms that drive the patterns of organism distribution (Kraft *et al*., 2007). Organism traits include morphological, physiological, and behavioural features operating at the level of the individuals. Species respond in different ways to environmental changes, which may be related to functional traits (McGill *et al*., 2006). Traits therefore offer a basis for establishing and testing mechanistic hypotheses about assembly of organisms in natural communities. Field studies aid in selection traits of interest, identify functional group, and thus understand processes that drive species' responses to environmental variation.

Based on the idea that phylogenetic distance between species could stand as a proxy for overall ecological differentiation, phylogenetic distance between community members that is greater than expected by chance has been suggested as potential evidence of competitive exclusion (Webb *et al*., 2002), but this approach assumes trait conservatism or at least phylogenetic signal for key traits (Losos, 2008). Partly to address this assumption, there is currently a focus on direct tests of the mechanisms linking phylogenetic relationships to community assembly. Although community phylogenetics was originally proposed to examine coexistence among species for which experimental approaches were intractable such as tropical trees (Webb *et al*., 2002), the field is quickly expanding to systems with faster dynamics and smaller spatial scales.

Most of these studies have also measured some kind of trait difference between species over the course of the study and found some degree of correlation between trait and phylogenetic distance. However, not all ecologically relevant traits show phylogenetic signal (Losos, 2008), and in fact, there is good reason to suspect that traits related to resource acquisition in animals might differ among closely related species (Bohning-Gaese and Oberrath, 1999; Johnson *et al*., 2008), perhaps as a means of reducing competition via habitat segregation (Losos, 1995). Exclusive access to alternative food resources via differences in fundamental feeding niche could thus have strong effects on resource competition. Phylogenetic relatedness captures a more comprehensive and unbiased index of similarity that integrates over multiple niche dimensions (Cadotte *et al*., 2008; Burns and Strauss, 2011), and may therefore predict additional variation in species distribution patterns that result from other important traits, such as interference competition, net reproductive rate or habitat use, some of which do show phylogenetic signal.

6.2 Methodology

To assess trait responses to environmental gradients we simultaneously analysed the information contained in three tables: L (species distribution across river reaches surveyed; 12 species*43 sites), R (environmental characteristics of samples; 43 sites* 12 environmental variables), and Q (species traits; 12 species*8 traits) in “ade4” in R (Dray and Dufor, 2007). The fourth-corner and RLQ methods are two alternatives that provide a direct way to test and estimate trait–environment relationships. Both methods are based on the analysis which crosses traits and environmental variables weighted by species abundances. RLQ is a multivariate technique that provides ordination scores to summarize the joint structure among the three tables, whereas the fourth-corner method mainly tests for individual trait–environment relationships i.e., one trait and one environmental variable at a time (Dray and Legendre, 2008; Dray *et al*., 2014).

Data on morphometric measurements like the body size, mass, tail, bill and tarsus length, clutch size, food if aquatic, terrestrial or a mixture of both were assimilated from Ali and Ripley 1968. Information on elevational distribution pattern of birds was collated from multiple years of field data spanning the breeding and wintering seasons (details in chapter 4). The information on the diet spectrum of the birds is based on field observations and information based on published literature (Ali and Ripley 1968; Buckton and Ormerod 2008). The diet spectrum of the studied group varied from wholly aquatic to a mixture of aquatic and terrestrial. Details on collection of the the environmental data has been detailed in chapter 5. Variables showing high correlation were dropped for this analysis. Data on species occupancy of different sites were used only from the summer season aiming to understand relationships for the breeding season (when species actively defend territories).

For the 16 bird species that were the focus of this study, 1,000 phylogenetic trees were downloaded from the backbone tree (www.birdtree.org), based on Jetz *et al*. (2012). The consensus tree (Figure 6.1) was obtained applying the 50% majority rule (i.e., the proportion of a split to be present in all trees) and thereafter modelled interspecific variation across the phylogeny. The R packages: “ape” (Paradis *et al*., 2004), were used for this analysis.

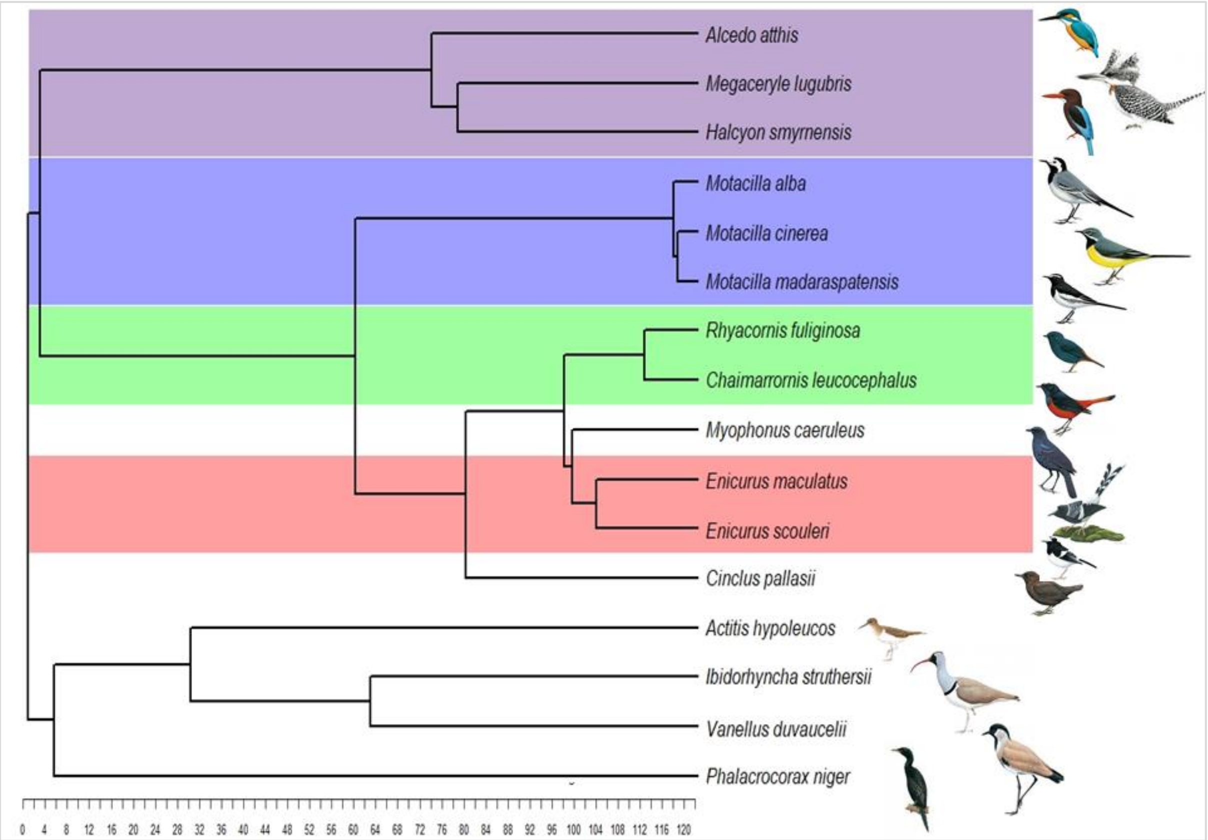


Figure 6.1. Dendogram showing the phylogeny of rivers birds of Western Himalaya

To measure the strength of the phylogenetic signal (Blomberg and Garland, 2003) in the 16 bird species, Blomberg's *K* statistic and statistic *K** (Blomberg *et al*., 2003) were used. The *K* statistic works as a mean square ratio, where the numerator is the error assuming that the trait evolves independently of the phylogenetic structure, and the denominator is corrected by the phylogenetic covariances. Blomberg's *K* statistic was estimated using the R package “phylosignal” (Keck *et al.*, 2016). Moran's correlograms were used to assess how phylogenetic autocorrelation changes across different phylogenetic distances. Moran's correlograms were plotted using the function “phyloCorrelogram” from the package “phylosignal” (Keck et al., 2016). All statistical tests were performed with R software version 3.2.4 (R Development Core Team, 2017).

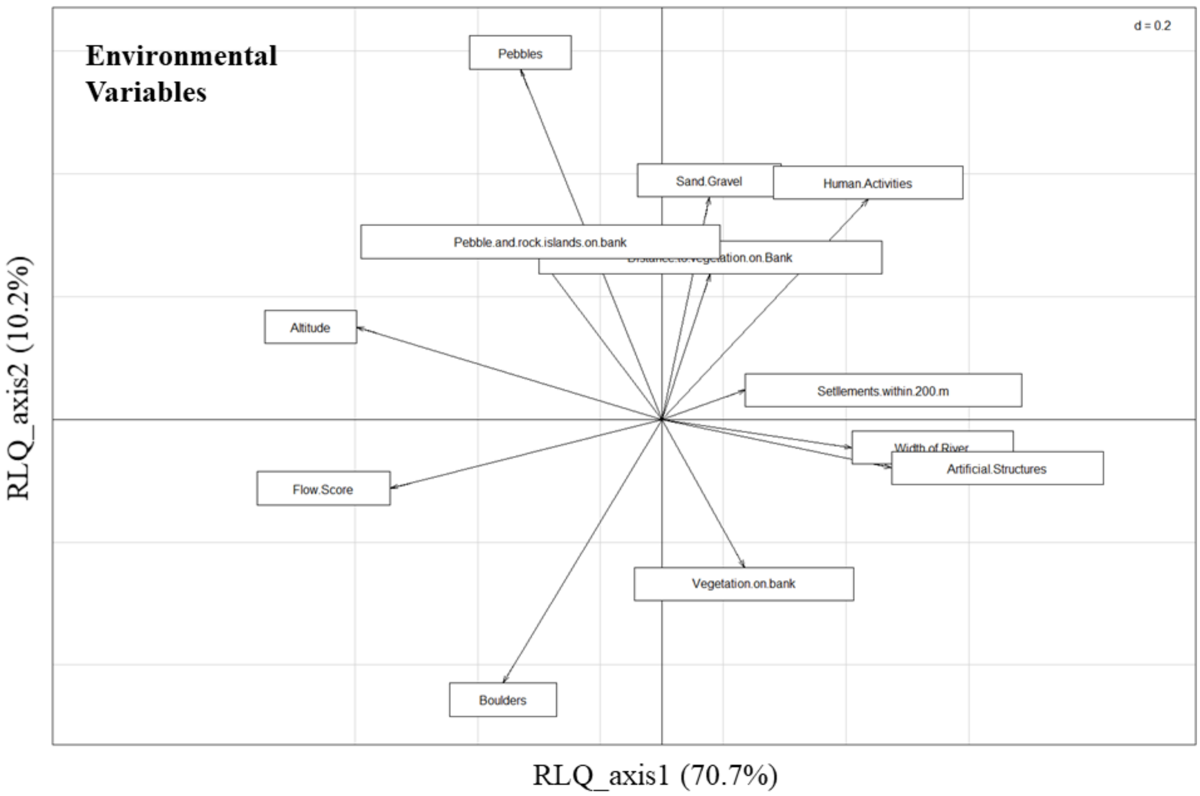
6.3. Results

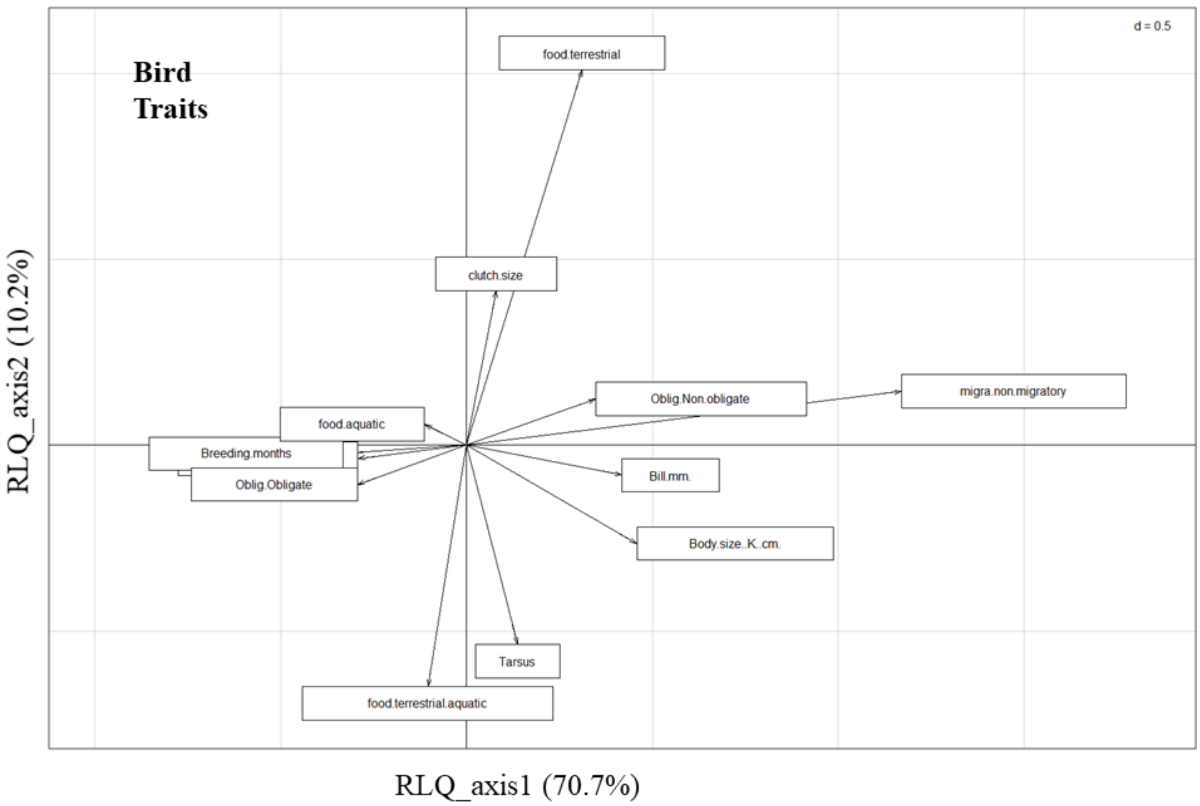
The first two axes of the RLQ multivariate analysis explained 80.896% of the total inertia of the three tables (Table 6.1) and accounted for most of the variability explained by the first two axes of the of environmental variables (R-table) and species’ functional traits (Q-table) separately. Although variability was better explained for traits (79%) than environmental factors (72%), the difference is not much (Table 6.1). Results indicated a stronger relation between environmental variables and traits on the first RLQ axis. Nevertheless, the correlation between scores of the species distribution across sites in RLQ was low for both axes (Table 6.1).

Table 6.0.1. Summary of the RLQ analysis.

Total inertia= 2.46			
Projected inertia (%)			
	Ax1	Ax2	
	70.699	10.197	
Eigenvalue decomposition			
	eig	covar	corr
eig1	1.739	1.3188	0.382
eig2	0.2509	0.501	0.246
Inertia and cointertia R:			
	inertia	max	ratio
eig1	3.777	4.691	0.805
eig1+2	5.384	7.506	0.717
Inertia and cointertia Q:			
	inertia	max	ratio
eig1	3.148669	4.008963	0.785
eig1+2	5.715597	7.224227	0.791
Correlation L:			
	correlation	max	ratio
eig1	0.382	0.502	0.762
eig2	0.247	0.406	0.608

The joint approach of RLQ and fourth-corner analyses allowed the investigation of the significance of the relations between environmental variables and traits. There was significant negative correlations between the first RLQ axis and flow score and banks with boulders, and a significant positive correlation with human settlements and human activities like camping, fishing etc., sandy banks and banks with distant riparian vegetation. This axis was significantly correlated with food habit trait; showing a positive association with birds with terrestrial prey and a negative association with birds having a diet which is a mixture of terrestrial and aquatic components (Figure 6.2). The first RLQ axis also showed positive correlation with migratory nature of birds. The second axis of the RLQ had a significant negative correlation with environmental variables like vegetation on bank, wide river channels and presence of artificial structure on banks and positive correlation with pebble banks, river stretches with pebble and boulder islands and high elevation river reaches. The second axis of RLQ showed negligible association with any traits on the positive axis but negative association with traits of body size, tarsus size and bill size (Figure 6.2).


d = 0.2
Environmental Variables
Pebbles
Sand.Gravel
Human.Activities
Pebble.and.rock.islands.on.bank
ation.on.Bank
Altitude
Setllements.within.200.m
Width.of.River
Artificial.Structures
Flow.Score
Vegetation.on.bank
Boulders
RLQ_axis2 (10.2%)
RLQ_axis1 (70.7%)


d = 0.5
Bird Traits
food.terrestrial
clutch.size
Oblig.Non.obligate
migra.non.migratory
food.aquatic
Breeding.months
Oblig.Obligate
Bill.mm.
Body.size..K..cm.
Tarsus
food.terrestrial.aquatic
RLQ_axis2 (10.2%)
RLQ_axis1 (70.7%)

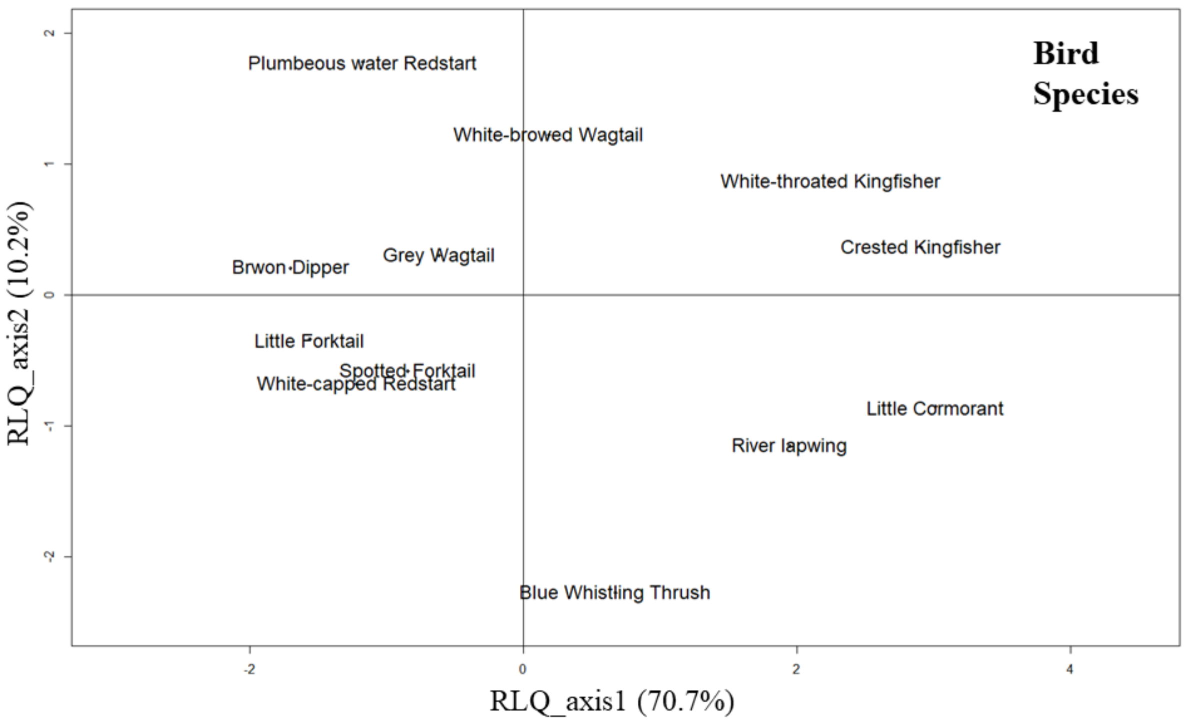


Figure 6.2. Biplot depicting the first two axes of the RLQ multivariate analysis. Plots represent projections in the plane of the first two main components of (a) environmental variables and (b) species traits and (c) bird species

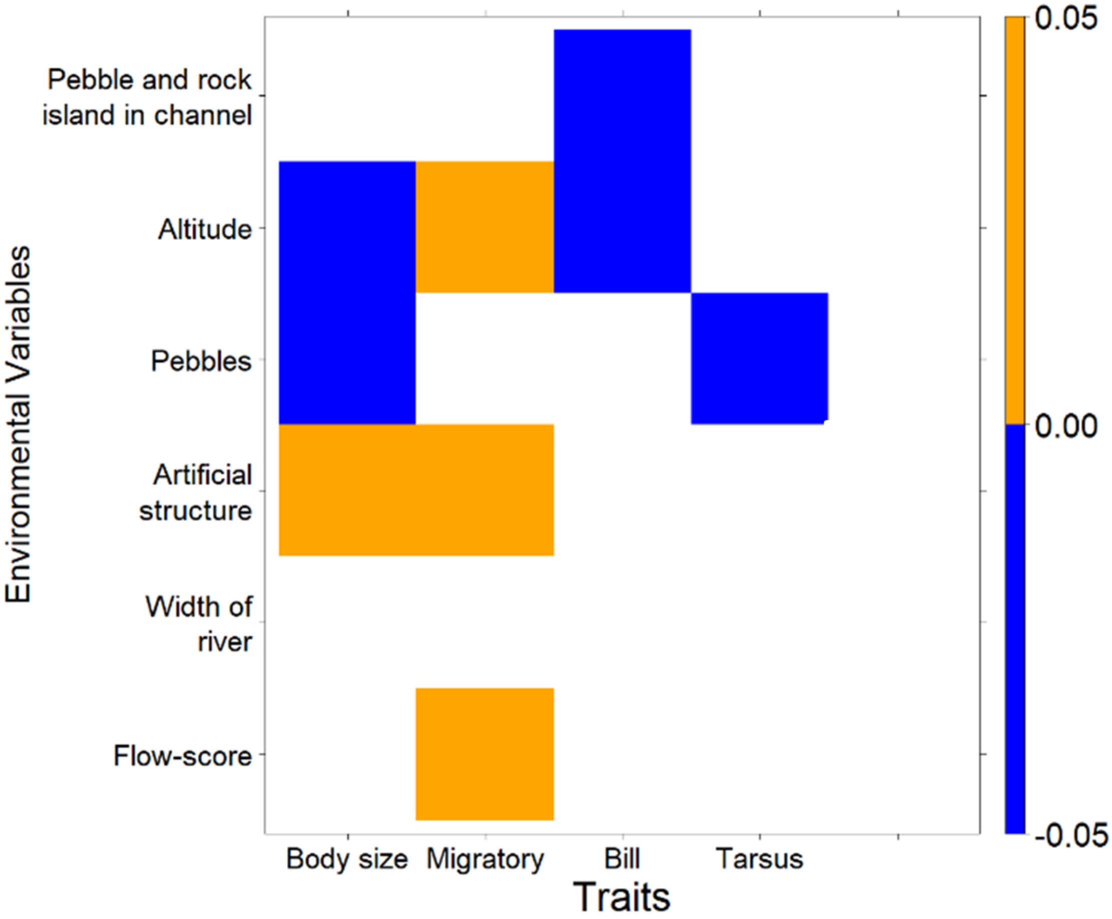


Figure 6.3. Results of the fourth-corner tests. Significant (P <0.05) positive associations are represented by orange cells, and significant negative associations correspond to blue cells.

Body size, migratory behaviour, bill size and tarsus length showed significant correlations with environmental factors. Body size showed a negative trend with altitude, natural pebble banks, and a positive relationship with artificial structures. Smaller body-sized birds were recorded with increasing elevation, species were not seen crossing certain elevational barriers. The passerines showed affinity for higher elevation breeding grounds and a characteristic migration pattern. The fourth-corner plot shows a positive trend of altitudinal migration with faster flows (Figure 6.3). The smaller body sized passerines which undertook altitudinal migration are adapted to actively forage from fast flowing river stretches. Bill size showed a negative trend with pebble and rock islands in mid channels. Birds with a smaller bill size showed preference of feeding from pebble and boulder islands in mid-channel probably owing to their smaller beaks which helped them in extracting food from the thin film of water which regularly inundates these micro-habitats. Tarsus length showed a negative association with natural pebble banks (Figure 6.3). Birds with a smaller tarsus length like the forktails, river chats and brown dippers preferred natural pebble banks with frequent inundation for feeding, probably because this trait aided in maintaining balance in these slippery surfaces.

When K approaches 1, trait evolution follows a mode of evolution that is consistent with Brownian motion. If $K > 1$ and <1, close relatives are more similar and less similar, respectively, than expected under Brownian motion, indicating a strong phylogenetic signal (Blomberg *et al*., 2003). Analysis of the phylogenetic signal for all the traits returned the statistically significant K and K^* values ($p < 0.01$) suggesting a generally high degree of phylogenetic signal in body size (K=1.2332), bill size (K=1.4098) and tarsus length (K= 1.0725).

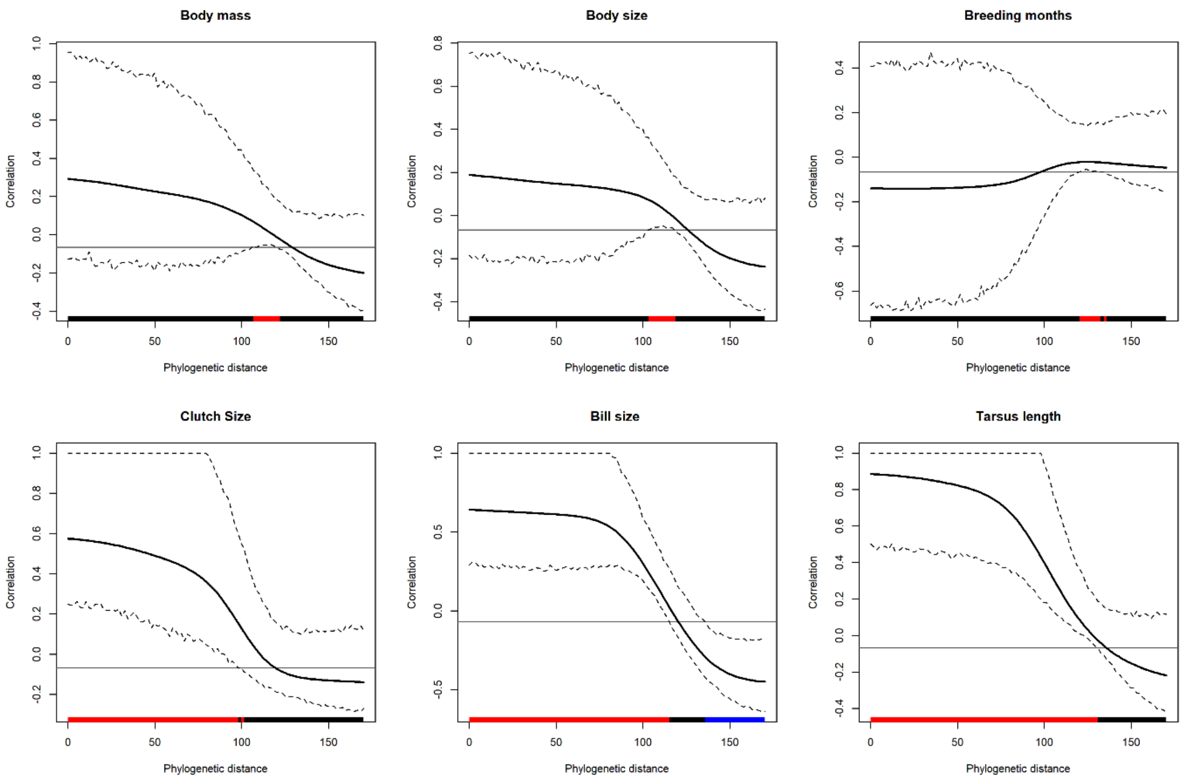


Figure 6.4. Phylogenetic correlogram for the six traits on diet, foraging behaviour, foraging substrate, habitat, for 16 bird species recorded in field surveys along the Bhagirathi river during this study. The figure shows the mean phylogenetic signal (solid bold black line represents the Moran's I index of autocorrelation) with a 95% confidence interval resulting from 100 bootstraps (dashed black lines represent both lower and upper bounds of the confidence interval). The coloured horizontal bars show whether the autocorrelation is significant: red is a significant positive autocorrelation, blue is a significant negative autocorrelation and black is a nonsignificant autocorrelation.

Table 6.2. Phylogenetic signal in the six traits of body mass, body size, breeding months, clutch, bill and tarsus size for the 16 species bird species included in this study

Trait	Blomberg's *K*	*K**
Body mass	1.233185	1.134855
	(0.004)	(0.009)
Body size	0.678041	0.629737
	(0.01)	(0.018)
Breeding months	0.389369	0.429449
	(0.172)	(0.167)
Clutch size	0.538168	0.598645
	(0.027)	(0.023)
Bill size	1.409769	1.377299
	(0.001)	(0.001)
Tarsus length	1.0725	1.117895
	(0.005)	(0.001)

With K-values closer to zero it is concluded that the trait has no phylogenetic signal (Blomberg *et al*., 2003) which was found for clutch size and breeding months although both were not statistically significant (Table 6.2).

6.4 Discussion

A primary aim of ecology is to delineate the processes governing how species assemblages and their functional traits vary across environmental gradients (McGill *et al*., 2006). Previous research dealt primarily with matrices of species presence and absence in community matrices (Diamond, 1975; Connor and Simberloff, 1979). Current approaches use evolutionary relationships (Webb *et al*., 2002; Cavender-Bares *et al*., 2009) along with species traits (Weiher and Keddy, 1995; McGill *et al*., 2006) to quantify differences between species that do and do not coexist. Combining both phylogenetic and functional methods has enhanced the understanding of evolutionary history shared by species in a community and mechanisms driving community assembly along environmental gradients (Harvey and Purvis, 1991; Xu *et al*., 2017)**.** The degree by which the constituent species differ in terms of their function, niche and evolutionary history, differences in functional and phylogenetic composition were measured, thus trying to understand the drivers of community assembly.

Results indicated that there were two assemblages shaped by variable habitat preferences of bird species along the Bhagirathi (Figure 6.2(a)). Accounting for functional composition (as determined by particular functional traits) and assessing the relationships between species traits and environmental characteristics allows for a better understanding of which environmental characteristics act as filters. The RLQ and fourth corner approaches highlighted that functional dispersion in river specialist birds varied according to different environmental variables in the riverine habitat, indicating that trait dispersion in the functional space of species are uncoupled in these communities. For example, passerines are morphologically pre-adapted to diverse foraging techniques which include fly catching, ground gleaning and aquatic foraging in stream or bankside habitats. In turn, these behaviours provide scope for different members to exploit the three main sections of the riverine environment, i.e. the channel, the bank and the riparian zone. This group has members from different genera, including Cinclus, Enicurus, Phoenicurus and Myophonus which vary in morphology (body size), habitat use and foraging techniques despite similarities in overall food spectra.

The statistical non-independence among species trait values because of their phylogenetic relatedness (Felsenstein, 1985; Revell *et al.*, 2008) is quantitatively estimated as the phylogenetic signal, the tendency for related species to resemble each other, more than they resemble species drawn at random from a phylogenetic tree (Blomberg *et al*., 2003). Measuring phylogenetic signal is most valuable for studies aiming to identify a pattern, that is, for comparative analyses and for studies requiring a proxy for species' niche similarity (Munkemmuler *et al*., 2012). When specific traits or groups of traits lack phylogenetic signal, it should be possible to separate the relative importance of particular traits versus overall phylogenetic relatedness as predictors of species co-existence wherever scopes of direct experimentation do not exist (Morelli *et al.*, 2019) like this study. A high phylogenetic signal indicates species traits that are more similar in close relatives than distant relatives, shown by bird traits which regulate foraging tactics, beak size, tarsus length and overall body mass. Thus, ecological similarity of close relatives resulting from niche conservatism likely allows their regional coexistence as a result of habitat filtering, especially in highly heterogeneous habitats like the Himalayan headwaters. Exclusive access to alternative food resources via differences in fundamental feeding niche could thus have strong effects on resource competition (Albrecht and Gotelli, 2001) as exemplified by the riverine bird community of the Western Himalaya which is dominated by closely related species, predominantly the songbirds.

Using data from different types of habitat may alter trait response to environmental variation by increasing the ranges of environmental gradients, that is analysing data simultaneously from other catchments could provide stronger support to hypothesis tested herein. Another factor influencing the results is the type of environmental variables used in this case study. Trends could change if we were to investigate environmental variables related to the availability of prey, instead of the bird traits which reflect accessibility to prey, the beak size and tarsus length. The presence of bird species with certain traits in different riparian habitats is probably a product of both the availability of prey and of the environmental characteristics that make them accessible for birds. Despite the caveats discussed above, our approach helps in understanding how tightly linked habitat features work at different hierarchical levels in creating local species pool. Because riverine systems are dynamic, the ways in which the environmental filters restrict community membership at different scales will change in space and time. This framework is also helpful in predicting trends how species composition in communities might change in response to modification of environmental filters at a variety of scales from micro-habitat to landscapes.

Chapter 7

CONSERVATION PERSPECTIVES

7.1 Rivers as threatened ecosystems

Rivers are among the most fragile and threatened ecosystems of the world. Riverscapes have historically remained hotspots of human activities from the earliest civilizations to current times (Sadoff and Grey, 2002). Across the globe, river corridors were substantially altered well before running water ecology developed as a distinct discipline (Allan, 2004; Revenga *et al.*, 2005; Reid *et al.*, 2018). The plethora of economic uses of river valleys have resulted in disturbing the natural riverine ecosystems to the point where many native species are imperilled or are extinct, invasive species are rampant, water and sediment quality are in significant decline, environmental flows are neglected, and yet increase in human needs are placing unprecedented demands on the remaining resources (Tickner *et al.*, 2020). Further, climate change, population growth, and the proliferation of chemicals place burdens on river resources and adjacent communities in ways that are yet not fully understood (Chessman, 2015; Daufresne *et al.*, 2004; Durance and Ormerod, 2009; Tockner *et al.*, 2010; Vorosmoty *et al.*, 2010; Reid *et al.*, 2018).

7.2 Freshwater biodiversity

Study (Collen *et al.*, 2014) by the World Wide Fund for Nature (WWF) on the Living Planet Index (LPI) disclosed that the index for populations of freshwater species fell more steeply (during 1970 to 2012) than the index of the marine and terrestrial populations (Figure 7. 1) (WWF, 2016). Freshwater megafauna has garnered global research attention recently as flagship and umbrella species simultaneous to being promising as indicators of the ecological integrity of ecosystems they inhabit (Carizzo *et al*., 2017; He *et al*., 2019).The economic value of fish intersects global issues of poverty, food insecurity and biodiversity conservation (Dudgeon, 2000; McIntyre *et al*., 2016) and because of the commercial demand of particular species (as an important source of dietary protein for human consumption); fishes have received public attention for decades worldwide (Oberdoff *et al*., 1995; Daufresne *et al*., 2009, McIntyre *et al*., 2016). Information on other megafauna like beavers, otters, porpoises, crocodilians and manatees, remain localised and patchy despite the fact that the rate of decline of vertebrate populations is much higher (81%) in freshwater systems than in terrestrial (38%) and marine (36%) realms (WWF, 2016; He *et al*., 2018).

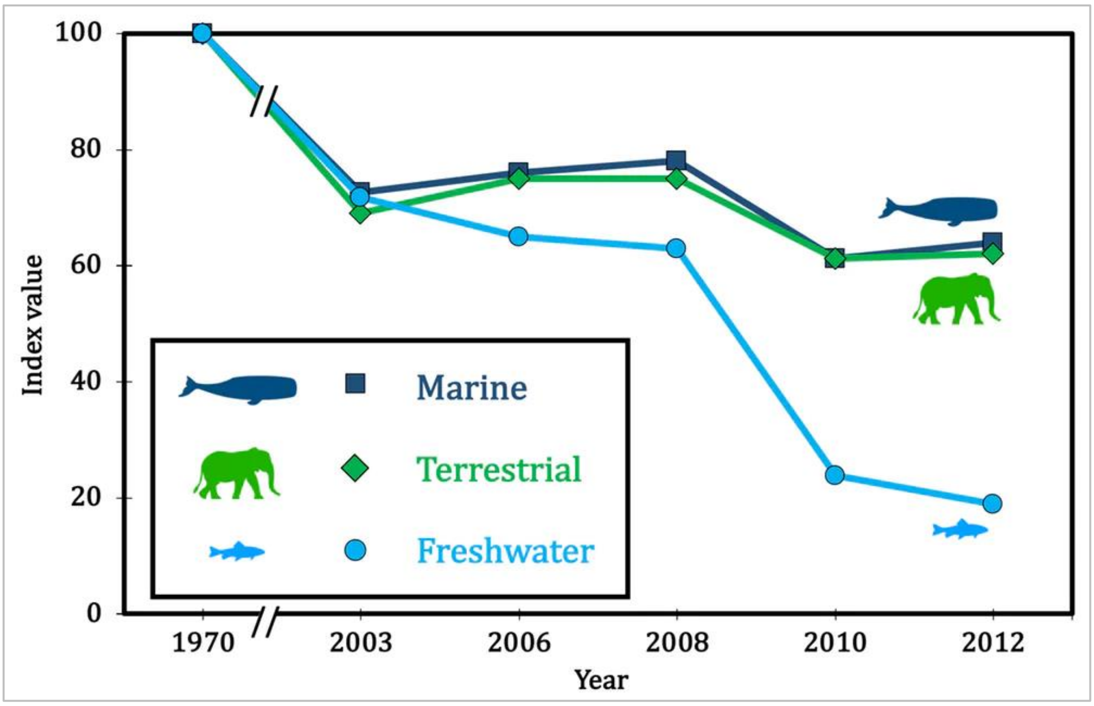


Figure 7.0.1 The World Wide Fund for Nature (WWF) Living Planet Index (LPI) shows population trend data for vertebrates in the freshwater, terrestrial and marine realms, revealing remarkable index decreases among freshwater species.

7.3 Challenges towards river conservation

River protection strategies are extremely complex, a major challenge being hydrologic flows which are of critical importance for defining the connectivity, character, and integrity of rivers originate upstream (Poff *et al.*, 1997; Lessman *et al.*, 2016; Tockner *et al.*, 2010; Johnson and Host, 2010). Legislative measures for the protection of rivers has remained challenging for decades as rivers traverse through large landscapes, often intersecting national and international administrative boundaries (Sadoff and Grey, 2002). To use riverine resources in a manner that is socially and ecologically acceptable is one of the greatest challenges that even the world's biggest economies in current times. Globally, 16% of the length of rivers are within protected areas or form their borders and are therefore considered locally protected (Abell *et al*., 2017). There are, however, wide geographic disparities in local protection with low protection in the Middle East, parts of Central and South Asia, North America, southern South America, northern Africa, and parts of Australia (Abell *et al.*, 2017). The level of catchment protection remains a largely unresolved question (Gergel *et al.*, 2002; Nel *et al*., 2007). To address the above issues and conserve riverine systems would require the holistic understanding of stressors of riverine ecosystems and accurate modelling of ecological responses of riverine fauna (Arthington *et al*., 2010).

7.4 Population trends of river birds

Research documenting population estimates of specialist river birds are scanty, with robust information available for few species like the well researched White-throated Dipper (see Nilsson *et al*., 2011) and the Louisiana Waterthrush (Latta *et al*., 2016). Unfortunately, there is limited ecological information on most of the species and research unravelling the causes leading to their decline in the wild has only gained attraction over recent decades (Cruz *et al.*, 2013; Classen *et al*., 2017, 2018; Vilaca *et al*., 2012).

Information on population trends and conservation status of the 66 bird species (see chapter 2; ww.iucn.com) revealed the populations of more than half of these species (N = 34) are declining. Twenty-two species have stable populations; while for six species trends are unknown. Over 15 species are endemic to islands, or small pockets in the mainland, and have small global distribution ranges (< 200,000 km^2); Sri Lankan Whistling Thrush (*Myophonous blighi)*, Wrybill *(Anarchynychus frontalis*), Blue Duck (*Hymenolaimus malacorhynchus*), Luzon Redstart (*Rhyacornis bicolor*), Rufous-throated Dipper *(Cinclus schulzi*), White-bellied Heron (*Ardea insigni*) and Javan Blue-banded Kingfisher (*Alcedo euryzona*) to name a few (Figure 7.2).

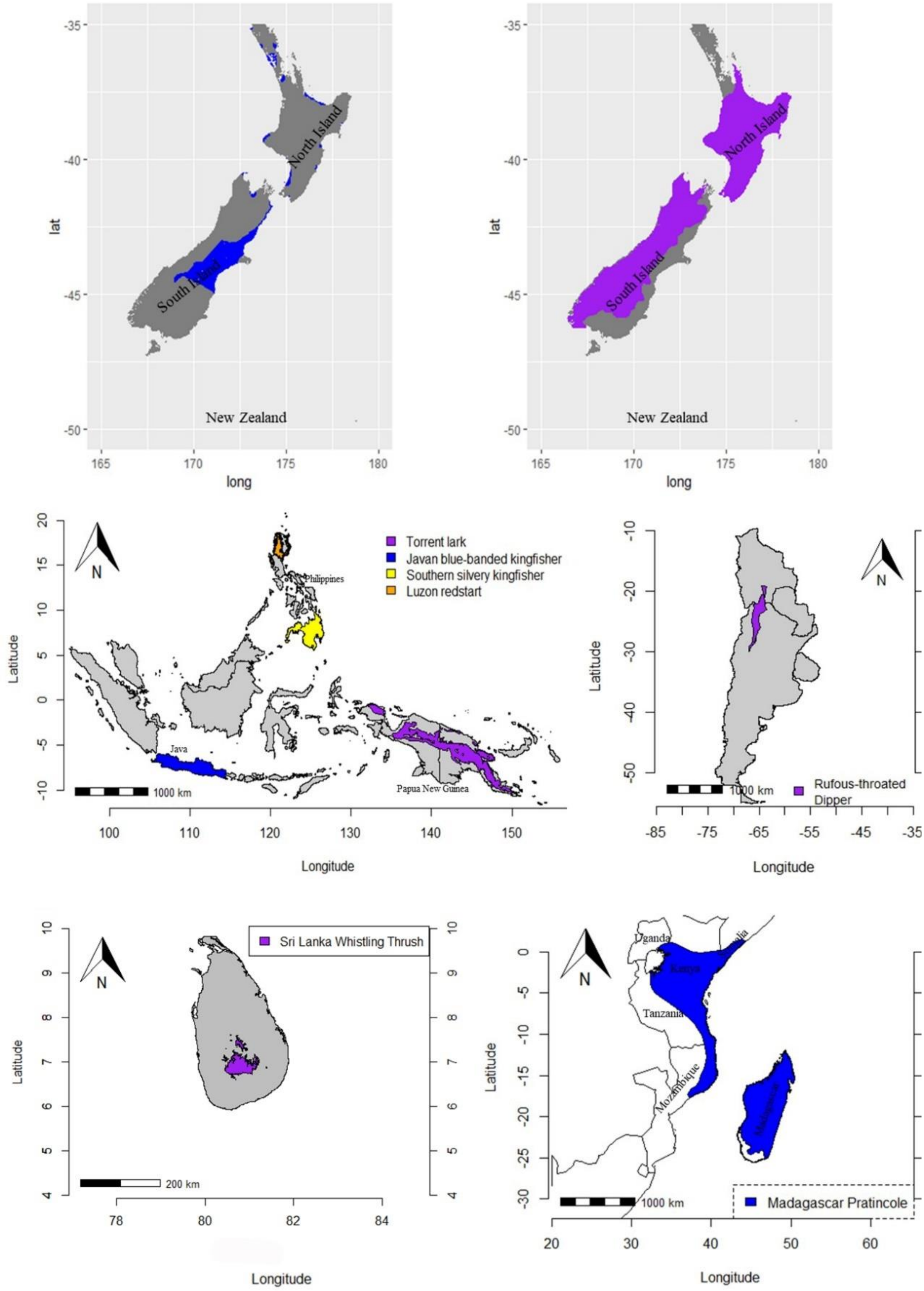
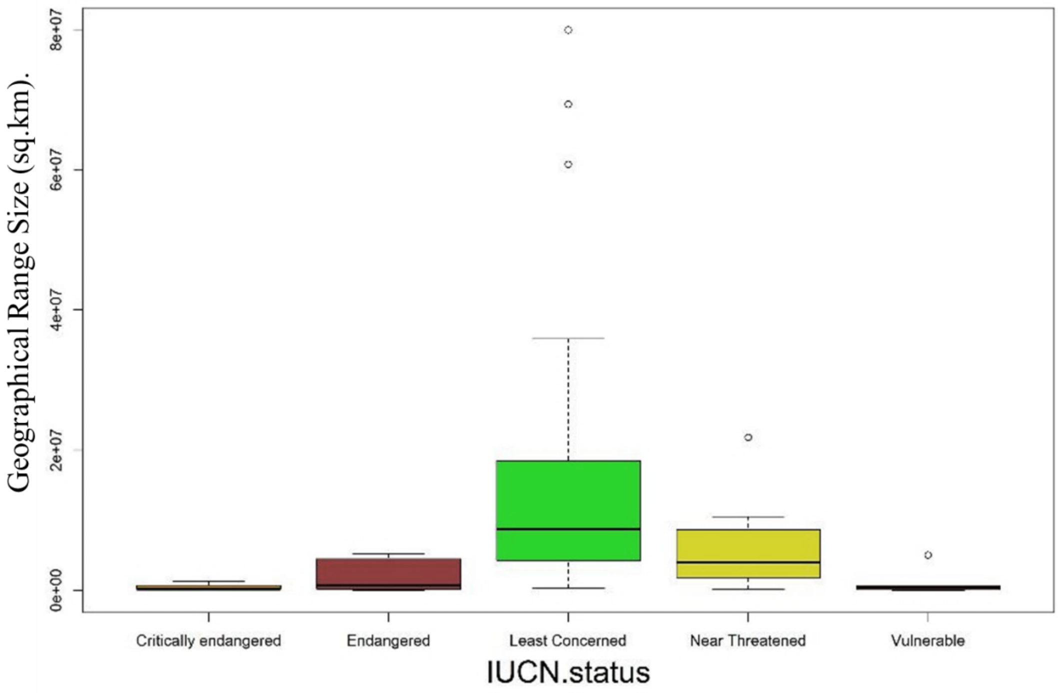


Figure 7.2. Maps showing the geographic distribution range of some specialist river birds which are restricted to small geographical areas. First row (left to right): Wrybill and Blue Duck in New Zealand , second row (left to right): (Torrent Lark, Southern Silvery Kingfisher,

Javan Blue-banded Kingfisher and Luzon Redstart, Rufous-throated Dipper in South America third row (left to right): Sri Lanka Whistling Thrush in Sri Lanka, and (e)Madagascar Pratincole in Africa.

Owing to their small geographic range and habitat specificity many are facing threats to extinction, the Brazilian Merganser (*Mergus octosetaceus*), White-bellied Heron (*Ardea insignis*) and Javan Blue-banded Kingfisher (*Alcedo euryzona*) being Critically Endangered. Twenty-two other bird species are listed as Endangered (5), Vulnerable (6) and Near Threatened (11) by the IUCN with multiple factors leading to their declining populations. Population trends of the global river bird assemblage shows that larger body-sized birds are more threatened compared to their smaller-sized counterparts (Figure 7.3 (a)).. Also, birds with a smaller geographical range (often endemic to islands) are the most threatened (Figure 7.3 (b)).

(a)



(b)

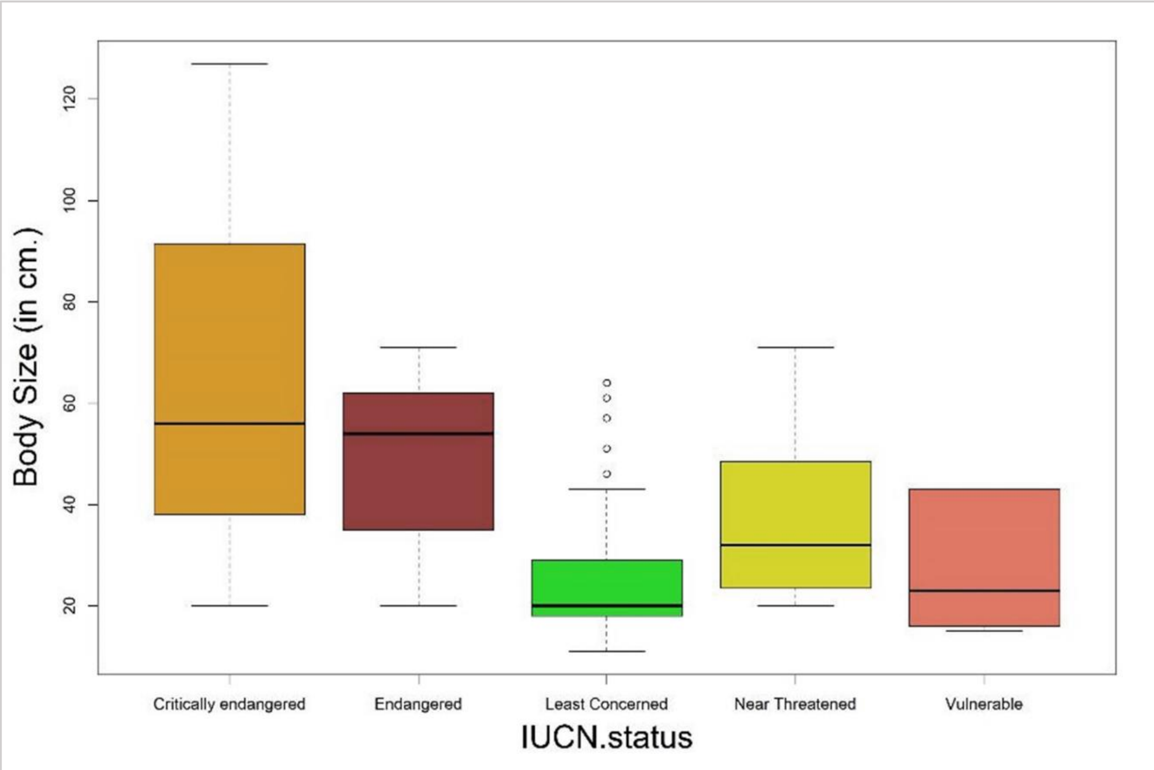


Figure 7.3. Population trend with (a) Body-size and (b) geographic range size of the global river bird assemblage

Although poorly documented, many species appear to be declining in both geographical range and total population abundance. Brazilian Merganser is one of the rarest birds of South America with three known remnant populations in Brazil and only 250 individuals existing in the wild, and it is likely that a population decline has occurred in recent times due to degradation and habitat loss (Benstead *et al*., 2017) as the species has disappeared from many sites in south central Brazil and nearby regions in Paraguay and Argentina, where it was once found (Collar *et al.*, 1992).

Studies of the avifauna of Laos (summarized by Dudgeon, 2001) have documented the fate of river birds in Asia, with birds becoming locally extinct in many countries. The Indian

Skimmer is currently reported from India, Pakistan, Bangladesh and Myanmar (Birdlife International, 2020). The bird seems to have disappeared from parts of Laos, Vietnam and Cambodia although there exist records from the nineteenth century (Dudgeon, 2001). The status of the White-bellied Heron remains uncertain across most of its range. Once considered common in parts of Burma, along the Mali Hka and Irrawaddy rivers; there is little recent information. The only stable population seems to be from Bhutan while some new records have surfaced very recently from eastern India although insights on the ecology of this Critically Endangered species is rudimentary.

7.5 Impacts of riverine habitat modification on river birds globally

The response of river birds to multiple stressors in riverine environments can differ in sensitivity, ranging from changes in physiology, behaviour and morphology to changes in survival and mortality (Royan *et al.,* 2014). Dams are a major threat to river birds worldwide according to IUCN although there is not much research-based evidence of impairments caused by dams and associated pathways (Figure 7.4). Agricultural practices especially in developing countries have altered native riparian land-use thus affecting multiple species like the White-throated dipper (*Cinclus cinclus).* Research has documented these birds as useful indicators of organochlorine (OC), polychlorinated biphenyl (PCB) and mercury (Hg) pollution in upland river catchments (Ormerod and Tyler 1990, 1992; O'Halloran *et al.,* 1993, 2003; Ormerod *et al.,* 2000) and adjacent land-use in the UK. Evidences stand of dippers returning to river stretches that were restored back reversing the impact of river water acidifications in Wales, yet recent research shows that the persistence of pollution in some regions may be negatively affecting both dippers and the benthic food web (Morrissey *et al.,* 2014; Windsor *et al.*, 2019). Long-term studies in Appalachian Highlands of South-western Pennsylvania have provided similar trends of response to acidic water by Lousiana

Waterthrushes (Mulvihill *et al.*, 2008). In the Western U.S., American Dippers have been known to abandon streams polluted with mining waste (Kingery, 1996).

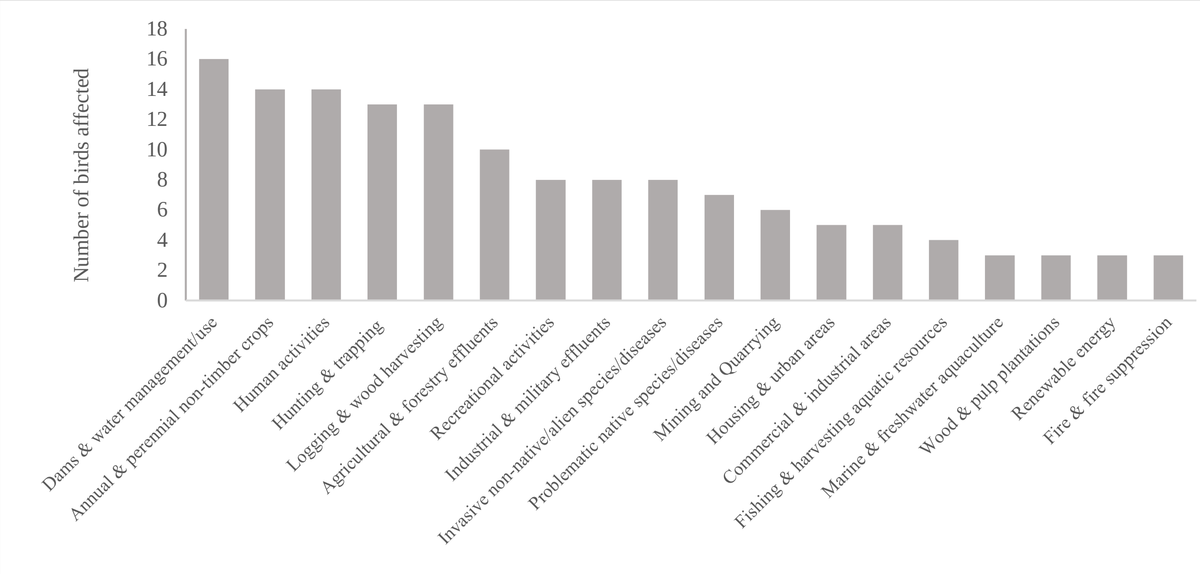


Figure 7.4. Prominent threats recognized by the IUCN affecting the global river bird assemblage

Information on threats recognized by the IUCN was collected for the 22 threatened species of specialist river birds. Dams and other water management schemes impact populations of more than fifteen species globally (Figure 7.4), notably the White-bellied Heron (Critically Endangered), Brazilian Merganser (Critically Endangered), Blue Duck (Endangered), Wrybill (Vulnerable) and Indian Skimmer (Vulnerable). Disturbance created by recreational activities and other human works in riparian zones like annual and perennial non-timber cropping are factors which affect most number of specialist river bird species after dams. Clearance of forest adjacent to watercourses in the form of logging and wood harvesting affects around twelve species including the Brazilian Merganser and Javan Blue-banded

Kingfisher (Critically Endangered); Luzon Redstart (Vulnerable), Rufous-throated Dipper (Vulnerable) and the Sri Lanka Whistling Thrush (Endangered).

7.6 River bird conservation in India

The range of twenty-three species of specialist river birds fall within the political boundaries of India with the eastern Himalaya having the highest species richness (Figure 7.5). The protected area network in India is scattered and covers negligible riverine habitats rich in river birds (Figure 7.5). The National Chambal Sanctuary is an important area which can be considered for the conservation of river dependent fauna as it is home to the Indian Skimmer (Vulnerable), Black-bellied Tern (Endangered), Great Stone Curlew (Near Threatened), River Tern (Near Threatened), River Lapwing (Near Threatened), Small Pratincole, Pied Kingfisher and Common Kingfisher (Nair, 2009). But the damming of the Chambal river upstream in Rajasthan has adverse effects on many of these species and remains yet undocumented.

Some species which require immediate attention in the Indian context are the White-bellied Heron, Black-bellied Tern and the Indian Skimmer. The decline of many of these species is attributable to widespread increases in human disturbance, exploitation and degradation of rivers and associated wetlands through fishing, transportation, domestic use, irrigation schemes and pollution from agricultural and industrial chemicals (Rajguru, 2017; Mittal *et. al*., 2019). These factors have reduced reproductive and foraging success in many other river dependent species although very less is properly documented as yet (Dudgeon, 2000). There is little literature on the Critically Endangered White-bellied Heron which is undergoing population decline due to habitat loss and degradation and hydroelectric projects which modify flow regimes of rivers and powerlines that cause mortality to flying birds (Price and Goodman, 2015).

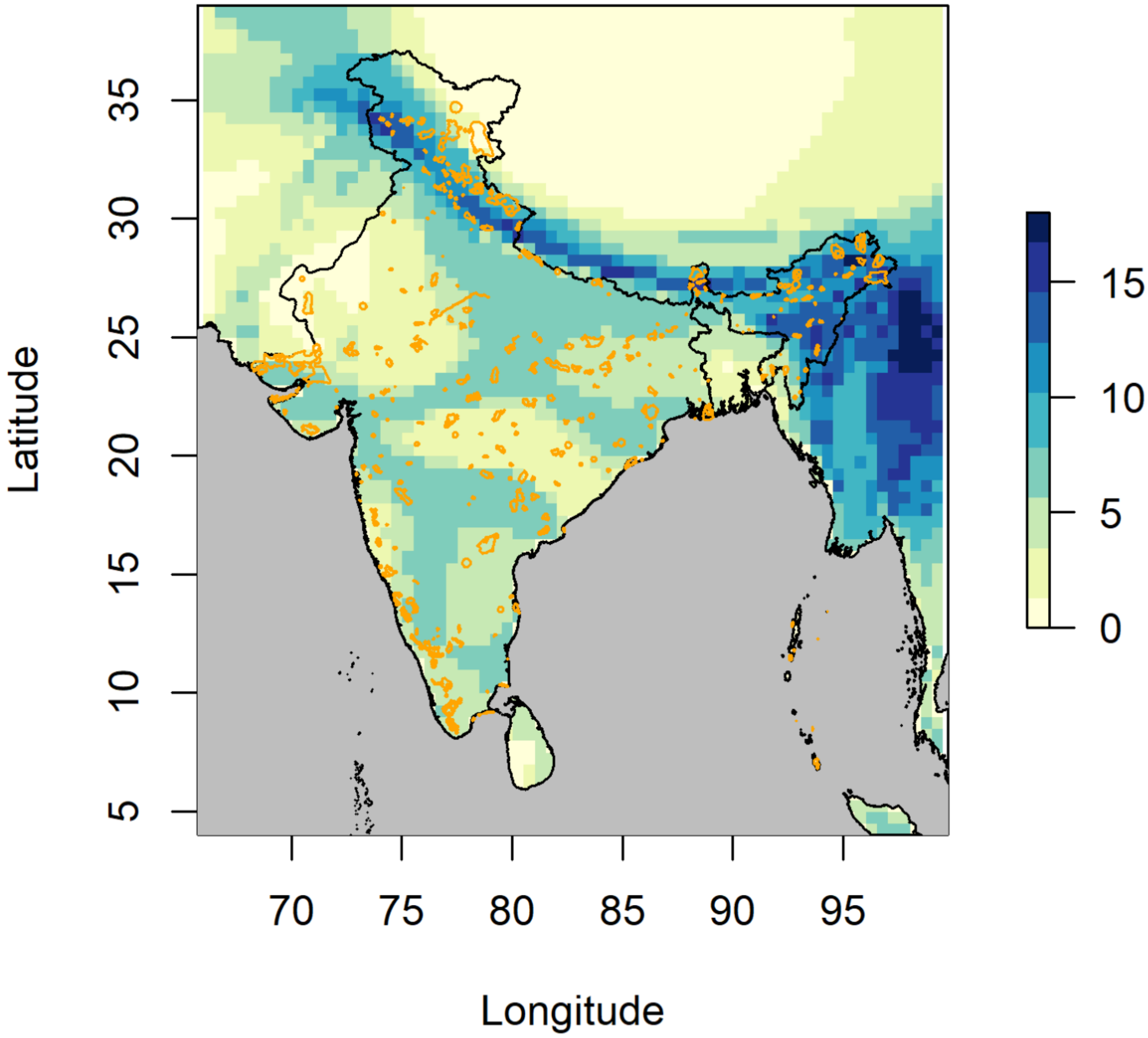


Figure 7.5. Map of India showing species richness of specialist river birds and boundaries of protected areas

7.7 River birds as model systems to understand the conservation strategies of river systems in the Western Himalaya

There is a major question about the extent to which human activities in the Himalayan region have modified river bird distribution. The distribution of some species like the because some species like the Crested Kingfisher, River Lapwing etc. occupy altitudinal ranges where human activities are now intense and widespread, such as the agricultural conversion of natural environments with subsequent downstream effects (Manel et al., 2000). Our study also brings forth how human activities have altered the nature of altitudinal gradients – for example by modifying river flow regimes. The Upper Ganga catchment is a rapidly growing landscape striding the transition between cold alpine to temperate and warm sub-tropical climates when the river leaves the mountains and small remote villages to big towns which are busy and developing. Factors such as land use, urbanisation and habitat modification contributed to some of the variates that explained river bird distribution (Figures 5.1 and 5.2). Investigators increasingly recognize that human actions at the landscape scale can affect the ecological integrity of river ecosystems, impacting habitat, water quality, and the biota via numerous and complex pathways (Allan *et al*., 1997; Ward, 1998; Strayer *et al*., 2003). Modification of natural banks to concrete embankments and removal of natural bank vegetation alters habitat structure in the channel and riparian zone with potential consequences for prey abundance. Additionally, the removal of natural riverine forest to enhance opportunities for agriculture alters allochthonous litter input to the channel, modifying nutrient cycling and food web character **(**Murakami and Nakano 2001). We recorded that the Brown Dipper and White-capped Redstart avoided river banks with intensive urban land-use and human settlements while Plumbeous Water Redstart, Blue Whistling Thrush and Grey Wagtail avoided river reaches with intensive agriculture. These results illustrate how the exploitation of river ecosystems and their catchments permeates beyond aquatic communities to influence riparian organisms such as river birds (Figures 5.1 and 5.2).

In India, the major Himalayan rivers are regulated to harness hydropower with over 300 hydroelectric projects (HEPs) under different stages (planned, commissioned, under construction) (Pandit and Grumbine, 2012). Almost every other major river is being subjected to or earmarked for cascade hydro-power development (dams built over the river channel in succession). Potentially more important in the region of our study are extensive changes in river networks that remove whole river sections or modify flow patterns fundamentally where rivers are impounded for hydro-power which is an important ecosystem service, but comes at a cost to the biodiversity of the landscape. Work elsewhere has shown how river regulation affects river birds adapted to feeding on emergent aquatic invertebrates (Jonsson *et al*., 2012; Strasevicius *et al*., 2013). In case of this community, river-obligates are the most vulnerable to considerable shifts in surface flows due to their specialized foraging techniques. In India, the location of most dams overlap with the most species rich areas in the Himalaya (Pandit and Grumbine, 2012). Specifically in the Bhagirathi basin, the development of Tehri dam, Koteshwar hydropower plant and Kotli-Bhel hydropower project (under development in Bhagirathi basin) has led to the diversion of approximately 68 km (31%) of the river Bhagirathi, while 85 km (39%) of the riverine buffer zone has been submerged to a width of 1 km (Rajvanshi *et al.,* , 2012). Dams alter the natural flow regime of the channel downstream creating pools which are deeper and wider and are avoided by all the river obligates species (Figure 5.2). Around 153 km of river length has been affected, or almost 71% of the entire river length in this major upper catchment tributary. Bank-nesting species – including several of those considered here - are vulnerable to both loss of riparian habitat as well as flow variability and nest flooding during sensitive periods of their annual cycles such as breeding (Chiu *et al.,* , 2008; Roche *et al.,* , 2012; Chiu *et al.,* , 2013; Strasevicius , 2013). Modified river flow regimes are postulated to affect species at higher trophic levels whose life cycles are often matched closely to specific flow conditions and food web character (Nakano *et al.,* , 2001; Jonsson *et al.,* , 2012; Alexander *et al.,* , 2013; Jonsson *et al.,* , 2013; Royan *et al.,* , 2013; Strasevicius *et al.,* , 2013). As well as their close association with certain specific prey types, these birds which feed from river environments use a range of features such as dead wood, shoal and shingle banks, boulders, riffles and vegetated margins – all of which are used actively Brown Dipper, Plumbeous Water Redstart, White-capped Water Redstart, Blue Whistling Thrush, Crested Kingfisher and Grey Wagtail (Figure 5. 3) Indeed, evidence suggests that such micro-habitat features are involved in resource partitioning among this group (Buckton and Ormerod, 2008). However, alterations in habitat structure in modified rivers are likely to arise through human activity both directly and through altered hydrological and hydraulic pattern (Nilsson and Bergrren 2000). Variability in flow conditions, especially large fluctuations in water velocity and depth caused by impoundment, affects the availability of foraging habitats which is liable to disrupt river-bird community structure (Cumming *et al.,* 2012).

This work contributes to the development of river birds as indicators by helping to understand how bird communities might respond to a range of anthropogenic activities along Himalayan rivers. I look forward to the application of this approach towards the generation of new insights and establishments of foundations for further work on modelling the impact of variability of habitat structure and anthropogenic land-use changes on rivers birds as important contributors to river biodiversity. Birds could then be used to convey the importance of trading-off the protection of ecological integrity, biological production and conservation value of river systems with the resource values of rivers and their catchment for people in India and beyond. Although further work is required for the full appraisal and use of river birds for ecological monitoring, this work suggests that by synthesizing the population and distribution data for a range of river bird species, it may be possible to detect a wide range of changes in river environments and thus can provide scientific basis for river resource management in the Himalayan region.

7.8. Special focus to conservation of headwater systems

The roles that headwater streams and their watersheds play in river ecosystem function is being increasingly recognized (Fisher et al., 1998; Lowe and Likens, 2005; Lowe et al., 2006). In the Himalayas, there is a certain gap in understanding the threats that are potential in altering the habitat of riverine organisms. Because of their close terrestrial–aquatic linkage, the ecosystem services provided by headwaters and the species they support tend to be very sensitive to natural and anthropogenic disturbance of surrounding lands. Along with other distinctive qualities, this close connection creates a unique set of challenges and opportunities related to the protection of headwaters, and to research in these systems. The high sensitivity of ecological processes and natural communities in headwater streams to atmospheric and terrestrial disturbances leads to low thresholds of impact.

Biodiversity assessments which form crucial components of Environmental Impact Assessments conducted prior to developmental projects along rivers exclusively target charismatic species, like big cats and pheasants without focussing on obligate river-dependent taxa. Recently, some organisms with conservation interest like the Golden Mahseer (*Tor putitora)* and Gangetic river Dolphin (*Platanista gangetica*) have been included in the list of target organisms for EIAs for dams. Design of the EIAs for hydropower projects which are rampantly increasing in this region (Pandit and Grumbine, 2012), often ignore ecosystem specific taxa which are more sensitive to even minute changes to the riverine environment mandate adequate consideration in future.

Degradation of freshwater ecosystems and the services they provide is a primary cause of increasing water insecurity globally (Alcamo *et al*., 2008) raising the need for integrated solutions to freshwater management. Local geomorphological characteristics, hydrological connectivity, species distribution ranges, or varying runoff contribution can render some areas of a catchment more important than others (Abell *et al.*, 2017). Optimized protection should focus on these critical landscape units and ecological elements that ensure the integrity of the watershed and maintenance of optimal ecosystem services (Higgins, 2003). Because rivers are shaped by numerous complex processes, PAs alone will rarely ensure their conservation, but with effective design and management they can make important contributions. The benefits of water provision on economic productivity are often accompanied by impairment to ecosystems and biodiversity, with potentially grave but unquantified costs. Devising interventions to reverse these trends, such as conventions to protect aquatic biodiversity and ensure the sustainability of water delivery systems are the need of the hour to ensure the protection of river dependent species. Many indicator systems and protocols have been developed for determining the condition of aquatic systems and for the evaluation of human impacts on these particular species, or group of species, whose function, population, or status can be used to determine ecosystem or environmental changes can act as biological indicator (Dziocketal.,2006). Overall the conservation of river birds globally should be guided towards maintaining natural riverine habitat conditions, with untampered flow regimes and river bank conditions.

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