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Conserving the World's Specialist Riverine Birds

Ankita Sinha[1,2] | Nilanjan Chatterjee[2] | Steve J. Ormerod[3]

[1]School of Biosciences, University of Sheffield, Sheffield, UK | [2]Senckenberg Biodiversity and Climate Research Center, Frankfurt, Germany | [3]Water Research Institute, School of Biosciences, Cardiff University, Cardiff, UK

Correspondence: Ankita Sinha (nmhsankitas@gmail.com)

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ABSTRACT

The ecotone connecting rivers with their riparian zones represents conditions where fluvial processes, abundant resources and reciprocal energetic subsidies have combined over evolutionary time to create multiple opportunities for niche development in a wide range of organisms. Among them, specialist riverine birds are diverse, conspicuous, and widespread globally, but they remain under-researched by both river ecologists and ornithologists. Globally, we identify 69 bird species that have evolved specialized lifestyles along high-gradient, fast-flowing rivers and here we review (i) spatial patterns in their distribution to identify hotspots of diversity; (ii) major threats to their status and (iii) regions that are candidates for their conservation. Only a few species of specialist riverine birds are well known ecologically, hindering understanding of population trends, distribution, and conservation requirements at regional, continental or global scales. Multiple threats include habitat impairments through dams and other water resource infrastructure; land management for agriculture, forestry and urbanization; invasive non-native species; pollution from well-known and emerging sources; and the effects of climate change on flow patterns and thermal regimes. Neither the direct nor indirect effects involved—for example through prey availability or species interactions—have been adequately addressed by ecologists in contrast to birds in terrestrial or marine ecosystems. We identify two urgent needs respectively, (i) to expand interdisciplinary research to understand the ecology of river birds and (ii) to enhance their conservation both through catchment-scale action and by protecting those regions that support threatened species and large species richness, notably in the tropics and sub-tropics.

This article is categorized under:

Water and Life > Nature of Freshwater Ecosystems

Water and Life > Stresses and Pressures on Ecosystems

Water and Life > Conservation, Management, and Awareness

1 | Introduction

Rivers and their riparian zones together form longitudinal ecotones that link terrestrial and running-water ecosystems where the wetted river channel interacts through fluvial and ecological processes with the surrounding catchment (Ward 1998; Ward et al. 2002). The resulting systems are characterized not only by physico-chemical heterogeneity, but also enhanced primary and secondary production that is exchanged reciprocally between freshwater and terrestrial realms (Nakano and Murakami 2001; Baxter et al. 2005). In combination, these circumstances have facilitated the adaptive radiation and niche development of a wide variety of organisms from both terrestrial and aquatic origins (Malmqvist and Rundle 2002; Tockner and Stanford 2002; Van der Velde et al. 2009). However, riverine and riparian environments are at significant risk through ongoing global change, human resource exploitation and anthropogenic modifications that combine to threaten river biodiversity (Meybeck 2003; Strayer and Dudgeon 2010; Sabater et al. 2018; Johnson et al. 2024). Globally, rivers and other freshwaters are considered among the world's most threatened ecosystems, yet some major groups of organisms that occupy the riparian/riverine ecotone have been neglected in research (Nilsson et al. 2005; Darwall et al. 2018).

Specifically, previous studies on riverine biodiversity have been heavily weighted toward aquatic organisms such as diatoms, macroinvertebrates, fishes, and amphibians which are all considered important by many river ecologists (Heino et al. 2005; Oberdorff et al. 2019; Wu et al. 2022; Kaijser et al. 2024, 2025). As a result, most biological assessments of water quality in rivers focus on these aquatic taxa (von der Ohe et al. 2007; López-López and Sedeño-Díaz 2015; Chen et al. 2022). Freshwater conservation initiatives also focus largely on aquatic organisms (Darwall et al. 2018). In contrast, and despite being an extensively studied taxon globally, birds have not gained the same attention in running-water ecosystems (Rushton et al. 1994; Buckton and Ormerod 2002). This is despite evidence that river birds can be powerful indicators of freshwater ecosystem quality when they are effectively researched and understood (Maznikova et al. 2024).

Although around 11%–23% of all bird species globally rely on freshwater ecosystems for some or all of their annual life cycle (Ormerod and Tyler 1993), 69 species can be recognized that have life histories and traits that are adapted closely to fast-flowing river environments (Table S1; Ormerod and Tyler 1991a; Sullivan et al. 2007; Lees and Peres 2008; Larsen et al. 2010; Becker et al. 2024). These species are definable as riverine specialists because (i) they feed at different trophic levels mostly on production from rivers in some combination of aquatic plants, aquatic or emergent insects, and fishes; and (ii) for most of their lives, they occupy river habitats created by fluvial processes, often occupying territories that are linear or centered on the river channel (Buckton and Ormerod 2002; Sinha et al. 2019, 2025). In these locations, specialist riverine birds occupy diverse river and riparian habitats, using a blend of the terrestrial and aquatic resources provided by river ecosystem structure (Buckton and Ormerod 2008; Figarski and Kajtoch 2015). Uses of river habitats include not only feeding, but typically also roosting and nesting (Claassen et al. 2018; Debata and Kar 2021; Sinha 2021; Liu et al. 2023). The aquatic and semi-aquatic lifestyle of river birds reflects diverse relationships between specific river features and bird distribution (Vaughan 2004; Sinha et al. 2019; Sinha, Chatterjee, et al. 2022; Sinha, Menzies, et al. 2022), thus making them ideal candidates to understand river and riparian ecosystems (Vaughan et al. 2007; Slaght, Horne, et al. 2013; Maznikova et al. 2024).

In this article, we review the global distribution of specialist riverine birds, outline their ecological roles in different running water habitats, and discuss their status, population trends and conservation in the face of widely recognized threats to freshwater ecosystems (Tickner et al. 2020; Dudgeon and Strayer 2025). Given the gaps in knowledge about many specialist riverine birds, one of our aims is to stimulate conservation-focussed research on this group by (i) river scientists, who can aid the understanding of the river ecological processes important to river birds and (ii) ornithologists and conservation biologists who could gain insight into river ecosystem functions that influence the distribution, abundance and life histories of this overlooked group. Lessons from a wide range of other ecosystems show how improved understanding of the ecology of birds and the human threats that affect them can raise public awareness and prompt effective conservation actions (Butler et al. 2010; Rosenberg et al. 2019; Barnes et al. 2023; Young and Vander Werf 2022). Although there have been calls for co-ordinated conservation action for birds in inland standing waters (Williamson et al. 2013), our review is the first to signal the need for global, evidence-based action to conserve specialist riverine birds. It accompanies recent calls to “bend the curve” of freshwater biodiversity loss through focussed actions to tackle issues such as pollution, habitat degradation and flow modification (McCluney et al. 2014; Cooke et al. 2026).

2 | Riverine Habitats and Their BirdDiversity

2.1 | A Note on the Species Considered

There are appreciable challenges in precisely demarcating “specialist riverine birds” from other water birds: the fast, upland rivers on which we focus form part of a continuum that progresses into slower lowland rivers, lakes, estuaries, and associated wetland environments. Particularly at the lowland end of this continuum, the array of wetland habitats used by groups such as herons, rails, wading birds and waterfowl is diverse even within individual species (see Ormerod and Tyler 1993). Examples include the pied/white wagtail *Motacilla alba*, which breed along running waters in some parts of Europe and Asia, or ducks such as the goosander *Mergus merganser* or common goldeneye *Bucephala clangula*, which use river ecosystems seasonally and are not dependent entirely on riverine resources. There are similar challenges in isolating specialist riverine birds from the wider array of “riparian” birds that occur in vegetated or wooded habitats that border freshwater ecosystems. Correlative evidence suggests that emergent insects might have important influences on a large number of such species, especially insectivores, although the mechanisms are not yet fully quantified (Schürings and Olden 2026).

Our starting point for the species that we consider riverine specialists was the list provided by Buckton and Ormerod (2002) who identified species from 16 families that were closely associated with fast-flowing rivers. There have since been some modifications to this list, for example where (i) some species (Mekong wagtail *Motacilla samveasnae*, Bornean forktail *Enicurus borneensis* have been reclassified phylogenetically); (ii) common English names have changed (e.g., buff-winged cinclodes *Cinclodes fuscus* was previously known as bar-winged cinclodes); and (iii) a small number of species have been added in view of their strong association with the mid and lower reaches of rivers for breeding activities (Debata et al. 2019; Debata and Kar 2021) and evidence of losses from large parts of their ranges specifically in riverine areas in SE Asia (e.g., the skimmers; *Laridae*) (Dudgeon2002; Claassen 2004).

2.2 | Habitat Diversity Within and Among Rivers

Natural variations in river habitat character reflect a combination of (i) global-scale variations among biomes that affect features such as climate, prevailing vegetation, and primary production (Buckton and Ormerod 2002); (ii) catchment-scale influences on rivers, through which features such as local geology, soils, and relief affect runoff character (Hynes 1975); (iii) altitudinal and longitudinal variations downstream that progressively affect factors such as thermal regimes, solute concentrations, oxygen concentrations, physiographic diversity and the relative balance between allochthonous and autochthonous energy sources (Vannote et al. 1980); and (iv) local variations in habitat structure through which river channels interact with their riparian zones, floodplains, and hyporheic environments (Covino 2017). These influences are considered to be nested hierarchically over different spatial extents and, together with seasonality and other temporal dynamics, influence the physical, hydrological, hydrochemical, and energetic character of river ecosystems (Frissell et al. 1986). Over evolutionary timescales, the resulting heterogeneity has acted as a habitat template into which the specific traits and life histories of river organisms have evolved (Southwood 1977; Poff et al. 1997; Townsend and Hildrew 1994). Aspects of geographical isolation and network connectivity within and among rivers have likely also influenced the richness and composition of communities (Sarker et al. 2019). These aspects of connectivity are particularly important to biodiversity in river networks because dispersal routes are often constrained either along the river corridor or between different catchments whose boundaries must be crossed by any dispersing organisms (Altermatt 2013; Tonkin et al. 2018; Oberdorff et al. 2019).

The occurrence and persistence of different birds, in any given river reach, therefore, reflects each species' adaptations and the way they match the available physical habitat, thermal regimes and flow conditions along with food resources (Buckton and Ormerod 2002; Sinha et al. 2019; Kar and Debata 2019). In the case of river birds, phylogenetic history and global biogeography have also influenced patterns of diversity (Sinha, Chatterjee, et al. 2022). The regional species pool is therefore an expression of past biogeographic events and evolutionary history coupled with regional or local filtering through which features such as primary productivity, catchment geomorphology, drainage density and hydrological regimes have shaped diversity patterns (Buckton and Ormerod 2002). More locally, species assemblages are shaped by physical features like the width and depth of the river, flow characteristics, riparian land use, vegetation quality, and hydrochemistry (Manel et al. 2000; Vaughan et al. 2007; Sinha et al. 2019; Sinha, Chatterjee, et al. 2022; Sinha, Menzies, et al. 2021), all of which ultimately determine the availability of key prey items besides feeding, roosting and nesting habitats (Ormerod and Tyler 1991a; see Section 2.4). Those species that we define as riverine specialists are typically found in clear, high-gradient, fast-flowing rivers with relatively shallow stretches for aquatic foragers, and diverse microhabitats, such as pools, glides, riffles, sand/gravel bars, and marginal habitats in which prey such as fishes, aquatic macroinvertebrates and emergent insects are available. In these locations, river birds can have important functional roles as predators or competitors, possibly also delivering important ecosystem services (Ormerod and Tyler 1991a; Box 1).

2.3 | Diversity and Global Distribution of Specialist Riverine Birds

Birds that we consider as riverine specialists have arisen from 19 different families ranging from ducks (Anatidae), kingfishers (Alcedinidae), and waders (Charadriformes) through to families more typically linked with terrestrial environments such as the old-world flycatchers (Muscicapidae) of Europe, Asia, and Africa. Morphologically, the species involved range from around 8–12 g in the case of the torrent tyrannulet *Serpophaga cinerea* or little forktail *Enicurus scouleri* to around 3.5 kg in the white-bellied heron *Ardea insignis*. The evolutionary ages, diversity, and macrogeographical distributions of the different orders and families involved suggest that adaptations to river environments have evolved multiple times across all birds.

Birds occupy riverine habitats in almost every part of the world except the north and south polar regions (Buckton and Ormerod 2002). A previous global-scale analysis showed how specialist river birds were more species rich in tropical and sub-tropical regions with high primary productivity, and high relief where fast-flowing streams drained montane regions (Buckton and Ormerod 2002; Section 2.4). Reflecting these effects, river basins in Asia (e.g., Indus, Ganges, Brahmaputra, Irrawaddy, Mekong and Yangtze) have the largest cumulative number of river bird species with the most diverse regions having between 14 and 24 species, followed by South America (La Plata and Amazon) and Africa (Congo, Chad, Niger) with 8–14 species each (Figure 1). Considering individual countries, India has the greatest diversity of riverine specialist birds. In all these species-rich locations, species often have overlapping occurrence at the reach scale but use resources in different ways (e.g., Buckton and Ormerod 2008). At the other extreme, northern temperate or boreal regions of Europe and North America have fewer specialist riverine birds (Figure 1). Temperate New Zealand has two riverine specialists, but mainland Australia has none, possibly reflecting the climatic and hydrological variability across its large semi-arid areas. A freshwater mammal, the duck-billed platypus *Ornithorhynchus anatinus* occupies a similar trophic niche to river birds elsewhere, for example New Zealand's blue duck *Hymenolaimus malacorhynchus* or the dippers *Cinclus* spp., though has a wider habitat amplitude that also involves the lowland reaches of rivers and some standing waters (Bino et al. 2019).

2.4 | Local Variations: Longitudinal Patterns

Although large rivers (> 50 m wide) provide a large surface area of freshwaters globally (Allen and Pavelsky 2018), smaller, headwater streams in piedmont and mountain regions dominate the world's running waters by length (Abell et al. 2017; Hildrew and Giller 2023). In regions with the greatest richness, these are the reaches where most river bird species are packed into overlapping biogeographical distributions

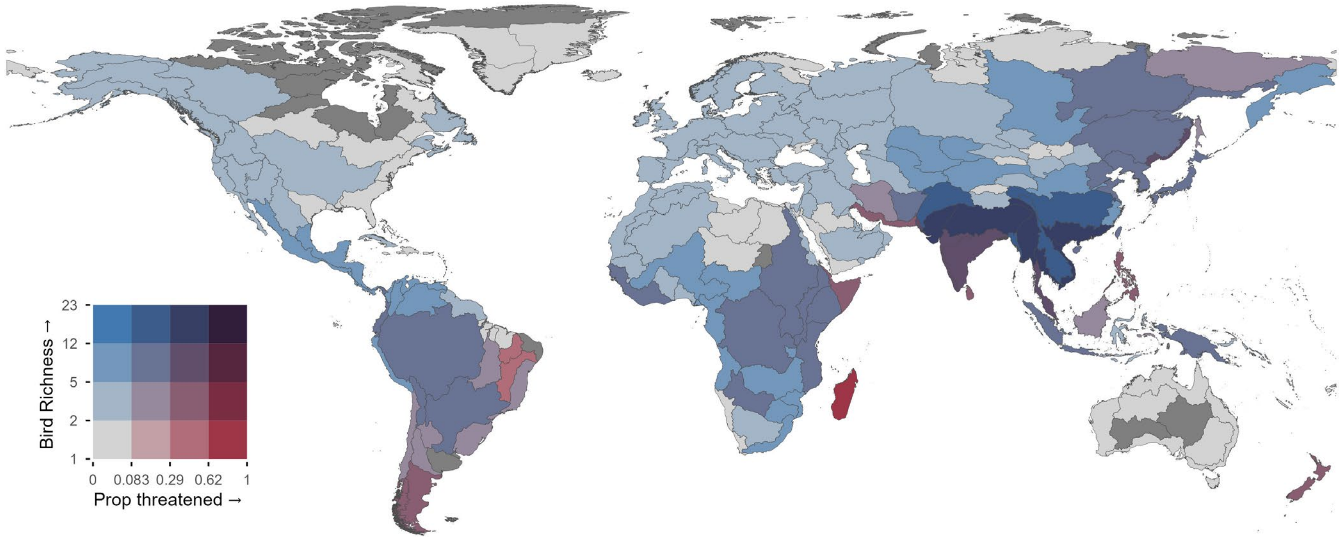

FIGURE 1 | Concordance map of specialist riverine bird species richness with proportion of species threatened within major river basins. Regions with dark gray do not have specialist riverine birds. (see Supporting Informations for methods and data sources).

(Buckton and Ormerod 2002). Here, fluvial processes and hydraulic patterns create dynamic and complex river structures in the margins and mid-channels from rocks, boulders, and other eroding materials (Montgomery and Buffington 1997). Relatively narrow channels also mean that headwater systems have close functional connections with their riparian zones, for example through reciprocal exchanges of matter and energy in the form of plant litter and emerging insects (Meyer et al. 2007; Allan et al. 2021). Particularly where headwaters drain woodland catchments, energy and carbon sources are expected to reflect increased terrestrial contributions alongside aquatic primary production (Vannote et al. 1980). Aquatic faunal communities in such headwaters are dominated by invertebrates which process both allocthonous and authochthonous production, in turn producing important prey items for birds feeding on both aquatic and aerial phases (Poff et al. 1997; Buckton and Ormerod 2008). Birds typical for these upland reaches included passerines such as dippers, old world flycatchers (Muscicapidae), tyrant flycatchers (Tyrannidae), ovenbirds (Funariidae), smaller kingfishers (Alcedinidae), Blakiston's fish owl *Ketupa blakistoni*, ibisbill *Ibidoryncha struthersii*, and the torrent duck *Merganetta armata*—one of just four duck species adapted to these environments (Buckton and Ormerod 2002; Wood et al. 2016). With downstream progression, trophic links between birds and rivers shift from insectivory toward piscivory (Sánchez-Hernández 2023), although some waders and species such as pratincoles (Glareolidae) still use invertebrates as prey.

Stream-dwelling communities are expected to show a gradual longitudinal replacement in dominant feeding types reflecting downstream trends in the resources available along the river continuum (Vannote et al. 1980). There has been no formal assessment that links birds to the river continuum concept, but some speculation is possible. For example, river bird species adapted to upper river reaches are mostly songbirds, respectively from the old and new world passerines in the Himalaya and Andes. These species feed by flycatching, gleaning, sallying and picking to prey on aquatic insects and emergent or riparian prey from the river margins, adjacent boulders and riparian vegetation along clear, undisturbed, fast-flowing streams and rivers (Buckton and Ormerod 2008; Mulvihill et al. 2008). Downstream progression involves a shift to larger non-passerines such as larger kingfishers, ducks and waders adapted to middle river reaches where insectivory gives way to piscivorous diets (Kear 2005). As river sizes increase, trophic connections with flood plains, lakes and wetlands increase (Tockner and Ward 1999). Although bird communities in these systems are extremely diverse globally, habitat amplitudes are such that species occurrences often involve a wide range of other aquatic environments, such as lakes and wetlands, that are no longer restricted specifically to lotic fluvial systems (Miqueleiz et al. 2025).

2.5 | The Autecology and Synecology of River Birds and Their Habitats

Two examples respectively at the species and assemblage level illustrate some of the ways that specialist river birds interact with river ecosystems and with each other.

At the species level, the world's five dippers in the genus *Cinclus* are specialists for fast-flowing rivers and streams and among the most extensively studied of all river birds. They occur on five of the world's continents typically in clear, unpolluted, piedmont to montane streams where their aquatic prey is abundant and accessible in relatively shallow riffles, glides, and pools (Ormerod et al. 1985, 1991). Abiotic and biotic features of the channel and riparian zone such as waterfalls, rocky ledges, and trees provide for roost sites as well as locations for the dippers' domed, waterproof nests constructed largely from mosses, grasses and leaves collected in the river corridor (Ormerod et al. 1986). Dippers have been shaped by these environments over evolutionary time. For example, morphological and physiological adaptations that are unique among passerines include closable nostrils, increased blood hemoglobin, increased feather density to aid thermoregulation, an enlarged preen gland for waterproofing, modified eyes for underwater vision, and wings developed for swimming and

BOX 1 | Ecosystem services provided by specialist riverine birds.

Freshwater organisms, especially fishes, are recognized as a source of cultural inspiration, for example for religion, spirituality, ritual, sense-of-place, social cohesion and the arts (Anderson et al. 2019; Lynch et al. 2023). Green and Elmberg (2014) recognized similar non-use "ecosystem service" values provided by waterbirds, but mostly considered species from standing waters. There are, nevertheless, multiple examples of specialist river birds in literary collections (e.g., "River" by the late UK poet laureate, Ted Hughes), artistic works, and national symbols such as currency or postage stamps (e.g., UK Royal Mail "River Wildlife", issued July 2023). In New Zealand, the blue duck, locally called the whio, is held sacred by the Maori people, who consider it as the guardian of the river which also figures on bank notes. As well as this intrinsic cultural value, birds can provide ecosystem services through provisioning, regulating and supporting processes (Gaston 2022). For river birds, however, quantification and understanding of service provision is still rudimentary and further studies are needed. This is distinct from roles in ecological functions for which some assessments exist (e.g. Ormerod and Tyler 1991a). For example, foraging in specialist riverine birds ranges from direct aquatic foraging in different parts of the river channel (e.g. piscivory/ insectivory/herbivory) to aerial fly-catching and ground gleaning in bankside and riparian habitats (Tyler and Ormerod 1994; Kear 2005; Buckton and Ormerod 2008; Khandu et al. 2021). River birds thus potentially contribute to nutrient flows between freshwater and terrestrial environments for example with respect to reciprocal transfers of macronutrients, energy, and pollutants (i.e., "dark-side" subsidies) across the riparian/river ecotone (see Nakano and Murakami 2001). Moreover, these processes in migratory species could link ecosystem processes and fluxes over larger spatial extents (Whelan et al. 2008) where migrant species such as wandering tattler, Harlequin duck *Histrionicus histrionicus* or mergansers move between different river segments or other aquatic ecosystems, thereby contributing toward nutrient redistribution (Solovyeva et al. 2014; Higa et al. 2016). More robust evidence exists of the indicator value of river birds in revealing the quality, status and trends in river ecosystems (Steinmetz et al. 2003; Mattsson and Cooper 2006; Sullivan et al. 2007; Cui et al. 2011). Within the stream corridor, river birds can respond to changes in surrounding habitats (Bryce 2006) while the value of more aquatic foragers such as the dippers in the bioassessment of streams and rivers has been demonstrated and discussed extensively (see Ormerod and Tyler 1993; Maznikova et al. 2024). Such established indicator value means that other river species might have the potential to provide low-cost bioindicators especially in inaccessible regions where more technical assessments are more challenging. Candidates include the Brazilian merganser *Mergus octosetaceus*, blue duck, Ibisbill, and white-bellied heron as top predators linked to both invertebrates and fishes in river food webs (Lamas 2006; Simpkins et al. 2015; Haq et al. 2022; Maheswaran et al. 2021). Through their conspicuous character, public interest value, charisma, and relative ease of identification and census, as well as indicator value they offer potential focus for conservation action (Maznikova et al. 2024).

diving—including simultaneous primary molt similar to some waterfowl (Tyler and Ormerod 1994). In combination with their robust build and body mass of around 45–80 g, these adaptations allow dippers to wade, swim, and dive into fast-flowing rivers where they exploit aquatic invertebrates and small benthic fishes in ways that change to match the needs of the annual life cycle: egg-formation, provisioning chicks of different ages, juvenile transition to independence, molt, over-wintering (Ormerod and Tyler 1991a). Further adaptations include a breeding period synchronized to the annual flow hydrograph and peak benthic food abundance, high-frequency songs and calls that penetrate the white-noise of cascading river environments and color patterns or bobbing movements that signal fitness, courtship, occupancy of their linear territories or predator awareness (all reviewed by Tyler and Ormerod (1994)). Many of the abiotic and biotic attributes of streams and rivers needed to satisfy the requirements of dippers are readily quantifiable and have been instrumental in understanding their ecology and their development as indicator organisms (Vaughan et al. 2007; Maznikova et al. 2024).

The Himalayan mountains provide the best example of how assemblages of specialist riverine birds interact with their abiotic and biotic environment over a range of scales. In this region, high primary production, elevation and physiographic diversity have created a template of habitats into which species have radiated from different phylogenetic origins (Buckton and Ormerod 2002; Sinha, Chatterjee, et al. 2022). Over a large altitudinal range up to almost 5000 m, changes in climate, river flow pattern, channel width, geomorphological structure, substratum, productivity, prey availability, riparian forest cover, and human disturbance combine to mediate species occurrence and assembly through environmental filtering of morphological and physiological traits (Manel et al. 2000; Sinha, Chatterjee, et al. 2022). Insectivorous species present at high altitude such as brown dippers *Cinclus pallasii*, plumbeous water redstarts *Phoenicurus fuliginosus* and white-capped redstarts *Phoenicurus leucocephalous* give way with downstream progression to species such as the pratincoles, skimmers, piscivorous kingfishers that use slower flows for foraging while depending on exposed rocks, eroding banks, gravel, and sandbars for tunnel-nests or colonies (Sinha, Menzies, et al. 2022; see Section 2.3). Other species, such as ibisbills, migrate over this range to occur along anastomosing channels at both high and lower altitudes depending on season.

More locally, several species of river birds often co-occur along reaches in middle altitudes where structurally complex habitats in the river channel and margins provide for niche differentiation and varied foraging opportunities. For example, brown dippers and little forktails both feed aquatically but in different micro-habitats and on prey of different size; spotted forktails *Enicurus maculatus* feed at the river margins blending aquatic and riparian prey; white-capped and plumbeous water redstarts respectively feed by ground-gleaning and aerial fly-catching, take primarily terrestrial or aerial prey by gleaning marginal surfaces and flycatching over channels (Buckton and Ormerod 2008). Reflecting the two-way energetic subsidy across the riparian ecotone, prey of both aquatic and terrestrial origin are involved. Other species, such as kingfishers, blue-whistling thrush *Myophonous caelerous*, and motacillid wagtails, sometimes augment this assemblage using niches that follow the same

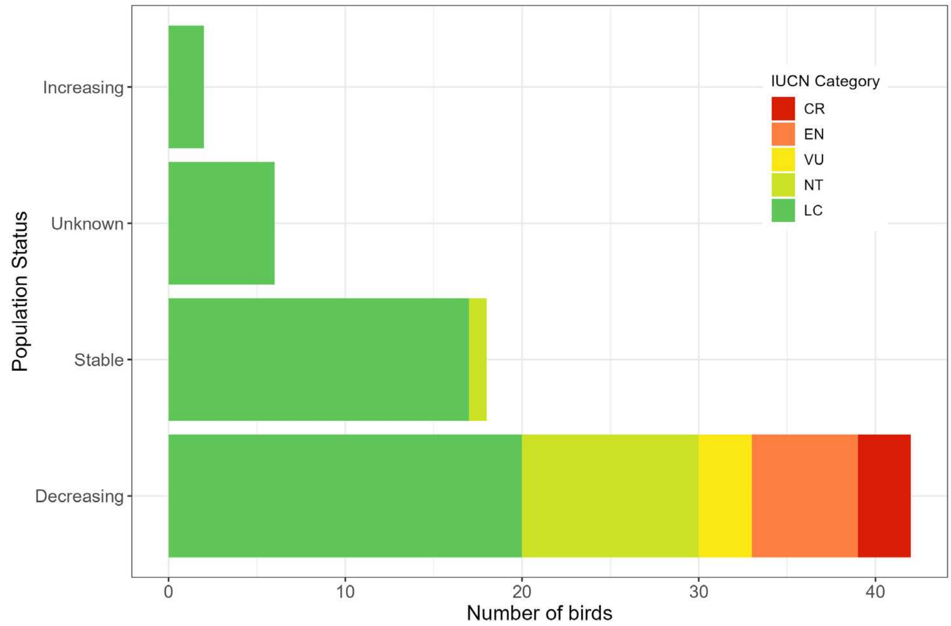

FIGURE 2 | Population trends of 67 species of specialist riverine birds of the world based on the population status of the IUCN assessment (retrieved in March 2025). The IUCN status is coded as Least Concerned~LC; Near Threatened~NT; Vulnerable~VU; Endangered~EN; Critically Endangered~CR.

principle of dietary or habitat segregation (Sinha, Chatterjee, et al. 2022).

These examples illustrate the scope for understanding how river birds interact with their abiotic and biotic environment while providing functional insight into options for river bird conservation. These include protecting or repairing food webs by maintaining water quality, protecting key habitats, ensuring natural flow patterns, and maintaining connectivity for migration and dispersal (Cooke et al. 2026). Conversely, such mechanistic understanding could aid in diagnosing threats to river birds if it were expanded across more species, as discussed in Section 3.

2.6 | Populations of Many Specialist Riverine Birds Are Declining

For reasons that are expanded below (Section 3), river ecosystems globally are under multiple threats with consequences likely for river birds. According to the latest IUCN global assessments (retrieved March 2025), over 50% of the populations of specialist riverine birds (over 40 species) are declining (Figure 2). Among the 69 species in Table S1, the population status of 67 has been assessed by the IUCN. Of these, 26 are categorized with a specific threat status, among which three species are Critically Endangered, six are Endangered, four are Vulnerable, and 13 are classed as Near Threatened (Figure 2). Assessments suggest that islands have the largest number of threatened species in proportion to the total number of species present (Figure 1). Otherwise, river basins in mainland South and South-east Asia (Figure 1), particularly the Ganges and Brahmaputra, host more than 10 species with overlapping range, including several declining species of conservation concern (Figure 1). This illustrates how pressures on river birds can arise in association with aspects of regional environmental change as well as through species-specific processes. In other cases, regional population reductions are occurring even among apparently widespread river species such as the white-throated dipper *Cinclus cinclus* (Figure 3ii), that are not assessed as threatened at a global scale by the IUCN Red List. In the UK, populations of this species have declined by around 50% over the last 30 years, with a slow decline apparent more widely across Europe (Heywood et al. 2025). In this and many other cases, the exact reasons for population decline require more systematic research and monitoring, although general degradation of river environments is implicated.

Against the background of the assessments globally, there are serious concerns around how effectively populations of river birds are monitored nationally or locally. Birds in many wetland ecosystems are assessed annually, for example through the International Waterbird Census (IWC), linked partly to their conspicuous aggregations and partly to the established importance of wetland ecosystems (Gilissen et al. 2002; Kingsford and Porter 2009; Amano et al. 2018; Brandis et al. 2018; Mundkur et al. 2017; Sayoud et al. 2017). In contrast, river birds have typically been monitored only sporadically either for specific research projects (Rushton et al. 1994; D'Amico and Hemery 2003; Simpkins et al. 2015; D'Amico et al. 2020; Das et al. 2021; Sinha et al. 2025) or through focussed ecological efforts on a small array of flagship species such as the white-throated dipper (see Nilsson et al. 2011) or the Louisiana waterthrush *Parkesia motacilla* (Latta et al. 2015). Effective methods are, nevertheless, available, one example being the British Trust for Ornithology's Waterbird Breeding Bird Survey (WBBS) which began in 1998 and replaced the preceding Waterways Bird Survey. The WBBS appraises bird numbers along linear waterways in the UK through a standard national protocol with the potential to assess spatial and temporal patterns in relation to habitat features (Vaughan et al. 2007; Royan et al. 2014). So far, this model has

FIGURE 3 | Birds inhabiting small montane fast flowing streams (i) spotted forktail *Enicurus maculatus* (ii) white-throated dipper *Cinclus cinclus*, (iii) scaly-sided merganser *Mergus squamatus* and (iv) ibisbill *Ibidoryncha struthersii*. Birds inhabiting wider rivers (iv) Indian skimmer *Rynchops albicollis* (vi) Harlequin duck *Histrionicus histrionicus*, (vii) black-bellied tern *Sterna auticauda* and (viii) river lapwing *Vanellus duvaucelii*. Image courtesy: Images (i), (ii), (iv), (v), (vii), and (viii): Nilanjan Chatterjee; (iii) Piao Longguo.

not been widely adopted in other nations. As a result, census data are often scarce, even for some of the world's scarcest river birds such as southern silvery kingfisher *Alcedo argentata*, Sunda forktail *Enicurus velatus*, torrent flyrobin *Monachella muelleriana*, Luzon redstart *Phoenicurus bicolor*, white-bellied heron, Javan blue-banded kingfisher *Alcedo euryzona*, Sri Lanka whistling thrush *Myophonous blighi* and the rufous-throated dipper *Cinclus schulzii*.

As well as quantitative information on population sizes and trends, for most river birds, ecological information on features such as detailed prey use, demography, and productivity is insufficient to fully understand causes of decline. Exceptions in some species nevertheless show how more detailed studies can provide valuable information to both diagnose and address pressures (Cruz et al. 2013; Claassen et al. 2017, 2018; Spurr and Ledgard 2016; Vilaça et al. 2012; Maznikova et al. 2024).

3 | Main Threats to Specialist Riverine Birds

Understanding population status and trends among river birds requires an assessment of the multiple stressors that affect river ecosystems (Best 2019; Albert et al. 2021; McCabe et al. 2025). They are considered to be among the most threatened ecosystems globally, reflecting their disproportionate importance for biodiversity,

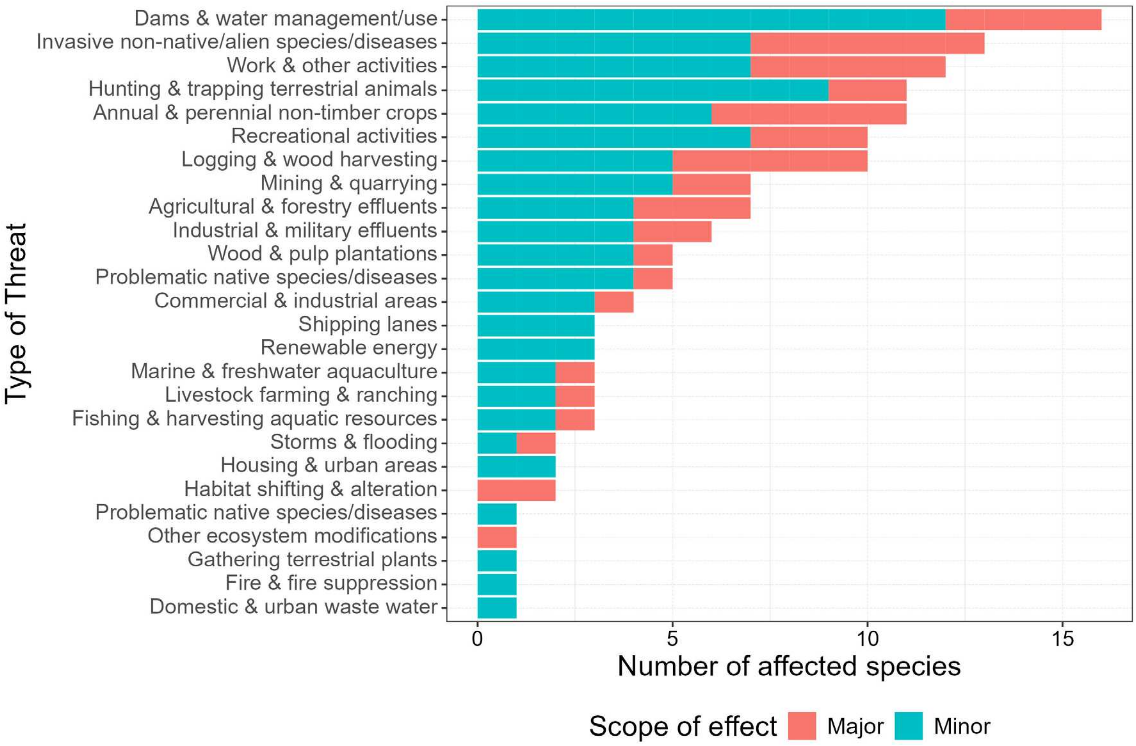

FIGURE 4 | Key threats identified by IUCN Red List affecting specialist riverine birds of the world. Threats are defined as major (50%–> 90% of the global population) and minor or unknown (< 50%), where evidence suggests that threats are smaller or less well quantified. The latter classification should be treated as a conservative assessment.

especially vertebrates (Strayer and Dudgeon 2010), simultaneously affected by long-standing and novel human impacts that include pollution, climate change, flow modification, habitat impairment, overexploitation, and invasive non-native species (Reid et al. 2019; Tickner et al. 2020). As well as birds, these effects are corroborated in other groups of freshwater organisms, for example, the megafaunal freshwater vertebrates such as large migratory fishes, beavers, otters, porpoises, crocodilians, and manatees (Carrizo et al. 2017; He et al. 2019; He et al. 2024; Spiller et al. 2025), and the non-avian species that are incorporated into the rapidly declining "living planet index" (WWF 2024; He et al. 2018).

In the case of river birds, assessments of threats have been categorized in different ways, for example those that emphasize sources (e.g., Figure 4). According to IUCN Red List assessments, dominant sources of threats to river birds are hydropower projects, water management schemes and non-native/invasive species. Direct hunting, trapping, and habitat loss due to farming and logging activities are also considered major threats (Figure 4). However, these assessments overlook some of the processes and stressors involved which can not only co-occur and potentially interact (Geary et al. 2019), but also can arise through terrestrial links with the wider catchment as well as through aquatic pathways (Figure 5). These more process-based assessments suggest threats such as human disturbance from recreational activities and bankside works, resource exploitation (e.g., fishing, harvesting, trapping), pollution from various sources, altered flow regimes, climate change, and habitat modification. Spatial patterns among the combinations of effects vary but are greatest among the increasingly densely populated regions in Asia, Africa, and South America (Figure 5). For example, as noted in Section 2.5, one of the clearest patterns is in the array of threats from agriculture, industry or domestic activity that affects the highly biodiverse river ecosystems of Asia (Figure 1; Figure 5) (Dudgeon et al. 2006). Invasive non-native species are a key threat to specialist riverine birds in New Zealand, while threats in Europe and North America are apparently low reflecting the smaller array of river birds present.

In the sections that follow, we provide examples of the threats and processes affecting river birds as recognized from IUCN sources (IUCN 2025) and from published scientific literature. Where possible, we draw on quantitative evidence, but in many cases such quantitative data are lacking.

3.1 | Flow Modifications

Rivers are characterized specifically by the downstream flow of water (Allan et al. 2021). River flow patterns are diverse in space and time, and reflect variations in discharge volume, velocity, variations in depth and hydraulics, and flow connectivity, all of which change seasonally or with events such as rainstorms, snowmelt, floods and droughts. These are not only key determinants of biota and biological processes in river ecosystems (Ward et al. 2002; Lytle and Poff 2004; Palmer and Ruhi 2019), but also they determine how matter, energy and organisms move among spatially defined units over diverse temporal and spatial scales (Amoros and Bornette 2002; Wohl 2017). Natural flow features have thus had a major influence on the evolution, life histories and niche development of river birds (Cerón and Boy 2014; Hong

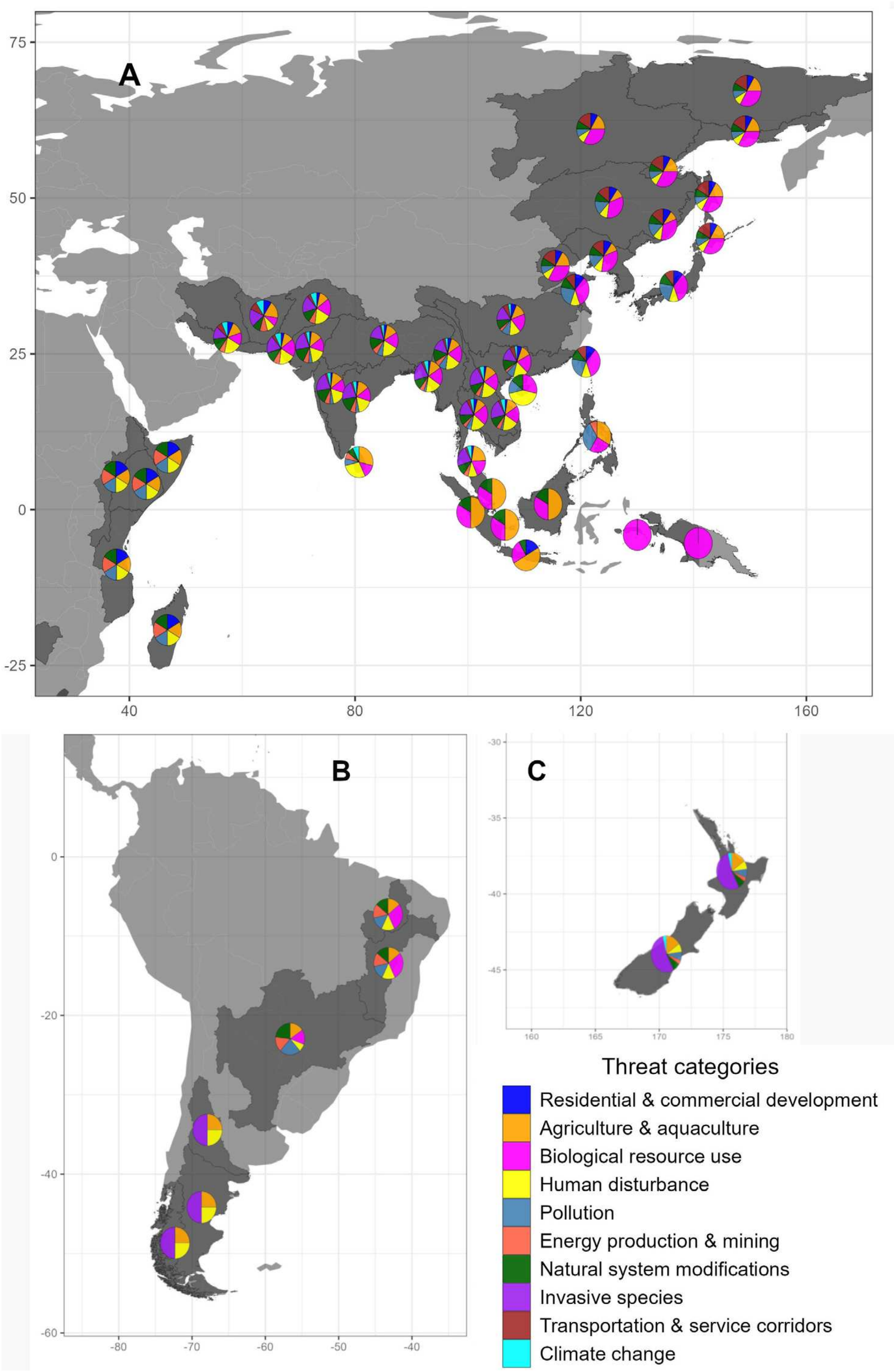

FIGURE 5 | Maps (A) Asia and Africa subcontinent, (B) South America and (C) New Zealand showing river basins of the world (dark gray) and the complexity of threats affecting threatened species of specialist riverine birds of the world. There is a separate pie chart, divided by recognized IUCN threat categories, for each major river basin with at least one threatened riverine bird species (IUCN 2025).

et al. 2019; Sinha et al. 2019). Adaptations include morphology and physiology in species such as the dippers, foraging strategies tied to different aquatic or emergent prey, and breeding strategies timed around seasonal hydrographs (Robinson et al. 2002; Lytle and Poff 2004; Hong et al. 2018). River flow regimes thus influence the spatio-temporal distribution of specialist riverine birds (Royan et al. 2013), habitat occupancy (Reiley et al. 2013; Sinha et al. 2019), abundance (Chiu et al. 2008; Sinha et al. 2025), breeding success (Strasevicius et al. 2013), time of breeding (Arthur et al. 2012), and survival (Chiu et al. 2013).

Increasingly, however, natural flow regimes in rivers and streams have been modified to meet the growing needs of domestic and commercial water supply, flood control, irrigation, transportation, and hydropower (Poff et al. 1997; Poff and Zimmerman 2010; Vörösmarty et al. 2010; Schneider et al. 2013;

Reid et al. 2019; Albert et al. 2021). Dams are considered among the most disruptive direct impacts on the ecological connectivity of a river through flow interruption and regulation (Ward and Stanford 1995; Nilsson and Berggren 2000; He et al. 2024). Dams and impoundments also modify water chemistry and dissolved gasses; thermal regimes; sediment, energy, and nutrient transfers downstream—often over extensive river lengths (Kemp 2015).

Negative effects of impoundments and associated water management schemes have been detected in more than 15 species of specialist riverine birds worldwide (Figure 4). The demand for sustainable energy production has rapidly increased the construction of hydropower schemes (Chen et al. 2016), and globally impoundments have been estimated to have reduced the number of remaining free-flowing large rivers by about 21% (Zarfl et al. 2015). Dams for hydropower, flood control, and agricultural irrigation are disproportionally located in catchment headwaters (Zhang and Gu 2023) and thus likely to affect river birds in montane ecosystems. This includes the threatened rufous-throated dipper, which is affected by altered flow patterns due to water abstraction and impoundments for irrigation (Tyler and Ormerod 1994; Politi et al. 2019).

Previous studies have shown that small hydropower projects might affect more bird species by disrupting river food webs and riparian character (Power and Dietrich 2002; Barter et al. 2014; Bovo et al. 2021; Wu et al. 2019). In contrast, large impoundments inundate former river channels and reduce velocity, with likely effects on rheophilic species like the dippers, torrent duck, Salvadori's teal, Brazilian merganser, blue duck, bronze-winged duck *Speculanas specularis*, and scaly-sided merganser *Mergus squamatus*. In other cases, flow modifications might affect floodplain landscapes through channel stabilization, flow variability, and vegetation cover, with potential consequences for birds tied to specific fluvial features such as torrent ducks (Pernollet et al. 2013) and scaly-sided merganser (Liu et al. 2023; Tang and Zhai 2025), or those using gravel bars such as Pratincoles, Wrybill, and Ibisbill (Yabuhara et al. 2015). In all these cases, however, many of the processes through which flow modifications affect river birds are not well understood and in need of further investigation.

3.2 | Pollution

Natural variations in water quality, for example concentrations of nutrients, salts, carbonates, inorganic and organic acids and oxygen, have large influences on the diversity and community composition of freshwater organisms (Wright et al. 1984). There are multiple consequences for the distribution and abundance of river birds, for example through alterations in prey availability (Ormerod and Tyler 1993). In addition, a wide range of point- and diffuse-source pollutants could potentially affect river birds both indirectly through effects on food resources or through bioaccumulation, biomagnification or physiological effects (Sorace et al. 2002; Morrissey et al. 2005). Pollutants vary from traditional (e.g., nutrients, organic waste) or legacy chemicals (e.g., PCBs, PBDEs) and sediments to emerging pollutants such as plastics, human or veterinary pharmaceuticals and non-natural sources of heat, light, and noise (Mason 2002; Kelly et al. 2026). Sources include domestic wastewater (Debata et al. 2019), agriculture (Mohsanin 2014; Collar 2020; Maclean and Kirwan 2020), inland aquaculture, mining, and quarrying (Collar 2020), industrial emissions that affect freshwaters locally or through atmospheric transport, and urbanization along with associated infrastructure such as road systems.

Global-scale inventories from the UN and others suggest the risks from the pollution of river ecosystems and their food webs are large, diverse, and extensive. For example, dissolved oxygen and nutrients impair good quality in over 40% of water bodies monitored globally, human pharmaceuticals exceed safe concentrations for aquatic organisms in around 25% of global sampling locations, and surface waters in over 40% of the global land area are at risk from agricultural insecticides (Kelly et al. 2026). Other than in well-researched species such as the Dippers *Cinclus* spp., however (Maznikova et al. 2024), most assessments of the effects of pollutants on river birds are qualitative. For example, the endemic Sri Lanka whistling thrush and Luzon redstart are threatened by mining and agrochemical run-off (Collar 2020). Similarly, in Argentina and Bolivia, rufous-throated dippers are at risk from mining effluents and nutrient enrichment (Tyler and Tyler 1996; Politi et al. 2019), while Brazilian mergansers are at risk from several pollution sources (Lamas 2006). Given the global scale of water quality impairment in rivers, this is a subject in need of considerably increased effort (Kelly et al. 2026).

The acidification of headwater systems by mine drainage or, more widely, by acid precipitation has provided one of the most comprehensively studied of all pollution effects on river birds. At low pH, soft-water streams and rivers are characterized by reduced abundances or losses of acid-sensitive ephemeropterans, trichopterans, crustaceans, mollusks, and fishes which are prey of major importance to several river birds at different life stages (Ormerod and Tyler 1991a; Mulvihill et al. 2008). In white-throated dippers, multiple effects replicated in different regions included reduced abundance, delayed breeding, altered calcium physiology, impaired breeding performance, reduced offspring growth and survival, and altered time-activity patterns (Ormerod et al. 1991; Vickery 1992). Similar effects were observed in north American for Louisiana Waterthrushes, including delayed and impaired breeding, increased territory length and fragmented population structure (Mulvihill et al. 2008). In this species, there is some capacity to switch from aquatic to terrestrial prey under acidified conditions (Trevelline et al. 2018) while facultative foraging strategies in gray wagtails and common sandpipers also provide a buffer against the loss of acid-sensitive prey (Ormerod and Tyler 1991b; Vickery 1991).

The predatory position of several river birds in food webs means they are at risk from bioaccumulating and biomagnifying pollutants (Windsor et al. 2020; Custer et al. 2010; Haq et al. 2021). *Cinclus* species in Europe and North America have figured strongly in the research through evaluations of contaminants such as mercury (Hg), selenium (Se), polychlorinated biphenyls (PCBs), PBDE flame retardants, and organochlorine pesticides in eggs, feathers, and blood (Ormerod and Tyler 1992; Morrissey et al. 2004, 2005; Henny et al. 2005; Wayland et al. 2006). During the period of peak use of some organochlorine chemicals such as dieldrin and DDT, there is some evidence that dippers might have accumulated pollutant burdens equivalent to those in terrestrial raptors (Ormerod and Tyler 1990). Research on dippers has also illustrated effects of other persistent pollutants such as PCBs and PBDE (polybrominated diphenyl ether) flame retardants on eggshell thinning, egg failure, alterations in brood sex ratios, and altered thyroid metabolism (Morrissey et al. 2005; Morrissey et al. 2014). In Wales, PCBs and PBDEs were the dominant nonpolar contaminants detected in dipper eggs along urban streams reflecting legacy sources in formerly industrial catchments (Morrissey et al. 2014). More subtle effects on contaminant burdens include dietary changes during egg laying and egg formation in both American dippers and white-throated dippers (Morrissey et al. 2010), while migratory behaviors also influence contaminant profiles (Morrissey et al. 2004).

As well as persistent pollutants, river birds are at risk from plastic pollution, for which rivers appear to be hotspots (Lebreton et al. 2017; Hurley et al. 2018), transporting plastics of all size fractions between terrestrial, floodplain, riparian and transitional ecosystems (Schmidt et al. 2017; Van Emmerik and Schwarz 2020). The analysis of feces and regurgitates from white-throated dippers in Wales, UK has illustrated how both adults and developing nestlings ingest hundreds of fragments per day via contaminated invertebrate prey, with these effects greatest in urban environments (D'Souza et al. 2020). So far, no adverse effects have been observed.

3.3 | Climate Change

Climate change combines increasing air and water temperatures with changes in the global water cycle that affect river hydrodynamics, hydraulics, and channel morphology with serious consequences for river ecosystem processes (Palmer et al. 2008; Milner et al. 2009; Milner et al. 2017; Kayitesi et al. 2022; Wang et al. 2024). Climate change is also changing the duration, magnitude, and frequency of floods and droughts (Prudhomme et al. 2014), creating novel flow regimes (Gudmundsson et al. 2021) that are likely to remove sensitive species and simplify food webs (Ledger et al. 2012). There are interactions with other stressors on freshwater biodiversity such as acidification, land-use change, wastewater pollution, and the proliferation of invasive non-native species (Durance and Ormerod 2007; Heino et al. 2009; Woodward et al. 2016; Wen et al. 2017; van Vliet et al. 2023). The array of pathways through which climate change could affect riverine birds is, therefore, complex and involves direct effects from altered thermal and hydrological regimes but also changes in oxygen solubility, pollutant discharge or dilution, habitat availability, and impacts on resources such as food or nest sites.

In well-studied species such as white-throated and brown dippers, the effects of changing discharge are already clear from demographic studies and accumulated long-term data. For example, breeding onset can be delayed by high flow, while inter-annual survival in dippers at temperate latitudes is reduced by floods that reduce prey availability (Marzolin 2002; D'Amico et al. 2003; Chiu et al. 2013; Chiu et al. 2013; Hong et al. 2019). Flooding also increases energetic costs in dippers before foraging ceases at the highest flows (O'Halloran et al. 1990; D'Amico and Hémery 2007). Climatic effects on varying discharge have also been observed or predicted to affect other river birds. In Glacier National Park (GNP), Montana, USA, alterations in streamflow across 24 years confirmed effects of floods on nutrient acquisition and nest-site selection in Harlequin ducks (image of bird species in Figure 3vi) (Hansen et al. 2019). Increasing flood risk in New Zealand is also seen as a contributor to extinction risk in blue ducks (Simpkins et al. 2015). The abundances of common sandpiper, wrybill, and ibisbill, all of which typically forage on exposed riparian mudflats, riparian shingle or gravel bars, are predicted to decrease with increasing frequency and duration of higher flows (Royan et al. 2014; Dowding et al. 2020; Haq et al. 2022). Effects in some species could also extend to genetic bottlenecks, for example in populations of the Andean riverine specialist, the torrent duck (Alza et al. 2019).

As well as elevated flow, reduced flows can affect river bird species, for example by increasing predator access to nests (Dowding and Murphy 2001; Debata et al. 2019; Das et al. 2021). In contrast, wrybill chicks in New Zealand survived better at lower minimum flows probably because nests and chicks were protected against higher flows that also reduced foraging opportunities (Cruz et al. 2013). Wrybills also abandoned river stretches with larger and frequent floods (Hughey 2012).

Climate change effects on river birds through altered thermal regimes are so far less clear than those of changing flow, but once again well-studied species provide some clues. In white-throated dippers, increasing temperatures have advanced laying dates (Nilsson et al. 2020). In sub-arctic latitudes in Scandinavia, earlier breeding linked to ice-free conditions, better access to prey supplies and increasing temperatures appears to increase dipper survival and population size (Nilsson et al. 2020; Nilsson et al. 2011; Nilsson et al. 2019; Saether et al. 2000). In both brown and white-throated dippers, such climate-mediated change effects could expand ranges or affect behavior in ways that offset other negative effects (Royan et al. 2014; Hong et al. 2018). In contrast, at temperate latitudes, rising river temperatures are affecting the distribution, abundances, and community composition of cool-water organisms used as prey by river birds, although ecological consequences for dippers have yet to be established (Durance and Ormerod 2007; Larsen et al. 2024). Model assessments have predicted northward shifts in the range of other cool-climate Palearctic river birds such as goosanders and common sandpipers, potentially reflecting thermoregulatory costs as well as sub-optimal conditions involving prey availability (Huntley et al. 2008). Other potential effects are more speculative, for example through phenological mismatches between prey used by river birds and breeding seasonality, and there is much scope for further work.

3.4 | Land-Use Change

Given that rivers are affected profoundly by the character of their catchments, it follows that changes in catchment character are likely to have downstream consequences (Hynes 1975). Globally, wider landscapes around rivers are often managed without full consideration of such downstream effects, such that urbanization, agriculture, industry, mining, or forest exploitation have multi-dimensional impacts on the riverine environment (Glassic et al. 2025). Prime examples include the conversion of natural catchment or riparian forest for agricultural land and urban development (Dudgeon 2000b; Clerici et al. 2014; Kroese et al. 2020). Land use changes at this scale affect water quality, catchment hydrology, sediment dynamics, physical habitat, floodplain or riparian connectivity, and energetic links through inputs of heat, light, or allochthonous leaf litter (Saunders et al. 2002; Broadmeadow and Nisbet 2004; Studinski et al. 2012).

The complex array of ways that river birds use river habitats means that the impacts of land use change on river birds can be both direct, through the modification of riparian habitats used in foraging, nesting and roosting, or indirect, via changes in prey availability (Manel et al. 2000; Buckton and Ormerod 2008). For example, in the UK, gray wagtails bred earlier along streams bordered by semi-natural broadleaved woodlands than at sites with non-native conifers or streamside agriculture (Tyler and Ormerod 1991). These effects reflected better foraging habitat and greater prey abundance at broadleaf sites, in part supplemented by terrestrial lepidopterans, while gray wagtail breeding also matched peak timing in prey numbers under broadleaves (Ormerod and Tyler 1991b). In Sri Lanka, the clearance of native forest and conversion to timber plantations is degrading habitat and reducing populations of the ground-gleaning Sri Lanka whistling thrush, but the exact processes are not clearly described (Collar 2020).

Elsewhere, forest logging in riparian zones threatens river waterfowl, waders and herons which depend on riverbank habitats such as scaly-sided merganser, Salvadori's teal, African black duck, blue duck, white-bellied heron, and Brazilian merganser (Lamas 2006; Silveira and Bartmann 2001; Maheswaran et al. 2021). Various kingfishers and fishing owls are also at risk, and for example Malay and Javan blue-banded kingfishers continue to decline with forest clearance throughout their range (Lambert and Collar 2002). In the Philippines, the southern silvery kingfisher is declining rapidly due to losses of lowland forest or conversion to exotic plantation alongside clear streams (Woodall and Kirwan 2020). In the Far east and Japan, the loss of riparian Taiga has been shown to affect the endangered Blakinston's fish owl (Slaght, Surmach, and Gutierrez 2013). One Russian study showed that 43% of optimal fish-owl habitat was within current logging leases, while protected areas included only 19% (Slaght and Surmach 2016).

In some cases, the impacts of riparian modification arise through the combined effects of habitat degradation and sediment mobilization which affect visual underwater predators such as blue duck and rufous-throated dippers through reduced water transparency (Martin et al. 2007; Politi et al. 2019). Sedimentation effects might also have knock-on effects on riparian or aerial insectivores such as the Luzon redstart by affecting prey abundance (Collar 2020).

The effects of land use change can extend beyond riparian zones and across the river channel to affect bird species on sidebars and mid-channel islands. For example, the conversion of river islands to agricultural lands threatens the breeding habitats of Indian skimmer *Rhynchops albicollis* (image of bird species in Figure 3iv) in Bangladesh and India (Mohsanin 2014). Irrigation for agriculture is widespread across the Indian range of this species and can reduce water levels to the point that breeding ceases (Sundar 2004; Malla et al. 2015). In Africa, threats to Madagascar pratincoles *Glareola ocularis* from agricultural conversion extend across Kenya, Somalia, Tanzania and eastern Madagascar, exacerbated by sand mining or oil and gas exploration (Maclean and Kirwan 2020). In Kenya's Tana Delta, agricultural changes reflect large-scale conversion for sugarcane, biofuels and oil seeds to meet export demands from economically richer countries. Similar effects including aggregate extraction, burning and cattle grazing also affect floodplain-nesting birds such as river tern, black-bellied tern (image of bird species in Figure 3vii) and great thick-knee with risks of population decline (Yabuhara et al. 2015; Claassen et al. 2018; Arjun et al. 2023).

3.5 | Invasive Non-Native Species

Relative to their global surface area, freshwater ecosystems are disproportionately vulnerable to invasion by non-native species as a reflection of (i) interactions with other stressors that increase invasion risk; and (ii) the extensive introduction of freshwater organisms, such as sport fishes, outside their native range (Francis 2012). In rivers specifically, longitudinal connectivity also facilitates the long-distance movement of invaders along the channel or riparian zone especially following the construction of new transport routes, such as canals, that link previously unconnected regions (Leuven et al. 2009). Typical freshwater invaders are also noteworthy as a non-random group of taxa that can have profound effects, for example aquatic or riparian plants that re-engineer habitats, invasive mollusks that disrupt food webs from the bottom up, and fishes that can restructure communities as consumers or apex predators (Strayer 2010). These processes affect the hydrology, biogeochemistry, energetics, structure, and biotic composition of invaded river ecosystems, all with the potential to affect river birds through resource competition or habitat modification.

Assessments suggest that invasive non-native species globally affect over 15 species of specialist riverine birds (Figure 4). One of the most frequent examples is through competition for aquatic invertebrate prey between widely introduced salmonids such as brown trout *Salmo trutta* with species including blue duck in New Zealand, Salvadori's teal in New Guinea, torrent ducks in South America, and rufous-throated dipper in Argentina and Bolivia (Eldridge 1986; Robertson et al. 2007; Kear 2005; Politi et al. 2019). There is anecdotal evidence that domesticated ducks might compete for food and space with scaly-sided mergansers along rivers in China (Shao et al. 2012).

Specialist riverine birds are also at risk from invasive non-native species at the interface between the terrestrial and riparian environment, for example introduced predators such as feral dogs *Canis familiaris*, cats *Felis catus*, or other mammals. In New Zealand, the range, population, and breeding success of blue duck have declined markedly and have been aggravated by predatory loss to introduced mammals, especially stoats *Mustella erminea* (Whitehead et al. 2008; Simpkins et al. 2015). Qualitative evidence also suggests that stoats and cats are a risk to wrybill populations through predation in the coastal Firth of Thames, one of the species' principal wintering locations (Battley and Moore 2004).

Riparian invaders also include non-native plants that modify foraging, roosting, and nesting habitats for river birds while also affecting the energetic subsidy of allochthonous litter to streams and rivers. The riparian zones of many European rivers have been invaded by Himalayan balsam (*Impatiens glandulifera*) and Japanese knotweed (*Reynoutria japonica*), with some local evidence that the latter has affected gray wagtails (*Motacilla cinerea*) and white-throated dippers (Hajzlerová and Reif 2014). In New Zealand, wrybill habitat has been affected by exotic species such as broom (*Cytisus scoparius*) and gorse (*Ulex europaeus*) (Dowding et al. 2020). In this and other cases, interaction with stressors such as water abstraction has facilitated the proliferation of invasive riparian plants or algae to affect wrybill and blue ducks respectively by habitat degradation and altered benthic food supply (Glaser et al. 2010; Wiersma and Kirwan 2023).

4 | Conservation Options and Actions

The deterioration of freshwater ecosystems globally, coupled with negative trends in freshwater biodiversity, has increased attention on the need for conservation action. Responses have ranged from the explicit policy recognition of inland waters in the Convention on Biological Diversity (Cooke et al. 2023) to growing advocacy about the conservation steps required (Tickner et al. 2020). Although not directed specifically toward river birds, if implemented the proposed actions could address key pressures upon them: protecting and restoring environmental flows; improving water quality; protecting and restoring critical habitats; managing the exploitation of freshwater ecosystem resources; preventing and controlling non-native species; and restoring river connectivity (Cooke et al. 2026). Each of these actions also requires supporting steps such as improved monitoring and research assessment of the processes affecting river organisms; legislation and regulations that are enforced; improved river and catchment management; and action to combat the systemic drivers of river degradation through education and reduced resource consumption (Kelly et al. 2026).

In addition to these generic actions, global biogeographical patterns of river bird diversity alongside population trends and the distribution of threats would suggest that conservation needs are most urgent in South-east Asia, South America, and New Zealand. One important option is the recognition of declining species in protected areas ideally at whole-basin scales, but otherwise along appropriate river reaches and riparian zones (see Box 2). In general, however, efforts to recognize rivers through protected areas fall below requirements and global targets (Abell et al. 2017; Sinclair et al. 2025). Key river birds in focus should include white-bellied heron, Brazilian merganser, Javan blue-banded kingfisher, black-bellied tern, Indian skimmer, Blakiston's fish owl, blue duck, scaly-sided merganser, wrybill, rufous-throated dipper, and Salvadori's teal (Table S1). In all of these species, information scarcity on ecological requirements underscores the need for expanded research effort to underpin conservation and management. Limited work so far includes radio-telemetry to understand home range sizes and movement patterns in Brazilian mergansers (Lamas 2006) and scaly-sided mergansers (Solovyeva et al. 2012). Local-scale conservation programs are also limited, although a notable exception in the case of the white-bellied heron in Bhutan is involving multiple participants, international collaboration, communities and The Royal Society for Protection of Nature (RSPN), Bhutan (Maheswaran et al. 2021). Simpler actions, such as the use of artificial nest-boxes, have been used to aid reproductive success in the endangered scaly-sided merganser (Solovyeva et al. 2013; Solovyeva and Vartanyan 2019) and Blakiston's fish owl (Slaght, Surmach, and Gutierrez 2013).

BOX 2 | Terrestrial protected areas and riverine bird conservation.

Despite explicit recognition of inland waters for biodiversity conservation, the incorporation of rivers into protected areas is at least as limited as for terrestrial ecosystems (Nel et al. 2007). Additionally, for rivers, there are specific limitations in that protection often focuses on the channel, sometimes with the riparian zone, but ideally should embrace whole catchments to encourage control of land management practices likely to have downstream effects (Saunders et al. 2002). This challenge of protecting freshwater biodiversity in protected areas continues and was most recently demonstrated in Europe (Sinclair et al. 2025). More widely, the protection for rivers for their biodiversity is most limited in the Middle East, Central and South Asia, North America, southern South America, and northern Africa (Abell et al. 2017). However, the World Protected Area Database is incomplete for some parts of the world, especially areas rich in river birds such as Asia. Apparent gaps for river bird protection include headwaters in Asia, Oceania, and South America. A key need is in understanding overlaps between the distributions of specialist river birds and other freshwater species of conservation concern to optimize protection.
Existing information from other groups such as freshwater mammals, amphibians, reptiles, fishes, crabs, and crayfish suggests limited congruence in broad-scale richness and threatened status (Collen et al. 2014).

In the case of New Zealand's blue duck, tactical actions have included active trapping of invasive predators, and in the Fiordland National Park there have been positive effects on nesting productivity (Whitehead et al. 2008). Captive breeding and release have also been trialed, and Operation Ark and Whio Operation Nest Egg (WHIONE) have successfully reared breeding pairs of blue ducks by removing eggs to hatch in captivity followed by subsequent release once the young are less vulnerable to predation (Glaser et al. 2010). Managed relocation beyond the native ranges of blue ducks has also been considered as a potential response to evidence suggesting limited gene flow between neighboring catchments (Triggs et al. 1992). However, translocation is also contested as alternative perspectives suggest that North and South Island populations differ genetically to the point that they should be treated as separate populations for conservation measures (Robertson et al. 2007).

As well as efforts focussed on threatened or declining species, conservation actions sometimes focus on regionally representative ecosystems, for example locations with elevated alpha richness or aggregations of representative species. Locations such as the Himalayan Mountains, with their large diversity of river birds, are strong candidates. Because of their wider indicator value for ecosystem quality (Maznikova et al. 2024) or value as "umbrella" species, focus on representative species can have wider conservation value. There is some evidence that priority species of river bird such Blakinston's fish owl and scaly-sided merganser can act as surrogates in this way for conserving riverine biodiversity regionally (Higa et al. 2016; Kajtoch and Piestrzyńska-Kajtoch 2016; Xu et al. 2021).

5 | Conclusion

Despite considerable progress in understanding rivers as integrated ecological systems, not all river organisms have figured equally in either research or conservation efforts. In particular, information on specialist riverine birds globally is unevenly distributed with considerable differences in data quality and quantity among countries and across species (Sinha 2021). Most advances have been in Europe and North America where freshwater ecologists, population biologists, and ecotoxicologists have taken specific interest in river birds (Ormerod and Tyler 1991a; Morrissey et al. 2010; Saether et al. 2000). This contrasts, however, with regions such as Asia, where river bird richness is greatest or regions with the most threatened river bird species. As a result, there are conspicuous knowledge gaps for many river birds on life history patterns, reproduction, prey use and feeding behavior, territoriality, migratory behavior, biotic interactions with other taxa, environmental requirements, and population estimates. The taxonomic diversity of river birds means that much of the required information will be species-specific, hence requiring considerably expanded effort especially in the world's less economically developed regions.

In view of the ongoing effects of global changes on river ecosystems and organisms, our review identifies the need to expand knowledge of river birds, but also to adopt approaches to suit their conservation and management (Paetzold et al. 2008). This includes recognizing and addressing the consequences of the exploitation of rivers and their catchments for human resources, impairments in water quality, the fragmentation of freshwater systems, the problems of invasive non-native species, and the challenges of applying appropriate governance, policy and legislation to river systems (Tockner and Stanford 2002; Dunham et al. 2018; Glassic et al. 2025). Addressing these issues should already be important in efforts aimed at river restoration, but we suggest increased direction to emphasize specialist riverine birds alongside other priority river organisms where this is appropriate (Bovo et al. 2021; Chen et al. 2022). Recent evidence suggests that the benefits of improved river conservation for birds could extend well beyond the shoreline and into wider riparian landscapes (Schürings and Olden 2026).

Although their effectiveness is sometimes debated, we suggest that the incorporation of river birds into the identification and notification of protected areas or other area-based protection measures is an important step (Abell et al. 2017). Locations that harbor representative river birds, multiple species that co-occur, or threatened species can all serve as a focus for conservation efforts regionally, nationally and internationally—recognizing the integrity of the river channel with its associated and often crucial riparian zones (Sinha et al. 2019). For example, India supports more than 16 species of specialist riverine birds, more than five of which are of conservation concern (Sinha 2021). Elsewhere, conservation priorities will reflect species with isolated populations (Maheswaran et al. 2021) or localized populations restricted to islands (Wiersma and Kirwan 2023). Above all, we contend that river birds require more explicit recognition in river ecology and conservation efforts than has been achieved so far (Strayer and Dudgeon 2010; Collen et al. 2014; He et al. 2017; WWF 2024).

Author Contributions

Ankita Sinha: conceptualization (lead), data curation (equal), formal analysis (equal), funding acquisition (lead), investigation (lead), methodology (equal), project administration (equal), resources (equal), writing – original draft (lead), writing – review and editing (lead). **Nilanjan Chatterjee:** conceptualization (equal), data curation (equal), formal analysis (equal), investigation (equal), methodology (equal), visualization (lead), writing – review and editing (equal). **Steve J. Ormerod:** conceptualization (equal), investigation (equal), methodology (equal), writing – review and editing (equal).

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study were derived from the following resources available in the public domain: https://www.iucnredlist.org/.

Related WIREs Articles

Food Web Perspectives and Methods for Riverine Fish Conservation.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** A list of specialist riverine birds of the world. The IUCN status is coded as Least Concerned~LC; Near Threatened~NT; Vulnerable~Vu; Endangered~En; Critically Endangered~CE.