RISK ASSESSMENT OF PLASTIC POLLUTION TO MIGRATORY SPECIES IN THE MEKONG AND GANGA RIVER BASINS

A METHODOLOGY AND RISK ANALYSIS

Prepared for the Secretariat of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, September 2021.

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COVER IMAGE

Osprey bringing large piece of plastic litter in for nest building. Bombay Hook NWR, New Jersey: © john581, CC BY 2.0 <https://creativecommons.org/licenses/by/2.0>, via Wikimedia Commons

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Foreword

Plastics have been used for a tiny fraction of human history yet have become an overwhelming environmental challenge. Over the last seventy years, 7 billion tons of the estimated 9.2 billion tons of plastics produced have ended up as plastic waste. Plastics are now found in every corner of the earth, from the highest mountains to the deepest ocean trenches. Plastics are being produced at a scale and pace that has overwhelmed the ability of countries around the world to cope.

Plastic pollution can have adverse impacts on the natural environment, both in the short and longer term. Migratory species have been found to be particularly vulnerable to plastic pollution, in part due to their likely exposure to plastic along their migratory pathways.

To date, much of the scientific and policy focus has been on the marine environment. A review of publications between 1980 and 2018 indicates that research on plastics in the freshwater environment account for only 13% of the plastics studied in all aquatic systems. Only 4% of peer-reviewed studies on the impacts of plastic pollution are relevant to terrestrial ecosystems. Yet research indicates that terrestrial and freshwater ecosystems are, like oceans, also long-term sinks for plastic waste. Considering the current scale of the problem and future trends, there is an urgent need to advance research, develop tools and assess risks posed by plastics to freshwater and terrestrial wildlife and ecosystems.

Recognizing this, in 2020 the 13th meeting of the Conference of the Parties of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) requested the CMS Scientific Council to develop a report summarizing the status of knowledge on the impact of plastic pollution on CMS-listed species that inhabit terrestrial and freshwater ecosystems, with support from the CMS Secretariat.

This report is the second report resulting from a collaboration between CMS and the UN Environment Programme as part of the CounterMEASURE II plastic pollution programme, generously funded by the Government of Japan, to expand research on the impacts of plastic pollution in freshwater and terrestrial ecosystems of the Asia-Pacific region. It was prepared for the CMS Secretariat by the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia.

This report examines the health risk posed by plastic pollution in the Ganges and Mekong River basins to twenty-three freshwater, terrestrial and avian species protected under CMS. It also presents a framework for estimating the risk of plastic pollution to species within freshwater and terrestrial ecosystems. It currently relies on the best available data from the Asia-Pacific region but can be improved on as additional research is conducted.

Among its conclusions, the report finds that in the Mekong River basin, the Mekong Giant Catfish and Irrawaddy Dolphin are at high risk from entanglement with plastic, and the Irrawaddy Dolphin is also at moderate risk from plastic ingestion. In the Ganges River basin, the report concludes that the Ganges River Dolphin and Gharial are at high risk from entanglement with plastic, and the Ganges River Dolphin is also at medium risk from plastic ingestion. It further found that in the

Asia-Pacific region, discarded fishing gear in freshwater ecosystems is a particular threat to migratory species.

This report provides an important contribution to better understanding the potential impacts of plastic pollution on terrestrial and freshwater species. In line with one of its main conclusions, significant additional research in this area is greatly needed.

Amy Fraenkel

Executive Secretary
Convention on the Conservation of Migratory Species of Wild Animals

Executive summary

Both the Lower Mekong Basin and the Ganga River Basin (also called Ganges River basin) are home to a huge diversity of wildlife species, many of which are listed as threatened or endangered by the IUCN. Additionally, they are home to a number of species which are protected under the Convention on Migratory Species (CMS). Unfortunately, these rivers are also thought to be among the most polluted in the world, transporting vast quantities of plastic and other anthropogenic litter from land-based sources to the ocean.

While there have been many studies on the risks that plastic litter poses to marine wildlife, the risks to freshwater species are less well studied. Nonetheless, this information is critical for decision-makers to be able to prioritise limited resources.

We took a risk assessment approach to determine the potential risks from plastic litter to the CMS-listed species in the Mekong (5 species) and in the Ganga (19 species). We conducted an extensive literature review to characterise both the likelihood that the species would interact with debris when it was encountered, as well as the outcome of that interaction. While there were few published studies on the species in question, we drew on information from closely related species, as well as data from wildlife hospitals to create a robust risk matrix.

From the results of the risk matrix, we estimate that only three species in the Mekong are at moderate or high risk from plastic litter, and only two species in the Ganga. The Mekong catfish and the Irrawaddy dolphin are at high risk from entanglement from fishing debris, the Eastern Imperial Eagle is at moderate risk from entanglement, and the Irrawaddy dolphin is at moderate risk from ingestion of plastic litter. In the Ganga, the Ganges River dolphin and the gharial are at high risk from entanglement, and the dolphin is also at moderate risk from ingestion.

These risk assessments are, in effect, worst case scenarios, and mortality rates will depend on the densities of litter that the animals encounter in the wild. In order to estimate the relative risk from ingestion that each species would encounter at various locations along the river, we used the results from our global modelling study to predict litter distributions in watersheds along the river and predicted a relative debris load at 14 sections of the LMB (including the Tongle Sap), and 6 sections of the Ganga River. In order to estimate the relative risk from fishing debris, we used observations on abandoned, lost, and discarded fishing gear (ALDFG) in the Ganga River, and population density as a proxy in the Mekong River.

From these estimates, we present risk maps of the relative level of risk to each species from both ingestion and entanglement, at a sub-river basin scale. We also present cumulative risk maps, summing our estimates across all species, to compare relative risk at various sections of the rivers.

The approach we used is designed to be able to incorporate additional data as and when it becomes available, to further refine risk estimates.

Part I Introduction

1 Preface

1.1 Background need for this report

The Mekong River and Ganga Rivers (also called Ganges River basin) have been identified among the ten rivers globally that are estimated to be transporting the largest quantities of plastic and other anthropogenic litter (henceforth, 'plastic litter') from land to the ocean (Schmidt 2017, Lebreton 2017). Both of these river basins are also home to a variety of internationally protected migratory species (CMS-listed), including numerous threatened species including the critically endangered Mekong giant catfish (*Pangasianodon gigas*), gharial (*Gavialis gangeticus*), and the Mekong river subpopulation of the Irrawaddy dolphin (*Orcaella brevirostris*) (IUCN, 2019).

There is very little empirical data on plastic in the environments of these major river basins, despite the published claim that these litters are major sources of coastal and marine pollution (Schmidt 2017). There is also currently little to no published data on the frequency of interactions between CMS-listed species and plastic litter in the environment, or about the outcomes or consequences of these interactions.

To inform management actions and better understand the emerging threat of plastic pollution to internationally protected migratory vertebrate aquatic species, it is necessary to understand the level of risk that is posed. This report takes a risk assessment approach and provides estimates of risk to CMS listed species from plastic litter in the Mekong and Ganga River basins, based on published scientific literature and modelling of empirical data.

1.2 Organisations involved

This work and the associated report were funded by the United Nations Environment Programme, through the CounterMEASURE II project. They were also supported by CSIRO Oceans and Atmosphere.

1.3 What is the purpose of this report?

The purpose of this report is to estimate the likelihood and nature of interaction between CMS-listed fauna and plastic litter in the Mekong and the Ganga River Basins. We estimated the risk of health consequences to CMS-listed fauna that might result from interaction with plastic litter and provide risk scores for the threat from ingestion of and entanglement in plastic litter by CMS-listed fauna in each of the river basins.

We segmented each river into several sections and provide a relative scoring across these sections to compare the risks from ingestion or entanglement within a species between the different sections of the river basin. Scores are consistent among species, so that risks can be compared between species within the same river basin.

We also discuss the potential population-level risk posed by plastic litter in the Mekong and Ganga River Basins, compared to other identified population level threats to these the taxa that are considered within this report.

1.4 What is beyond the scope of this report?

- Quantification of the expected mortality to CMS-listed species, by plastic litter or other threats.
- Quantification of the frequency of interactions (for example, how many animals eat or become entangled by plastic litter) between CMS-listed species and plastic litter in their environment.
- Estimation of the density (mass, count) or quantification of plastic litter in the Mekong and Ganga River Basins.

1.5 How to use this report’s findings

We intend this report as a tool which to provide preliminary information which can be made available to decision makers to assess the risk that plastic litter poses to CMS listed species in the Mekong and the Ganga River Basins.

We present a framework for the estimation of risk that incorporates the best currently available data, and that can easily be adapted to incorporate future sources of information to improve the granularity or accuracy of the estimates used here.

2 Introduction to litter in aquatic environments

2.1 Plastic litter in aquatic environments

Currently, the majority of the research on plastic litter in aquatic environments is focused on marine ecosystems (Wendt-Potthoff et al., 2020). However, we also know that most plastic litter originates from land, and much of it is transported to the ocean via river systems (L. C. M. Lebreton et al., 2017; Meijer, van Emmerik, van der Ent, Schmidt, & Lebreton, 2021) . This means that it is critical to understand not only how much litter is travelling through these river systems, but also the impacts it may have to wildlife and commercially important species.

Recently, more attention has been paid to rivers as potentially major sources or pathways for plastic pollution. Several studies have attempted to model the amount of litter flowing through the world's rivers. Most studies estimating litter transport from rivers on a global or regional scale rely on modeling a variety of factors, including per capita mismanaged waste, runoff, and artificial barriers (L. C. M. Lebreton et al., 2017; Schmidt, Krauth, & Wagner, 2017), and calibrating these models based on a review of studies providing litter volumes within the rivers (L. C. M. Lebreton et al., 2017; Schmidt et al., 2017). In contrast, Meijer et al assessed the macroplastic load on land, and the probability of mismanaged waste to leak to aquatic systems (2021). The results of the model were calibrated against literature reports of macroplastic observations at 51 rivers and predicted that plastic loads were distributed across a broader range of rivers than was previously believed.

Many of these publications highlight the contribution from Asian rivers such as the Mekong and the Ganga (Van Calcar and Emmerick), which have consistently been ranked among the top 10 (or 11) rivers in the world (L. C. M. Lebreton et al., 2017; Schmidt et al., 2017) .

A major focus of these studies has been to estimate the magnitude of litter volumes emanating from various rivers around the world. Fewer studies focus on the relative litter levels along a single river, and even fewer are conducted along Asian rivers.

2.1.1 Plastic litter in rivers in Asian rivers

Plastic litter in the Mekong River basin

Despite several global studies naming the Mekong as one of the world's most polluted rivers (Schmidt et al., 2017), there is little empirical information to support this claim. An estimate of the volume of mismanaged plastic waste in the Tonle Sap basin using "economic, population and waste data at provincial and national levels, coupled with high resolution population and flood datasets" found that approximately 221,700 tons of plastic entered the basin between 2000 and 2020. The study projected that 282,300 ± 8700 tons will enter the basin between 2021 and 2030 (Finnegan & Gouramanis, 2021)

While not part of the Lower Mekong basin, a study conducted in Ho Chi Minh City, Vietnam assessed the amount of both micro and macroplastics in several canals, as well as in the Saigon River. This study found per capita mismanaged waste to be significantly higher than that predicted in a global modelling study (L. C. M. Lebreton et al., 2017), but much lower than that measured by similar methods in a high-income country, France (Lahens et al., 2018).

Plastic litter in the Ganga River basin

Similarly to the Mekong, there are few published studies which focus on plastic pollution within the Ganga River, although a recent expedition along the Ganga studied microplastic loads at 11 sites along the river and its tributaries, and estimated that the Ganges, Brahmaputra and Meghna rivers collectively (GBM), could release up to 1–3 billion microplastics into the Bay of Bengal every day (Napper et al., 2021).

Ganga basin, with an area of 860,000 sq. km, is sprawling across 11 states of India. The major cities such as Delhi, Kolkata, Kanpur, Lucknow, Patna, Agra, Meerut, Varanasi and Allahabad are situated in the basin which is expanding rapidly. The amount of mismanaged waste from these urban areas into this river system is extensive.

At present integrated sewage collection facilities including the treatment of industrial, municipal, domestic and hospital wastes are inadequate in India. The operational treatment capacity is only 37% of the total sewage generated in the country. These partially treated sewage waters commonly discharge into rivers, bringing with them not only potential pathogens but also plastics and other waste material (Yeung et al., 2009).

National Capital Territory of Delhi contributes more than 50% of the pollutants into Yamuna River, a tributary of the Ganga River (Bhardwaj, Gupta, & Garg, 2017; Yeung et al., 2009) . These and other pollutants from the city result in a high number of microplastics entering the river. Urban rivers in the region have nearly twice the density of microplastics as do rural rivers (Lechthaler et al., 2021).

2.2 Size of littered plastic items

Plastic litter comes in a range of sizes, from the microscopic to the very large. The size of items in the environment is key to understanding both the risk of interaction and the risk of the impact/consequences of that interaction. This is because most species will only interact with items within a particular size range; some items are too large or small to pose a risk. When describing the size of plastics, the most commonly reported plastic litter items are those within the visible size range. Litter is typically sorted into the following size categories:‘mega’ (items >1m) ‘macro’ (items 25mm – 1m), ‘meso’ (items 5mm – 25mm), ‘micro’ (items 0.1 µm−5mm) and ‘nano’ (items 0.001–0.1 µm). Meso- and micro-sized items are often formed from the breakdown of larger items. Nano-sized items are poorly studied, as their small size makes them difficult to quantify consistently. Therefore, nano particles are not further considered in this report.

Size	Micro	Meso	Macro	Mega
Dimension	<5mm	5mm – 25mm	25mm – 1m	>1m
Item examples	Microfibres, nurdles / plastic pellets, small plastic fragments, plastic microbeads.	Torn food wrapper, plastic fragment from larger item, cap from small container.	Food wrappers, plastic bags, plastic bottles, take-out container, disposable cutlery.	Tarpaulin, fishing net, agricultural sheeting, woven polypropylene sack, drum.
				

Figure 1. Commonly agreed size categories of plastic litter in the visible size range.

2.2.1 Meso, macro and mega-sized litter

Meso, macro and mega plastic litter is easy to see along the banks of many watercourses. Tangled in riverside vegetation, in rocks on the riverbanks, and trailing across infrastructure such as pipework, dam walls and the support piers of bridges, such litter creates an eyesore in these aquatic systems. Though commonly observed in this environmental snagging context, macro and mega sized litter tends to be less numerically common than meso- and micro-sized litter in aquatic habitats (Blettler, Ulla, Rabuffetti, & Garello, 2017), especially in the sediment and water column where it is likely to interact with wildlife. Plastic tends to dominate plastic litter in aquatic environments (Bruge et al., 2018; van Emmerik & Schwarz, 2020). Food wrappers (mainly polypropylene and polystyrene), smoking-related items, bags (high- and low-density polyethylene), bottles (polyethylene terephthalate), and disposable Styrofoam food containers (expanded polystyrene) are common macro-sized items in freshwater systems (Blettler et al., 2017; Bruge et al., 2018). Macro- and mega-sized items can break down into meso and micro sized items with exposure to the environment, with one item sometimes fragmenting into hundreds or thousands of smaller ones given enough time and exposure to the elements. Meso-sized plastics are common in the river sediment in the Ganga river, with one study finding meso-plastic in the sediment at all sites surveyed in eastern India (Sarkar et al., 2019).

2.2.2 Micro-sized litter

Where studies specifically seek to find micro-sized litter, the presence of microplastics and microfibres are reportedly widespread in the environment and biota. Rivers can contain high levels of microplastics, especially where there is input of untreated wastewater (Woodward, Li, Rothwell, & Hurley, 2021). The presence of microfibres reflects input into the environment. Polyethylene terephthalate and polyethylene are the dominant plastic materials in the Ganga (Sarkar et al., 2019). Film-like plastics and fibres are the dominant microplastic types in the sediments of Ganga River and fibres are the dominant microplastic type in the surface water (Napper et al., 2021; Sarkar et al., 2019; N. Singh et al., 2021).

In addition to river systems, microplastics are ubiquitous in wetlands throughout the world (Kumar, Sharma, & Bandyopadhyay, 2021). Microplastics pollution has been observed in wetlands with an abundance of up to 5531 particles/m^3 and 6360 particles/kg[1] in water and sediment samples (Kumar et al., 2021). Due to their ubiquity in aquatic ecosystems worldwide, it is perhaps unsurprising that microplastics are widespread in the aquatic food chain and are taken up by fauna ranging from invertebrates to waterfowl.

3 Interactions between aquatic fauna and plastic litter

3.1 The context of interactions between CMS listed fauna and plastic litter interactions in this report

This report aims to quantify the likelihood of interactions between CMS listed fauna and plastic litter, and the risk of these interactions to the animals' health and survival. To estimate the risk to wildlife from plastic litter, it is important to first understand how each of the listed species might interact with plastic litter. However, there is often a lack of information on the interaction between specific species and plastic litter in their environment. In data deficient situations, it is useful to consider known litter interactions between related species in similar environments. There are several ways that wildlife can interact with plastic litter that may result in negative consequences on their health and survival: through ingestion, entanglement, entrapment, and inhalation.

Animals can eat plastic litter, typically referred to as 'ingestion'. When animals ingest litter, often the ingested item is not able to be digested but passes through the gastrointestinal system and is voided with faeces. However, uncomplicated transition through the gut is not guaranteed, and health problems can occur if an item becomes trapped or lodged in the gut. With entanglement and entrapment in litter, problems can occur when an animal is unable to free itself. Debilitating and sometimes fatal consequences can result. In rare cases, an animal might also inhale litter, which can become trapped in the animals' airway. However, inhalation of litter is very uncommon, especially in aquatic environments, and thus we do not explore inhalation further in this report.

3.2 Ingestion interactions

3.2.1 Ingestion interactions between wildlife and plastic litter

The ingestion of plastic litter is commonly reported among aquatic taxa, however marine animals have been better studied than freshwater species. A 2020 review found that among marine vertebrates, the ingestion of plastic had been reported in 56.1% of all marine mammals (69/123 species), 44% of all seabirds (180/409 species) and 100% of marine turtles (7/7 species) (Susanne Kühn & van Franeker, 2020). Marine fish, invertebrates and sea snakes are less studied than marine megafauna, but the study reported plastic ingestion in 363 fish species (of 31,243 extant species), 82 invertebrates (of 159,000 + species) and no sea snakes (of 62 species) (Susanne Kühn & van Franeker, 2020). Where wild marine fish have been assessed for plastic ingestion, a 2020 review found that plastic ingestion was detected in 323 (65%) of 494 examined fish species, and in 262 (67%) of 391 examined commercial fish species (Markic, Gaertner, Gaertner-Mazouni, & Koelmans, 2020).

There are three main ways that animals ingest plastic litter. Primary ingestion is the best known, where an animal chooses to eat a litter item. Secondary ingestion occurs where an animal eats another animal that has ingested plastic, for example, a dolphin eating a fish with plastic inside it. Accidental/incidental ingestion occurs where an animal accidentally eats plastic while targeting prey or drinking. For example, a whale that feeds by suction may pull in plastic along with its intended prey while feeding. Wildlife can be prone to ingesting plastic litter through just one, two or all of these mechanisms, depending on their biology such as behaviour, prey choice and foraging method.

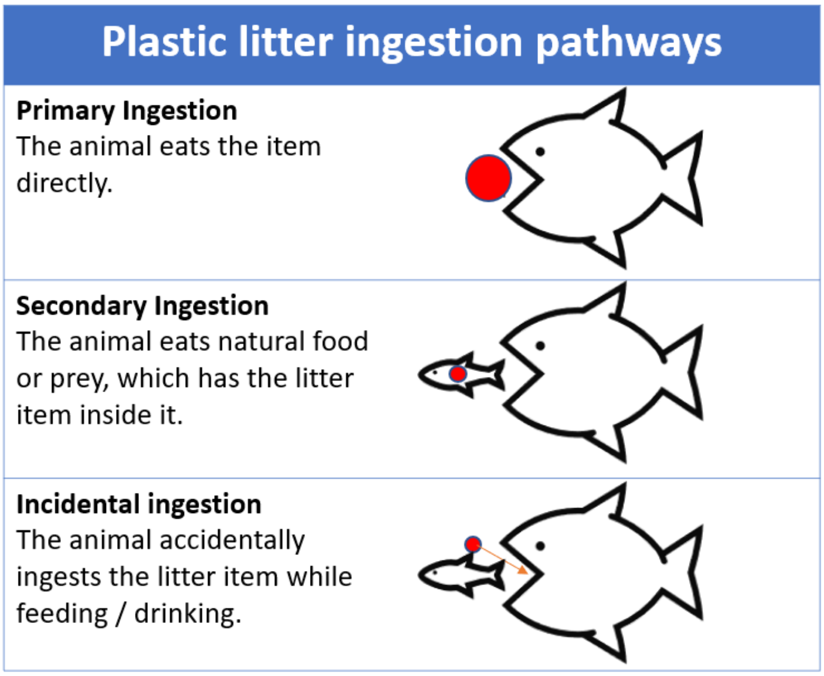


Figure 2 Ingestion pathways for plastic and other anthropogenic litter.

Primary ingestion

Primary ingestion occurs when an animal directly eats plastic litter by choice and represents the best-studied type of plastic litter ingestion. This may be due to mistaking the item for something edible from visual (Roman, Wilcox, Hardesty, & Hindell, 2019), olfactory (Savoca, Wohlfeil, Ebeler, & Nevitt, 2016) and/or tactile cues. Plastic litter ingestion may also be due to curiosity, especially in young or juvenile animals, which are more likely than adults to eat litter across many species (Acampora, Schuyler, Townsend, & Hardesty, 2014; Baird & Hooker, 2000; Robson Guimarães Santos, Andrades, Boldrini, & Martins, 2015) or an act of desperation from hunger (Roman, Bryan, Bool, Gustafson, & Townsend, 2021). Generalist foragers, those taxa that eat a wide range of different food items, are more likely to eat litter through primary ingestion than species that specialize on just one or a small suite of prey types (Caldwell, Seavey, & Craig, 2020; Peters, Thomas, Rieper, & Bratton, 2017).

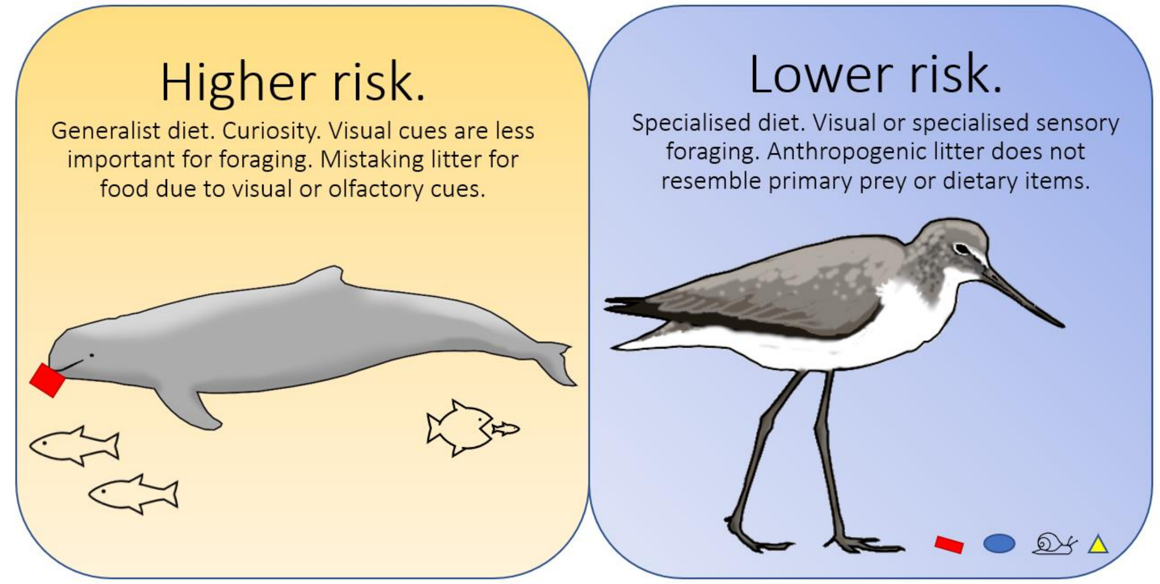


Figure 3 Primary ingestion of plastic litter.

Secondary ingestion

Species that prey on those that are known to ingest plastic litter are likely to secondarily ingest litter; for example, raptors that prey on ducks in areas where duck shotting occurs commonly secondarily ingest lead shot (swallowed by ducks, which ingest lead shot as gastroliths) (Miller, Wayland, Dzus, & Bortolotti, 2000). Predatory species are more likely to secondarily ingest plastic than those that primarily forage on plant foods, insects or herbivorous prey.

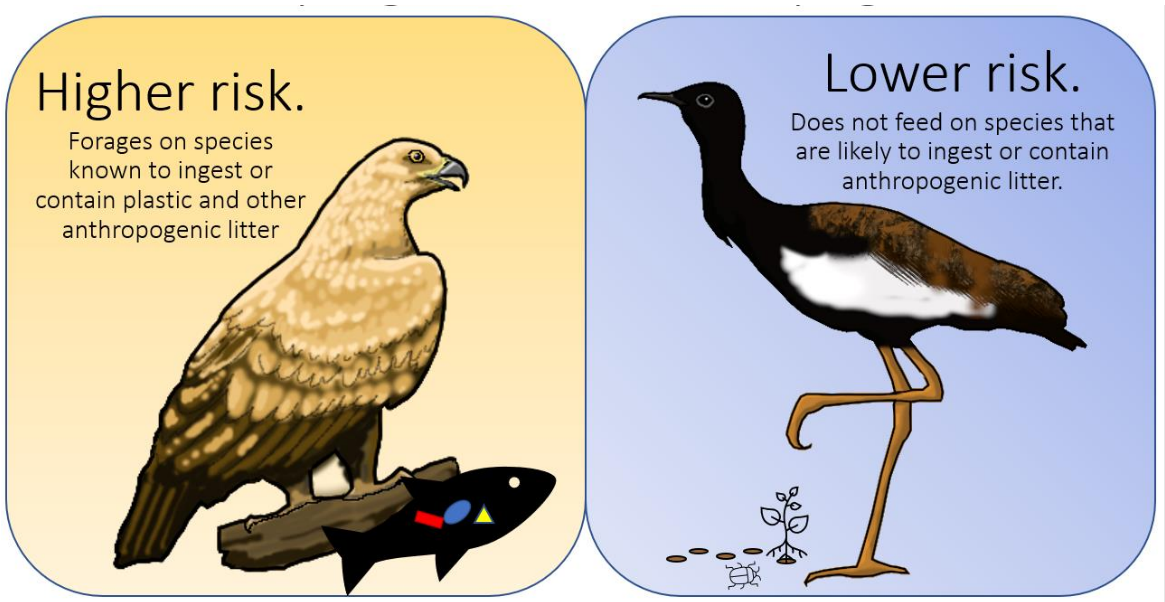


Figure 4 Secondary ingestion of plastic litter.

Incidental ingestion

Incidental ingestion occurs when an animal ingests plastic litter from the environment while targeting its natural food. Animals that forage by suction or swallowing water/sediment and filtering food are more likely to accidentally/incidentally ingest litter than those that focus their energy on selectively targeting the prey and foraging visually (López-López et al., 2018; Roman, Schuyler, Hardesty, & Townsend, 2016). Incidental ingestion may also occur more commonly where visibility is poor, such as in turbid water. For example, some of the highest known loads of ingested plastic litter come from the sperm whale, *Physeter macrocephalus*, (Alexiadou, Foskolos, & Frantzis, 2019; De Stephanis, Giménez, Carpinelli, Gutierrez-Exposito, & Cañadas, 2013; Jacobsen, Massey, & Gulland, 2010) a species that commonly forages by suction in the deep ocean where light does not penetrate, precluding visual foraging. Animals that directly and selectively hunt for their prey or food are less likely to incidentally ingest plastic litter.

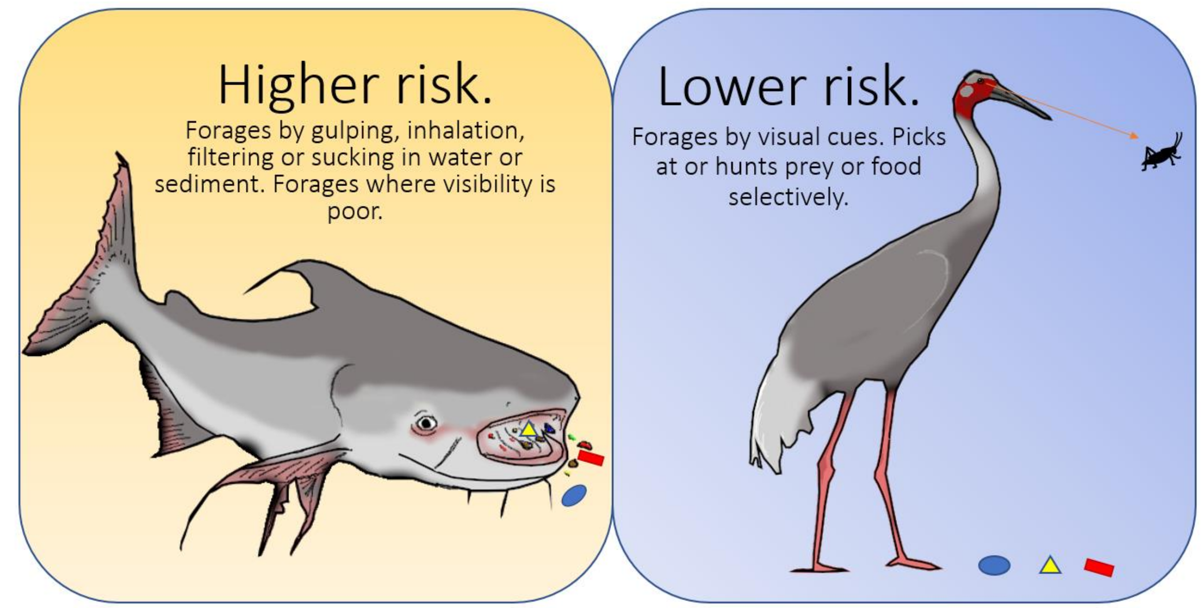


Figure 5 Incidental ingestion of plastic litter.

3.3 Entanglement and entrapment interactions

A 2020 review of entanglement of marine vertebrates in plastic litter, predominantly fishing debris, found that entanglement had been reported in 39.8% of all marine mammals (49/123 species), 27.4% of all seabirds (112/409 species) and 100% of marine turtles (7/7 species) (Susanne Kühn & van Franeker, 2020). Marine fish, invertebrates and sea snakes are less studied than marine megafauna, but the review reported entanglement in 101 fish species (of 31,243 extant species), 83 invertebrates (of 159,000 + species) and two sea snakes (of 62 species) (Susanne Kühn & van Franeker, 2020). It is generally considered that freshwater species have a lower risk of entanglement than marine species, and this has been demonstrated quantitatively in birds, where 36% of marine species are known to become entangled in plastic litter, compared to just 10% of freshwater species (Ryan, 2018).

However, the risk of entanglement depends on the local fishing effort, the types of gear used and norms and practices concerning retrieval and disposal of derelict fishing gear.

3.4 Litter interactions: size matters

3.4.1 Size of items ingested by aquatic fauna groups

Plastic litter comes in a range of sizes, which are important to consider in the context of the probability an item is eaten. The size of the animal, especially its mouth, is a key factor in what size of litter that animal can eat (Jâms, Windsor, Poudevigne-Durance, Ormerod, & Durance, 2020). Generally, most animals eat plastic items that are about 5% of their body size, though this ratio varies by species (Jâms et al., 2020). Whether a species ingests plastic litter through primary, secondary, or incidental ingestion can be linked to the size of litter ingested. This is because items sizes eaten by primary ingestion tend to be larger than items secondarily or incidentally ingested.

In vertebrate fauna, ingestion of items larger than 5 mm long is more likely to result from primary ingestion, except in the case of very large animals that may secondarily/incidentally ingest macro-litter. Micro-sized items less than 5 mm long are more commonly secondarily/incidentally ingested by vertebrate animals, except for very small species (for example, small predatory fish) where they might be eaten by primary ingestion (Lehtiniemi et al., 2018). Due to the ubiquity of microplastics in aquatic ecosystems worldwide, it is perhaps unsurprising that microplastics are also widespread in the aquatic food chain and are taken up by fauna, ranging from invertebrates to waterfowl. Microplastics in the size range of 0.12–9.5 mm are commonly reported in the bodies of wetland biota (Kumar et al., 2021).

3.4.2 Size of items causing entanglements in aquatic fauna groups

Entanglement and entrapment of wildlife in plastic litter, predominantly fishing gear, is a global issue affecting a variety of species in marine and aquatic environments (Duncan et al., 2017; Jepsen & de Bruyn, 2019; Laist, 1997; Parton, Galloway, & Godley, 2019; Stelfox, Hudgins, & Sweet, 2016). Though animals can become entangled and entrapped in a variety of plastic litters, discarded fishing debris, especially ropes, nets and monofilament line, is responsible for the overwhelming majority of fatal entanglements and entrapments of wildlife (Jepsen & de Bruyn, 2019; Laist, 1997; E. Moore et al., 2009; Ryan, 2018). Entanglement and entrapment occur primarily with larger litter items. High-risk plastic litter items for entanglement and entrapment risk other than discarded fishing gear include six-pack drink holders, strings or ribbons, including those attached to balloons (Donnelly-Greenan, Nevins, & Harvey, 2019; E. Moore et al., 2009), and kites (Babu, Subramanya, & Dilawar, 2015; Ryan, 2018). Entrapment typically involves items that are larger than the animal entrapped, though entrapment of part (for example, a limb or the animal's head) can also occur. Entrapment of invertebrates can be common in limited specific situations, for example, the entrapment of hermit crabs in plastic bottles (Lavers, Sharp, Stuckenbrock, & Bond, 2020). Overall, the entrapment of vertebrate animals is rare.

3.5 A brief introduction to litter interactions in aquatic wildlife

3.5.1 Fish

Ingestion

Microplastic ingestion is widespread among both freshwater and marine species, and consequently, fish are the most common taxa studied to investigate the frequency of microplastic ingestion by biota in freshwater environments (Karthik et al., 2018; O'Connor et al., 2020). Meso and larger items are also ingested by fish, but lesser reported and less studied than micro plastics. This may be a true pattern in size-selection, with freshwater fish rarely eating meso and larger sized items (except perhaps in large fish species). It may also be a bias of study design - studies of plastic in fish are usually lethal (Collard, Gasperi, Gabrielsen, & Tassin, 2019).

The exposure of fish to microplastic tends to be higher for benthic (river bottom / sea floor) than pelagic fish, which are exposed to higher concentrations of microplastic trapped in the sediment (Collard et al., 2019; Jabeen et al., 2017). In river basins and estuaries in Brazil, three species of catfish, Cathorops spixii, Cathorops agassizii and Sciades herzbergii showed high frequencies of plastic ingestion. Overall, 18%, 33% and 18% of all individuals, respectively, had plastic in their stomachs, predominantly nylon fragments from cables used in fishery activities (Fernanda E. Possatto, Barletta, Costa, Ivar do Sul, & Dantas, 2011). In the Thames River (United Kingdom), a third of fish contained microplastics, the majority of which were fibres (Horton, Jürgens, Lahive, van Bodegom, & Vijver, 2018). This study found that the plastic ingested by fish increased downriver, and more plastic was found in larger fish. In an Amazon river estuary, microplastics occurred in 13.7% of 14 fish species investigated, predominantly pellets, and the authors observed that the number of microplastics ingested was positively correlated with fish body size (Pegado et al., 2018).

In the Ganga and Mekong rivers, it is likely that microplastic ingestion is more widespread among fish than reported elsewhere, given the amount of untreated wastewater entering these rivers (Napper et al., 2021; Sarkar et al., 2019). One study of freshwater fish in China found microplastics in 95.7% of freshwater fish and mesoplastics in 43.5% of freshwater fish studied, representing six species (Jabeen et al., 2017). We expect that the frequency and amount of microplastic in fish will increase as rivers approaches the ocean, as microplastic increases from source to sea in the Ganga (Napper et al., 2021) and microplastic has been observed to increase downriver (Horton et al., 2018).

Entanglement

Fishing gear, especially fishing nets, are designed with the primary purpose of entangling fish. It is therefore not surprising that non-target fish species become entangled in both active and derelict fishing gear in aquatic environments. Capture of non-target fish in active fishing gear is a massive global problem, however, for the purposes herein, it is derelict fishing gear that is contextually important. The capture of fish by derelict fishing gear is often called “ghost fishing”. Fishing gear that is lost (intentionally or unintentionally) will continue to sweep the environment, indiscriminately entangling animals in its path, as though the fishing is being undertaken by ghosts (Macfadyen, Huntington, & Cappell, 2009). Abandoned, lost or otherwise discarded fishing gear (ALDFG) is commonly called “ghost nets” or “ghost gear”. ALDFGs are estimated to constitute 10% of global marine litter by quantity and can cause potential widespread ecological threats to marine biota (Mugilarasan et al., 2021). Though such ghostnets likely cause massive mortalities in fish and other marine animals annually, it is difficult to predict the true scale of mortality, especially for taxa such as fish which decompose quickly. The highest risk ALDFG for capturing fish and other marine animals include gillnet, tuna purse seine with fish aggregating devices, and nets from bottom trawl fisheries (Gilman et al., 2021). In the Ganga and Mekong rivers, fishing with gillnets is common, and derelict gillnets pose an entanglement threat to native freshwater fish species.

3.5.2 Aquatic birds (waterfowl, herons/egrets/cranes and wading birds)

Ingestion

Studies of litter ingested by aquatic birds regularly find microplastics in the birds’ gastrointestinal tracts (English et al., 2015; Holland, Mallory, & Shutler, 2016; Zhao, Zhu, & Li, 2016). The excretion of microplastics in faeces, especially in ducks and other waterfowl, is commonly reported, showing that these items are frequently ingested and excreted (Holland et al., 2016; Zhao et al., 2016). Evidence for the presence of meso-sized items is sparse in all aquatic bird groups, except for waterfowl where there exist some meso-plastic records (English et al., 2015). Evidence of larger plastic items (macro and larger) in waterfowl and other aquatic birds (excluding seabirds, where plastic ingestion is common) is sparse and limited to a handful of incidental records and wildlife veterinary hospital case studies (English et al., 2015; Goulart et al., 2019).

Evidence for the presence of microplastics in aquatic bird species including herons, egrets, cranes and wading birds is less clear than the evidence for microplastics in ducks and waterfowl, which is widespread throughout the world. We found just one study reporting microplastics in egrets and wading birds (Zhao et al., 2016), but multiple examples of microplastic ingestion in waterfowl (English et al., 2015; Holland et al., 2016; Reynolds & Ryan, 2018). This study of terrestrial birds in China found 364 items of microscopic plastic litter, ranging in size from 0.5 to 8.5 mm, in 16 of 17 (94.1%) specimens of terrestrial bird, with an average of 22.8 (± 33.4) items per bird. The species examined included those relevant to this study including a cattle egret, *Bubulcus ibis* (similar foraging behaviour to cranes), little grebe, *Tachybaptu sruficollis* (similar foraging behaviour to diving ducks) and wading birds (dunlin, *Calidris alpina* and common sandpiper, *Actitis hypoleucos*) (Zhao et al., 2016).

In Canada, one study examined plastic litter in the gastrointestinal tracts of 17 freshwater duck and waterfowl species, finding microplastics, but not meso or larger items, in 9 species (Holland et al., 2016). The average frequency of ingestion was 11.1% across all species studied, however this frequency varied among species from 0% in some species and up to 33% in others (Holland et al., 2016). Well represented species, with 10 or more samples, included two geese, four dabbling ducks and a diving duck. Among geese, the snow goose, *Chen caerulescens* and Canada goose, *Branta canadensis*, ingested 2.1% plastic litter / 2.0% non-plastic litter and 4.7% plastic litter / 14.0% non-plastic litter respectively (Holland et al., 2016). Among dabbling ducks, the American wigeon, *Mareca americana*, had a litter ingestion frequency of 6.3% plastic litter / 3.1% non-plastic litter, mallard, *Anas platyrhynchos*, had 5.0% plastic litter / 2.5% non-plastic litter, northern pintail, *Anas acuta,* had 10.0% plastic litter /10.0% non-plastic litter, while green-winged teal, *Anas carolinensis*, had ingested no litter among 15 birds sampled (Holland et al., 2016). The well-represented diving duck, white-winged scoter, *Melanitta deglandi*, 6.3% had ingested plastic litter and none had ingested non-plastic litter. This study showed that though there is variation in litter ingestion among waterfowl species, where good representation occurred, most species ingested plastic litter in low (<10% of individuals) frequencies irrespective of foraging method; grazing geese, dabbling or diving ducks (Holland et al., 2016). Another study of waterfowl in Atlantic Canada found higher frequencies of plastic litter (46.1%) in the stomach of mallards, while a similar frequency of litter ingestion (6.9%) among American black ducks, *Anas rubripes* (English et al., 2015). This demonstrates that litter ingestion among species can vary according to study location, even within the same country, probably as a consequence of the amount of litter in the environment.

Microplastics were found in 5% of faecal samples and 10% of feather brushings from seven duck species in South Africa, with significantly higher amounts recorded for sites that received treated sewage effluent (Reynolds & Ryan, 2018). These frequencies reflect the fundings of the prevalence of microplastics in the digestive tracts of Canadian waterfowl. However, in Spain, the frequency of micro (and to a lesser extent, meso) plastics in waterfowl faeces is much higher, 60% in European coot, *Fulica atra*, 45% of mallard, *Anas platyrhynchos* and 43.8% in shelduck, *Tadorna tadorna* (Gil-Delgado et al., 2017). Though there are no studies of aquatic birds in the Mekong or Ganga River basins, microplastics are so abundant throughout the global locations where studies have been conducted, including regions with much lower human population densities, we expect microplastic to also be abundant in aquatic birds, and potentially mesoplastics in waterfowl (but not other aquatic birds) in the Asian region.

Entanglement

Entanglements have been recorded in numerous aquatic bird species, including 12% of all ducks, geese and swans (*Anatidae*, 16 of 135 species), 16% of storks (*Ciconiidae*, 3 of 19 species), 14% of ibises and spoonbills (*Threskiornithidae*, 5 of 35 species), 18% of herons, egrets, bitterns (*Ardeidae*, 12 of 66 species), all aquatic cormorants/Anhingas (*Anhingidae*, 4 of 4 species), and 13% of cranes (*Gruidae*, 2 of 15 species) (Ryan, 2018). Wader birds have been recorded to become entangled, but less commonly than waterfowl and large aquatic birds. Entanglements have been recorded in 2% of rails, crakes and coots (*Rallidae*, 3 of 134 species), 9% of plovers and lapwings (*Charadriidae*, 6 of 66 species) and 7% of sandpipers, snipes & allies (*Scolopacidae*, 9 of 91 species),

Among freshwater birds, 91% of all recorded entanglements have involved fishing gear (83% lines and 17% nets and netting) (Ryan, 2018). Other ropes and string are the next most disproportionately entangling item, involved in 16% of entanglements, balloon strings with 4% of entanglements and kite strings at 1% of entanglements (Ryan, 2018). Plastic litter is sometimes involved in waterbird entanglements; 6-pack rings are involved in 7% of entanglements and plastic bags are involved in 6% of entanglements, with diving aquatic birds especially prone to getting the handles of plastic bags caught around their necks (Ryan, 2018).

Fishing line is disproportionately responsible for entanglements, and it can be difficult to determine whether aquatic birds that have been found entangled interacted with active or derelict lines. However, many nest-building aquatic birds also choose to collect derelict fishing line for their nests and can consequently become entangled during the nesting period. Since fishing line is the material disproportionately responsible for entanglements, fishing line entanglement is unlikely to occur in locations where line fishing is not common.

3.5.3 Cetaceans

Ingestion

Plastic litter ingestion, including items across the size-range spectrum, is well known in marine cetaceans, where the topic has been explored both using gut content analysis (Amy L. Lusher, Hernandez-Milian, Berrow, Rogan, & O'Connor, 2018; A. L. Lusher et al., 2015) and faecal content analysis (Sarah E Nelms et al., 2019). Mega- and macro-plastics have been found, typically on necropsy of stranded animals, in more than half of cetacean species worldwide (Susanne Kühn & van Franeker, 2020). In some of these stranding records, large plastic items are thought to have resided in the gut for a long period of time, and sometimes the ingested item is found to be the cause of death of the animal, especially when items have melded together and formed a wad (Fernandez, Santos, Carrillo, Tejedor, & Pierce, 2009; Jacobsen et al., 2010; Secchi & Zarzur, 1999).

When microplastics are specifically examined, irrespective of global sampling locale, near 100% of individuals examined across most studies have microplastics in the gut (Zantis, Carroll, Nelms, & Bosker, 2021). Microplastics in the gut of cetaceans are considered to be ubiquitous but transitionary (Sarah E Nelms et al., 2019). Cetaceans can swallow microplastic directly from the water (Germanov, Marshall, Bejder, Fossi, & Loneragan, 2018), through secondary ingestion (Burkhardt-Holm & N'Guyen, 2019) as well as fragmentation of directly ingested macro items (Denuncio et al., 2011; Di Beneditto & Ramos, 2014; Fernandez et al., 2009). The ingestion of plastic of river dolphins is less well studied than marine dolphins, but their similar foraging behaviours and the high abundance of microplastics in rivers means that microplastic ingestion is likely common in river dolphins also.

Entanglement

Entanglements, especially in fishing gear, are recognised as a major cause of death of cetaceans worldwide (Alexiadou et al., 2019; Duras et al., 2021; Puig-Lozano et al., 2020). Most of the literature involving the interaction between fishing gear and cetaceans involve marine species, however, several records exist detailing entanglement of dolphins in aquatic environments (Kelkar & Dey, 2020). Studies that report interactions between cetaceans and fishing gear often involve active gear. In the situations where dolphin carcasses are found, these studies often do not (or cannot) distinguish whether active or derelict fishing gear was involved in the encounter. Among gear types, gill nets are frequently singled out as a gear type frequently associated with dolphin mortality (Kastelein, Au, & de Haan, 2000; Andrew J. Read, Danielle M. Waples, Kim W. Urian, & Dave Swanner, 2003) as dolphins have difficulty detecting gillnets with echolocations, especially in quiet conditions (Kastelein et al., 2000).

3.5.4 Raptorial birds

Ingestion

There are few studies that specifically examine ingestion of litter items in raptorial birds, though where these analyses are conducted, microplastics are common, but not larger items. A study in Florida examined microplastics in 9 species of raptorial birds of prey (n = 63), finding microplastics in all individual birds and all species, at 6.22 (±2.46) per individual (Carlin et al., 2020). A study in China similarly detected microplastic in all examined raptors including common buzzard, *Buteo buteo*; black kite, *Milvus migrans lineatus* and common kestrel, *Falco tinnunculus* (Zhao et al., 2016). Raptorial birds have not yet been examined for microplastics in the Mekong or Ganga River Basin regions. We expect that due to the expected high exposure of fauna to microplastics in these river basins and the common presence of microplastics from other studies; that microplastic occurrence is expected in raptors in this region.

Entanglement

Entanglements have been recorded for raptorial birds around the world, mostly involving fishing line in countries where shore-based line fishing occurs, such as Australia and the United States (Ryan, 2018). Entanglements involving kite strings are another common interaction that is location-specific, and this interaction is often reported in India (Ryan, 2018). Entanglement involving twine (Dwyer, Hindmarch, & Kratz, 2018) and balloon strings have also been recorded (Ryan, 2018). From examining the records of entanglements from Ryan (2018), it appears that raptor entanglements are disproportionately common in coastal and aquatic raptor species compared to inland raptors species, possibly because these species are more likely to overlap with fishing debris.

Plastic litter, especially fishing line, is common among the nesting material of some raptor species, especially ospreys, posing an entanglement risk (Rattner & McGowan, 2007; Ryan, 2018). In Chesapeake Bay, USA, plastic materials were present in more than 60% of 139 Osprey, *Pandion haliaetus*, nests surveyed, and many of these nests contained fishing line (Rattner & McGowan, 2007). Wildlife hospital admissions of Australian coastal raptors show that fishing equipment entanglement is an important threat for coastal raptors (Thomson, Jones, McBroom, Lilleyman, & Pyne, 2020). Fishing equipment entanglement accounts for 21% of raptors for which the cause of admission could be determined in one Australian wildlife hospital (Thomson et al., 2020). On occasion, multiple birds can become entangled in a single item, for example, a long piece of fishing line (Ryan, 2018; Thomson et al., 2020).

4 Impacts/consequences of plastic litter interactions on aquatic animal health

4.1 The context of wildlife health impacts of plastic litter interactions in this report

Understanding the risk of plastic litter interactions to wildlife is a challenge, more so in the face of unknowns about the frequency of litter interactions and the health consequences of these interactions. This poses a challenge for decision-makers and conservationists, who are tasked with balancing the social and economic costs of addressing plastic litter, with the need to take the precautionary principle in conservation of species in the face of unknowns. Such decision making necessitates using the best available information based on sound scientific evidence. How is this achieved when empirical data is lacking? Here we provide a precautionary framework to predict the impacts of plastic litter on aquatic animal health where little data is available.

To fully appreciate the risk of the interactions between plastic litter and CMS-listed aquatic species to inform decision making, we must consider not only the exposure of species to litter and frequency of interaction, but the likely outcome of those interactions. Interactions between plastic litter and animals can be broadly grouped into three categories.

1. Interactions that result in lethal or potentially lethal impacts
2. Interactions that result in sub-lethal health impacts (but are not likely to involve lethal impacts).
3. Interactions that are unlikely to cause a health impact.

When gauging population-level threats to species relative to the myriad of threats to that species survival, we are most interested in which interactions are frequently expected to result in lethal impacts. Sub-lethal impacts, while important, are a lesser consideration when compared to interactions that are expected to cause direct mortality. Here we explore the evidence for which interactions are likely to cause lethal impacts, sub-lethal impacts, and which interactions are not likely to cause health impacts to vertebrate animals.

4.2 Lethal and potentially lethal impacts of plastic litter interactions

4.2.1 The context of lethal impacts of plastic litter interactions in this report

In this section, we explore the lethal risks from ingestion of and entanglement in plastic litter to aquatic animals, as they are relevant to CMS-listed species in this report. Interactions that result in the death of animals are the most important to consider when assessing the risk that a threat has to a population. Understanding the frequency of an interaction resulting in death is easier to determine for threats where the pathology is external (for example, a net entangling an animal) compared to internal (for example, plastic in the stomach of the animal), where determination of death necessitates internal examination or post-mortem examination by an experienced person. For this reason, observation biases can occur when it comes to determining which threats have greater consequences to a species. Visible threats (for example, external oiling or an animal that has been hit by a car) tend to get more attention than less visible threats (for example, diseases that do not manifest externally, or the impacts of pollution). Here we describe the state of knowledge of lethal threat that plastic litter poses to animals.

4.2.2 Ingestion

There is significant evidence in the literature for humans (especially young children) and animals ingesting plastic items. Termed 'ingested foreign bodies' once swallowed, these can occasionally lead to lethal impacts (Arana, Hauser, Hachimi-Idrissi, & Vandenplas, 2001; Ikenberry et al., 2011; Susanne Kühn & van Franeker, 2020; Roman, Schuyler, Wilcox, & Hardesty, 2021; Velitchkov, Grigorov, Losanoff, & Kjossev, 1996). In humans, medical researchers estimate that most ingested foreign bodies presenting to practitioners pass without incident (Arana et al., 2001; Velitchkov et al., 1996), though there is a risk of perforation in approximately 1% of cases (Chang & Yen, 2004; Sarwa et al., 2014), endoscopic removal is needed in 10–20% of the cases and in about 1% of the cases surgical intervention is required, depending on the nature, shape, size, number and location of the foreign bodies (Arana et al., 2001; Sarwa et al., 2014; Webb, 1995). Human medical studies typically present cases of macro-sized items in varying body sizes from infant to adult (Arana et al., 2001; Velitchkov et al., 1996; Webb, 1995). In humans, foreign body obstructions are more likely to occur with larger foreign bodies, and perforations are more likely to occur where long, thin and/or sharp items are swallowed (Arana et al., 2001; Velitchkov et al., 1996), which is likely also the case for animals. We presume that given a similar digestive physiology; a comparable proportion of complications may occur where a similar item size to body size ratio occurs. However, as endoscopic intervention is rare in wild animals, serious health impacts may occur in about 10-20% of cases (corresponding to the human endoscopic removal category) of ingestion of macro-sized foreign bodies.

The dangers of plastic litter ingestion to the health of animals have been known since the 1950s, where deaths among captive marine animals at aquariums and oceanariums often resulted from swallowing indigestible foreign material (Walker & Coe, 1989). Wildlife deaths due to eating plastic litter have been recorded among cetaceans, pinnipeds, marine reptiles (predominantly sea turtles) and (marine) birds (Alexiadou et al., 2019; Roman, Hardesty, Hindell, & Wilcox, 2019; Wilcox, Puckridge, Schuyler, Townsend, & Hardesty, 2018). Though there is less evidence for the deaths of aquatic wildlife than their marine counterparts as a direct result of plastic litter ingestion, the gastrointestinal physiology is similar between aquatic and marine animals of the same taxa, and we propose that the risk of death is similar given similar exposure to similar items.

Though ingested foreign bodies rarely result in death among humans due to medical intervention, there are numerous ways that deaths among animals can result from eating plastic. Common causes are gastric blockage and/or starvation following foreign body obstruction (Pierce, Harris, Larned, & Pokras, 2004; Roman, Hardesty, et al., 2019). When sharp items are swallowed, perforation or rupture of the gastro-intestinal tract can occur, along with consequent peritonitis and septicaemia. (Baulch & Perry, 2014; Panti, Baini, Lusher, Hernandez-Milan, Bravo Rebolledo, et al., 2019; Unger et al., 2017) Faecal compaction and wasting (S. E. Nelms et al., 2016; Rosolem Lima et al., 2018; Wilcox et al., 2018) can also occur. However, some animal groups can better tolerate the ingestion of plastic litter than others. For example, some species can regurgitate or vomit and are better able to liberate ingested foreign bodies than those that cannot.

Importantly for this risk analysis, a review of the lethality of plastic litter ingestion to marine vertebrates shows that not all items are equally deadly to all animals (Roman, Schuyler, et al., 2021). As in humans, there is a large body of literature that demonstrates that complications and death are more likely to occur when large (relative to the animals' body size) or sharp items are swallowed (Sarah E Nelms et al., 2019; Roman, Schuyler, et al., 2021) and that micro-sized items largely pass without incident when swallowed, except in very small animals. Among marine megafauna, there are a limited number of plastic litter items that are disproportionately likely to be lethal when swallowed (Roman, Schuyler, et al., 2021). These include film-like plastics (such as plastic bags and food wrappers), derelict fishing gear and rubber (including balloons), while micro-sized items rarely cause health complications (Roman, Schuyler, et al., 2021). While abundant, there is no evidence that the death of any megafauna has occurred from the ingestion of microfibres (Roman, Schuyler, et al., 2021).

4.2.3 Entanglement and entrapment

The entanglement of animals in plastic litter, especially fishing gear, is a known cause of death and debilitation to a variety of marine and aquatic species (Donnelly-Greenan et al., 2019; Gregory, 2009; Kelkar & Dey, 2020; Laist, 1997; Parton et al., 2019; Ryan, 2018). Entanglement and the resultant injury to wildlife is better understood and more frequently reported than ingestion of litter, as entanglements are typically external on the animals' body, hence are visible to observers, and entanglement interactions often occur near human populations where fishing occurs. Annually, entanglements (mainly in fishing gear) are responsible for significant proportions of wildlife hospital admissions of coastal and aquatic fauna, including 7.2% of all wildlife admissions to an Australian wildlife hospital (Taylor-Brown et al., 2019). Entanglements disproportionately impact on some coastal and aquatic taxa. For example, entanglements (predominantly fishing line) are responsible for 42.5% of all seabird admissions to a Portuguese animal rehabilitation centre (Costa et al., 2021), 21% of wildlife admissions for raptors in Australia (Thomson, Jones, McBroom, Lilleyman, & Pyne, 2020) and 17% of mute swans, *Cygnus olor*, admitted to a British wildlife hospital (Kelly & Kelly, 2004). Entanglement interactions frequently lead to the death of the entangled animal. Wildlife hospitals report that most animal patients suffering from entanglements would have died without intervention or treatment.

Entanglements pose a significant threat to some aquatic fauna groups and in specific locations where there are frequent opportunities to encounter entangling materials. In the Melbourne region of Australia, up to 1.5% of the platypus, *Ornithorhynchus anatinus*, residing in the waterways of greater Melbourne area and 0.5% of those living in regional Victoria are estimated to be at risk of entanglement-related injuries or death at any point in time (Serena & Williams, 2021).

Entanglement can kill animals by restricting their movement, causing them to drown or by preventing them from feed, escaping predation and by exposure (S. Kühn, Bravo Rebolledo, & Van Franeker, 2015; Laist, 1997; Reynolds & Ryan, 2018). Occasionally, entanglements can cause animals to become tied in place if the entangling line becomes entangled in the environment, such as in vegetation, leading to death by starvation, predation or exposure. Entanglements can cause deep lacerations, which can become infected and cause death, debilitation and the loss of limbs. In platypuses, items that had cut through skin and (in most cases) deeply into underlying tissue, recovered from carcasses or from rescued animals that were unlikely to have survived without human intervention included elastic hair-ties, fishing line, a hospital identification wristband, an engine gasket and a plastic ring seal from a food jar (Serena & Williams, 2021).

Unlike litter ingestion, where many ingested items can pass without incident, entanglements where the animal is not able to free itself often lead to death or serious debilitation of the entangled animal.

4.3 Sublethal effects of plastic litter interactions

4.3.1 The context of sub-lethal effects of plastic litter interactions in this report

In this section, we explore the sub-lethal risks of the ingestion of plastic to aquatic animals, as they are relevant to CMS listed species in this report. The primary context is where a species ingests, or is likely to ingest, microplastics only, which are unlikely to cause lethal impacts (as discussed in the previous section: Lethal and potentially lethal effects of plastic litter interactions: Ingestion). We do not detail the sub-lethal risks of entanglement, because for all species where entanglement interactions are anticipated, there is the probability of a lethal outcome. Therefore, sub-lethal risks of entanglement are not contextually relevant for the risk assessment components in this report.

The research on sub-lethal impacts of plastic litter ingestion on human and animal health, particularly for whole organism to population-level impacts, is still in its infancy. However, a range of studies examine potential sub-lethal effects of plastic across a variety of organisms. Many of these studies involve experiments with laboratory animals that are fed whole plastics or plastic-associated chemicals, or describe observational correlative relationships between the presence of plastic (e.g., in the gut) and pathologies that are considered to be a consequence of that plastic. However, a recent spate of critical reviews have identified that often there is a mismatch between the speculative impact of sub-lethal effects on humans and animals discussed in the primary literature, and what has been demonstrated in the laboratory or observed in the field. As an example, though many research papers discuss the potential for sub-lethal impacts to cause harm that affects an animal's health, behaviour and survival, there are very few instances of such organism-level consequences that have been demonstrated under experimental or otherwise quality-controlled conditions, raising serious questions about the ecological relevance of these findings from a conservation triage outlook. This is not to say that sub-lethal impacts are insignificant or unimportant, as some impacts only manifest themselves through time (chronic health impacts) or can be masked by co-morbidities and/or other cumulative stressors that the animal is experiencing. Understanding the sub-lethal effects of plastic at conservation-relevant whole-animal level is complicated and multifaceted, and though we have included sub-lethal impact discussion in this report, we have not sought to forecast mortality or ecological risk due to sub-lethal impacts in our risk modelling.

4.3.2 Disentangling the demonstrated from speculative sub-lethal impacts of plastic ingestion - summarizing the major findings of critical reviews.

Critical reviews examining the primary literature on studies of sub-lethal risks of plastic to the health of organisms often come to the similar conclusions. Namely, that there is a mismatch between the impacts that are perceived to occur and demonstrated evidence of these impacts occurring in an environmentally relevant scenario. Critical literature reviews typically conclude that readers need to consider the study's conclusions with a healthy critique of the quality of the evidence presented and contextual information, including the environmental relevance of loads/dosages that animals have been exposed to. Given the extensive literature on sub-lethal impacts to individuals, our understanding of the ecologically relevant context of these threats is particularly important when making decisions with respect to scientifically sound policies for the conservation of species. Such critical reviews help decision-makers filter the quality of these studies, understand the main avenues of threat, and enable them to make informed conservation decisions that balance the real magnitude of these threats. Here we briefly summarize the conclusions from four critical reviews on this topic in marine and aquatic environments that have been published in high-impact scientific journals over the past six years.

Shortlisted critical reviews and their major findings

Critical review 1.

Rochman et al. 2016. “The ecological impacts of marine debris: unravelling the demonstrated evidence from what is perceived”.

Major finding: Demonstrated ecologically relevant organism-level impacts of marine litter occurred due to the ingestion of large marine litter items. Most identified threats occurred at the suborganismal levels (e.g., molecular, cellular, tissue) without demonstrated evidence that these impacted on the animal at a higher organismal level (Rochman et al., 2016).

> *Abstract: Anthropogenic debris contaminates marine habitats globally, leading to several perceived ecological impacts. Here, we critically and systematically review the literature regarding impacts of debris from several scientific fields to understand the weight of evidence regarding the ecological impacts of marine debris. We quantified perceived and demonstrated impacts across several levels of biological organization that make up the ecosystem and found 366 perceived threats of debris across all levels. Two hundred and ninety-six of these perceived threats were tested, 83% of which were demonstrated. The majority (82%) of demonstrated impacts were due to plastic, relative to other materials (e.g., metals, glass) and largely (89%) at suborganismal levels (e.g., molecular, cellular, tissue). The remaining impacts, demonstrated at higher levels of organization (i.e., death to individual organisms, changes in assemblages), were largely due to plastic marine debris (>1 mm; e.g., rope, straws, and fragments). Thus, we show evidence of ecological impacts from marine debris, but conclude that the quantity and quality of research requires improvement to allow the risk of ecological impacts of marine debris to be determined with precision. Still, our systematic review suggests that sufficient evidence exists for decision makers to begin to mitigate problematic plastic debris now, to avoid risk of irreversible harm.*

Critical review 2.

Ziccardi et al. 2016. "Microplastics as vectors for bioaccumulation of hydrophobic organic chemicals in the marine environment: A state-of-the-science review".

Major finding: There is demonstrated evidence that microplastics absorb hydrophobic organic chemicals (HOCs) from the environment and that these can transfer to organisms. However there is only (at the time of publication) weak evidence supporting ecologically significant adverse effects on aquatic life, though more data is needed (Ziccardi, Edgington, Hentz, Kulacki, & Kane Driscoll, 2016).

> *Abstract: A state-of-the-science review was conducted to examine the potential for microplastics to sorb hydrophobic organic chemicals (HOCs) from the marine environment, for aquatic organisms to take up these HOCs from the microplastics, and for this exposure to result in adverse effects to ecological and human health. Despite concentrations of HOCs associated with microplastics that can be orders of magnitude greater than surrounding seawater, the relative importance of microplastics as a route of exposure is difficult to quantify because aquatic organisms are typically exposed to HOCs from various compartments, including water, sediment, and food. Results of laboratory experiments and modeling studies indicate that HOCs can partition from microplastics to organisms or from organisms to microplastics, depending on experimental conditions. Very little information is available to evaluate ecological or human health effects from this exposure. Most of the available studies measured biomarkers that are more indicative of exposure than effects, and no studies showed effects to ecologically relevant endpoints. Therefore, evidence is weak to support the occurrence of ecologically significant adverse effects on aquatic life as a result of exposure to HOCs sorbed to microplastics or to wildlife populations and humans from secondary exposure via the food chain. More data are needed to fully understand the relative importance of exposure to HOCs from microplastics compared with other exposure pathways.*

Critical review 3.

de Ruijter et al. 2020. "Quality Criteria for Microplastic Effect Studies in the Context of Risk Assessment: A Critical Review".

Major finding: Though there are many studies that seek to examine the impact of microplastics on the health of aquatic animals, many are poorly designed. The best evidenced impacts of harm from microplastics to aquatic animal health are inhibition of food assimilation and/or decreased nutritional value of food, internal physical damage, and external physical damage (de Ruijter, Redondo-Hasselerharm, Gouin, & Koelmans, 2020).

> *Abstract: In the literature, there is widespread consensus that methods in plastic research need improvement. Current limitations in quality assurance and harmonization prevent progress in our understanding of the true effects of microplastic in the environment. Following the recent development of quality assessment methods for studies reporting concentrations in biota and water*

samples, we propose a method to assess the quality of microplastic effect studies. We reviewed 105 microplastic effect studies with aquatic biota, provided a systematic overview of their characteristics, developed 20 quality criteria in four main criteria categories (particle characterization, experimental design, applicability in risk assessment, and ecological relevance), propose a protocol for future effect studies with particles, and, finally, used all the information to define the weight of evidence with respect to demonstrated effect mechanisms. On average, studies scored 44.6% (range 20−77.5%) of the maximum score. No study scored positively on all criteria, reconfirming the urgent need for better quality assurance. Most urgent recommendations for improvement relate to avoiding and verifying background contamination, and to improving the environmental relevance of exposure conditions. The majority of the studies (86.7%) evaluated on particle characteristics properly, nonetheless it should be underlined that by failing to provide characteristics of the particles, an entire experiment can become irreproducible. Studies addressed environmentally realistic polymer types fairly well; however, there was a mismatch between sizes tested and those targeted when analyzing microplastic in environmental samples. In far too many instances, studies suggest and speculate mechanisms that are poorly supported by the design and reporting of data in the study. This represents a problem for decision-makers and needs to be minimized in future research. In their papers, authors frame 10 effects mechanisms as "suggested", whereas 7 of them are framed as "demonstrated". When accounting for the quality of the studies according to our assessment, three of these mechanisms remained. These are inhibition of food assimilation and/or decreased nutritional value of food, internal physical damage, and external physical damage. We recommend that risk assessment addresses these mechanisms with higher priority.

Critical review 4

Koelmans et al. 2021. Weight of Evidence for the Microplastic Vector Effect in the Context of Chemical Risk Assessment

Major finding: There is overwhelming evidence that microplastics are unlikely to be a vector affecting chemical toxicity risks to humans and wildlife under present natural conditions.

Abstract: The concern that in nature, ingestion of microplastic (MP) increases exposure of organisms to plastic-associated chemicals (the 'MP vector effect') plays an important role in the current picture of the risks of microplastic for the environment and human health. An increasing number of studies on this topic have been conducted using a wide variety of approaches and techniques. At present, the MP vector effect is usually framed as 'complex', 'under debate' or 'controversial'. Studies that critically discuss the approaches and techniques used to study the MP vector effect, and that provide suggestions for the harmonization needed to advance this debate, are scarce. Furthermore, only a few studies have strived at interpreting study outcomes in the light of environmentally relevant conditions. This constitutes a major research gap, because these are the conditions that are most relevant when

informing risk assessment and management decisions. Based on a review of 61 publications, we propose evaluation criteria and guidance for MP vector studies and discuss current study designs using these criteria. The criteria are designed such that studies, which fulfil them, will be relevant to inform risk assessment. By critically reviewing the existing literature in the light of these criteria, a weight of evidence assessment is provided. We demonstrate that several studies did not meet the standards for their conclusions on the MP vector effect to stand, whereas others provided overwhelming evidence that the vector effect is unlikely to affect chemical risks under present natural conditions.

4.3.3 Pathways of sub-lethal plastic ingestion impacts on aquatic fauna

There are two main pathways of sub-lethal effects of plastic interaction on aquatic fauna, and these are broadly applicable to both humans and animals. First, there is the concern of chemical toxicity from the transfer of plastic-additive and plastic-adsorbed chemicals between plastic and organism. Secondly, the sub-lethal physical impacts of plastic interaction such as physical damage to the digestive tract and nutritional consequences to the animal.

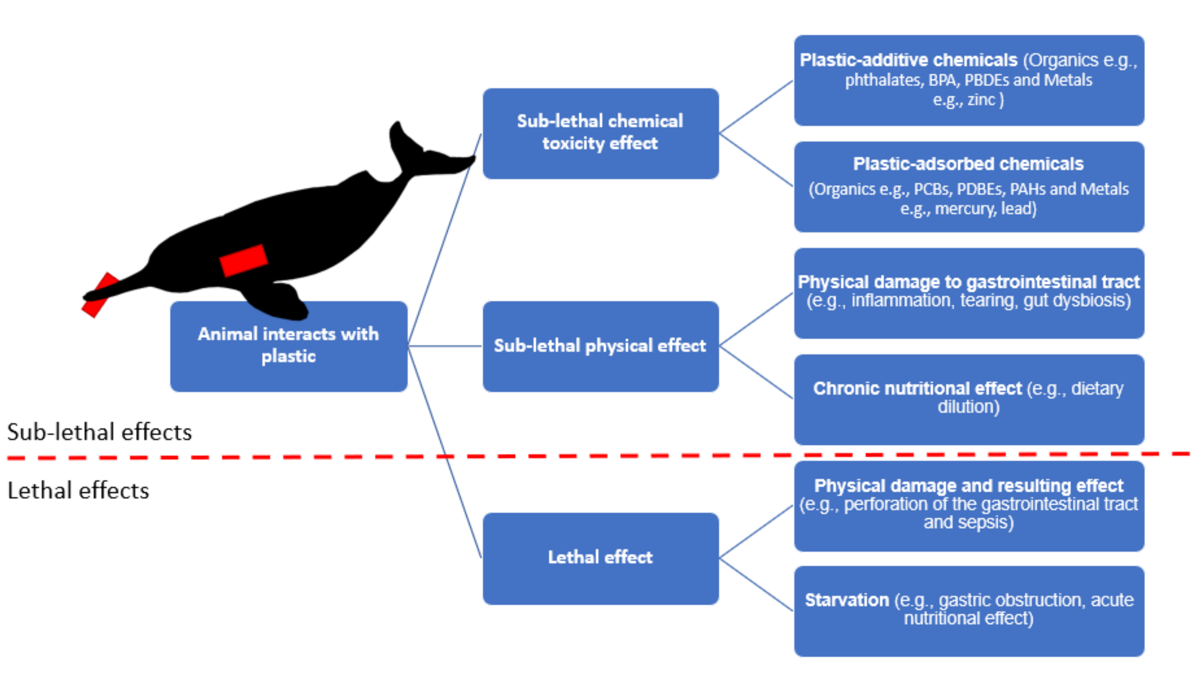


Figure 6 Pathways of sub-lethal and lethal plastic ingestion impacts on aquatic fauna.

4.3.4 Plastic ingestion and chemical toxicity risk

Plastics are manufactured using a range of ‘additive’ chemicals, including a suite of well-known endocrine-disrupting chemicals (EDCs). Examples of plastic-additive chemicals of health concern include bisphenol A and related chemicals, brominated flame retardants - especially polybrominated diphenyl ether flame retardants (PBDEs) - phthalates, per- and polyfluoroalkyl substances (PFAS). In addition to plastic-additive chemicals, plastics also adsorb a range of hydrophobic organic and heavy metal contaminants to their surface from the environment. These plastic-adsorbed chemicals they may be magnified at concentrations tens-to-hundreds of times the background concentration (for example, in the sea, lake or river water). Examples include many legacy-persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT) and breakdown products, and dioxins, as well as heavy metals including lead, cadmium and mercury (R. Robin et al., 2020).

“The dose that makes the poison”

“The dose makes the poison”, or "Sola dosis facit venenum" in Latin, is an axiom that explains a fundamental principle of toxicology. In short, this principal clarifies that any substance can produce harmful effects in a biological system, such as the body of a human or animal, but only if the concentration is high enough to elicit toxicity.

There are widespread concerns among scientists, the public and policymakers that human and animal exposure to plastic, through the ingestion of plastic, may pose a health concern if plastic-additive and plastic-adsorbed chemicals leach from plastics when ingested and are absorbed into the body, causing toxicity. While there is widespread agreement on the toxicity potential from these chemicals, the actual risk of toxicity posed by the ingestion of plastic at current levels of ‘normal’ environmental exposure is highly debated in the scientific community (see above: Disentangling the demonstrated from speculative sub-lethal impacts of plastic ingestion- summarizing the major findings of critical reviews). The crux of the argument usually boils down to one main point of disagreement: does the exposure to these chemicals, through plastic as a vector, exceed the threshold for toxicity in the given species? This problem is made more complicated by the diversity of plastic polymer types, a variety of environments with differing loads of background chemical contamination; and different species and life stages- each with their own differing toxicity thresholds.

“The dose makes the poison”, or "*Sola dosis facit venenum*" in Latin, is an axiom that explains a fundamental principle of toxicology. In short, this principal clarifies that any substance can produce harmful effects in a biological system, such as the body of a human or animal, but only if the concentration is high enough to elicit toxicity. This concept is critical to understanding the chemical toxicity risk to humans and wildlife from the ingestion and interaction with plastics, especially microplastics, where the surface area available for chemical transfer is often very small compared to the body size of all but the smallest vertebrate animals. There has been a large recent interest in plastic-mediated toxicity to wildlife, with the best available evidence involving studies that examining the toxicity that microplastics pose to small vertebrate animals, predominantly freshwater fish (such as zebrafish, *Danio rerio* and Japanese medaka, *Oryzias latipes*) and larvae fish under laboratory conditions.

Reported toxic effects of ingestion of microplastics to fish in laboratory conditions include liver stress (Rochman, Hoh, Kurobe, & Teh, 2013), induction of an imbalance in reactive oxygen species (ROS) production and antioxidant capacity, causing oxidative damage, alter immune responses due to physical and chemical toxicity, and neurotoxicity, altering Acetylcholinesterase (AchE) activity (Kim, Yu, & Choi, 2021). Reported sub-lethal effects from microplastic dosing of the diet of fish larvae include decreased head/body ratios, increased ethoxyresorufin-O-deethylase (EROD) activity and DNA breaks and alterations to swimming behaviour (Pannetier et al., 2020). As previously mentioned, while these effects are concerning, more research conducted at environmentally relevant concentrations and scenarios is required.

4.3.5 Plastic ingestion and sub-lethal physical impact risk

Sub-lethal physical effects, including nutritional impacts through inhibition of food assimilation and/or decreased nutritional value of food and physical damage are among the better-evidenced sub-lethal impacts from the ingestion of plastic (de Ruijter et al., 2020). Ingested plastic and other plastic litter occupies physical space in the gut, which can dilute the space available for nutritious food (S. Kühn et al., 2015; McCauley & Bjorndal, 1999) and affect satiety, suppressing the animals' desire to eat (Robson G Santos et al., 2020). Plastic in the gut can also cause sub-lethal physical damage, such as inflammation, ulceration and gut dysbiosis, especially if the items have sharp edges or become lodged in the gut over a long period of time (Abreo, Macusi, Blatchley, & Cuenca, 2016; Gregory, 2009; Pierce et al., 2004).

There are numerous studies where animals fed plastic under controlled or laboratory conditions show impaired growth, feeding or poorer body condition (Hariharan, Purvaja, Anandavelu, Robin, & Ramesh, 2021). However, it is not clear how well these relationships identified in the laboratory reflect the feeding behaviours of wild animals. Nutrition relationships are difficult to identify in situations that involve wild animals, as it is difficult to sample ingested plastic through non-destructive/non-sacrificial means and to eliminate other causes of variation in body condition. Most studies that exist provide correlations between the presence of plastic in the gut and body condition of incidentally killed animals. Without knowing the history of the animals, it is difficult to disentangle whether the ingestion of plastic is the cause of, a response to, or unrelated to each animals' body condition. One study found that albatross chicks that had been fed large quantities of plastic by their parents fledge with lower body masses than those without plastic, or with less plastic (Sievert & Sileo, 1993). In another study of seabirds that examines mineral nutrients rather than body condition, individuals that had eaten plastic had lower concentrations of mineral nutrients in their liver among birds that had washed up dead during a storm (Roman et al., 2020). A study of sea turtles found that ingestion of plastic impacts on satiety; that plastic ingestion induced changes in feeding behaviour, altering the food intake and that accumulation of plastic in the gastrointestinal tract may lead to plastic-induced satiety, decreasing food intake and the animals' fitness (Robson G Santos et al., 2020).

One of the challenges with understanding the relationship between ingested plastic and physical impacts, especially where nutrition is concerned, is knowing whether an effect would take place irrespective of whether plastic was available to a foraging animal (Ogonowski, Gerdes, & Gorokhova, 2018). Many of the effects elicited by plastic are also elicited if an animal has eaten a natural non-nutritional item such as cellulose, pebbles or silt, which are naturally abundant. Had the animal not eaten plastic, it may have eaten one of these other non-nutritive items instead (Ogonowski et al., 2018). In these cases, it is the aberrant behaviour of the animal that drives the effect (such as poor body condition causing the eating of non-nutritive items) and the presence of the plastic is incidental.

Various sub-lethal physical impacts of ingestion of plastic have been identified. For example, physical abrasion of the gastrointestinal tract (Ahrendt et al., 2020), including intestinal injury (Qiao et al., 2019) and gut inflammation (Jin et al., 2018) have been found in fish fed microplastics, including beads, fragments and fibres. In addition to these acute or short-lived impacts, the long-term presence of microplastics in the gut may disrupt the symbiosis between host and the natural community and abundance pattern of the gut microbiota, (Fackelmann & Sommer, 2019) which has been observed in both vertebrate (Jin et al., 2018; Kang et al., 2021; Lu, Wan, Luo, Fu, & Jin, 2018) and invertebrate (Chae, Kim, Choi, Cho, & An, 2019) fauna. This 'dysbiosis' might be caused by the consumption of microplastics, associated mechanical disruption within the gastrointestinal tract, the ingestion of foreign and potentially pathogenic bacteria, as well as chemicals, which make-up or adhere to microplastics (Fackelmann & Sommer, 2019). Though research into gut dysbiosis due to the physical impacts of the chronic ingestion of plastic is still in its infancy, there are concerns that dysbiosis may interfere with the host immune system, trigger the onset of chronic diseases, promote pathogenic infections, and alter the gene capacity and expression of gut microbiota (Fackelmann & Sommer, 2019). However, more research, especially in wild animals under realistic exposure scenarios, is needed.

4.3.6 Considering cumulative stressors

In wild conditions, the ingestion of plastic litter does not occur separately and in isolation from other threats. Multiple stressors must be considered in the context of risk to species. However, quantifying the cumulative impact of stressors is an emerging field, and one that lacks quality empirical data due to the difficulty of measuring multiple threats, including plastic ingestion, in wild animals. In seabirds, poor food conditions may lead to less selective foraging choices, such as the ingestion of non-food items, including pumice stones (Roman, Bryan, et al., 2021). Such a behaviour shows that ingestion of non-food, such as plastic litter, may also occur as a response to other stressors, like lack of prey. When considering the risk of litter to CMS-listed species, it is important to keep in mind other stressors that might affect the species, such as the quality and abundance of prey. For example, an animal that might not choose to eat litter when well-fed, may be vulnerable to eating plastic to satisfy its hunger when food stressed. Though cumulative stressors are not predicted in this report, they are a key factor in understanding the risk that plastic litter ingestion poses to wildlife.

4.4 No / unlikely effects of plastic litter interactions

Not all instances of interaction with litter are harmful. For example, no effects are likely to result if an animal interacts with litter but does not eat or become entangled/entrapped by it. As mentioned previously in this report, in most instances of the ingestion of litter, the ingested item passes through the digestive tract without causing measurable harm. As you are reading this report, hundreds of thousands of free-living wild and healthy animals are going about their lives with plastic in their stomachs. Where there is no evidence of measurable harm from an interaction (or only in exceedingly rare circumstances), we consider these interactions are unlikely to cause a health impact to the animal.

5 Understanding risk at the intersection of plastic litter interaction and impact

5.1 The context of sub-lethal effects of plastic litter interactions in this report

This report seeks to answer the question “What risk does plastic litter pose to CMS-listed species within the Mekong and Ganga River Basins?”. Ultimately, the information from this risk analysis will be made available to decision-makers for policy decisions with the aim to support the conservation of these species. There are several ways to approach the idea of risk, depending on the conservation goal or question. Ultimately, this analysis can determine only relative risks to the species. With the information currently available to us, we cannot estimate the total mortality to any of these species from plastic litter in their environment.

How do we approach understanding the relative risk that plastic litter poses to CMS listed species? First, do we seek to understand what is the risk to a species within its range? For example, where within the Mekong River Basin is the Mekong River Catfish at most risk from plastic litter? Second, do we seek to understand what is the relative risk among CMS listed species in the Mekong and Ganga River Basins? For example, among all CMS listed species in the Mekong and Ganga River Basins, which are at the most risk from plastic litter? Or, finally, do we seek to understand the risk of species within the Mekong and Ganga River Basins relative to other aquatic and marine fauna impacted by plastic litter. Understanding what information decision makers seek is key to how the information can be used to support conservation policy objectives.

Here we present our best estimate of the level of risk to each of the CMS-listed species in the Mekong and Ganga River Basins, scaled by the relative litter densities we predict at various sections of the rivers.

Part II Methodology

Due to the lack of availability of published literature with quantitative data on the impacts of interactions between the CMS listed species and plastic pollution, our approach to this project was to begin with a traditional semi-quantitative risk matrix approach for litter encounters for each species (Ni, Chen, & Chen, 2010). Following the recommendations in the ISO Standard 13000 (Lalonde & Boiral, 2012), we defined a set of unique categories to describe the likelihood of interaction for each species if it encountered litter, and a second set of categories to describe the consequence of that interaction (Markowski & Mannan, 2008).

In order to add additional resolution and utility to the assessment, we then apportioned the risk along sections of the two rivers relative to the predicted density of litter (for ingestion) or the predicted fishing pressure (for entanglement) at each section. Finally, we created a map of the cumulative risk to species from litter for both ingestion and entanglement for each section of the river.

We have created a robust risk assessment framework which currently relies on the best available data gathered during an extensive literature review, but which can be improved as additional data and research are conducted. Here we provide an overview of the steps of the risk assessment.

Step 1: Create risk matrix (Interaction Score x Consequence)

Step 2: Determine relative pressure from each threat that species will encounter in each river section (Relative Litter Load or Relative Fishing effort)

Step 3: Determine overlap of listed species with each river section (Habitat Overlap)

Step 4: Calculate the expected risk posed by plastic litter to each of the CMS listed species in each section of the river

6 Step 1. Create a risk matrix

Following the ISO 31000 Risk assessment standard (Lalonde & Boiral, 2012), we first identified the likelihood of interaction between CMS species and litter, and the consequence of that action. Risk categories were determined following an extensive literature review.

6.1 Literature review

We conducted five systematic literature searches to determine the likelihood of the species of interest ingesting or becoming entangled in plastic litter. We sought demonstrated evidence of whether the target species, or related species, ingest or become entangled in plastic litter.

Our initial focus was to search for information at the species level, however we did not find many published papers on litter interactions at this level, so we increased the taxonomic level of our search to find more information on broader taxa. We used this literature review to inform us on the likelihood of interaction with litter for each species, as well as the probable outcomes from that interaction, be it ingestion or entanglement.

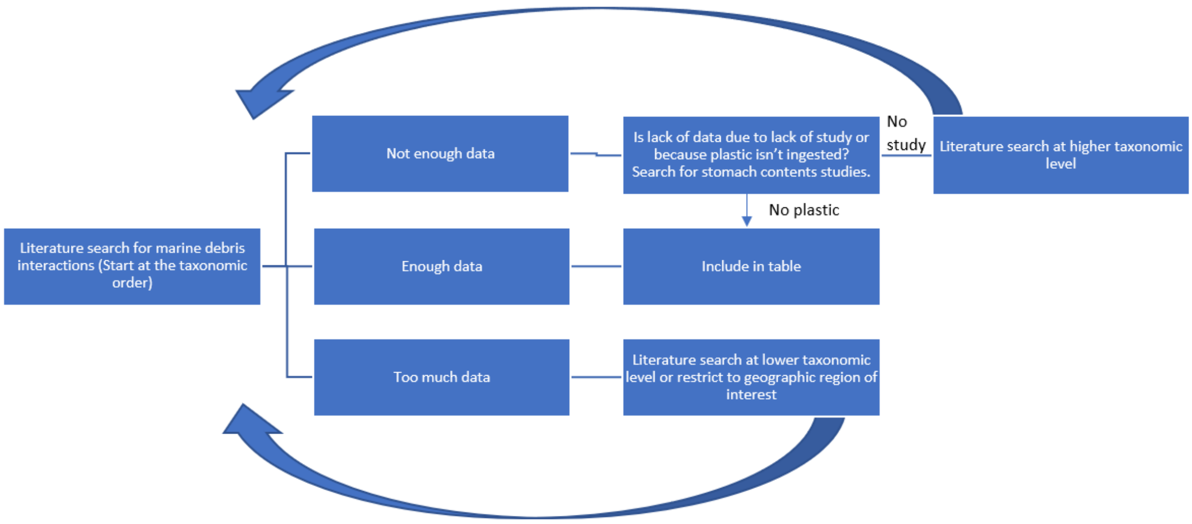


Figure 7. Schematic for literature review approach.

Where no data was found for a species, we performed a literature search to look for studies that might include litter interactions, but not as the main focus of the study. For example, studies of diet of that animal. In addition to these, we also performed a search of wildlife hospital records to see how regularly litter interactions featured among the inpatients.

In brief, we:

1. Conducted initial literature reviews for the interaction (ingestion and entanglement) between taxa and litter, one for each Mekong and Ganga.
2. Conducted secondary literature searches to investigate diet studies for species where no information was retrieved, one for each Mekong and Ganga.
3. Conducted a final literature search for wildlife hospital records that might be relevant to this report and plastic litter risk analysis.

In all, five separate systematic literature searches were conducted.

6.2 Mekong River Species Literature Search

Species

1. Mekong catfish (*Pangasianodon gigas*)
2. Irrawaddy dolphin (*Orcaella brevirostris*)
3. Bengal Florican (*Houbaropsis bengalensis bengalensis*)
4. Eastern Imperial Eagle (*Aquila heliaca*)
5. Sarus Crane (*Antigone Antigone*).

We conducted a systematic literature review of the CMS listed species and their interactions with litter. Details on the search terms and results can be found in Appendix A. We retrieved 1,357 potentially relevant results, of which 53 were relevant.

We excluded studies specifically about by-catch and entanglement interactions with active fishing gear but included studies where the conclusions could be applicable to entanglement in derelict fishing gear (for example, damage suffered or behaviour around active fishing gear that may also apply to derelict fishing gear).

Of the relevant papers, only five concerned a listed species, four papers on Irrawaddy dolphin (*Orcaella brevirostris*) and one on the Mekong catfish (*Pangasianodon gigas*).

The remaining concerned other species within related taxa, for example, catfish, dolphin, crane and eagle. No relevant studies about floricans/bustards were retrieved.

Table 1. Number and subject of the studies reviewed as part of the primary systematic literature search for Mekong River speces. Note, though all studies cover a single taxon, some studies cover more than one compartment of threat. Interactions with of metal hooks was considered as fishing gear rather than metal.

Interaction	Material	Catfish	Dolphin	Florican / Bustard	Eagle	Crane	Total studies (interaction)
Ingestion	Litter / plastic	4	7	0	1	0	**12**
	Metal	0	0	0	6	0	**6**
	Fishing gear (derelict)	1	4	0	0	0	**5**
Ingestion behaviour / risk		3	1	0	1	1	**6**
Entanglement or entrapment	Litter / plastic	0	0	0	0	0	**0**
	Metal	0	0	0	0	0	**0**
	Fishing gear (derelict)	2	25	0	1	0	**28**
Entanglement behaviour / risk		1	4	0	0	0	**5**
Total studies (taxa)		**11**	**41**	**0**	**9**	**1**	

6.2.1 Are the zeroes true zeros, or lack of evidence due to lack of research? Mekong River – secondary literature search (diet studies)

We conducted a secondary literature search of diet studies. Search terms and details of results can be found in Appendix A.

We chose only the studies where plastic would likely be observed by the methodology, such as where examination of the stomach contents was conducted, or faeces of the birds were investigated. We excluded visual observations of foraging birds or other analyses (DNA, stable isotopes, etc) not likely to detect plastic.

Of 93 potentially relevant studies, 16 contained information that was useful for assessing whether species closely related to the Bengal Florican (*Houbaropsis bengalensis bengalensis*) and the Sarus Crane *(Antigone Antigone*) ingest plastic.

Table 2 Number and subject of the studies reviewed as part of the secondary systematic literature search for the Mekong River, for diet studies for floricans and cranes.

Interaction	Diet study type	Florican / Bustard	Crane	Total studies
Ingestion	Observation	0	0	**3**
	Stomach contents	0	0	**6**
	Fecal contents	0	0	**10**
		8	**8**	**16**

6.3 Ganga River Species Literature Search

6.3.1 Ganga River - Initial literature search (all taxa)

We conducted a systematic literature review of the CMS-listed species and their interactions with litter. Details on the search terms and results can be found in Appendix A. We retrieved 810 potentially relevant results, of which 94 were relevant (Table 3).

We excluded studies specifically about by-catch and entanglement interactions with active fishing gear but included studies where the conclusions could be applicable to entanglement in derelict fishing gear (for example, damage suffered or behaviour around active fishing gear that may also apply to derelict fishing gear).

Of the relevant papers, only nine concerned a listed species; six papers on Ganga River dolphin (*Platanista gangetica gangetica*) and three on the gharial (*Gavialis gangeticus*).

The remaining concerned other species within related taxa, for example, dolphins, eagles, ducks and geese. No relevant publications about elephants or wading birds were retrieved. two publications for cranes revealed no entanglement or ingestion.

6.3.2 Are the zeroes true zeros, or lack of study? Ganga River secondary literature search (diet studies)

We conducted a secondary literature search of diet studies for elephants, cranes and waders. We conducted the search for cranes and waders separately to the search for elephants, due to different search terms used considering the size and behaviour differences.

The search terms and details of results can be found in Appendix A. The search returned a total of 409 potentially relevant studies, of which 63 were relevant for cranes and waders, and three were relevant for elephants. (Table 4).

We chose only the studies where plastic would likely be observed by the methodology, such as those examining the stomach contents or faeces of the birds. We excluded visual observations of foraging birds or other analyses (stable isotopes, etc) not likely to detect plastic.

6.3.3 Wildlife hospital search

Most of the literature from our first four searches detail healthy populations, which can miss cases that present to wildlife hospitals. A search for wildlife hospitals, rescue or rehabilitation facilities returned 874 results, though only five usable relevant results. We included only the cases where specific injuries/causes for admission could be allocated to specific fauna concerned with this report (many wildlife hospitals record pooled admissions by type).

Table 3. Number and subject of the studies reviewed as part of the primary systematic literature search in the Ganga River. Note, though all studies cover a single taxon, some studies cover more than one compartment of threat. Interactions with of metal hooks was considered as fishing gear rather than metal.

Interaction	Material	Elephant	Dolphin	gharial / Crocodilian	Eagle	Duck and goose	Crane	Wading bird	Total studies (interaction)
Ingestion	Litter / plastic	0	6	1	1	4	0	0	**12**
	Metal	0	0	0	7	6	0	0	**11**
	Fishing gear (derelict)	0	5	1	0	1	0	0	**7**
Ingestion behaviour / risk		0	0	0	0	0	0	0	**0**
Entanglement or entrapment	Litter / plastic	0	0	0	0	0	0	0	**0**
	Metal	0	0	0	0	0	0	0	**0**
	Fishing gear (derelict)	0	81	7	1	2	0	0	**91**
Entanglement behaviour / risk									
Total studies (taxa)		**0**	**92**	**8**	**8**	**13**	**0**	**0**	

Table 4 Number and subject of the studies reviewed as part of the secondary systematic literature search for Ganga River, for diet studies for waders, cranes, and elephants.

Interaction	Diet study type	Waders	Crane	Elephants	Total studies
Ingestion	Observation	17	3	1	**3**
	Stomach contents	17	3	0	**6**
	Pellets	5	0	**NA**	**5**
	Fecal contents	31	0	2	**10**
		65	**6**	**3**	**16**

Table 5 Results from searches at wildlife hospitals for Ganga River.

Admission type	Elephant	Dolphins	gharial/ crocodilian	Eagle / raptor	Ducks / waterf owl	Cranes	Wading birds
Entanglement in fishing line / fishing hook				2	2		
Ingestion of fishing line / fishing hook				1	2		
Lead poisoning through diet (consuming species affected by lead shot)				2	1		

Most publications that list relevant threat categories do not report which species were affected. Two publications report the affected numbers of birds, but not the species. For example, 1.4% of all birds (n= 6058) submitted to wildlife hospitals in Portugal over ten years were due to fishing entanglement and ingestion (hooks, lines and nets) (Costa et al., 2021). and interaction with fishing gears (5.3%) of seabird admissions in Bay of Biscay (Garcia-Baron et al., 2019).

Relevant results included raptors (eagles) and waterbirds (ducks).

6.4 Risk matrix

To determine the level of risk to each species from ingestion or entanglement of litter, we first established four tiers to describe the likelihood that individuals from the species of interest would interact with plastic litter, if they were to come into contact with it. Because there were few studies published on the specific species of interest, our categories include evidence from related species.

The categories are based on a combination of factors, including direct evidence of ingestion or entanglement. In the absence of direct evidence, we rely on evidence of behavioural and ecological attributes of the species (e.g., foraging behaviour, diet). As previously summarised, there are a variety of behavioural adaptations that may make species either more or less prone to ingesting litter.

Table 6. Risk table for the evidence of interaction between species and macro-sized plastic litter.

Interaction likelihood	Numeric score	Explanation
No interaction/ interaction unlikely	**1**	Numerous studies in target or related species seeking evidence for interaction or where an interaction would be expected to be encountered and reported (for example, diet studies or faecal analysis), find no evidence for the interaction.
Low	**2**	Interactions in the target or related species are possible but uncommon, and key behaviours in the target species that makes interaction unlikely or uncommon.
Moderate	**3**	Interactions are known to occur in the target or related species and key behaviours in the target species that makes interaction possible / likely.
High	**4**	Regular interactions are known to occur in the target or related species, and these interactions are likely to frequently occur.

Once an animal interacts with a piece of litter, the next step is to determine the likely outcome of that interaction. We established four tiers of potential impact of litter on a given individual, ranging from no effect or unlikely effects, to lethal effects. Here again we relied on the literature review to inform the placement of each species in a tier. We estimated the worst-case scenario.

Table 7. Risk table for the evidence of maximum impact of macro-sized marine litter on animals.

Impact likelihood	Numeric score	Explanation
No effect / effects unlikely	**1**	**Effects unlikely:** Studies in target or related species seeking to evidence for impact / where an impact would be expected (for example, the interaction is common), no impacts are recorded or are exceedingly rare relative to the frequency of interaction
Sublethal effects (SL)	**2**	**Sub-lethal impact possible, but unlikely to die:** Potential sublethal impacts of the interaction are recognized in the taxa, however, these are very unlikely to lead to lethal impacts in most circumstances.
Potentially lethal impact (PL)	**3**	**Die from it some of the time:** Lethal impact suggested or likely based in target or related species, but expected to be uncommon.
Lethal impact (L)	**4**	**Die from it most of the time:** Lethal impacts are demonstrated or likely based on target or related species, are likely to occur in the circumstances of the interaction.

By multiplying the likelihood of interaction by the consequence of that interaction, we can determine the level of risk that is likely to ensue, using a risk matrix. Note that the risk to a given species may vary for ingestion risk as opposed to entanglement risk. Some species (e.g. Irrawaddy dolphins) have a higher likelihood of interacting with entangling litter than ingesting it and will therefore exhibit a higher level of risk in a context of fishing effort than for general presence of macro-sized plastic litter.

Importantly, for this risk assessment we have focused specifically on macro-sized litter. The scores we have assigned to each species might differ if we focused on micro litter. For example, while a gulping predator like the catfish has a moderate likelihood of ingesting macro-litter, it would have a high likelihood of ingesting micro-litter, simply because of the near ubiquitous nature of microplastics. However, this might not result in a higher overall risk, because the consequence of ingesting microplastics would be lower than that of macroplastics.

Table 8. Risk matrix for ingestion and entanglement in macro litter.

		Consequence / impact			
		Unlikely effects	**Sublethal**	**Potentially lethal**	**Lethal**
Likelihood of interaction	**High**	4	8	12	16
	Moderate	3	6	9	12
	Low	2	4	6	8
	Unlikely	1	2	3	4

Negligible risk	Low risk	Medium Risk	High risk

7 Step 2: Relative level of pressure from litter or entanglement

7.1 Litter load in river sections (Relative Litter)

Because there are limited data on macro litter within the Ganga and Mekong River basins, and the litter data that do exist are patchy, we used the results from CSIRO's Global Plastics Project to predict the relative litter loads along each river.

One of the main aims of CSIRO's Global Plastics Project is to better understand the relationship between observed litter densities and covariates that can be measured on a global scale, so that we can make more accurate predictions of mismanaged waste in areas that have not yet been surveyed. Most global estimates of mismanaged waste rely predominately on theoretical models which are calibrated against existing published studies (e.g., Meijer et al 2021, Lebreton et al., 2017). While these studies have provided varying quantitative estimates of the amount of litter entering the world's oceans, for this project we were more concerned with understanding the relative risk to the species of interest at a finer scale resolution, along sections of both the Mekong and Ganga Rivers. In contrast, the empirical studies that have been conducted in these regions are restricted in scale, or focus primarily on microplastics (e.g., Napper et al, 2021). Our approach attempts to bridge the gap between the global and local studies, by using empirical data to inform predictions of microplastic load using global covariates.

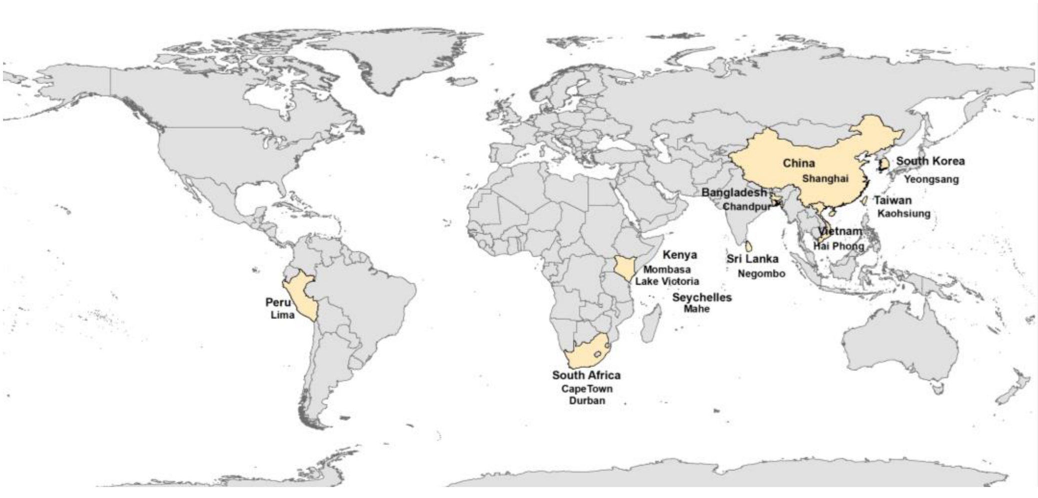


Figure 8 Map of countries in which surveys were conducted.

As part of the CSIRO Global Plastics Project we conducted field surveys in both rural and urban areas surrounding 12 different cities in ten countries (Figure 8). Sites were selected using a stratified random sampling technique, to ensure that surveys were conducted over a wide range of covariates of interest, including population density, landcover, and infrastructure. At each of a total of 395 sites, we surveyed 3-6 transects of 25 m^2 each.

Transects were primarily 12.5 m long by 2 m wide, except for when they occurred along roadways, when they were 25 m long by 1 m wide to ensure the safety of the observer. Surveyors counted and categorised all litter that could be seen from a standing height into one of 84 categories. For a complete methodology, see the Handbook of Survey Methodology: Plastic Leakage (Schuyler, Willis, Lawson, Mann, & Wilcox, 2018).

We identified a number of globally available covariates that might be able to explain the variability in the observed data. These included population density within 1 km (Center for International Earth Science Information Network, 2018), mean nightlights (a measure of both population as well as captures some socio-economic data) (Earth Observation Group, 2020), human development index (HDI) and gross domestic product (on a sub-national scale)(Kummu, Taka, & Guillaume, 2018), distance to the nearest road (Center For International Earth Science Information Network –Columbia University, 2013), distance to the nearest river (Lehner & Grill, 2013) , landcover (Sulla-Menashe, Gray, Abercrombie, & Friedl, 2019) and landuse (Ellis & Ramankutty, 2008) . We also used a subnational estimate of mismanaged waste (L. Lebreton & Andrady, 2019). We assessed all of these covariates with generalised additive models (GAM) and compared the AIC scores for each possible combination of covariates. To get the best fit model, we did model averaging on all models that were within 3 AIC scores of the top model. When selecting models, we ensured that no one model could include variables that scored higher than 0.6 on a Pearson's correlation test.

To be able to directly compare the covariates and determine which best predict the observed litter amounts, we calculated the effect size. Effect size is calculated by multiplying the median value of the covariate by its coefficient. Terms with a positive effect size have a positive correlation with the amount of litter, while terms with a negative effect size are negatively correlated with the amount of litter. The higher the absolute value of the effect size, whether positive or negative, the more that particular covariate explains the variability in the litter found (

Figure 11).

We generated a fishnet of points across each river basin, with points every 5km. We determined the global covariates at each of these points, and then used the best-fit model to predict litter densities at each point (Figure 12 andFigure 15). We determined the watershed boundaries of each river (OpenDevelopment Cambodia, 2019), and divided each river up into sections, based on the watersheds for that section. We summed the predicted litter within each watershed leading to each section of the river, and determined a relative litter density for each river section (

Figure 13Figure 16). In order to account for downstream flow, we presumed a 30% transmission rate, meaning that 70% of the litter would be retained within each section, while the rest would be available to move downstream.

We were unable to find empirical data on the density of macroplastics in the Mekong and Ganga Rivers to validate our model assumptions. However, microplastics measurements were taken at 5 locations in the Lower Mekong Basin (Pirika, 2020. Survey on Microplastic Leakage in the Mekong River Basin), and at 3 locations in the Ganga Basin (Toxics link, 2020). Additionally, a survey on microplastics was carried out at 10 locations along the Ganga River as part of the Source to Sea Expedition (Napper et al., 2021). While microplastic density does not necessarily correlate with macroplastic density, we ranked the measurements and compared them to our predicted rankings for each river section.

7.2 Relative level of pressure from fishing activity

We did not have a map of fishing effort along the length of each river, so we used the best available data to estimate the relative level of pressure from fishing. For the Mekong River, we had no data on fishing effort or surveys ALDFG, so instead we used a proxy measure of the number of people living within 10km of the river bank. We calculated population density along each section of the river, and scaled from 0-1, with 1 being the most densely populated section of the river.

For the Ganga River, we found two data sources on fishing pressure, one reported by the Indian Institutes of Technology (IIT), which estimates average landings between 1955/56 – 2008/09 at 7 stations along the Ganga River (Indian Institutes of Technology, 2012) (Figure 9), and a more recent study which measured and ranked ALDFG at 9 sites along the Ganga River (Nelms et al., 2021) (Figure 10).

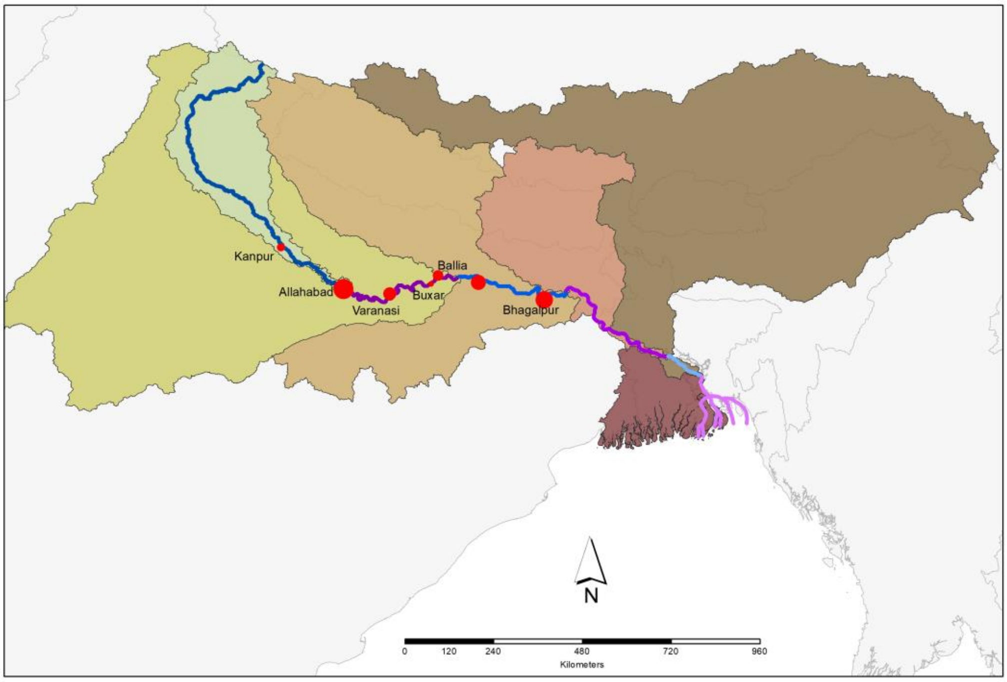


Figure 9. Stations where fishing catch levels were reported by the Indian Institutes of Technology. Sizes of circles represent mean catch levels between 1955/56 – 2008/09.

The IIT stations are not spread along the entire river, so we could not use this to rank fishing pressure. We therefore used the data collected by Nelms et al, ranked the studies from low-high, and took the average rank of the observations falling within each river section. From these numbers, we calculated a relative fishing pressure for each section of the river.

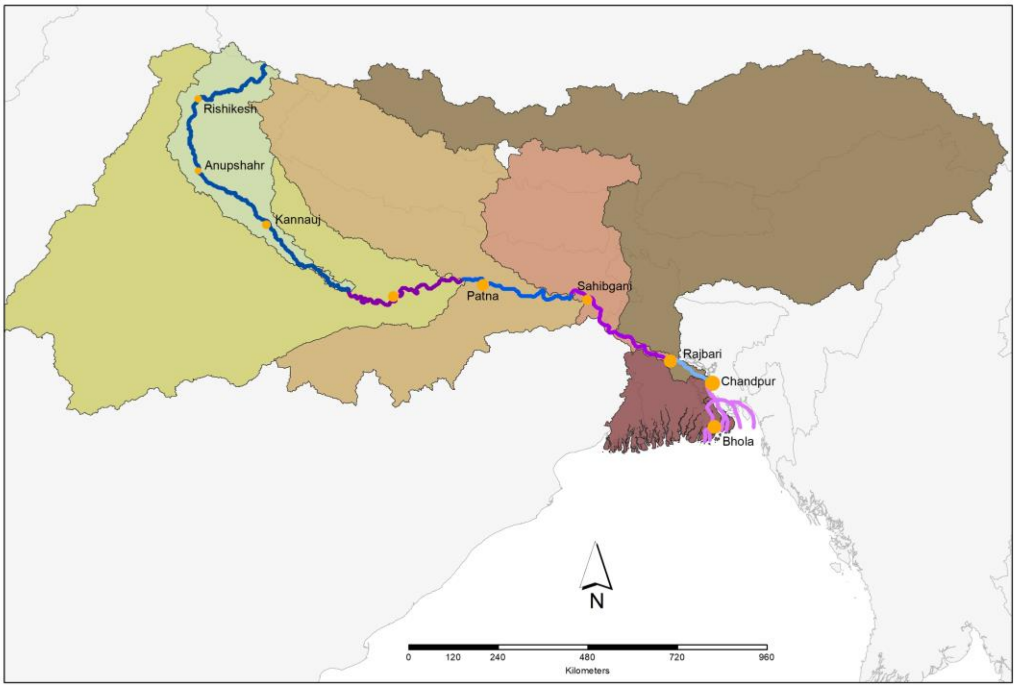
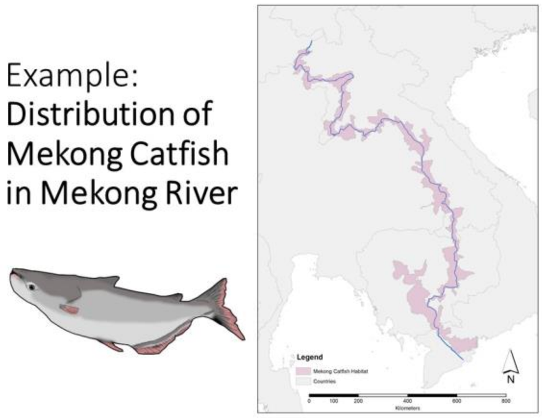
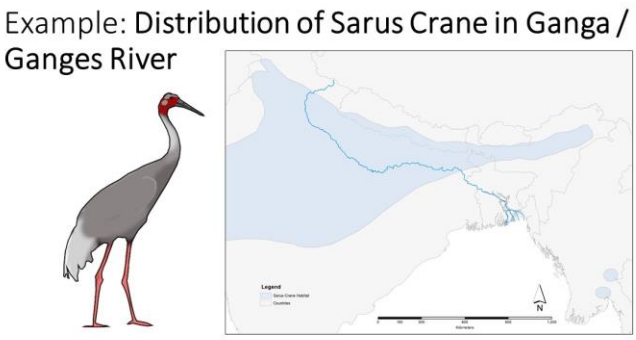


Figure 10 Locations of ALDFG surveys reported in Nelms et al. (2021).

8 Step 3: Determine overlap of listed species with each river section (Habitat Overlap)

We sourced species distribution maps from reputable online sources. The highest quality (and most conservative) species distribution maps were the species distribution shapefiles made publicly available by the International Union for Conservation of Nature (IUCN, 2019). IUCN species distribution maps were not available for the Ganges river dolphin, so we used distribution maps compiled by the Wildlife Institute of India (WIA) (WII-GACMC, 2018).





9 Step 4: Calculate the expected risk posed by plastic litter to each of the CMS listed species

In order to determine the relative risk to each individual species at each section of the river, we multiplied the risk score (behaviour score * impact score) by the relative pressure from either litter (ingestion risk) or fishing pressure (entanglement risk).

Relative Ingestion Risk = Risk Score * Relative Litter Density

Relative Entanglement Risk = Risk Score * Relative Fishing pressure

We then mapped the relative risk at each section of the river where the species occurs. Because the risk assessment is based on semi-qualitative tiers, or rankings, as opposed to observed probabilities of interaction and impact, we report only the relative risk level, comparable across species. Note that the maximum possible risk score would be for a species that has a high probability of interacting with litter, with a lethal outcome, living in the section of the river with the highest litter (or fishing pressure). This would be represented by the top end of the colour scale, red. It is important to note here that this highest level of risk is relative, and comparable across river sections. Without quantitative data on the volumes of litter or fishing pressure encountered at each river section, or on the mortality expected from these interactions, we cannot provide an absolute estimate of the risk of mortality within the river basins, nor is it possible to rank the impact from litter ingestion and entanglement alongside the other potential threats to the species (see Discussion section for more details).

We also assessed the relative cumulative risk to species for each section of the river, for both ingestion and entanglement. To do this, we multiplied the risk score by the proportion of the river section that each species inhabits, and add the total scores. For this analysis, we ranked the river sections by their total combined risk scores.

Overall ingestion risk per river section = sum (Risk Score * Relative Litter Density * Habitat Overlap)

Overall entanglement risk per river section = sum (Risk Score * Relative Fishing Pressure * Habitat Overlap)

Part III Literature review and litter interaction / impact risk determination

Overview of CMS listed species-specific interaction with aquatic plastic litter (with a focus on macro-litter), based on the information retrieved from five systematic literature searches, and the risk categories that have been assigned.

10 Mekong River Species

In this section, we present the findings of our literature review, and score the risk of each the interactions and impact of interactions with plastic litter for CMS listed species.

10.1 Mekong species risk overview

Species

1. Mekong catfish (*Pangasianodon gigas*)
2. Irrawaddy dolphin (*Orcaella brevirostris*)
3. Bengal Florican (*Houbaropsis bengalensis bengalensis*)
4. Eastern Imperial Eagle (*Aquila heliaca*)
5. Sarus Crane (*Antigone Antigone*).

We summarise our major findings from the review in the table below. Where no results were retrieved, we left the cells blank.

Table 9 Interaction risks posed by specific items mentioned in studies of CMS listed species or related taxa. We include the risk of fatal interactions but do not summarise numerous potential or sub-lethal effects mentioned in discussion sections.

Item	Catfish	Dolphin	Florican /Bustard	Eagle	Crane
Litter items such as plastic bags / packaging		Ingestion risk across multiple dolphin taxa in multiple locations (Alexiadou et al., 2019; Bearzi, Reeves, Remonato, Pierantonio, & Airoldi, 2011; Byard, Machado, Walker, & Woolford, 2020; Coombs et al., 2019; Denuncio et al., 2011; Fernandez et al., 2009; Puig-Lozano et al., 2018). Fatal in some interactions (gastric obstruction).		Plastic cage substrates were eaten by captive animals leading to anorexia and death. Reason for pica unknown(Applegate, Van Wettere, Christiansen, & Degernes, 2017). As these interactions occurred in captive animals, the cases may not be relevant to wild animals.	
Microplastic / small fragments/ fiber / plastic thread	Ingestion risk across multiple catfish taxa (Lubis, Melani, & Syakti, 2019; Park et al., 2020; F. E. Possatto, Barletta, Costa, do Sul, & Dantas, 2011; Ribeiro-Brasil et al., 2020). Plastic fibers were considerably more abundant than other plastic types (F. E. Possatto et al., 2011; Ribeiro-Brasil et al., 2020). Plastics determined to be ingested during normal feeding activity. No fatal interactions mentioned.	Ingestion risk across multiple dolphin taxa in multiple locations (Alexiadou et al., 2019; Bearzi et al., 2011; Byard et al., 2020; Coombs et al., 2019; Denuncio et al., 2011; Fernandez et al., 2009; Puig-Lozano et al., 2018). No fatal interactions mentioned.			
Lead shot				Ingestion risk due to secondary ingestion (ingestion of shot prey or from predation of waterfowl that had ingested lead shots as a	

			gastrolith) across multiple raptor taxa (Cochrane, Lonsdorf, Allison, & Sanders-Reed, 2015; Franson & Russell, 2014; Franzen-Klein, McRuer, Slabe, & Katzner, 2018; Mateo, Green, Lefranc, Baos, & Figuerola, 2007; Miller et al., 2000; Rattner & McGowan, 2007). Fatal in some interactions (lead poisoning).
Monofilament fishing line, hook and tackle		Entanglement and hooking risk across multiple dolphin taxa in multiple locations. Many recorded fatal interactions (physical trauma, debilitation leading to starvation, asphyxiation and drowning).	Entanglement risk noted in one study due to use of monofilament line by birds during nest building (Rattner & McGowan, 2007).
Gillnet	Entrapment of catfish in gillnets as bycatch species (M. Eighani, S. M. Bayse, S. Y. Paighambari, & M. K. Broadhurst, 2020)	Entanglement risk across multiple dolphin taxa in multiple locations, including Irrawaddy dolphin. Many recorded fatal interactions (physical trauma, debilitation leading to starvation, asphyxiation and drowning).	
Fishing pot / trap	Entrapment of catfish in crab pots as by-catch (J. W. Page, M. C. Curran, & P. J. Geer, 2013)		

10.2 Mekong catfish (*Pangasianodon gigas*)

10.2.1 Risk overview

Our literature search retrieved numerous studies that indicate both the ingestion of plastic (Lubis et al., 2019; Park et al., 2020; F. E. Possatto et al., 2011; Ribeiro-Brasil et al., 2020) and fishing-related debris (F. E. Possatto et al., 2011) and entanglement in fishing gear (Morteza Eighani, Shannon M Bayse, Seyed Yousef Paighambari, & Matt K Broadhurst, 2020; James West Page, Mary Carla Curran, & Patrick John Geer, 2013) for various catfish taxa. Though ingestion of plastics is common in catfish and other fish that feed in the sediment, we found no evidence of lethal impacts for large fish, though there is extensive evidence in the literature for potential sublethal impacts in fish from experimental work. Catfish are likely to become entangled or entrapped in gillnets (Morteza Eighani et al., 2020) and pot-style traps (James West Page et al., 2013). If entangled/entrapped, the consequences are likely to be lethal for the fish.

Interaction score

We assigned the Mekong catfish as a “Moderate” risk of ingesting plastic litter, as with other catfish taxa and fish that feed in the sediment. We assigned the impact of litter ingestion as “Sub-lethal”, due to the expansive experimental evidence for potential sub-lethal effects, but lack of evidence of lethal effects in wild fish despite frequent plastic ingestion. The entanglement in fishing debris is a known cause of death for catfish, and multiple lines of evidence suggest that entrapment/entanglement is a serious lethal threat to Mekong catfish. Therefore, we scored the likelihood of entanglement as “High” and the impact as “Lethal”.

Table 10 Risk scoring for the Mekong catfish (*Pangasianodon gigas*).

Mekong catfish (*Pangasianodon* gigas)		
Scores	**Interaction**	**Impact**
Plastic litter	3	2
Fishing-related Debris	4	4

10.3 Irrawaddy dolphin (*Orcaella brevirostris*)

10.3.1 Risk overview

Our literature search retrieved numerous studies that indicate that both the ingestion of plastic (Alexiadou et al., 2019; Bearzi et al., 2011; Byard et al., 2020; Coombs et al., 2019; Denuncio et al., 2011; Fernandez et al., 2009; Puig-Lozano et al., 2018) and fishing-related debris (Alexiadou et al., 2019; Byard et al., 2020; Denuncio et al., 2011; Fernandez et al., 2009) and entanglement in fishing gear (Panti, Baini, Lusher, Hernandez-Milan, Bravo Rebolledo, et al., 2019) occur reasonably commonly among dolphins. The ingestion of litter has the potential to cause death, though most instances of ingested plastic were not the cause of death.

Interaction score

There are multiple lines of evidence showing that dolphins ingest and become entangled in plastic litter. However, dolphins are highly intelligent, and we do not expect ingestion and entanglement to result from most encounters, so we have scored the risk of both as "Moderate". There is evidence that cetaceans may die from the ingestion of plastic, but this does not occur in most instances of plastic ingestion, and we have scored the impact as "Potentially Lethal". Entanglement, however, especially in gill nets, is a major and well-known cause of death of cetaceans, and we have scored the impact of entanglements as "Lethal".

Table 11 Risk scoring for the Irrawaddy dolphin (*Orcaella brevirostris*).

Irrawaddy dolphin (*Orcaella* brevirostris)		
Scores	**Interaction**	**Impact**
Plastic litter	3	3
Fishing-related Debris	3	4

10.4 Bengal Florican (*Houbaropsis bengalensis bengalensis*)

10.4.1 Risk overview

Our literature search did not return any evidence for the interaction between floricans/bustards and plastic litter through ingestion nor entanglement. There is no significant evidence that terrestrial birds that forage visually for small, mobile prey such as insects and forage on seeds and grains are at risk of ingesting plastic and other types of plastic litter. While this evidence does not rule out the presence or ingestion of plastics (especially microplastics), given the high frequency of their presence in aquatic environments, the lack of evidence suggests that it is unlikely that plastics pose a notable threat to the Bengal florican. However, if litter is ingested, sub-lethal effects may occur, as for other terrestrial birds. If floricans/bustards became entangled, the entanglement may be lethal, as for other birds.

Interaction score

There was no evidence for the ingestion of litter or entanglements in floricans/bustards, and we have scored both as "Unlikely". We have scored the potential impact of ingestion of litter as 'Sub-lethal' and entanglement as 'Potentially Lethal', reflecting what would generally be expected in cases of litter ingestion and cases of entanglement among aquatic and terrestrial birds.

Table 12 Risk scoring for the Bengal Florican (*Houbaropsis bengalensis bengalensis*).

Bengal Florican (Houbaropsis bengalensis bengalensis)		
Scores	**Interaction**	**Impact**
Plastic litter	1	2
Fishing-related Debris	1	3

10.5 Eastern Imperial Eagle (*Aquila heliaca*)

10.5.1 Risk overview

Our literature review found some evidence for infrequent / uncommon ingestion of plastic litter in captive raptorial birds. There is a chance of secondary ingestion of litter (lead shot) in raptorial birds, and therefore secondary ingestion of litter may also occur if the eagle preys on plastic-ingesting prey. There is good evidence for cases of fishing line entanglement of raptorial birds, particularly in Australia, though these reports involve species associated with coastal/marine environments. If litter is ingested, there is the potential for death if gastrointestinal foreign body obstruction occurs. There is a risk of death if raptorial birds become entangled in fishing line.

Interaction score

We assigned the Eastern imperial eagle as a "Low" risk of ingesting plastic litter and a "Moderate" risk of becoming entangled. We scored the risk of impact of both litter ingestion and entanglement as "Potentially Lethal".

Table 13 Risk scoring for the Eastern Imperial Eagle (*Aquila heliaca*).

Eastern Imperial Eagle (*Aquila* heliaca)		
Scores	**Interaction**	**Impact**
Plastic litter	2	3
Fishing-related Debris	3	3

10.6 Sarus Crane (*Antigone antigone*).

10.6.1 Risk overview

Our literature search did not return any evidence for the interaction between cranes and plastic litter through ingestion or entanglement. There is no significant evidence that terrestrial birds that forage visually for small, mobile prey such as insects and small aquatic animals are at risk of ingesting plastic and other types of plastic litter. Based on this lack of behavioural predisposition for intentionally or accidentally eating large plastic and plastic litter, we consider the sarus crane at low risk of litter ingestion.

However, if litter is ingested, sub-lethal effects may occur, as for other terrestrial birds. From previous publications (Ryan 2018), we know that aquatic birds can become entangled where line fishing occurs, but at low frequencies. If cranes became entangled, the entanglement may be lethal, as for other birds.

Interaction score

There was no evidence for the ingestion of litter or entanglements in cranes, and we have scored both as “Unlikely”. We have scored the potential impact of ingestion of litter as ‘Sub-lethal’ and entanglement as ‘Potentially Lethal’, reflecting what would generally be expected in cases of litter ingestion and cases of entanglement among aquatic and terrestrial birds.

Table 14 Risk scoring for the Sarus Crane (*Grus Antigone*).

Sarus Crane (*Antigone* antigone)		
Scores	**Interaction**	**Impact**
Plastic litter	1	2
Fishing-related Debris	1	3

11 Ganga River Species

In this section, we present the findings of our literature review, and score the risk of each interactions and impact of interactions with plastic litter for CMS-listed species.

We summarise our major findings from the review in the table below. Where no results were retrieved, we left the cells blank.

Ganga River species

1. Ganges River Dolphin
2. gharial
3. Asian Elephant
4. Sarus Crane
5. Greylag Goose
6. Common Shelduck
7. Gadwall
8. Northern Pintail
9. Common Teal
10. Red-crested Pochard
11. Tufted Duck
12. Greater Spotted Eagle
13. Common Crane
14. Black-tailed Godwit
15. Eurasian Curlew
16. Marsh Sandpiper
17. Common Greenshank
18. Green Sandpiper
19. Temminck's Stint

Table 15 Interaction risks posed by specific items mentioned in studies of CMS listed species or related taxa. We include the risk of fatal interactions but do not summarise numerous potential or sub-lethal effects mentioned in discussion sections.

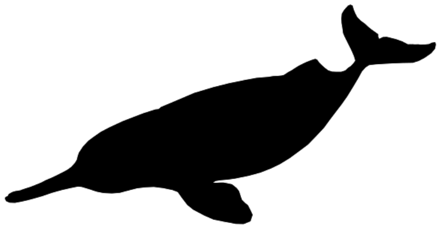
Item	Elephant	Dolphins	gharial/crocodilian	Eagle	Ducks	Crane	Wading birds
Litter items such as plastic bag / packaging	Ingestion risk at dump sites while elephants target food inside packaging. Plastic is not mentioned as eaten in other contexts (such as marine litter) and is probably not likely to be eaten unless there is food inside. Unlikely to be fatal. One study mentioned that consumed plastic items were regularly excreted, retention and obstruction of the alimentary tract are unlikely in elephants. Another linked to a news article saying elephant deaths were linked to plastic consumption at a dump site, but the cause of these deaths was not confirmed. (Electric fence for Vic Falls dumpsite. . . 8 elephants dead from consuming plastics | The Herald)	Ingestion risk across multiple dolphin taxa in multiple locations Fatal in some interactions (gastric obstruction).		Plastic cage substrates were eaten by captive animals leading to anorexia and death. Reason for pica unknown (Applegate et al., 2017). As these interactions occurred in captive animals, the cases may not be relevant to wild animals.			
Microplastic / small fragments/	One study mentioned elephants refusal to eat	Ingestion risk across multiple dolphin taxa in multiple locations			Ingestion risk across multiple	None mentioned in studies of feces	None mentioned despite many

fiber / plastic thread	small plastics when offered.	No fatal interactions mentioned.			species and multiple studies for fibres and other microplastics. Unlikely to be fatal.	and stomach contents.	studies of feces and stomach contents.
Lead shot				Ingestion risk due to secondary ingestion (ingestion of shot prey or from predation of waterfowl that had ingested lead shots as a gastrolith) across multiple raptor taxa. Fatal in some interactions (lead poisoning).	Lead shot ingestion across multiple species and multiple studies. Can cause lead poisoning and can be fatal.		
Monofilament fishing line, hook and tackle		Entanglement and hooking risk across multiple dolphin taxa in multiple locations. Many recorded fatal interactions (physical trauma, debilitation leading to starvation, asphyxiation and drowning).		Entanglement risk noted in one study due to use of monofilament line by birds during nest building (Rattner & McGowan, 2007). Entanglement also known from	Entanglement and ingestion risk known from wildlife hospital admissions.		Entanglement possible (entanglement recorded in other waterbirds) but probably uncommon

				wildlife hospital admissions.		
Gillnet	Entrapment of catfish in gillnets as bycatch species	Entanglement risk across multiple dolphin taxa in multiple locations, including Ganges River Dolphin. Gillnets pose the greatest risk. Many recorded fatal interactions (physical trauma, debilitation leading to starvation, asphyxiation and drowning).	Entanglement risk across multiple species and multiple studies. Gillnets post a risk to gharials.		Entanglement risk.	One study mentions 100+ wader carcasses sourced through accidental drowning of waders in active net (not gillnet but similar). Entanglement possible but probably uncommon.
Fishing pot / trap	Entrapment of catfish in crab pots as by-catch					

11.1 Ganges River Dolphin (*Platanista gangetica gangetica*)

11.1.1 Risk overview



Our literature search retrieved numerous studies that indicate that both the ingestion of plastic (Alexiadou et al., 2019; Bearzi et al., 2011; Byard et al., 2020; Coombs et al., 2019; Denuncio et al., 2011; Fernandez et al., 2009; Puig-Lozano et al., 2018) and fishing-related debris (Alexiadou et al., 2019; Byard et al., 2020; Denuncio et al., 2011; Fernandez et al., 2009) and entanglement in fishing gear (Panti, Baini, Lusher, Hernandez-Milan, Bravo Rebolledo, et al., 2019) occur reasonably commonly among dolphins. The ingestion of litter has the potential to cause death, though most instances of ingested plastic were not the cause of death.

Interaction score

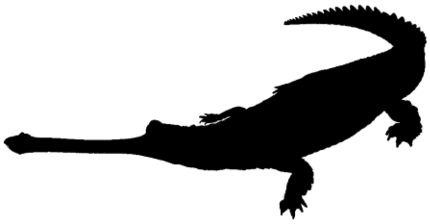
There are multiple lines of evidence showing that dolphins ingest and become entangled in plastic litter. However, dolphins are highly intelligent, and we do not expect ingestion and entanglement to result from most encounters, and we have scored the interaction risk of both as "Moderate". There is evidence that cetaceans may die from the ingestion of plastic, but this does not occur in most instances of plastic ingestion, and we have scored the impact as "Potentially Lethal". Entanglement, however, especially in gill nets, is a major and well-known cause of death of cetaceans, and we have scored the impact of entanglements as "Lethal".

Table 16 Risk scoring for the Ganges River Dolphin (*Platanista gangetica gangetica*).

Ganges River Dolphin (*Platanista* gangetica gangetica)		
Scores	**Interaction**	**Impact**
Plastic litter	3	3
Fishing-related Debris	3	4

11.2 Gharial (*Gavialis gangeticus*)

11.2.1 Risk overview



Our literature search seeking interaction between gharials or other crocodilians with plastic litter retrieved one mention of ingestion of derelict fishing gear (Warner, Combrink, Myburgh, & Downs, 2016) and numerous studies concerning entanglement of gharials and other crocodilians (Aust, Boyle, Fergusson, & Coulson, 2009; Hussain, 2009; Kyle, 1999; Platt & Van Tri, 2000; Shaney et al., 2019; H. Singh & Rao, 2017; Thorbjarnarson, Platt, & Khaing, 2000). Furthermore, a review into plastic ingestion in reptiles found no reported evidence for plastic ingestion in crocodilians (Staffieri, de Lucia, Camedda, Poeta, & Battisti, 2019), nor any studies showing evidence of harm.

Interaction score

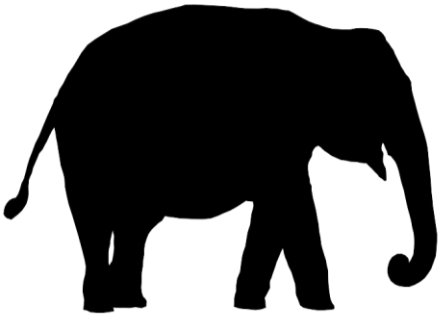
There is limited evidence for litter ingestion and no evidence for impact from ingestion, but multiple lines of evidence show that gharials and other crocodilians become entangled in plastic litter, especially fishing-related debris. Their rough scaled body likely makes them particularly vulnerable to entanglement. Due to the limited evidence for litter ingestion, though the potential for secondary ingestion of litter, we have scored this interaction likelihood as “Low” and the impact risk as “Unlikely”. Due to extensive evidence for entanglements and the lethal risk of entanglements, we have scored the interaction score as “High” and risk score as “Lethal”.

Table 17 Risk scoring for the gharial (*Gavialis gangeticus*).

Gharial (*Gavialis* gangeticus)		
Scores	**Interaction**	**Impact**
Plastic litter	2	1
Fishing-related Debris	4	4

11.3 Asian Elephant (*Elephas maximus indicus*)

11.3.1 Risk overview



Our literature review found no evidence that Asian elephants ingest or become entangled in plastic litter, with a single behavioural exception. There is evidence that elephants will ingest packaged food and raid dump sites, therefore there is a limited risk of litter ingestion in a scenario where packaged food is present. We found no reliable evidence of harm from litter ingestion to elephants. We found no evidence for entanglements occurring in elephants.

Interaction score

There is limited evidence for litter ingestion and no evidence for impacts. There is evidence that elephants will ingest packaged food and raid dump sites, therefore there is a limited risk of litter ingestion in a scenario where packaged food is present, though this is unlikely in a discarded litter environment with respect to the Ganga, and we have scored the risk of ingestion as “Low”. Due to lack of evidence of litter ingestion impacts, and the large size of the elephant’s stomach compared to the litter it might ingest, we have also scored the impact of litter ingestion as “Unlikely” to cause effects. We scored both the likelihood and impact of entanglement as “Unlikely”, because of lack of evidence, also because the large size of the elephants’ limbs makes it unlikely that they would become entangled, and if so, unlikely that the entanglement would remain for long enough to cause harm.

Table 18 Risk scoring for the Asian Elephant (*Elephas maximus indicus*).

Asian Elephant (*Elephas* maximus indicus)		
Scores	**Interaction**	**Impact**
Plastic litter	2	1
Fishing-related Debris	1	1

11.4 Greater Spotted Eagle (*Clanga* clanga)

11.4.1 Risk overview

Our literature review found some evidence for infrequent / uncommon ingestion of plastic litter in captive raptorial birds. There is a chance of secondary ingestion of litter (lead shot) in raptorial birds, and therefore secondary ingestion of litter may also occur. There is good evidence for cases of fishing line entanglement of raptorial birds, particularly in Australia, though these reports involve species associated with coastal/marine environments. If litter is ingested, there is the potential for death if gastrointestinal foreign body obstruction occurs. There is a risk of death if raptorial birds become entangled in fishing line.

Interaction score

We assigned the Eastern imperial eagle as a "Low" risk of ingesting plastic litter and a "Moderate" risk of becoming entangled. We scored the risk of impact of both litter ingestion and entanglement as "potentially lethal".

Table 19 Risk scoring for the Greater Spotted Eagle (*Clanga clanga*).

Greater Spotted Eagle (*Clanga* clanga)		
Scores	**Interaction**	**Impact**
Plastic litter	2	3
Fishing-related Debris	3	3

11.5 Sarus Crane (*Antigone* antigone) and Common Crane (Grus *Grus*)

11.5.1 Risk overview

Our literature search did not return any evidence for the interaction between cranes and plastic litter through either ingestion or entanglement. There is no significant evidence that terrestrial birds that forage visually for small, mobile prey such as insects and small aquatic animals are at risk of ingesting plastic and other types of plastic litter. Based on this lack of behavioural predisposition for intentionally or accidentally eating large plastic and plastic litter, we consider the sarus crane at low risk of litter ingestion.

However, if litter is ingested, sub-lethal effects may occur, as for other terrestrial birds. From previous publications (Ryan 2018), we know that aquatic birds can become entangled where line fishing occurs, but at low frequencies. If cranes became entangled, the entanglement may be lethal, as for other birds.

Interaction score

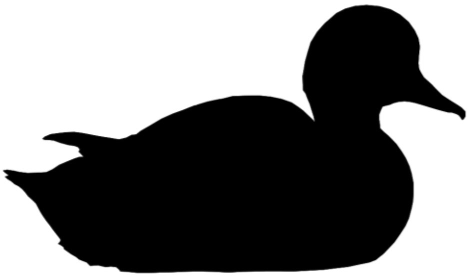
There was no evidence for the ingestion of litter or entanglements in cranes, and we have scored both as “Unlikely”. We have scored the potential impact of ingestion of litter as ‘Sub-lethal’ and entanglement as ‘Potentially Lethal’, reflecting what would generally be expected in cases of litter ingestion and cases of entanglement among aquatic and terrestrial birds.

Table 20 Risk scoring for the Sarus Crane (*Antigone antigone*) and the Common Crane (*Grus Grus*).

Sarus Crane (*Antigone* antigone)		
Scores	**Interaction**	**Impact**
Plastic litter	1	2
Fishing-related Debris	1	3
Common Crane (Grus *Grus*)		
Plastic litter	1	2
Fishing-related Debris	1	3

11.6 Waterfowl: Greylag Goose (*Anser anser*), Common Shelduck (*Tadorna tadorna*), Gadwall (*Anas strepera*), Northern Pintail (*Anas acuta*), Common Teal (*Anas crecca*), Red-crested Pochard (*Netta rufina*) and Tufted Duck (*Aythya fuligula*)

11.6.1 Risk overview



Our literature reviewed multiple lines of evidence that show the occasional ingestion of plastic litter, and entanglement in fishing debris, by ducks. Though there is no evidence of harm by ingestion of litter in waterfowl (except a single record of harm resulting from ingestion of fishing debris in a Muscovy duck, likely domestic), there are multiple lines of evidence of debilitation and death of waterfowl entangled in fishing-related debris.

Interaction score

There is ample evidence for the moderate rates of litter ingestion by waterfowl across multiple countries, and we have scored the risk of litter ingestion in waterfowl as “Moderate”. However, despite this frequent litter ingestion, the only evidence retrieved of harm came from one single study of a potentially domestic Muscovy duck. As there is such limited evidence of harm despite the globally frequent occurrence of litter ingestion by ducks, we have scored the likely impact as ‘Sub-lethal’, which we felt would best represent the overwhelming majority of cases. There were infrequent case reports of entanglements of waterfowl in fishing debris. However, these records were mostly limited to what appeared as local situations (for examples, mute swans and fishing line in the UK) which may or may not extrapolate to wild ducks in the Ganga. As a result, we have scored the likelihood of entanglement as “Low”, but the impact as “Potentially lethal”, as drowning may occur, and reflecting the debilitation outcomes for other aquatic birds submitted to wildlife hospitals and suffering entanglement.

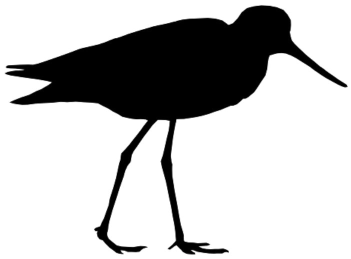
Table 21 Risk scoring for all Waterfowl.

All Waterfowl		
Scores	**Interaction**	**Impact**
Plastic litter	3	2
Fishing-related Debris	2	3

11.7 Wader birds: Black-tailed Godwit (Limosa limosa), Eurasian Curlew (*Numenius* arquata), Marsh Sandpiper (Tringa stagnatilis), Common Greenshank (Tringa nebularia), Green Sandpiper (Tringa ochropus) and Temminck's Stint (Calidris temminckii)

11.7.1 Risk overview

Despite an extensive literature available on waders, our literature search did not return any evidence for the interaction between wader birds and plastic litter through ingestion or entanglement. From previous publications (Ryan 2018), we know that wader birds can become entangled where line fishing occurs, but at low frequencies.



Interaction score

There was no evidence for the ingestion of litter or entanglements in wader birds, and we have scored both as "Unlikely". We have scored the potential impact of ingestion of litter as 'Sub-lethal' and entanglement as 'Potentially Lethal', reflecting what would generally be expected in cases of litter ingestion and cases of entanglement among aquatic and terrestrial birds.

Table 22 Risk scoring for all Wader birds.

All waders		
Scores	**Interaction**	**Impact**
Plastic litter	1	2
Fishing-related Debris	1	3

Part IV Results

12 Step 1: Risk matrix

Overall, ingestion interactions are expected to be more frequent than entanglement interactions. However, entanglement interactions are more likely to be potentially lethal or lethal. Only three CMS-listed species in the Mekong River are at high or moderate risk from interactions with litter: the Mekong catfish, the Irrawaddy dolphin, and the Eastern Imperial Eagle. These are all at risk from entanglement, and the Irrawaddy dolphin is additionally at moderate risk from ingestion.

Table 23. Risk scores for litter interactions in Mekong River CMS listed species.

	Plastic litter ingestion			Fishing debris entanglement		
Species	**Interaction**	**Impact**	**Risk score**	**Interaction**	**Impact**	**Risk score**
Mekong catfish	3	2	**6 LOW**	4	4	**16 HIGH**
Irrawaddy dolphin	3	3	**9 MODERATE**	3	4	**12 HIGH**
Bengal Florican	1	2	**2 NEGLIGIBLE**	1	3	**3 NEGLIGIBLE**
Eastern Imperial Eagle	2	3	**6 LOW**	3	3	**9 MODERATE**
Sarus Crane	1	2	**2 NEGLIGIBLE**	1	3	**3 NEGLIGIBLE**

For the Ganga, only two species are at high or moderate risk from debris interactions: the Ganges River dolphin (high risk from entanglement, moderate risk from ingestion), and the gharial (high risk from entanglement).

Table 24. Risk scores for litter interactions in Ganga River CMS listed species.

	Plastic litter ingestion			Fishing debris entanglement		
Species	**Interaction**	**Impact**	**Risk score**	**Interaction**	**Impact**	**Risk score**
Ganges River Dolphin	3	3	**9 MODERATE**	3	4	**12 HIGH**
Gharial	2	1	**2 NEGLIGIBLE**	4	4	**16 HIGH**
Asian Elephant	2	1	**2 NEGLIGIBLE**	1	1	**1 NEGLIGIBLE**

		Plastic litter ingestion		Fishing debris entanglement		
Sarus Crane	1	2	**3 NEGLIGIBLE**	1	3	**3 NEGLIGIBLE**
Greylag Goose	3	2	**3 NEGLIGIBLE**	2	3	**3 NEGLIGIBLE**
Common Shelduck	3	2	**6 LOW**	2	3	**6 LOW**
Gadwall	3	2	**6 LOW**	2	3	**6 LOW**
Northern Pintail	3	2	**6 LOW**	2	3	**6 LOW**
Common Teal	3	2	**6 LOW**	2	3	**6 LOW**
Red-crested Pochard	3	2	**6 LOW**	2	3	**6 LOW**
Tufted Duck	3	2	**6 LOW**	2	3	**6 LOW**
Greater Spotted Eagle	2	3	**6 LOW**	3	3	**9 MODERATE**
Common Crane	1	2	**2 NEGLIGIBLE**	1	3	**3 NEGLIGIBLE**
Black-tailed Godwit	1	2	**2 NEGLIGIBLE**	1	3	**3 NEGLIGIBLE**
Eurasian Curlew	1	2	**2 NEGLIGIBLE**	1	3	**3 NEGLIGIBLE**
Marsh Sandpiper	1	2	**2 NEGLIGIBLE**	1	3	**3 NEGLIGIBLE**
Common Greenshank	1	2	**2 NEGLIGIBLE**	1	3	**3 NEGLIGIBLE**
Green Sandpiper	1	2	**2 NEGLIGIBLE**	1	3	**3 NEGLIGIBLE**
Temminck's Stint	1	2	**2 NEGLIGIBLE**	1	3	**3 NEGLIGIBLE**

13 Step 2: Relative level of pressure from litter or fishing effort

13.1 Predicted litter densities

The best fit model for the empirical data that we used included a socio-economic proxy, total value of the built environment. However, this data set is not available for Thailand, so we re-fit the model without it to predict litter in the Lower Mekong Basin.

We initially used a landcover layer generated from Modis satellite data (Sulla-Menache and Friedl, 2018). This layer was chosen because it gave a slightly better AIC value and higher deviance explained when fitting the empirical data. However, when we predicted for the Ganga with this model we noticed an anomaly caused by the presence of large amounts of “barren” landcovers. In the empirical data we collected, barren areas had a higher litter load, potentially because they were used as dumping grounds. However, large sections of the Himalayas are also categorised as “barren”, and the modelling yielded artificially high estimates in these zones. For the Ganga model, we therefore selected an anthropogenic land use layer produced by SEDAC (Ellis & Ramankutty, 2008) which doesn’t suffer from the same anomalies. This layer characterises biomes based in part on how they have been utilised by humans.

Mekong models and litter predictions

Out of the full suite of covariates that we tested in our models, HDI, mismanaged waste, mean nightlights, certain landcovers, and the distance to the nearest road were statistically significant in the best fit model for the Mekong (

Figure 11). GDP, population density, distance to the nearest river, and nightlights within 1km were not statistically significant, but including them lowered the AIC score, so we incorporated them into the final model. The other covariates that we tested did not appear in the best-fit model.

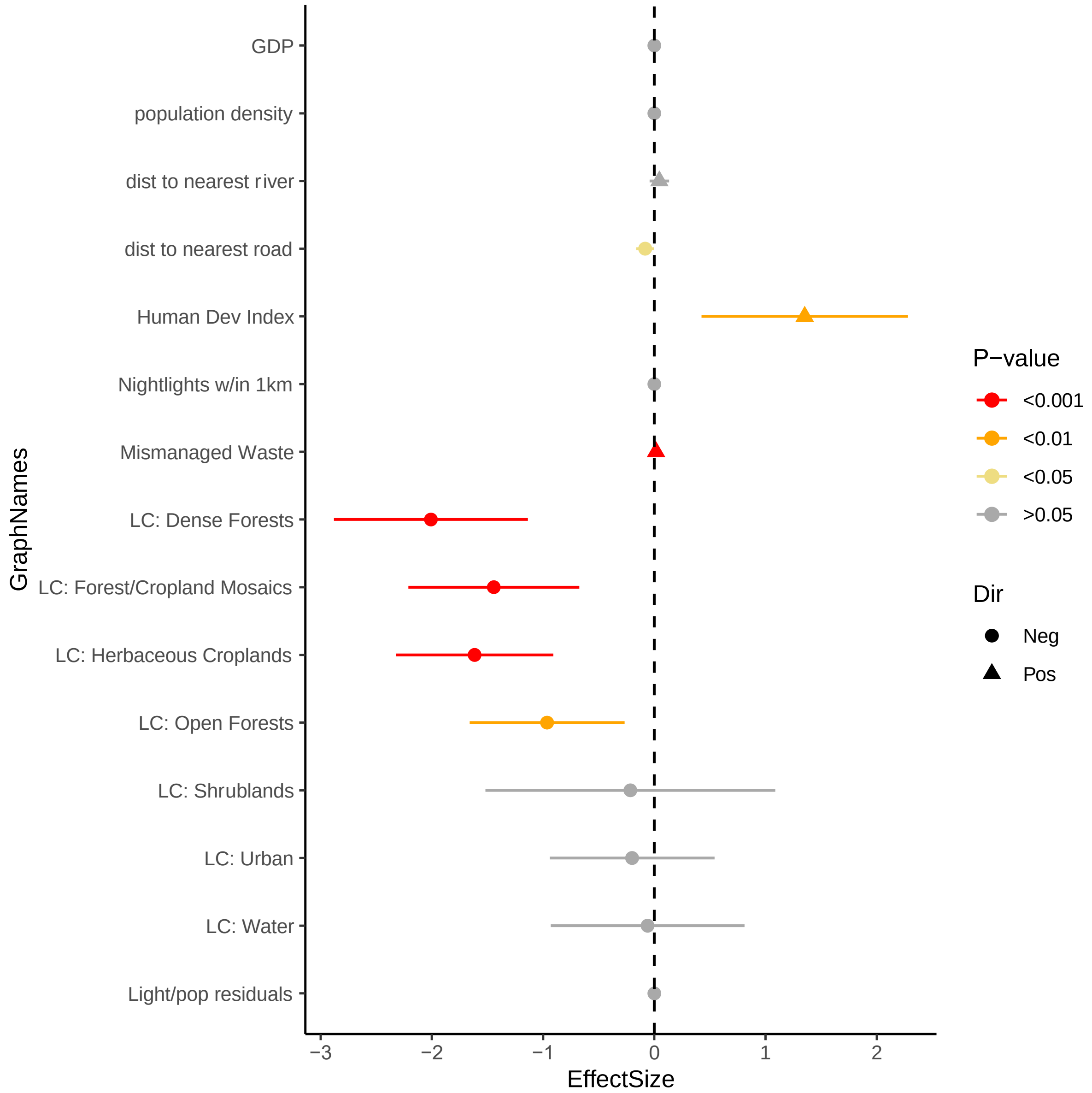


Figure 11 Model average effect size plot for Mekong model. Colour represents the p-value significance level, and the lines are the standard error for each term. Triangles denote a positive coefficient for a given factor, whereas circles denote a negative coefficient. The effect size is calculated as the median value of the factor times its coefficient. The reference level for landcover is Barren.

The terms with the highest effect size are several of the landcover categories, and the human development index (HDI).

The median litter density predicted for points in the Mekong River basin was 0.32 items per km (min 0.004, max 6.28). Using the watershed boundaries, we were able to split the river into 12 sections, with an additional two sections representing the Tonlé Sap lake and river.

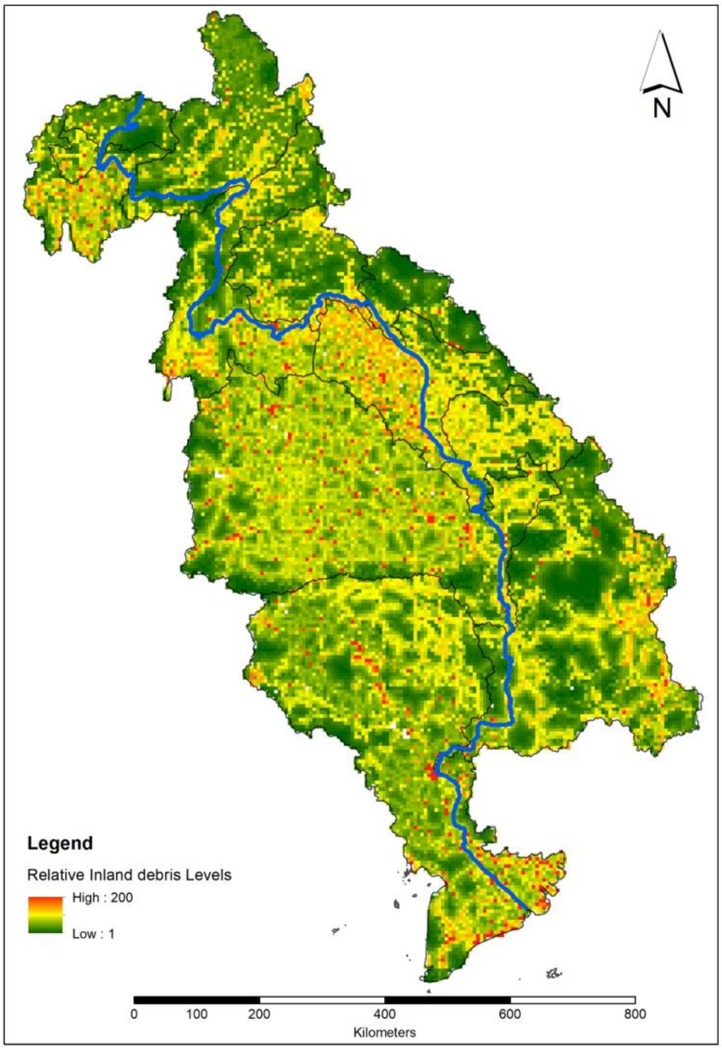
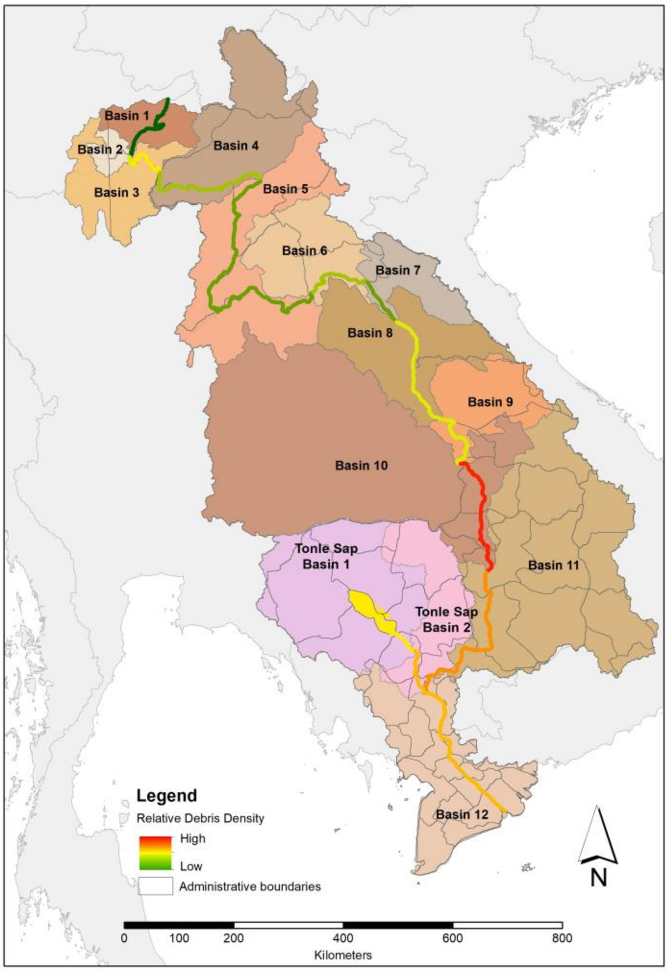


Figure 12 Relative predicted litter density in inland areas of Lower Mekong Basin watersheds.

Figure 13 Relative litter densities for each of 12 sections of the Mekong river, and two sections of the Tonle Sap lake and river. Note that these values do not represent a predicted litter density that would be within each section; rather they represent the litter density that we would expect within each section relative to the other sections. The highest value of any of the basins is scored at 1, with the other basins relative to that.



Ganga model and predictions

For the Ganga model, significant terms included HDI, several of the landuses (rice villages, residential irrigated cropland), population density, mismanaged waste, value of the built environment, and the residuals between nightlights and population density.

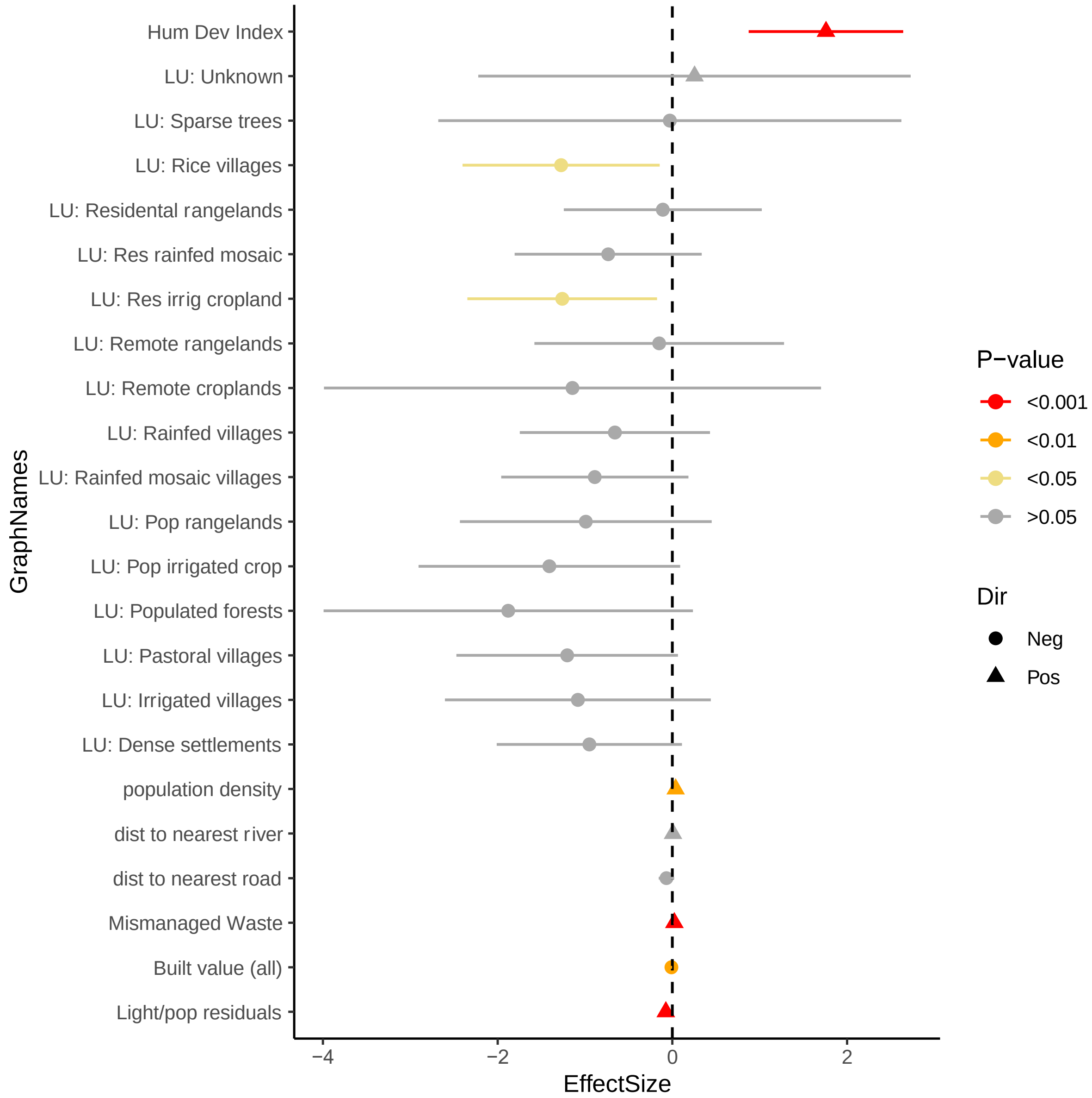


Figure 14 Model average effect size plots for Ganga model. Colour represents the p-value significance level, and the lines are the standard error for each term. Triangles denote a positive coefficient for a given factor, whereas circles denote a negative coefficient. The effect size is calculated as the median value of the factor times its coefficient. The reference level for landcover is Cropped and Pastoral Villages.

Using the best fit models, the median value of the predicted litter distributions in the Ganga was 0.43 (min 0.00372 – 77.70646).

We split the Ganga River basin into 6 sections.

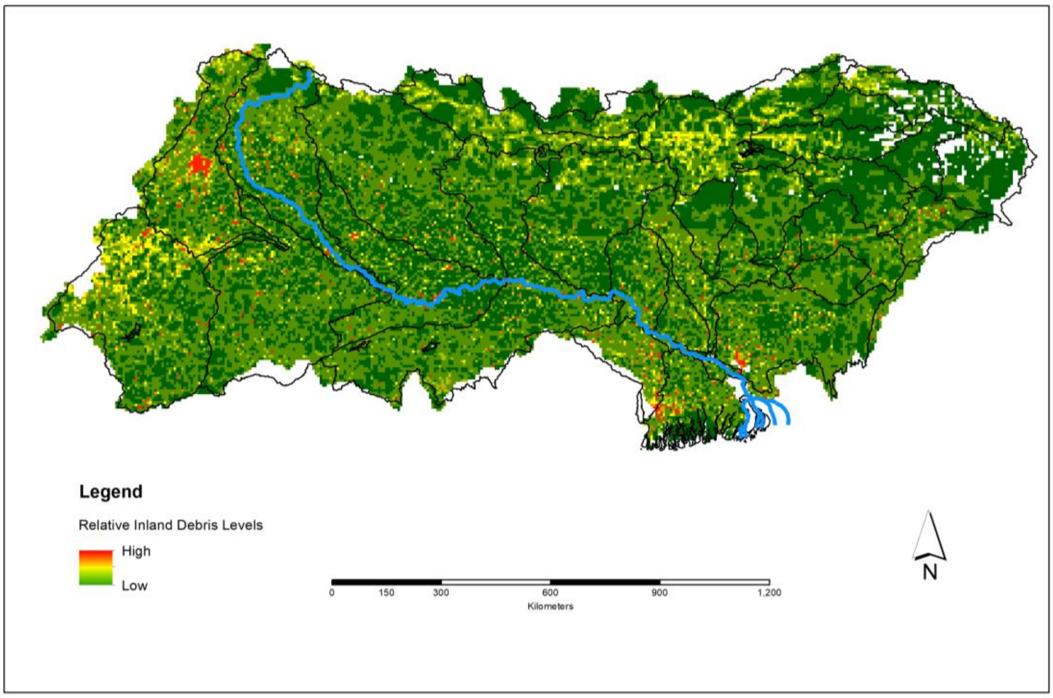


Figure 15. Relative predicted litter density in inland areas for Ganga River Basin.

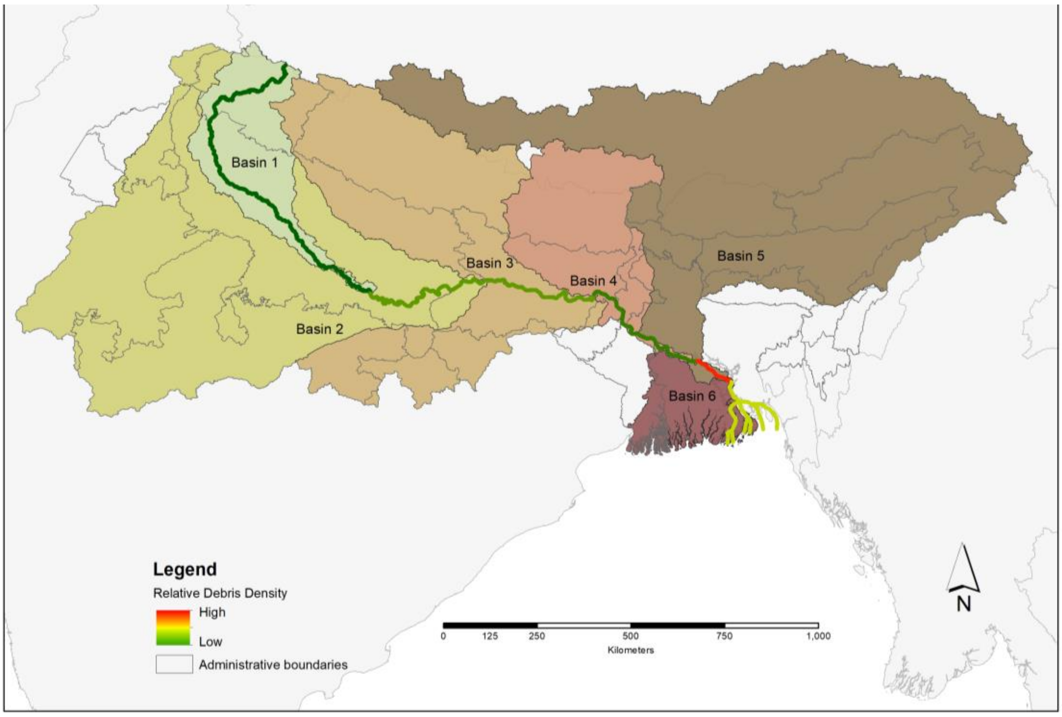


Figure 16 Relative litter densities for each of 6 sections of the Ganga river. Note that these values do not represent a predicted litter density that would be within each section; rather they represent the litter density that we would expect within each section relative to the other sections.

Comparison of relative predicted litter densities to measured microplastics concentrations in the Mekong and Ganga rivers

The Pirika study conducted along the Mekong River only reports observations in 4 out of the 14 river sections that we identified. We have reported the rank order of litter densities from low to high (observed and predicted).

Table 25. Predicted rank for the 14 sections of the Mekong river, and microplastics observations from 4 of these sections

River section	Predicted rank	Observed rank
1	1	N/A
2	8	N/A
3	10	1
4	5	N/A
5	2	2
6	4	N/A
7	3	N/A
8	6	N/A
9	7	N/A
10	14	3
11	13	N/A
12	12	4, 5 (4,5)
TLS1 (Lake)	9	N/A
TLS 2	11	N/A

The results from a correlation test indicate that the correlation is not significant ($p = .56$), and the correlation estimate is 0.44.

For the Ganga, we have observations in all 6 river sections we identified, though they are not evenly spread. For the pre-monsoon data, the correlation test yields a p value of 0.15, with a correlation of 0.662. The post-monsoon correlation yields a a p-value of 0.3366 and correlation estimate of 0.48.

Table 26 Predicted rank for litter density for the 6 sections of the Ganga River, and microplastics observations from these sections

River section	Predicted rank	Mean Observed rank (pre-monsoon)	Mean Observed rank (post-monsoon)
1	1	(1,4,6,2) 3.25	3.25
2	3	9	5
3	4	3	3
4	2	4	8
5	6	10	8
6	5	(7,8) 7.5	(6,10) 8

13.2 Relative fishing pressure

Mekong fishing pressure

For the Mekong river, using the proxy of population density within 10 km of the river, we calculated the relative fishing pressure as in Figure 17.

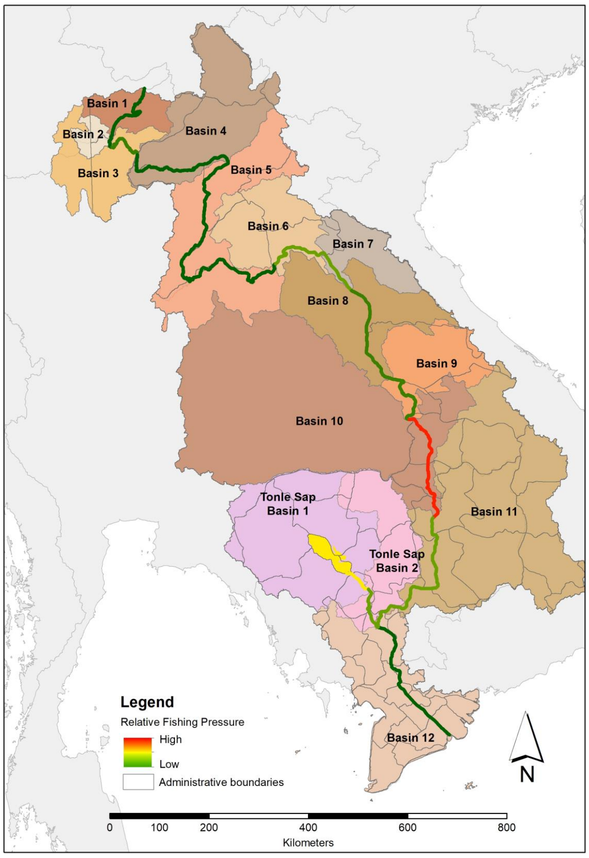


Figure 17 Relative fishing pressure at sections along the Mekong River, using a proxy of population density within 10km of the river.

For the Ganga River, using the average ranks of observed ALDFG at each section of the river (Napper et al, 2021), we calculated the relative fishing pressure as in Figure 18.

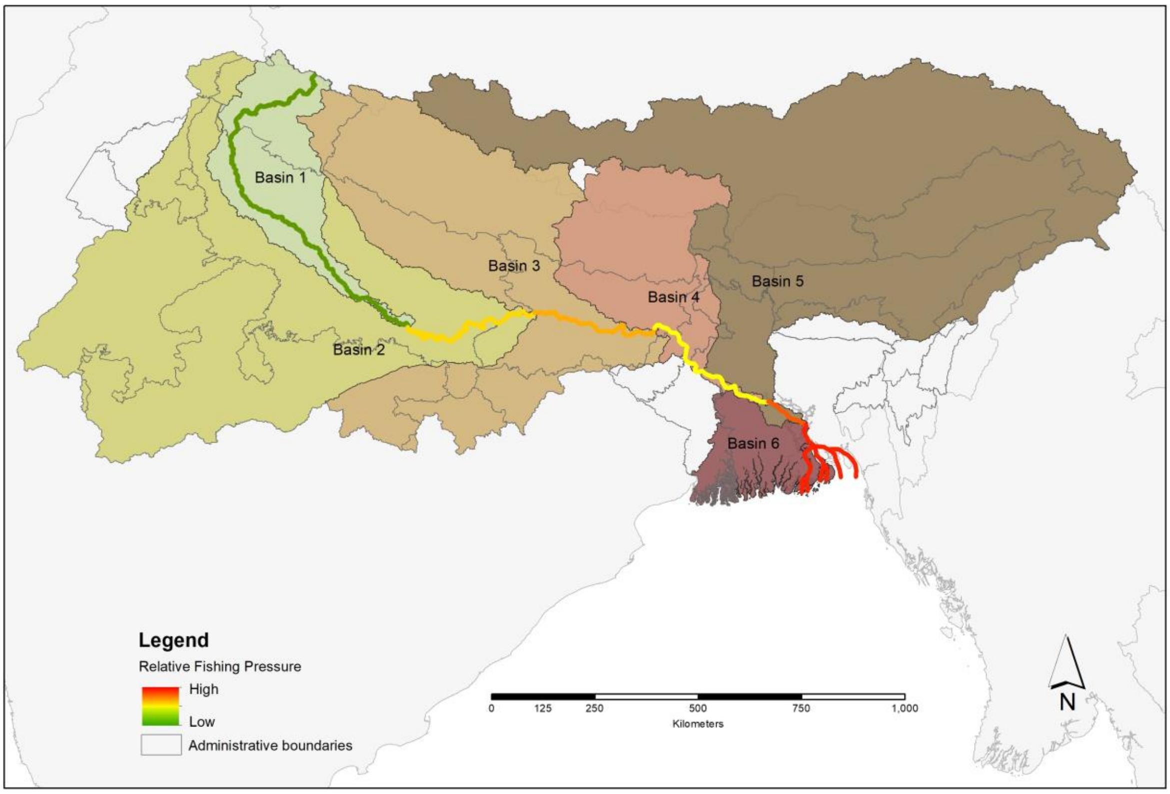
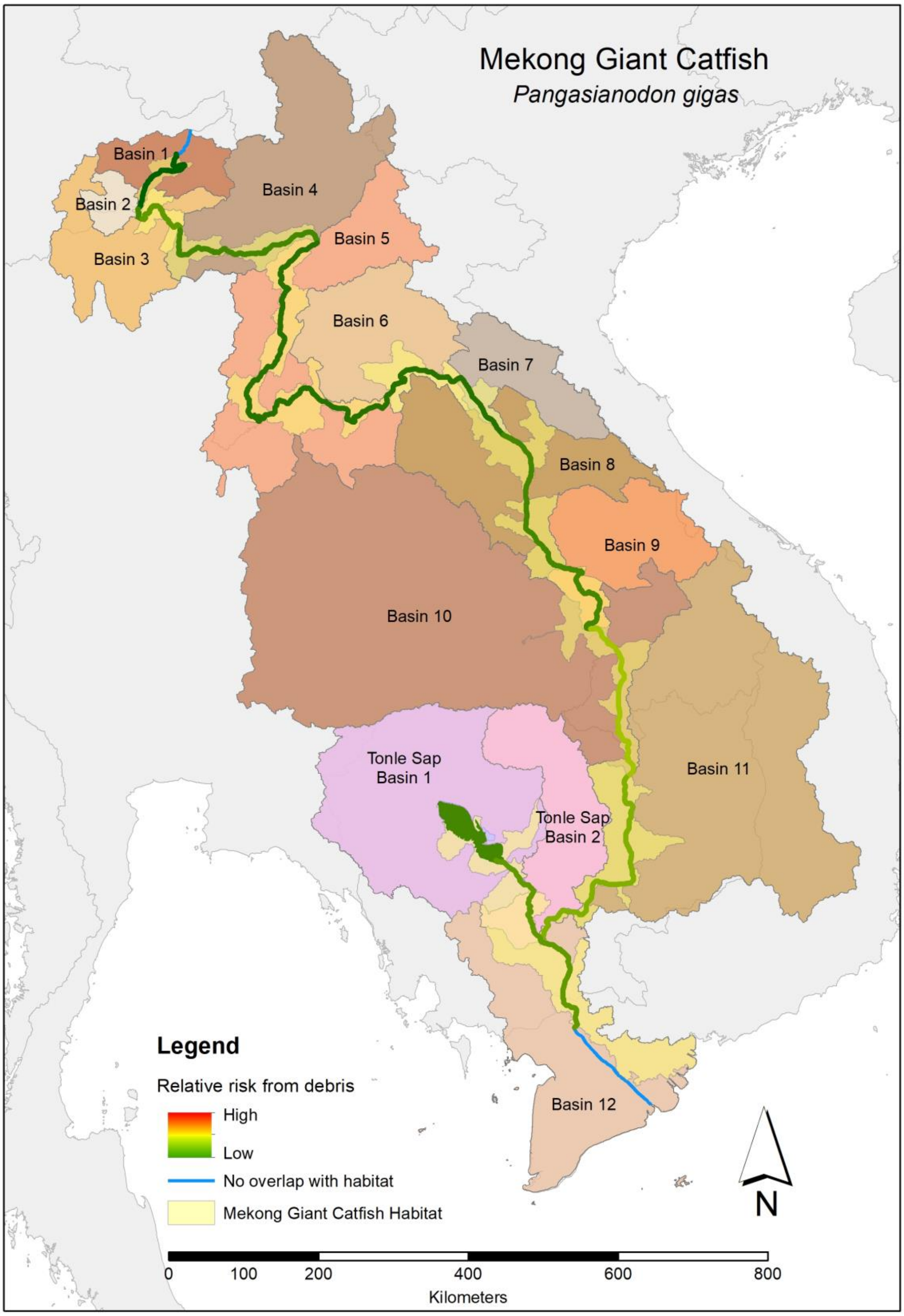


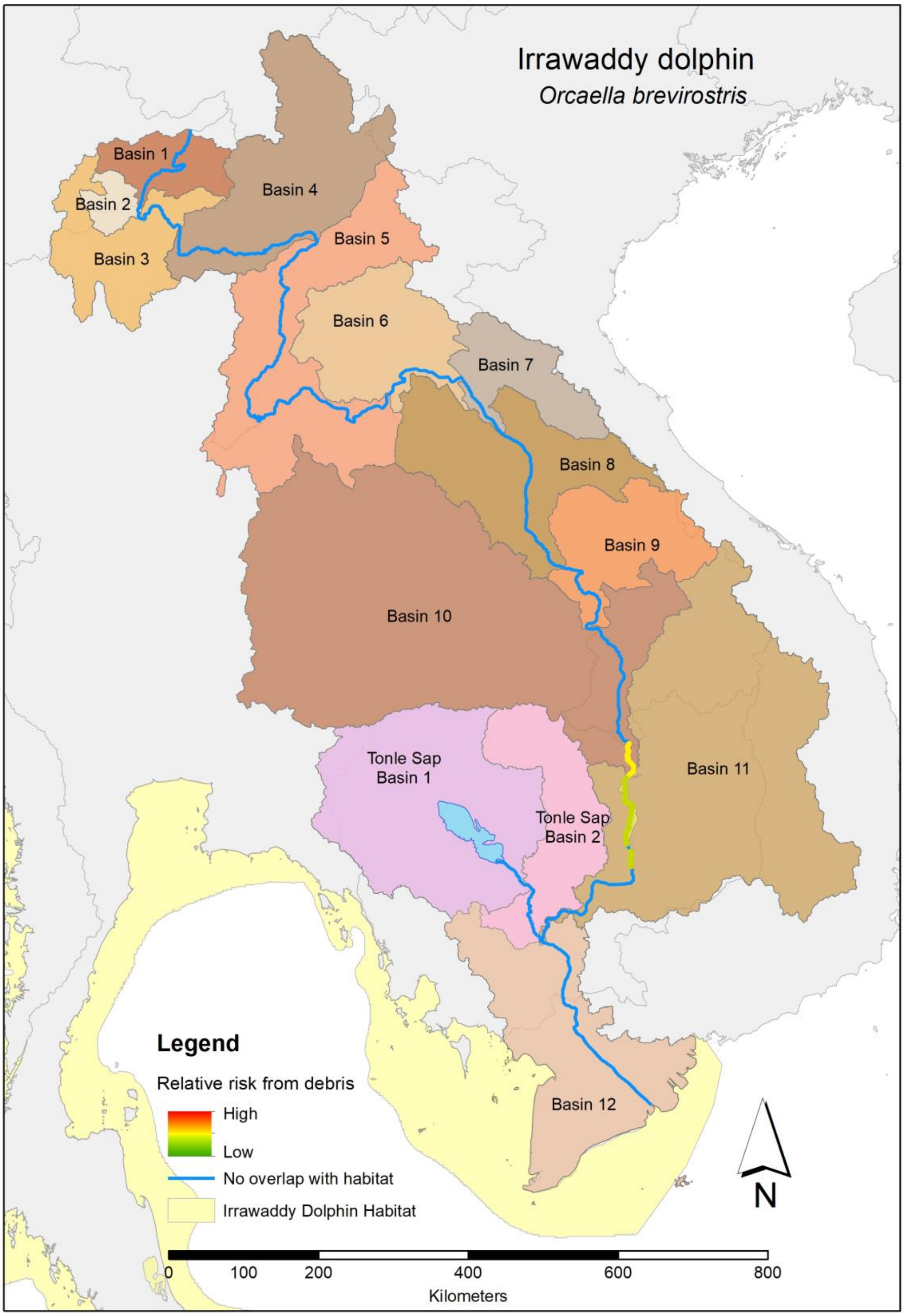
Figure 18 Relative fishing pressure at sections along the Ganga River, using observed ranked densities of ALDFG (Napper et. al, 2021)

14 Risk maps

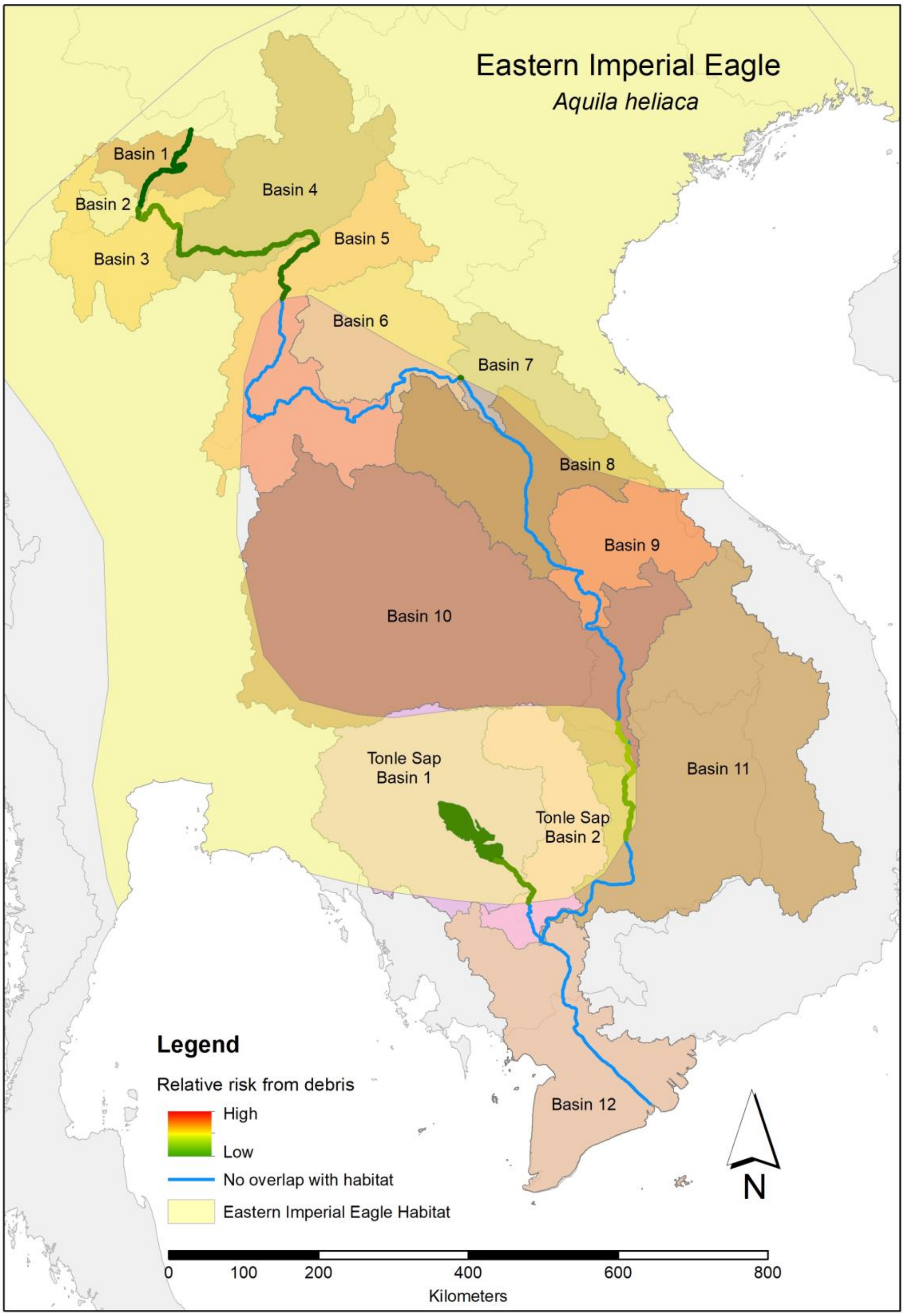
14.1 Mekong River CMS species relative risk from litter ingestion

The following maps present the relative risk to CMS-listed species from ingesting litter across 14 sectors of the Mekong River (including the Tonlé Sap basin). Note that the maximum level of risk would occur in a species with a high likelihood of interacting with litter, and an expected lethal outcome from that litter, in the section of the river with the highest expected litter load.


Mekong Giant Catfish
Pangasianodon gigas
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Basin 7
Basin 8
Basin 9
Basin 10
Basin 11
Tonle Sap Basin 1
Tonle Sap Basin 2
Basin 12
Legend
Relative risk from debris
High
Low
No overlap with habitat
Mekong Giant Catfish Habitat
N
0
100
200
400
600
800
Kilometers


Irrawaddy dolphin
Orcaella brevirostris
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Basin 7
Basin 8
Basin 9
Basin 10
Basin 11
Tonle Sap Basin 1
Tonle Sap Basin 2
Basin 12
Legend
Relative risk from debris
High
Low
No overlap with habitat
Irrawaddy Dolphin Habitat
N
0
100
200
400
600
800
Kilometers


Bengal Florican
Houbaropsis bengalensis bengalensis
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Basin 7
Basin 8
Basin 9
Basin 10
Basin 11
Tonle Sap Basin 1
Tonle Sap Basin 2
Basin 12
Legend
Relative risk from debris
High
Low
No overlap with habitat
Bengal Florican Habitat
N
0 100 200 400 600 800
Kilometers

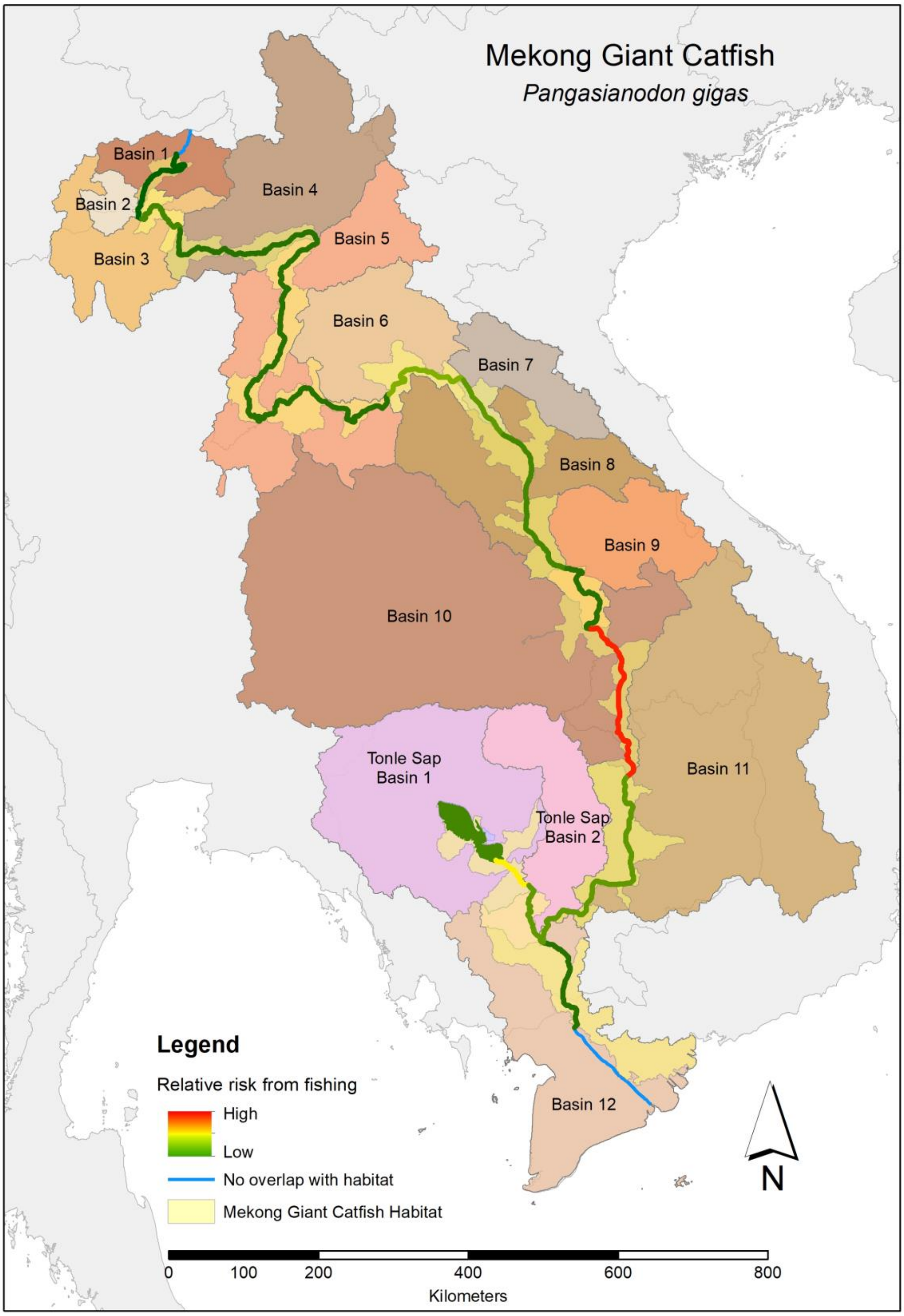


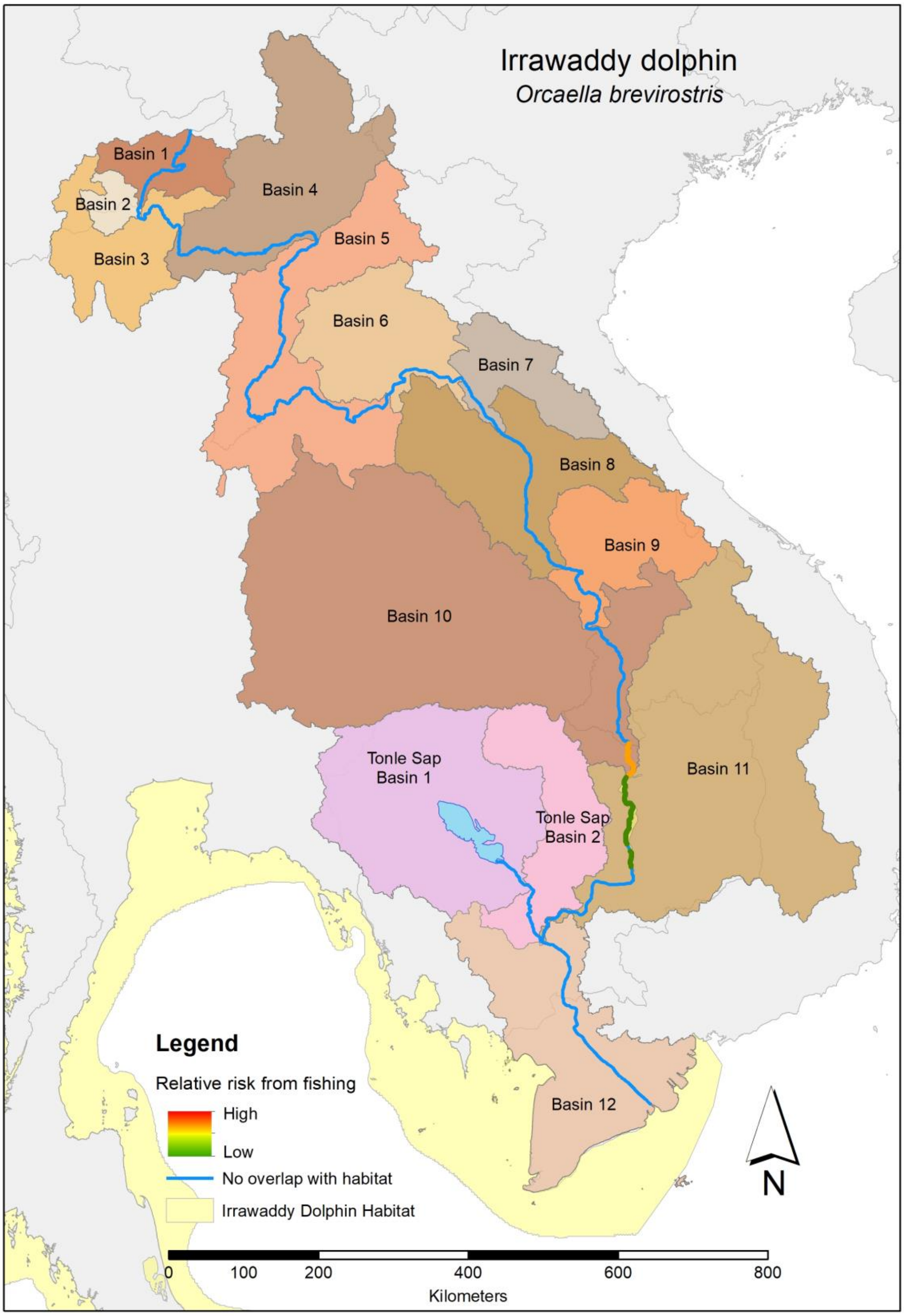
Eastern Imperial Eagle
Aquila heliaca
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Basin 7
Basin 8
Basin 9
Basin 10
Basin 11
Basin 12
Tonle Sap Basin 1
Tonle Sap Basin 2
Legend
Relative risk from debris
High
Low
No overlap with habitat
Eastern Imperial Eagle Habitat
0
100
200
400
600
800
Kilometers
N


Sarus Crane
Antigone Antigone
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Basin 7
Basin 8
Basin 9
Basin 10
Basin 11
Tonle Sap Basin 1
Tonle Sap Basin 2
Basin 12
Legend
Relative risk from debris
High
Low
No overlap with habitat
Sarus Crane Habitat
0
100
200
400
600
800
Kilometers
N

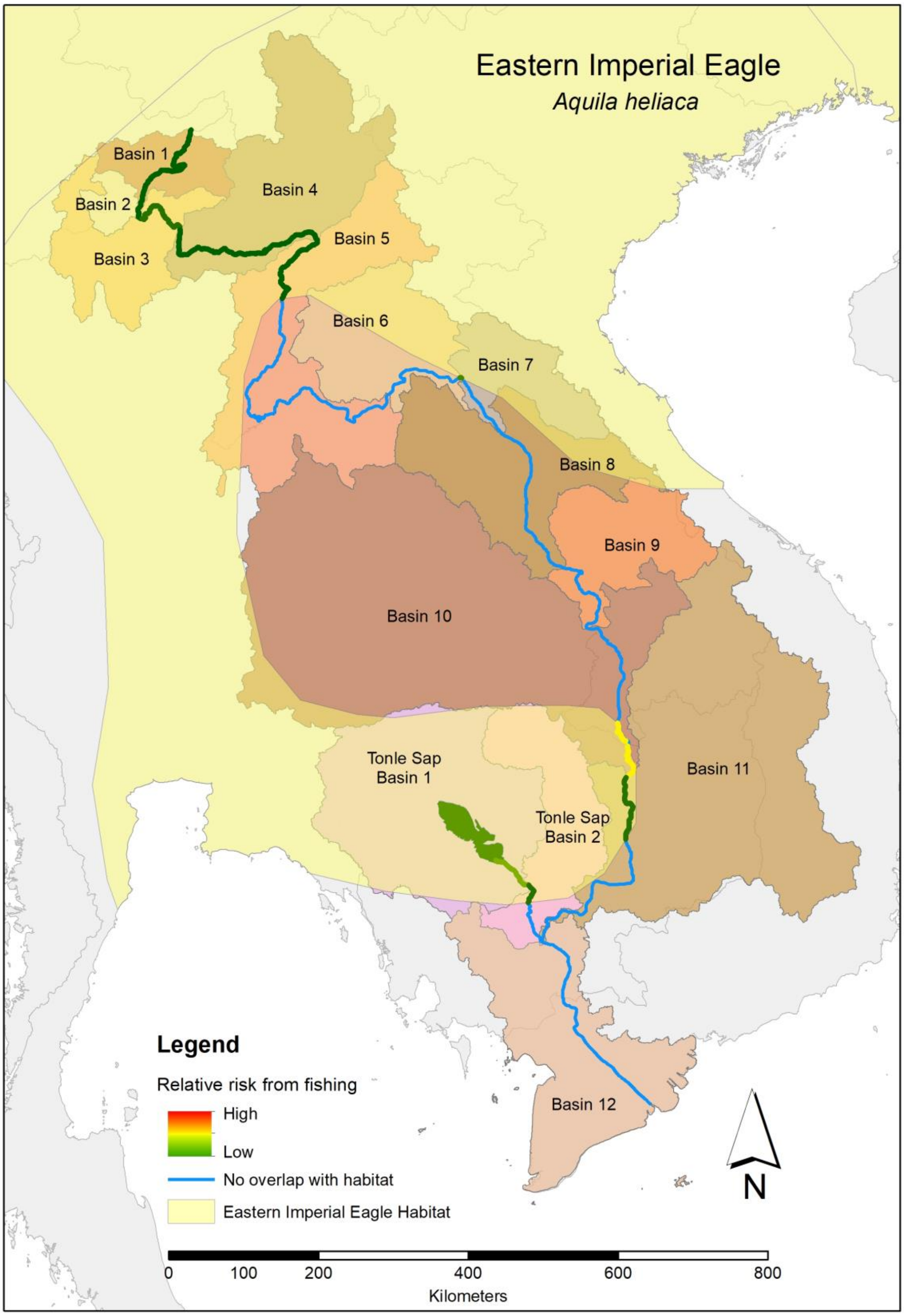
14.2 Mekong River CMS species relative risk from fishing debris

The following maps present the relative risk to CMS-listed species from entanglement with fishing debris across 14 sectors of the Mekong River (including the Tonlé Sap basin). Note that the maximum level of risk would occur in a species with a high likelihood of interacting with debris, and an expected lethal outcome from that debris, in the section of the river with the highest expected fishing pressure.


Mekong Giant Catfish
Pangasianodon gigas
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Basin 7
Basin 8
Basin 9
Basin 10
Basin 11
Tonle Sap Basin 1
Tonle Sap Basin 2
Basin 12
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Mekong Giant Catfish Habitat
0 100 200 400 600 800
Kilometers
N


Irrawaddy dolphin
Orcaella brevirostris
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Basin 7
Basin 8
Basin 9
Basin 10
Basin 11
Tonle Sap Basin 1
Tonle Sap Basin 2
Basin 12
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Irrawaddy Dolphin Habitat
0
100
200
400
600
800
Kilometers
N

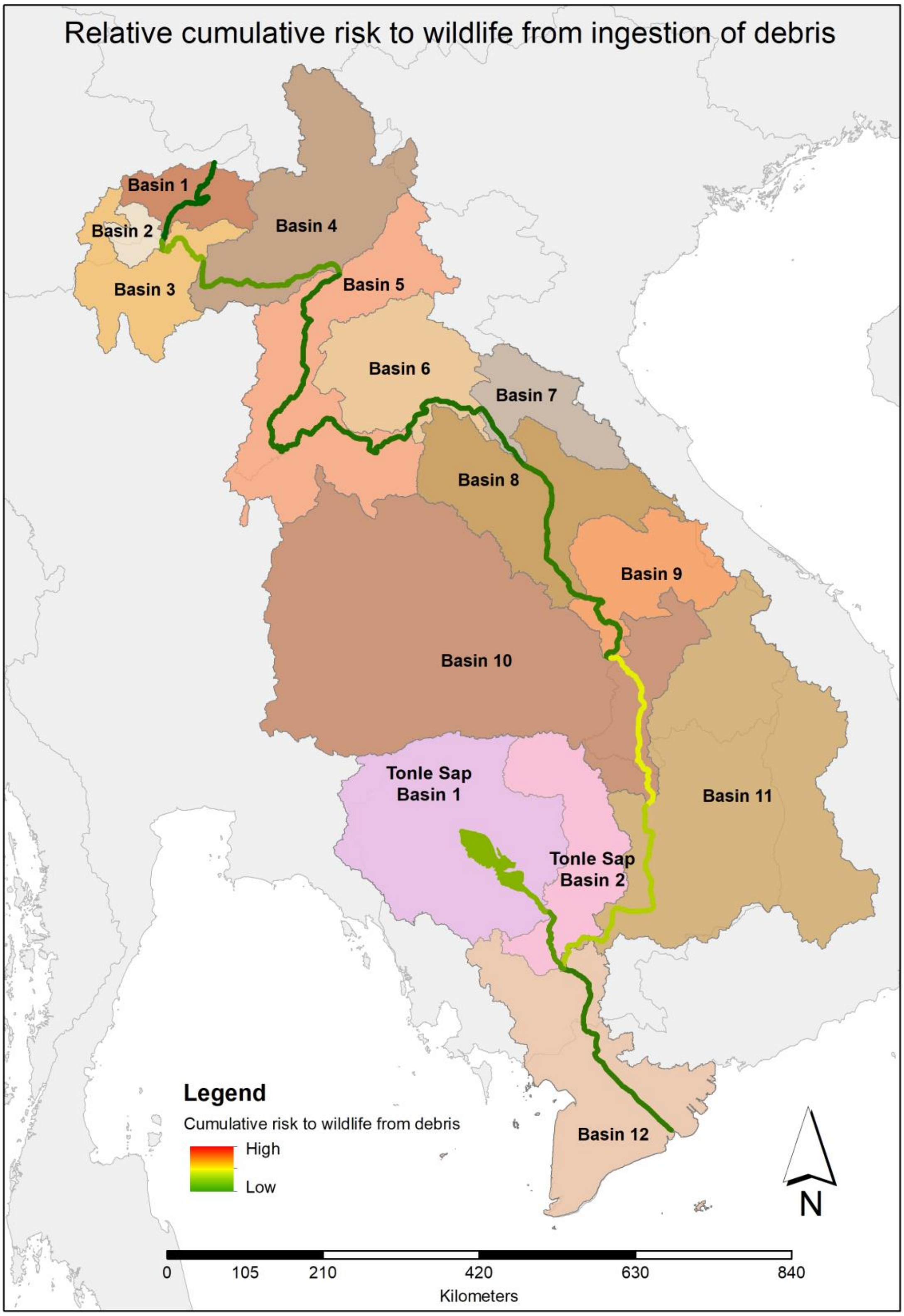

Bengal Florican
Houbaropsis bengalensis bengalensis
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Basin 7
Basin 8
Basin 9
Basin 10
Basin 11
Tonle Sap Basin 1
Tonle Sap Basin 2
Basin 12
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Bengal Florican Habitat
0 100 200 400 600 800
Kilometers
N

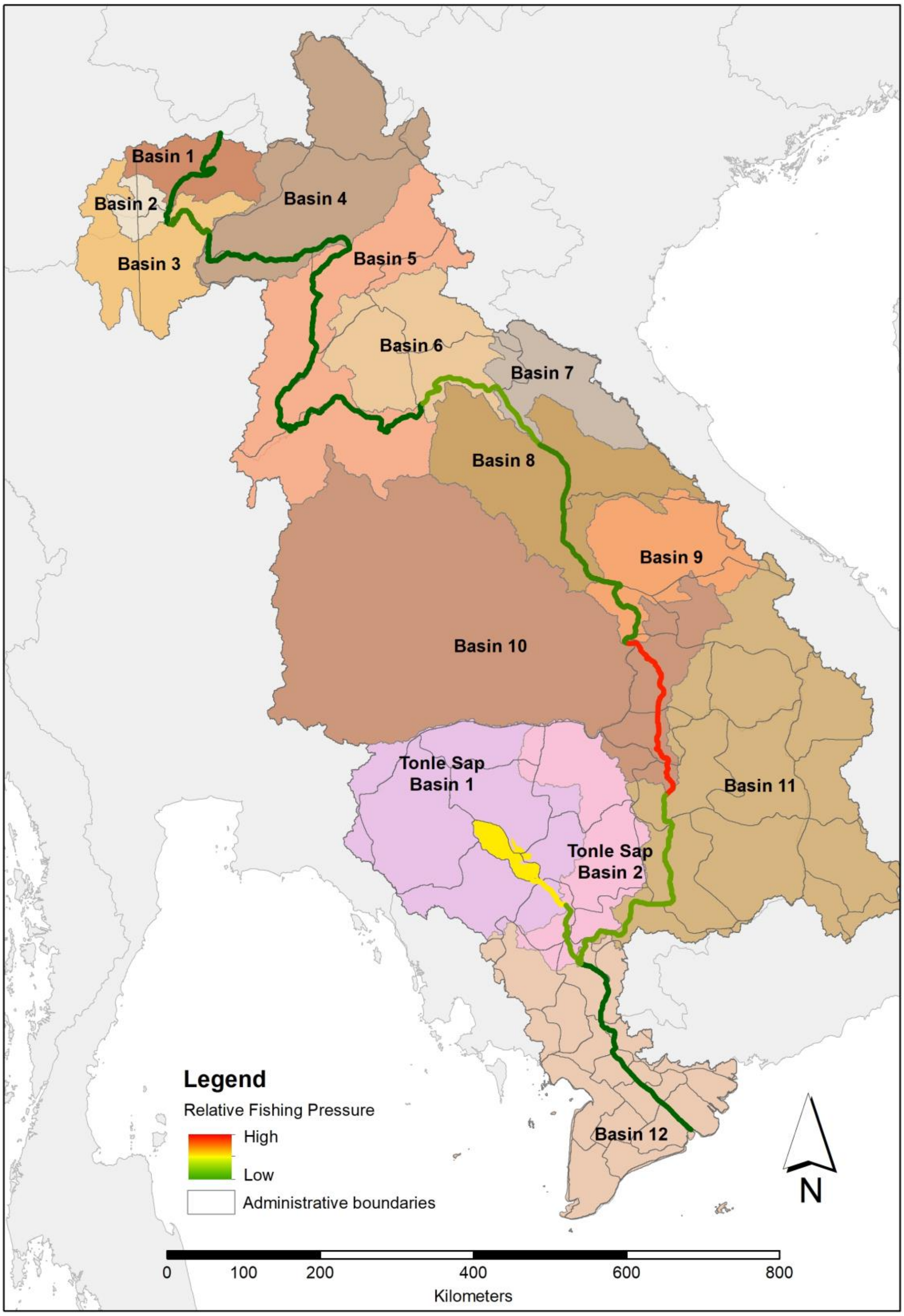

Eastern Imperial Eagle
Aquila heliaca
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Basin 7
Basin 8
Basin 9
Basin 10
Basin 11
Basin 12
Tonle Sap Basin 1
Tonle Sap Basin 2
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Eastern Imperial Eagle Habitat
0
100
200
400
600
800
Kilometers
N

Sarus Crane
Antigone Antigone
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Basin 7
Basin 8
Basin 9
Basin 10
Basin 11
Basin 12
Tonle Sap Basin 1
Tonle Sap Basin 2
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Sarus Crane Habitat
N
0
100
200
400
600
800
Kilometers

14.3 Mekong River CMS species cumulative risk

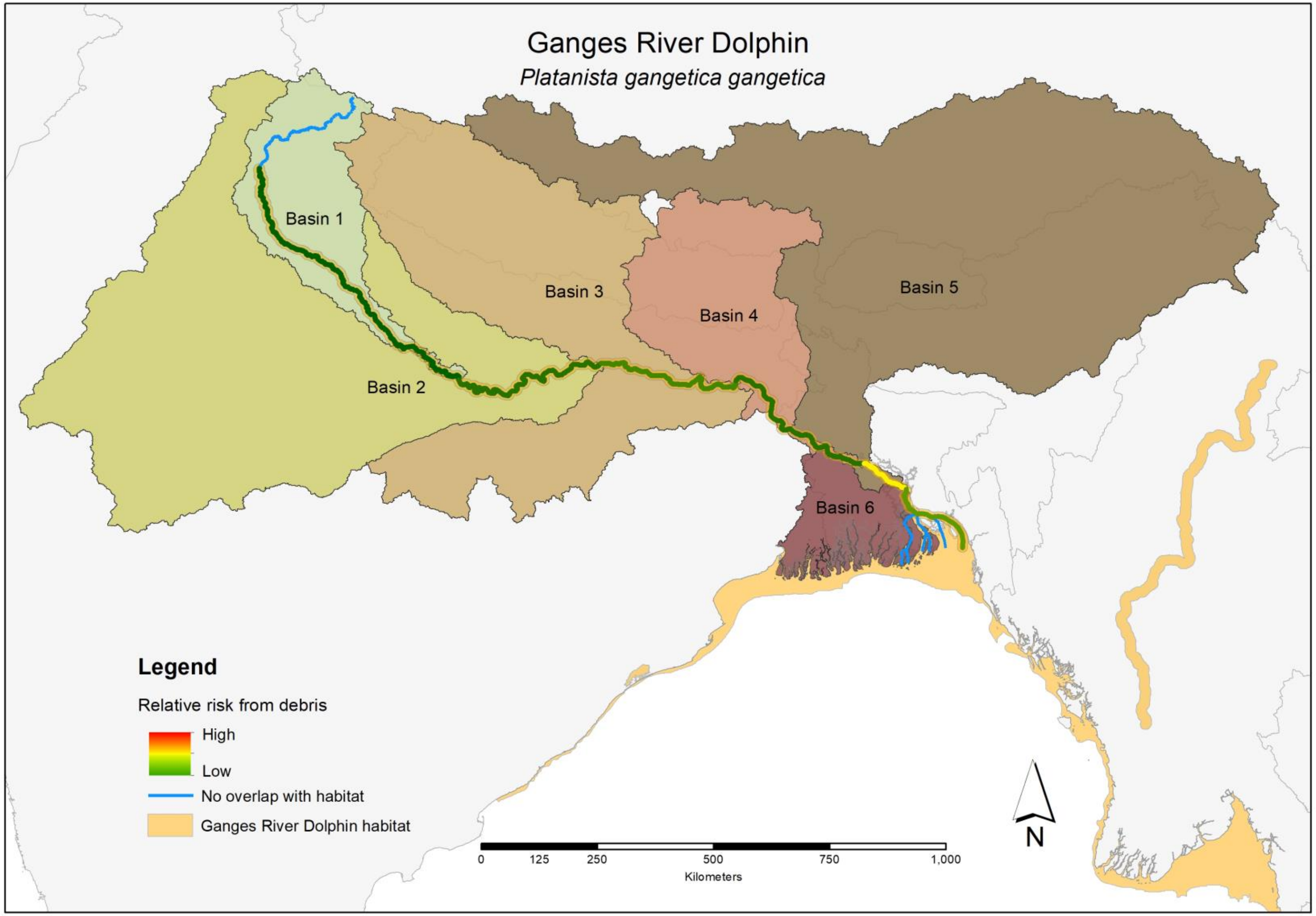
The following maps present the cumulative risk to CMS-listed species from ingesting litter and from entanglement in fishing debris across 14 sectors of the Mekong River (including the Tonlé Sap basin). Note that the risk is scaled to the maximum cumulative risk for any section of the river, across both ingestion and entanglement risk, so as to provide a comparative risk score.


Relative cumulative risk to wildlife from ingestion of debris
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Basin 7
Basin 8
Basin 9
Basin 10
Basin 11
Tonle Sap Basin 1
Tonle Sap Basin 2
Basin 12
Legend
Cumulative risk to wildlife from debris
High
Low
N
0
105
210
420
630
840
Kilometers

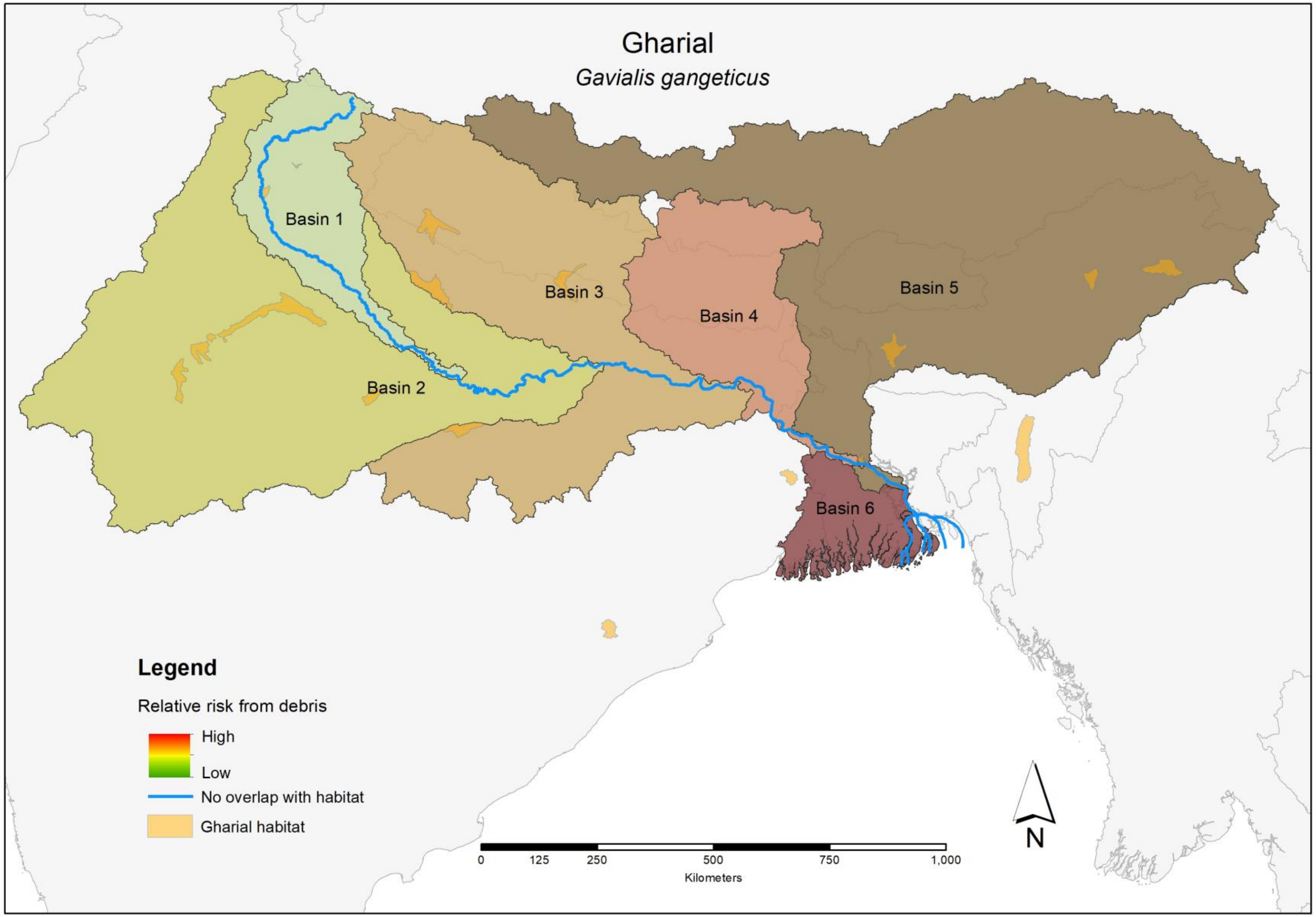

Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Basin 7
Basin 8
Basin 9
Basin 10
Basin 11
Tonle Sap Basin 1
Tonle Sap Basin 2
Basin 12
Legend
Relative Fishing Pressure
High
Low
Administrative boundaries
N
0
100
200
400
600
800
Kilometers

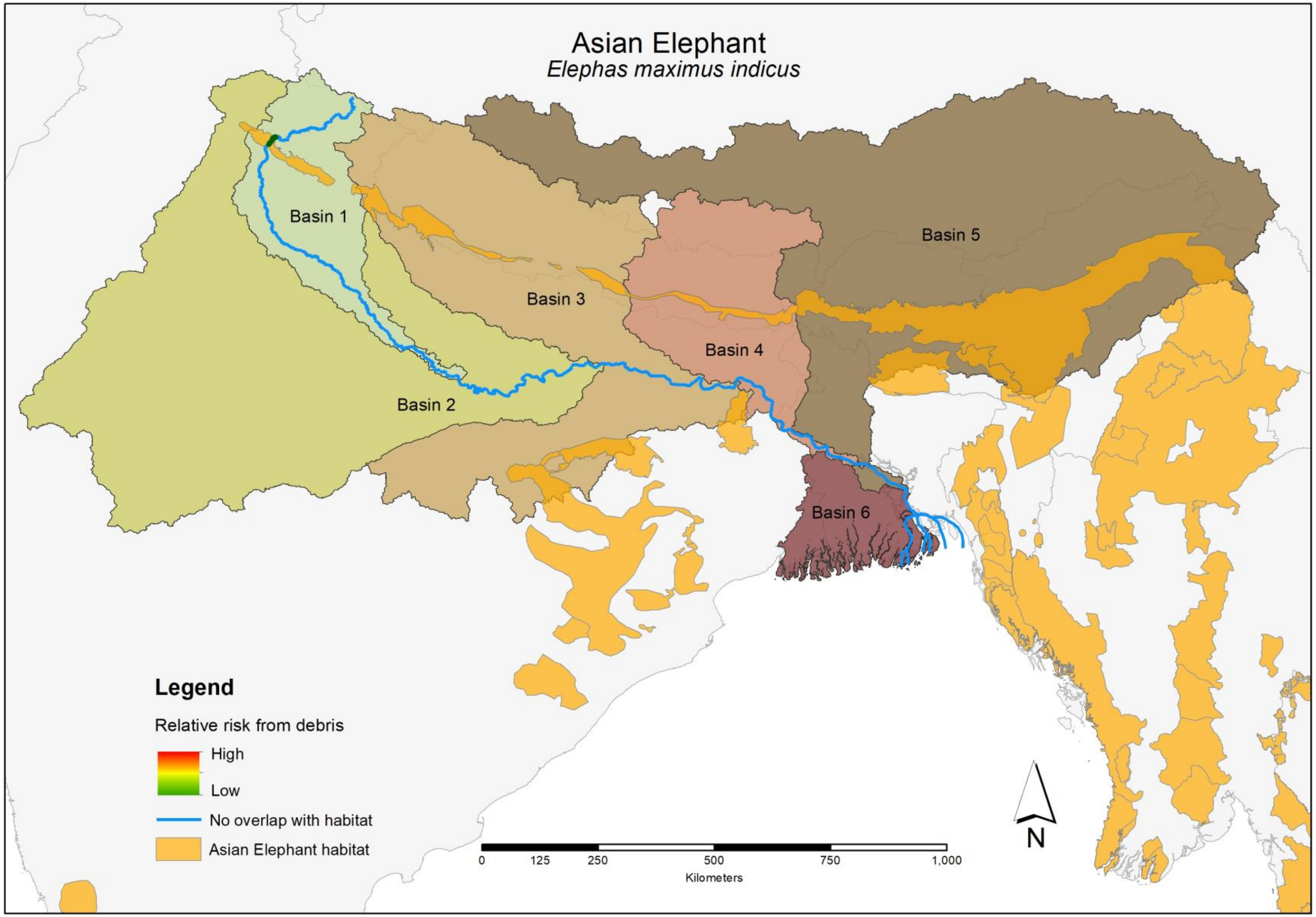
14.4 Ganga River CMS species relative risk from litter ingestion

The following maps present the relative risk to CMS-listed species from ingesting litter across 6 sectors of the Ganga River. Note that the maximum level of risk would occur in a species with a high likelihood of interacting with litter, and an expected lethal outcome from that litter, in the section of the river with the highest expected litter load.

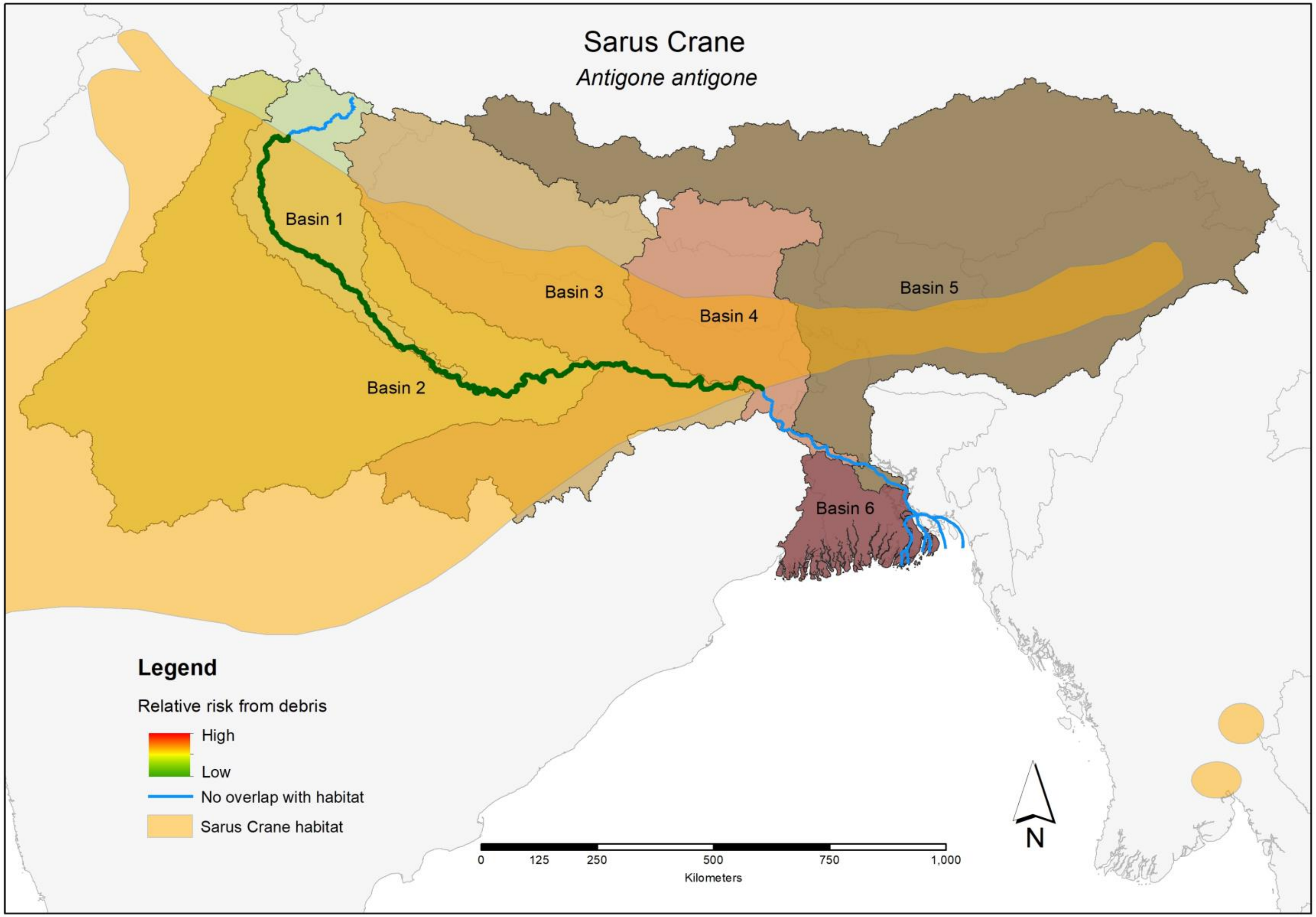


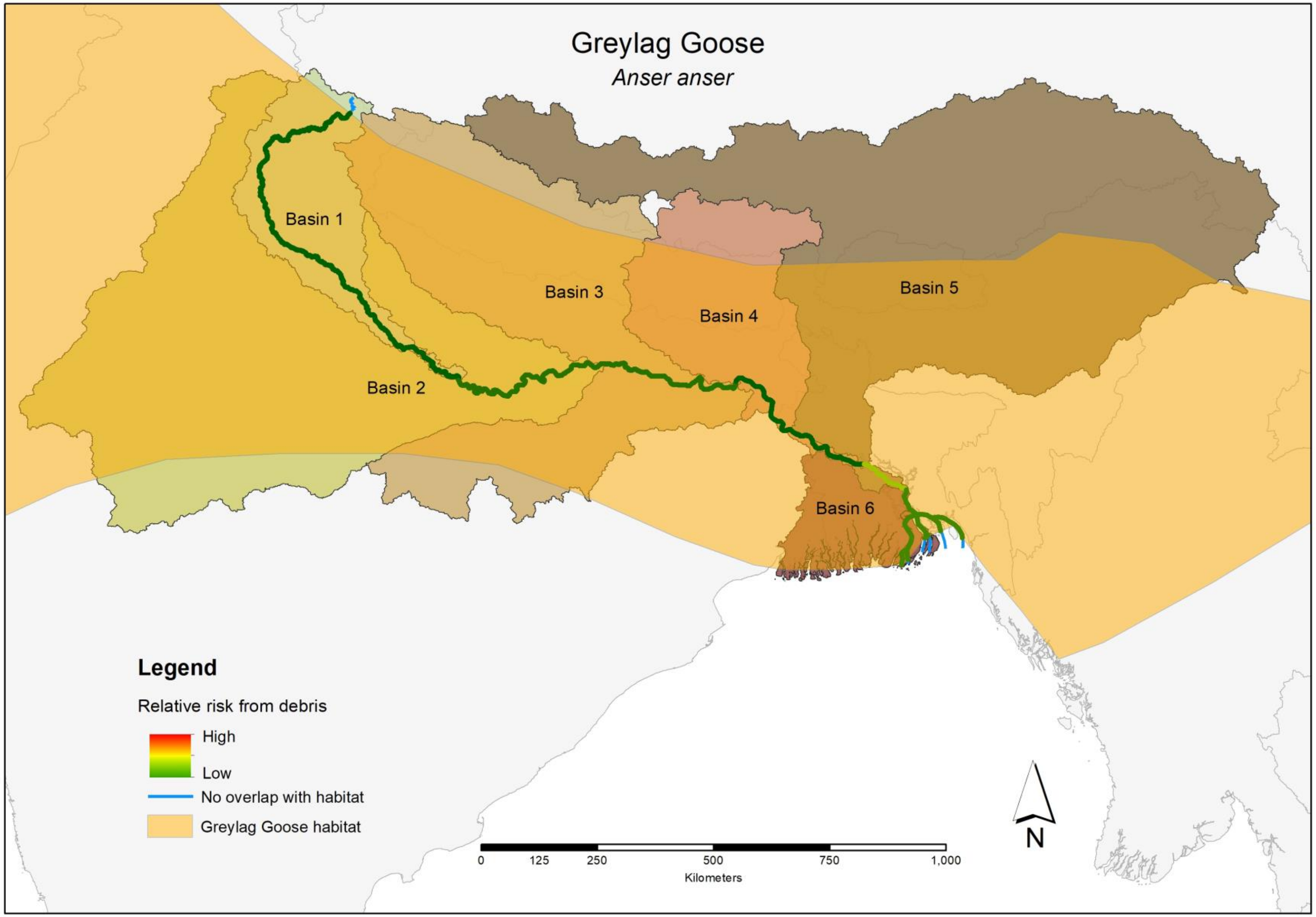
Ganges River Dolphin
Platanista gangetica gangetica
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Ganges River Dolphin habitat
0
125
250
500
750
1,000
Kilometers
N

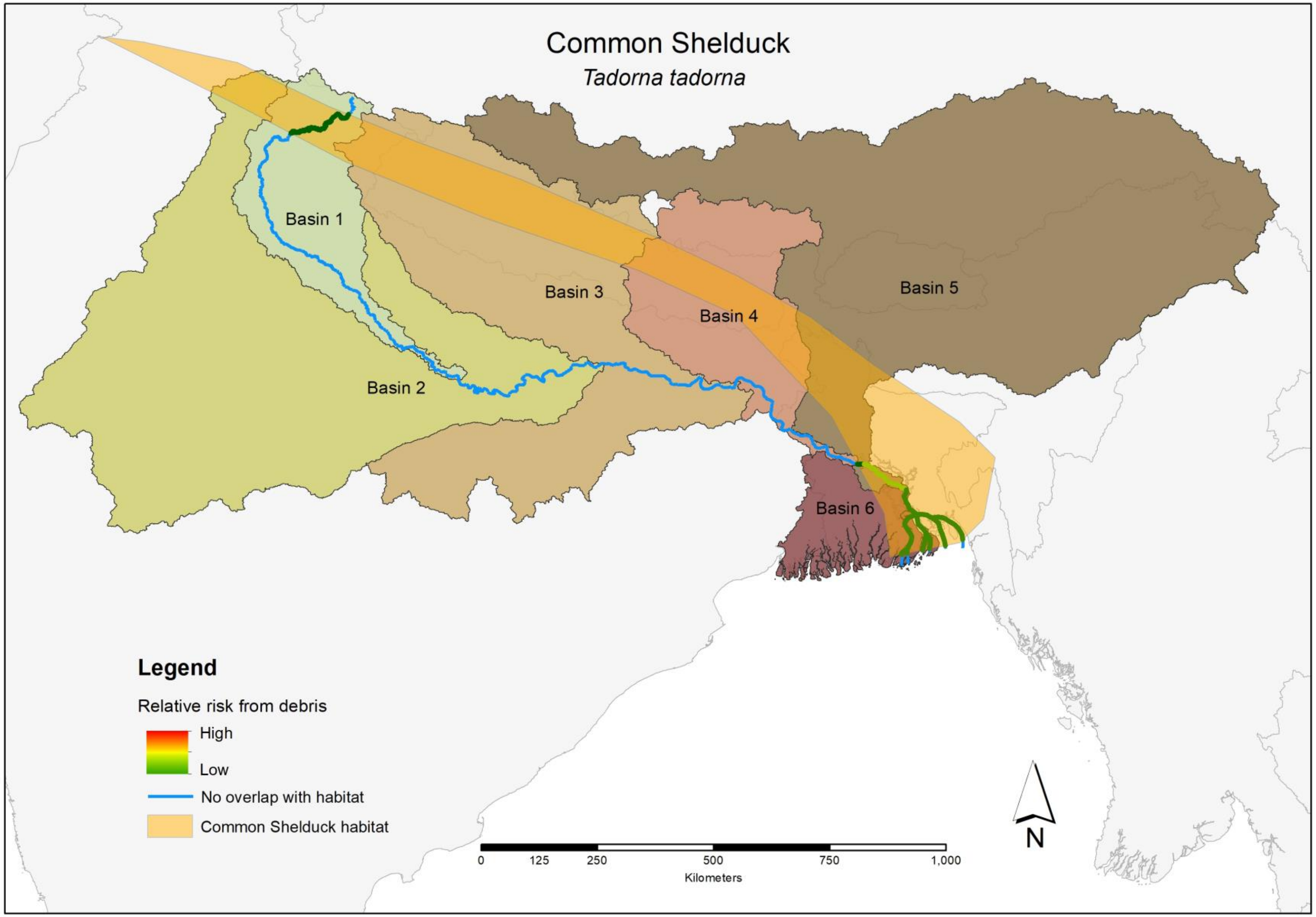

Gharial
Gavialis gangeticus
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Gharial habitat
0
125
250
500
750
1,000
Kilometers
N

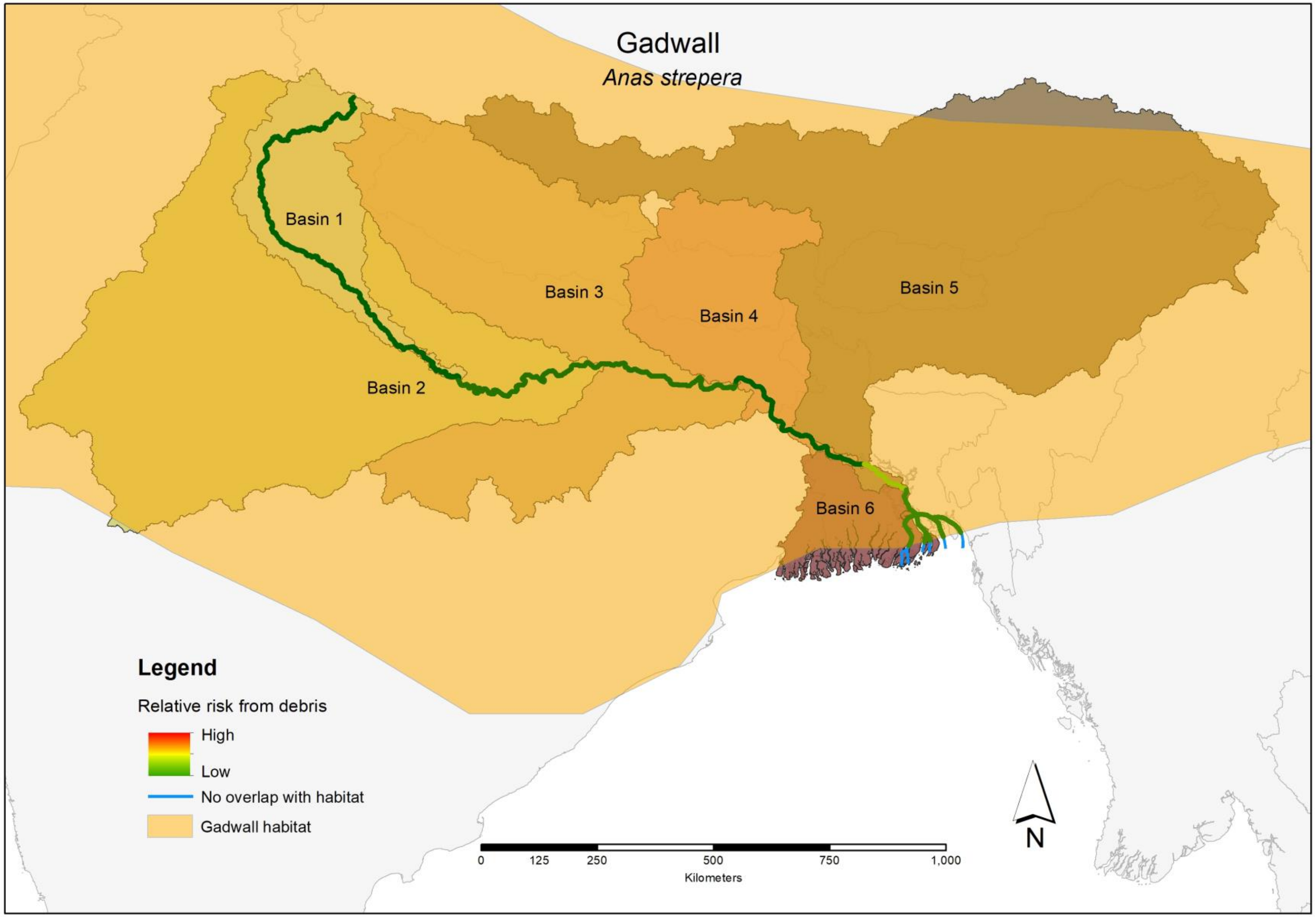


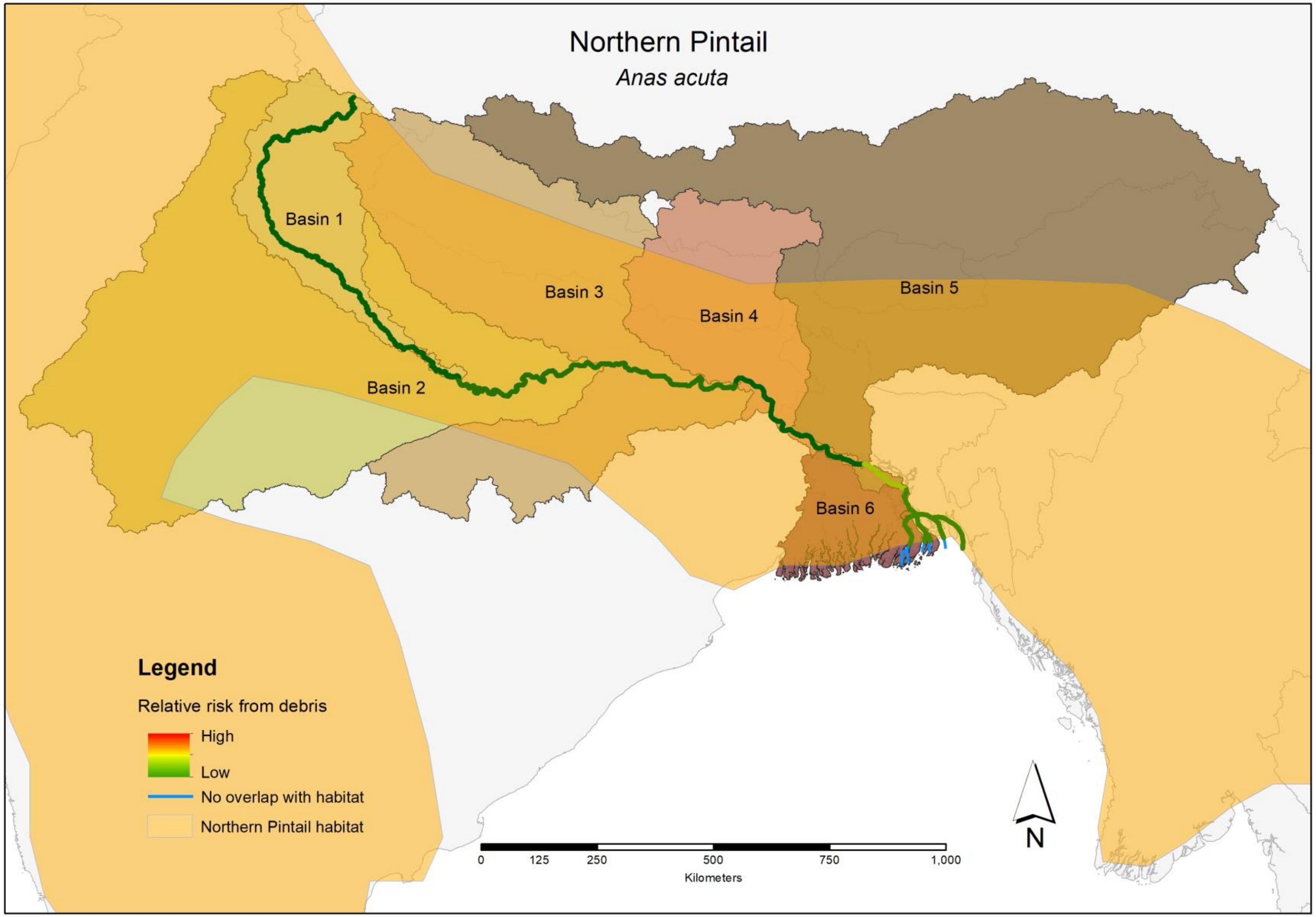
Asian Elephant
Elephas maximus indicus
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Asian Elephant habitat
0
125
250
500
750
1,000
Kilometers
N

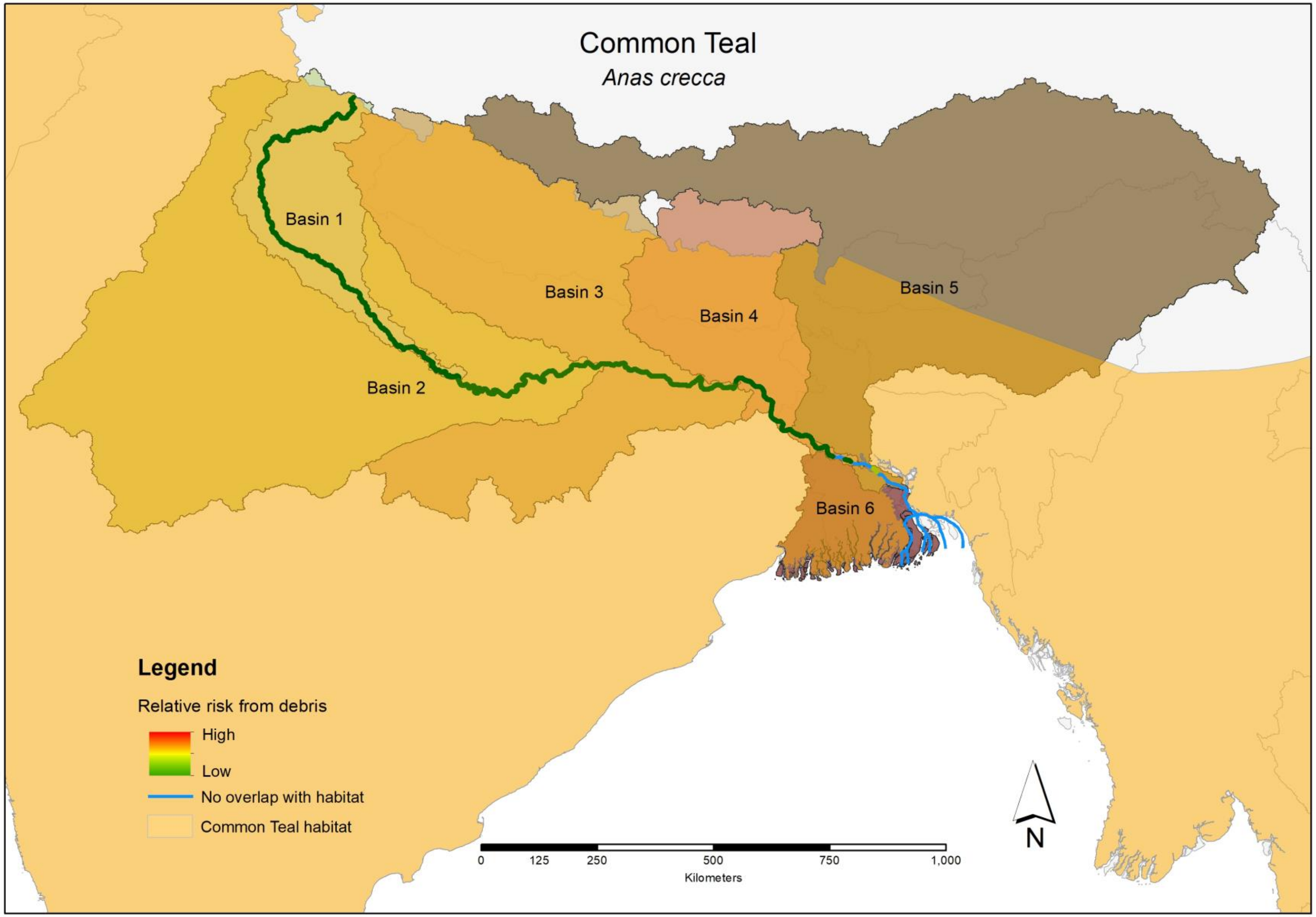

Sarus Crane
Antigone antigone
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Sarus Crane habitat
0
125
250
500
750
1,000
Kilometers
N

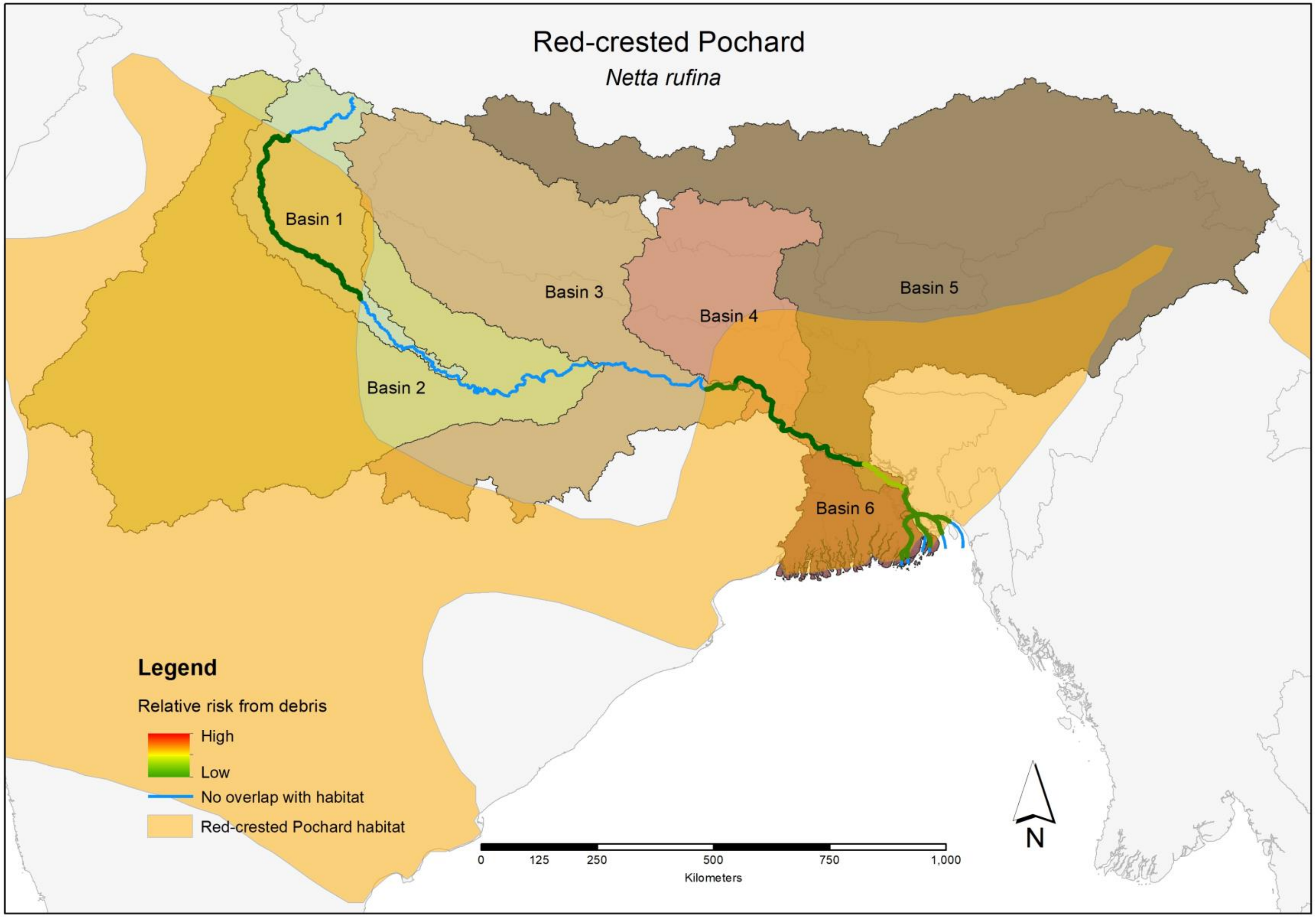

Greylag Goose
Anser anser
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Greylag Goose habitat
0
125
250
500
750
1,000
Kilometers
N

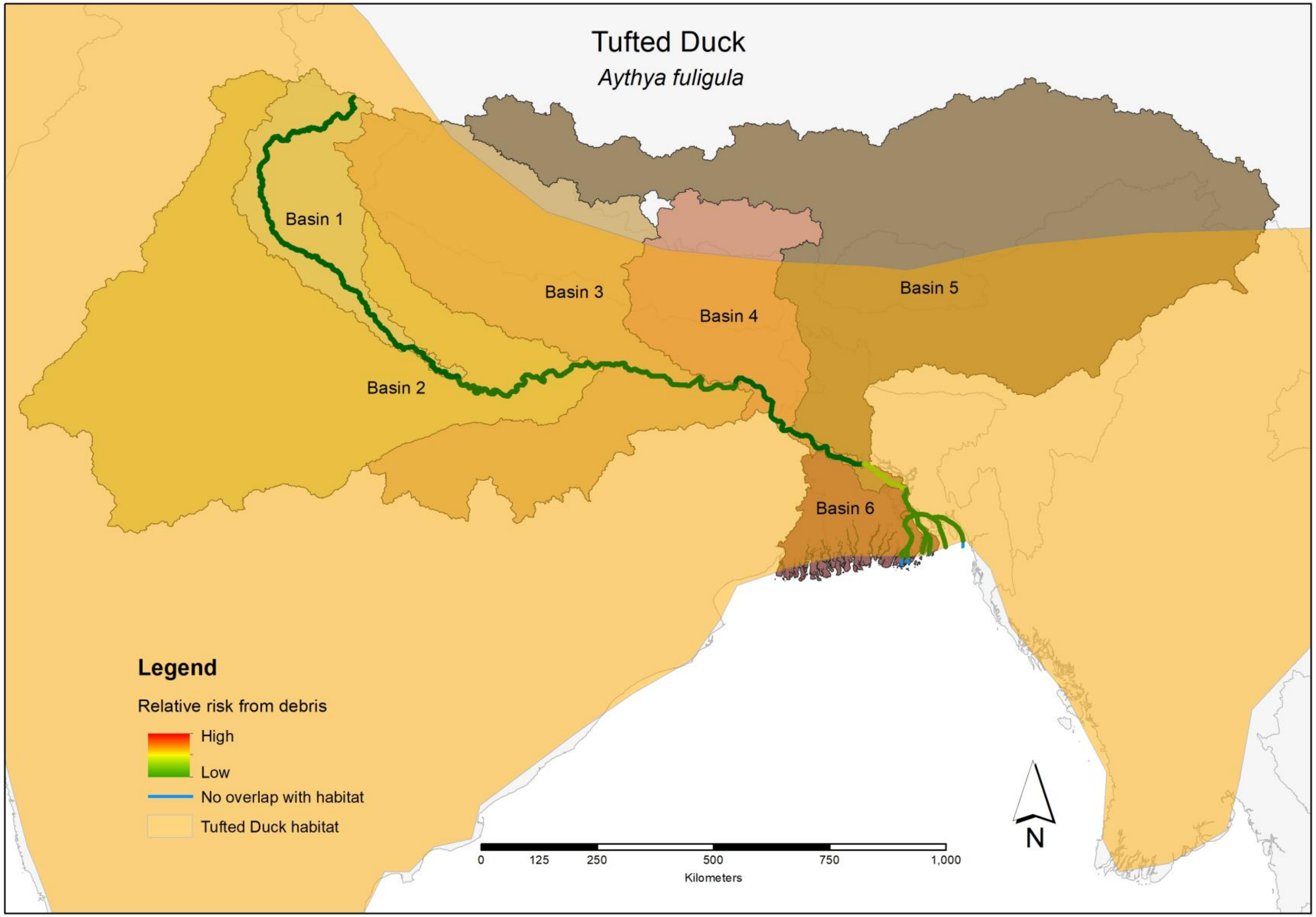

Common Shelduck
Tadorna tadorna
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Common Shelduck habitat
0
125
250
500
750
1,000
Kilometers
N

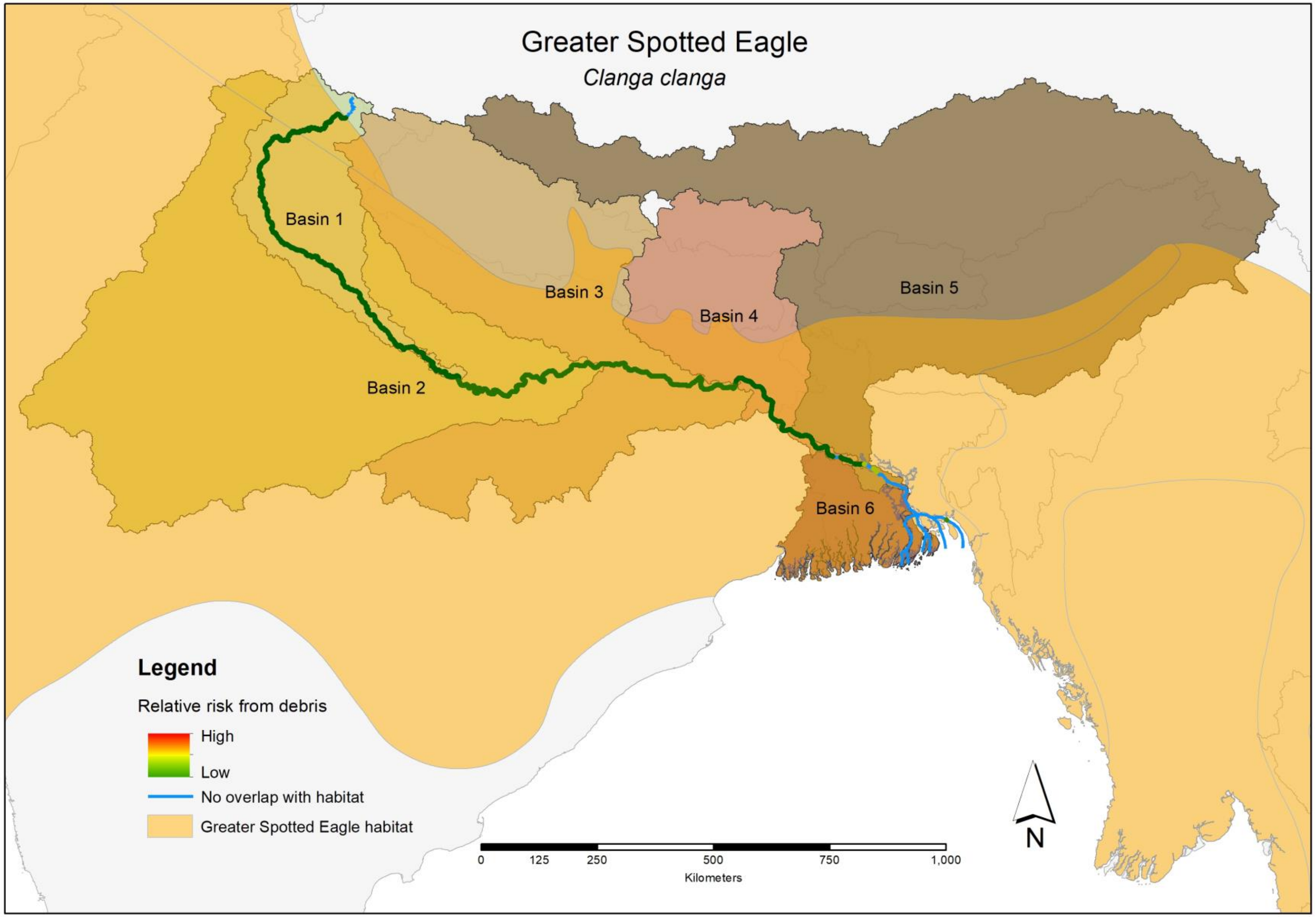

Gadwall
Anas strepera
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Gadwall habitat
0
125
250
500
750
1,000
Kilometers
N

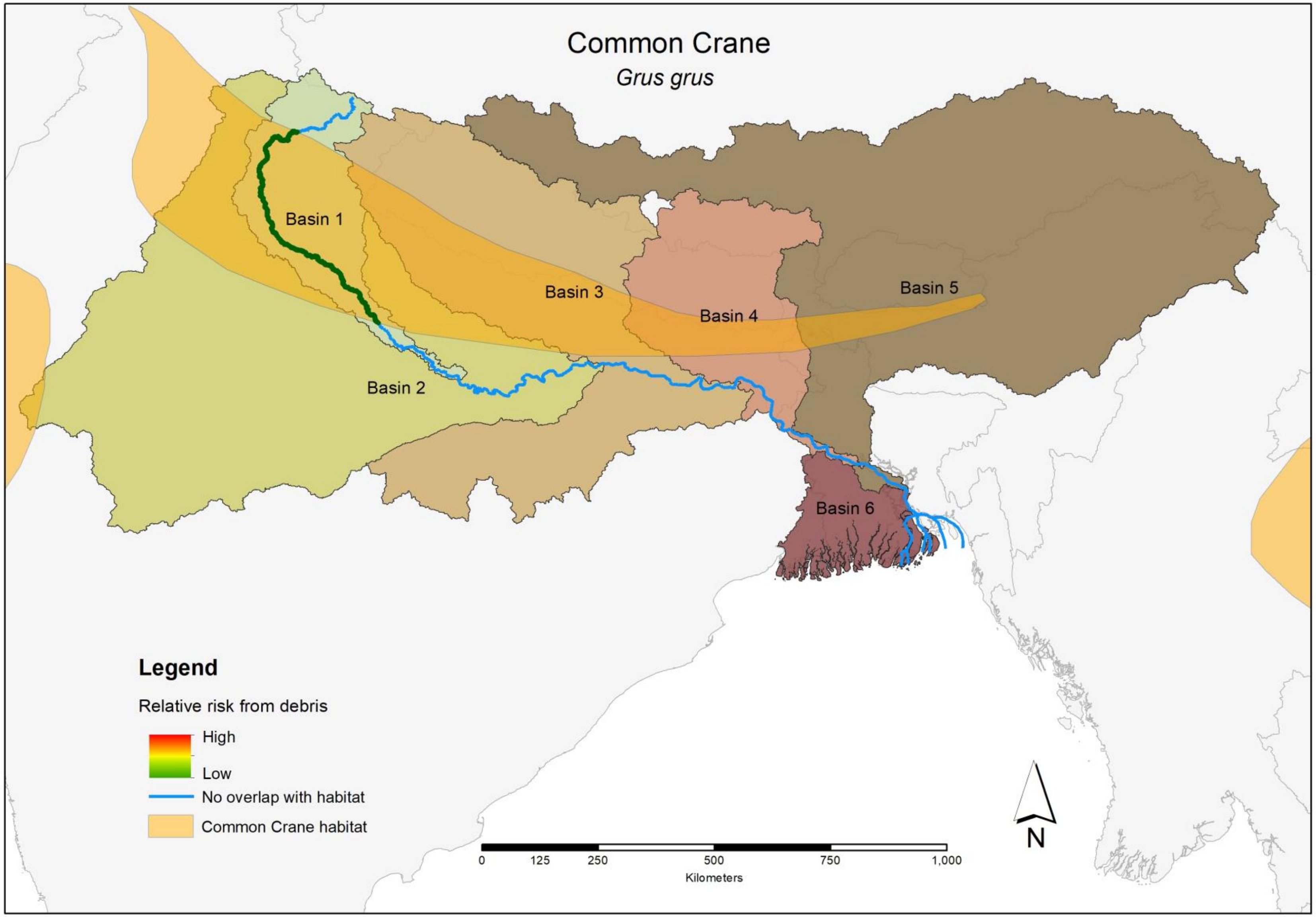

Northern Pintail
Anas acuta
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Northern Pintail habitat
0
125
250
500
750
1,000
Kilometers
N


Common Teal
Anas crecca
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Common Teal habitat
0
125
250
500
750
1,000
Kilometers
N

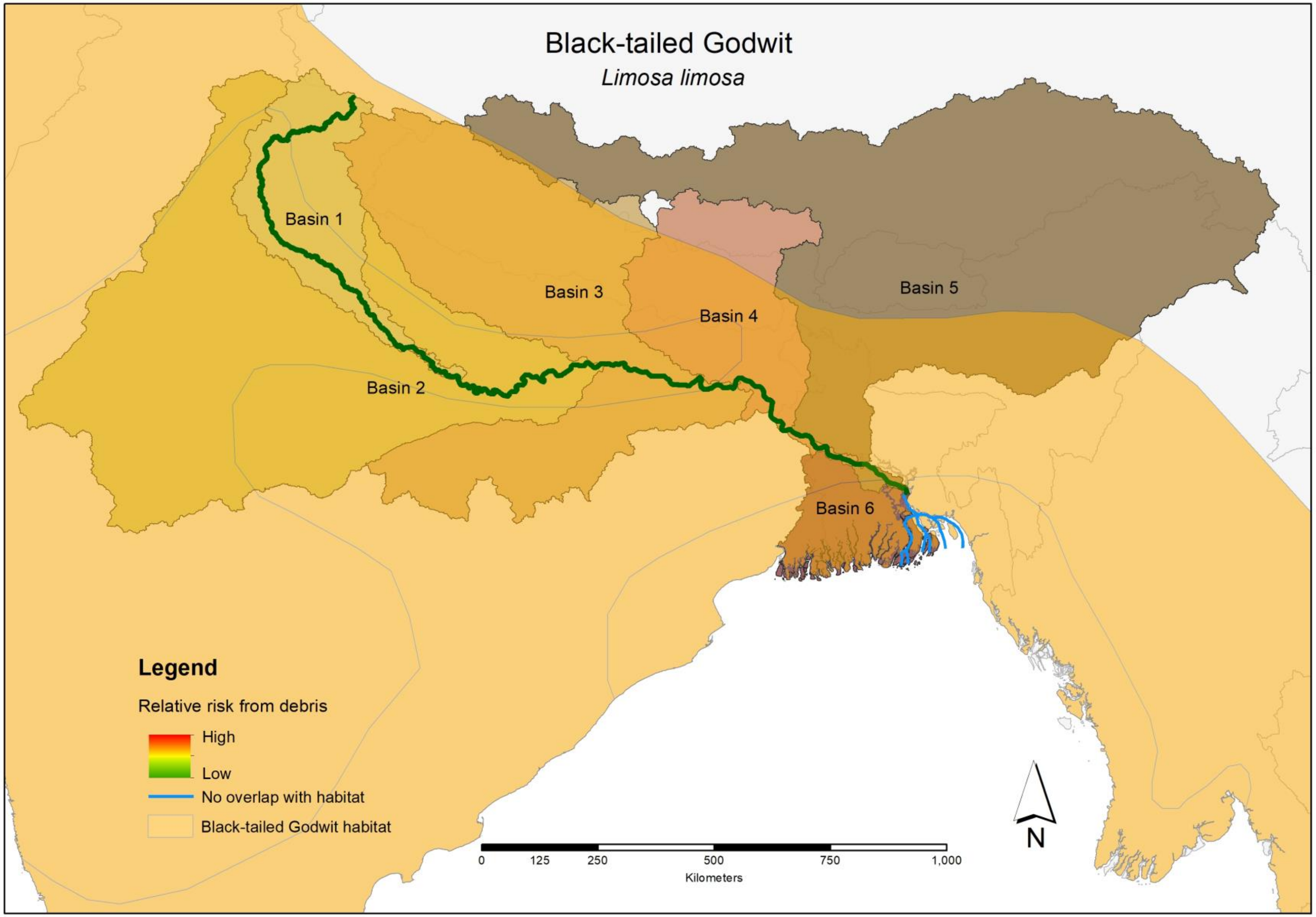

Red-crested Pochard
Netta rufina
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Red-crested Pochard habitat
0
125
250
500
750
1,000
Kilometers
N

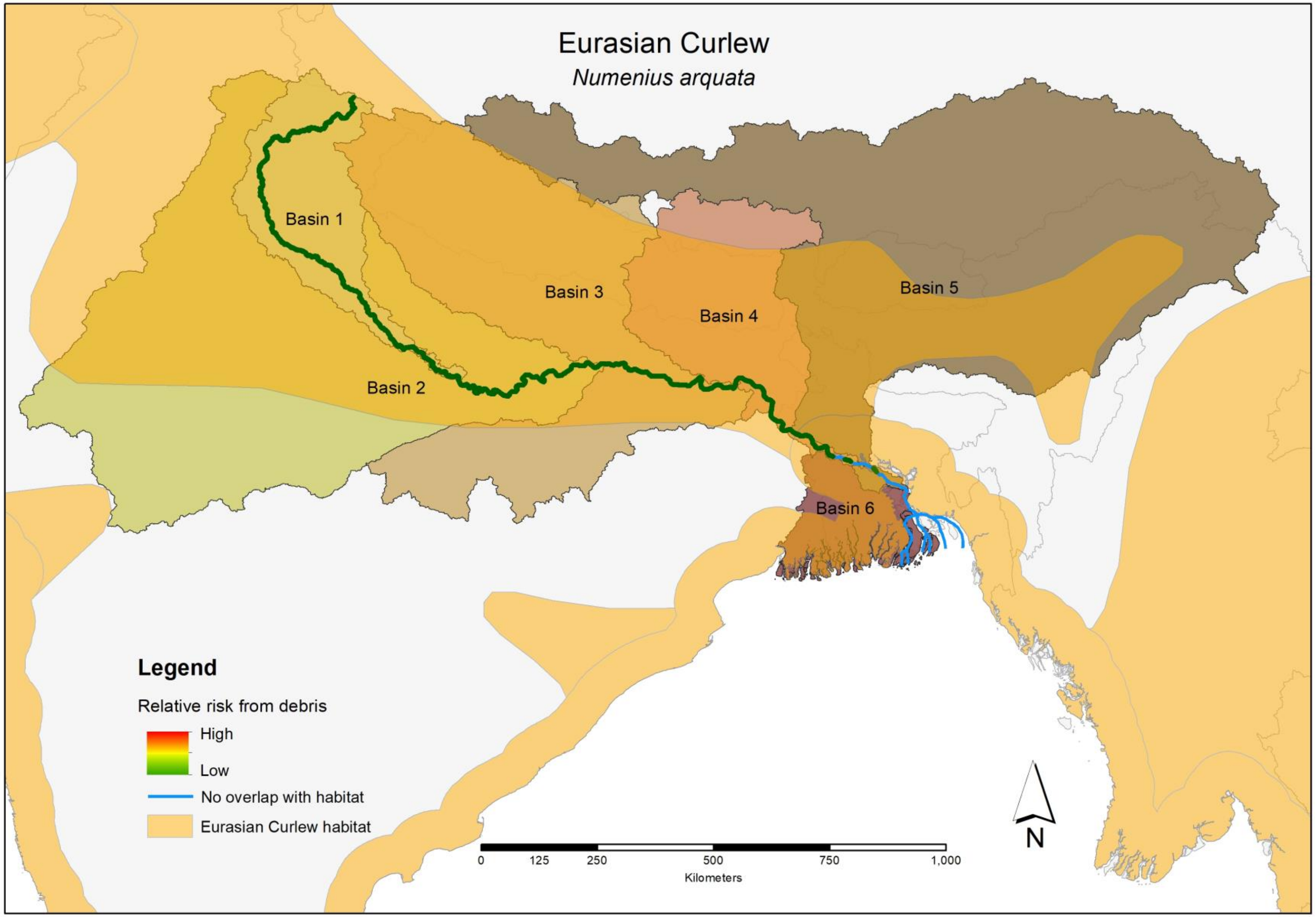

Tufted Duck
Aythya fuligula
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Tufted Duck habitat
0
125
250
500
750
1,000
Kilometers
N


Greater Spotted Eagle
Clanga clanga
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Greater Spotted Eagle habitat
0
125
250
500
750
1,000
Kilometers
N

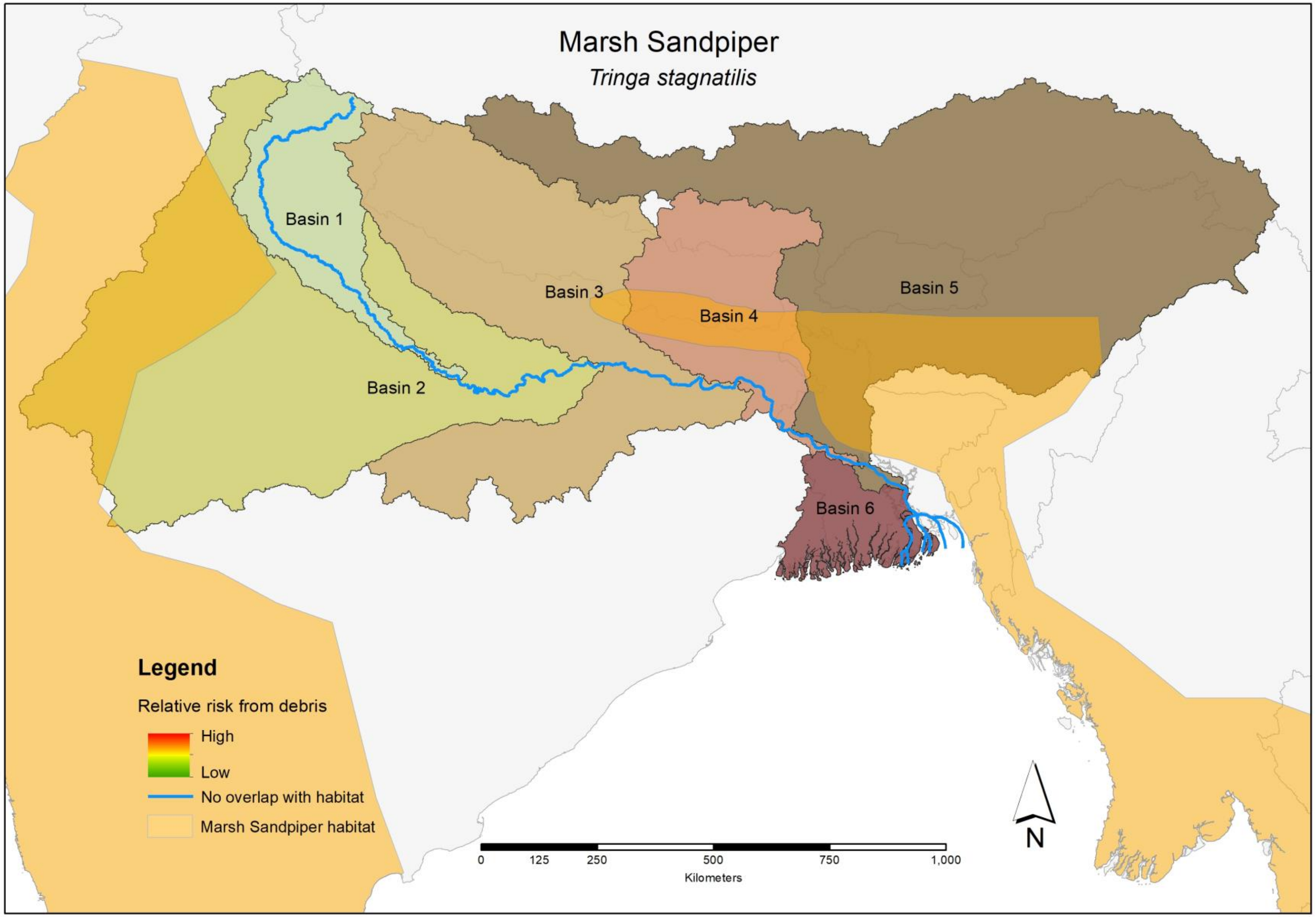


Common Crane
Grus grus
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Common Crane habitat
0
125
250
500
750
1,000
Kilometers
N

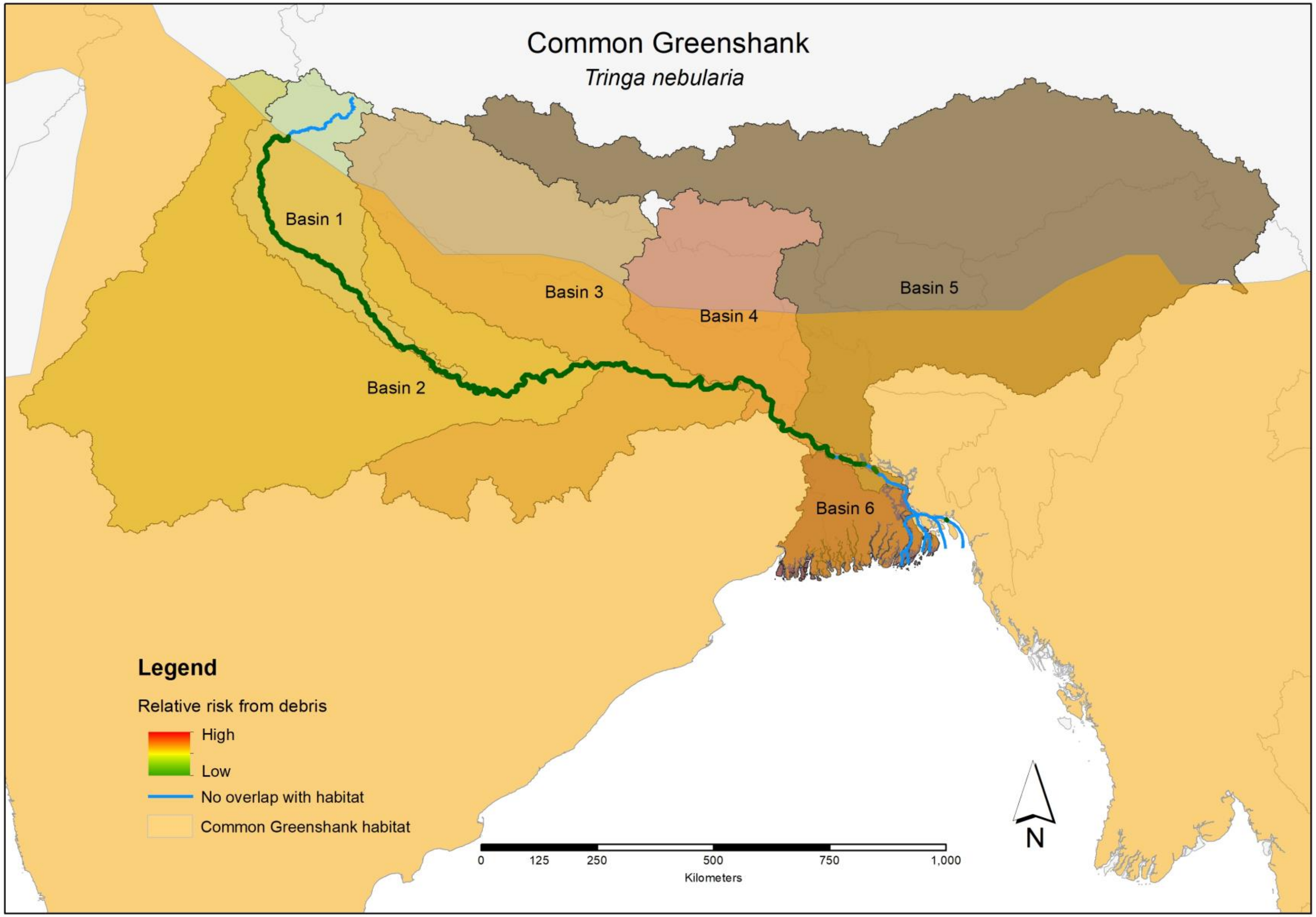

Black-tailed Godwit
Limosa limosa
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Black-tailed Godwit habitat
0 125 250 500 750 1,000
Kilometers
N

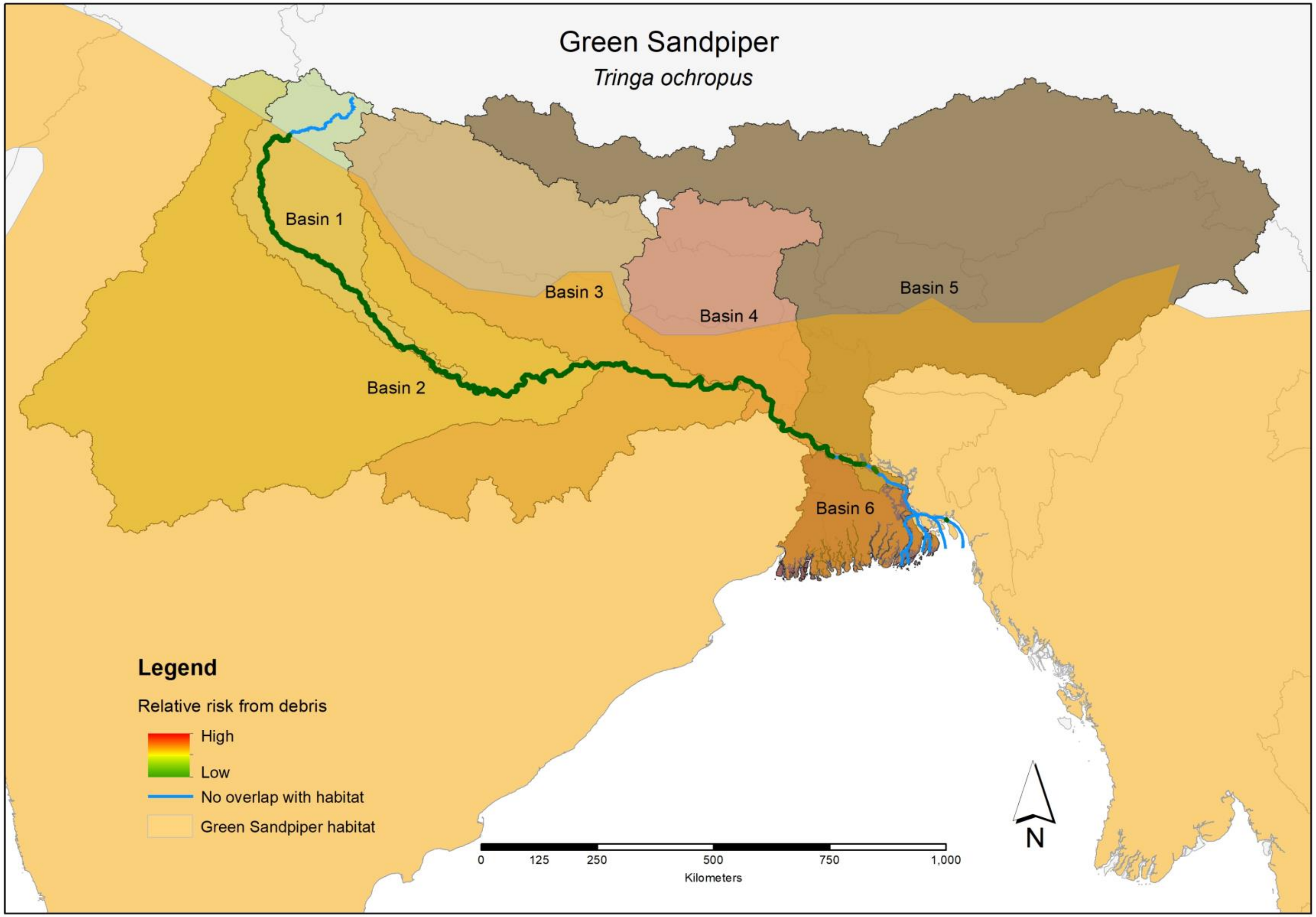


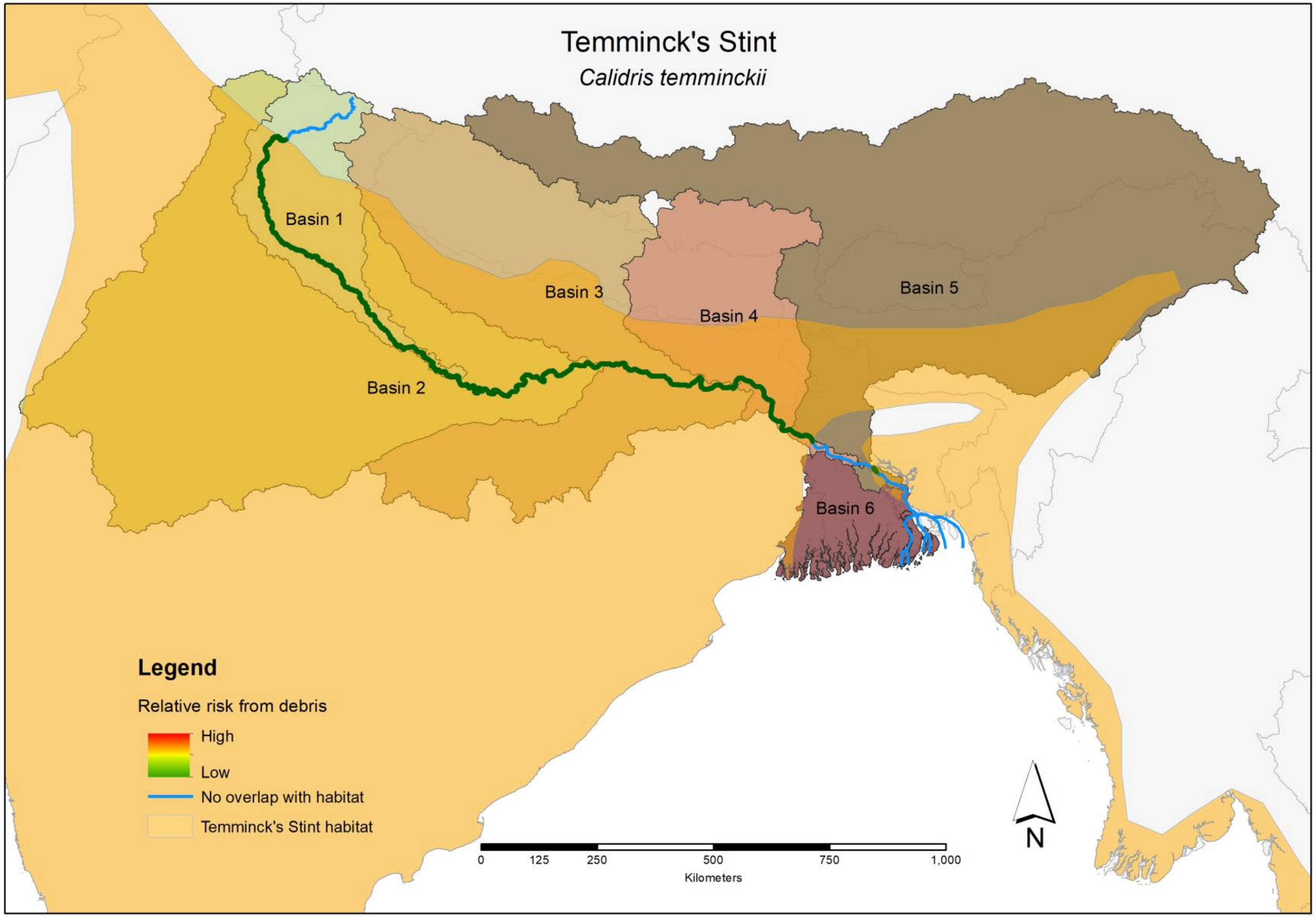
Eurasian Curlew
Numenius arquata
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Eurasian Curlew habitat
0
125
250
500
750
1,000
Kilometers
N



Marsh Sandpiper
Tringa stagnatilis
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Marsh Sandpiper habitat
0
125
250
500
750
1,000
Kilometers
N

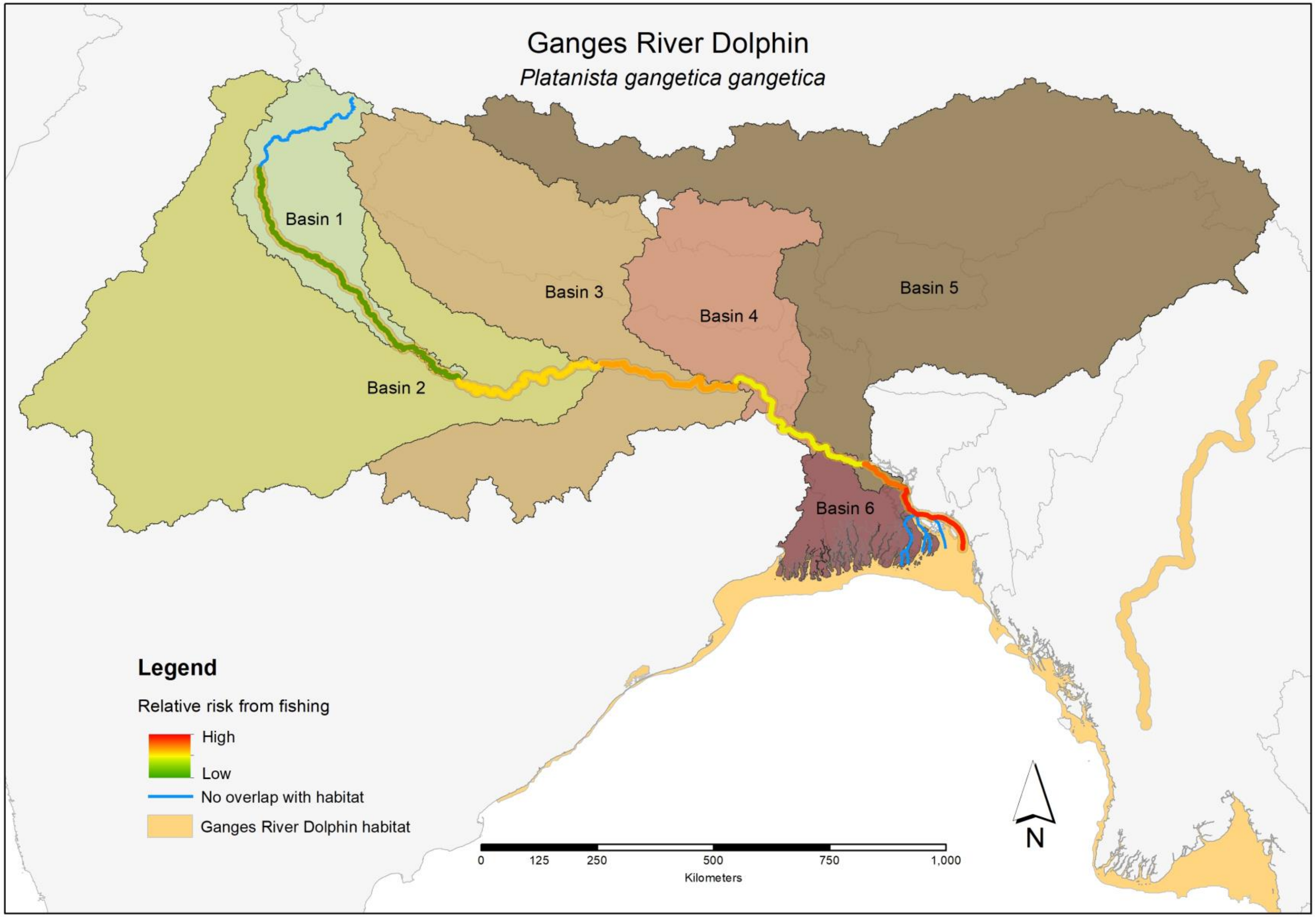

Common Greenshank
Tringa nebularia
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Common Greenshank habitat
0
125
250
500
750
1,000
Kilometers
N

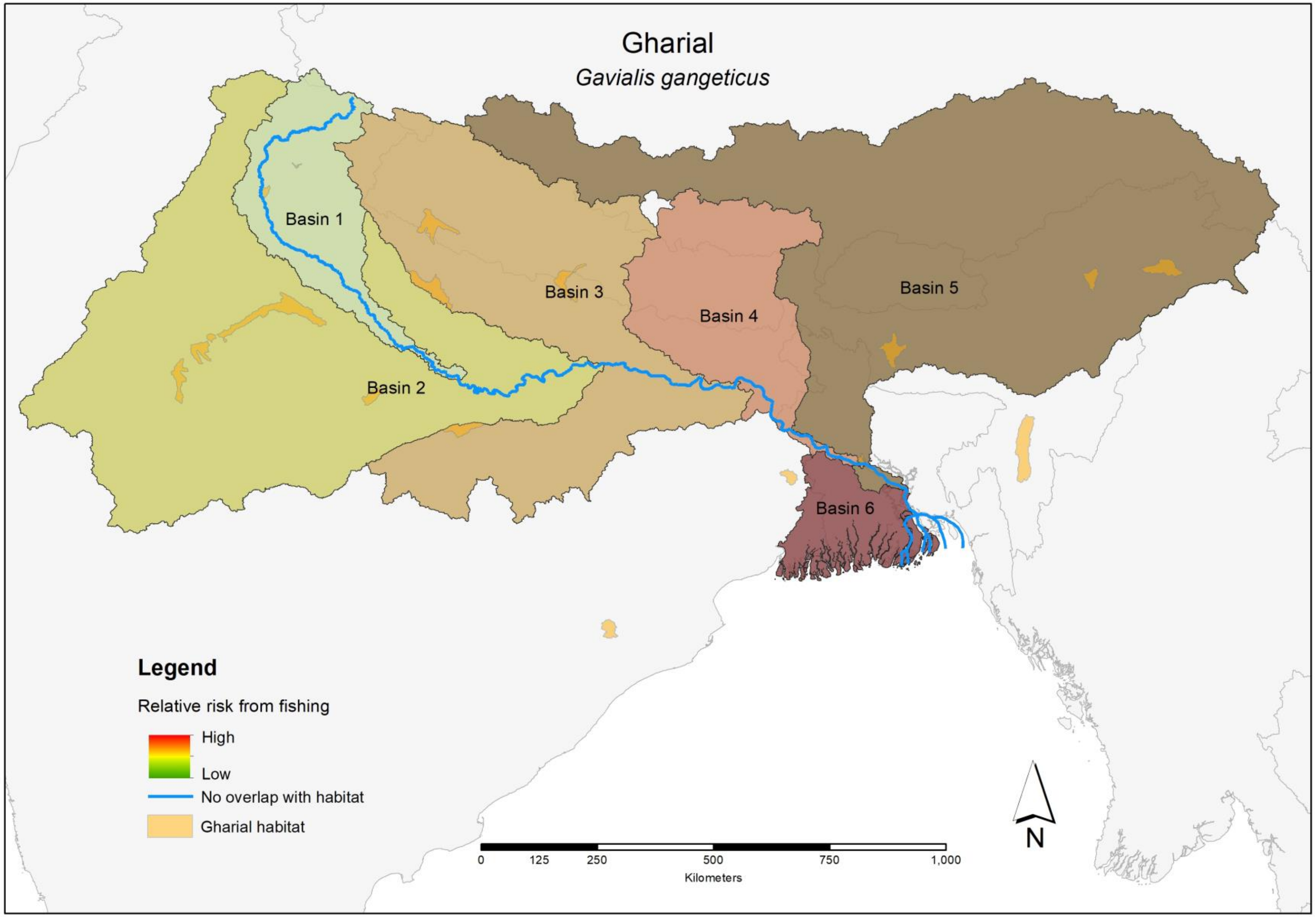

Green Sandpiper
Tringa ochropus
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Green Sandpiper habitat
0
125
250
500
750
1,000
Kilometers
N

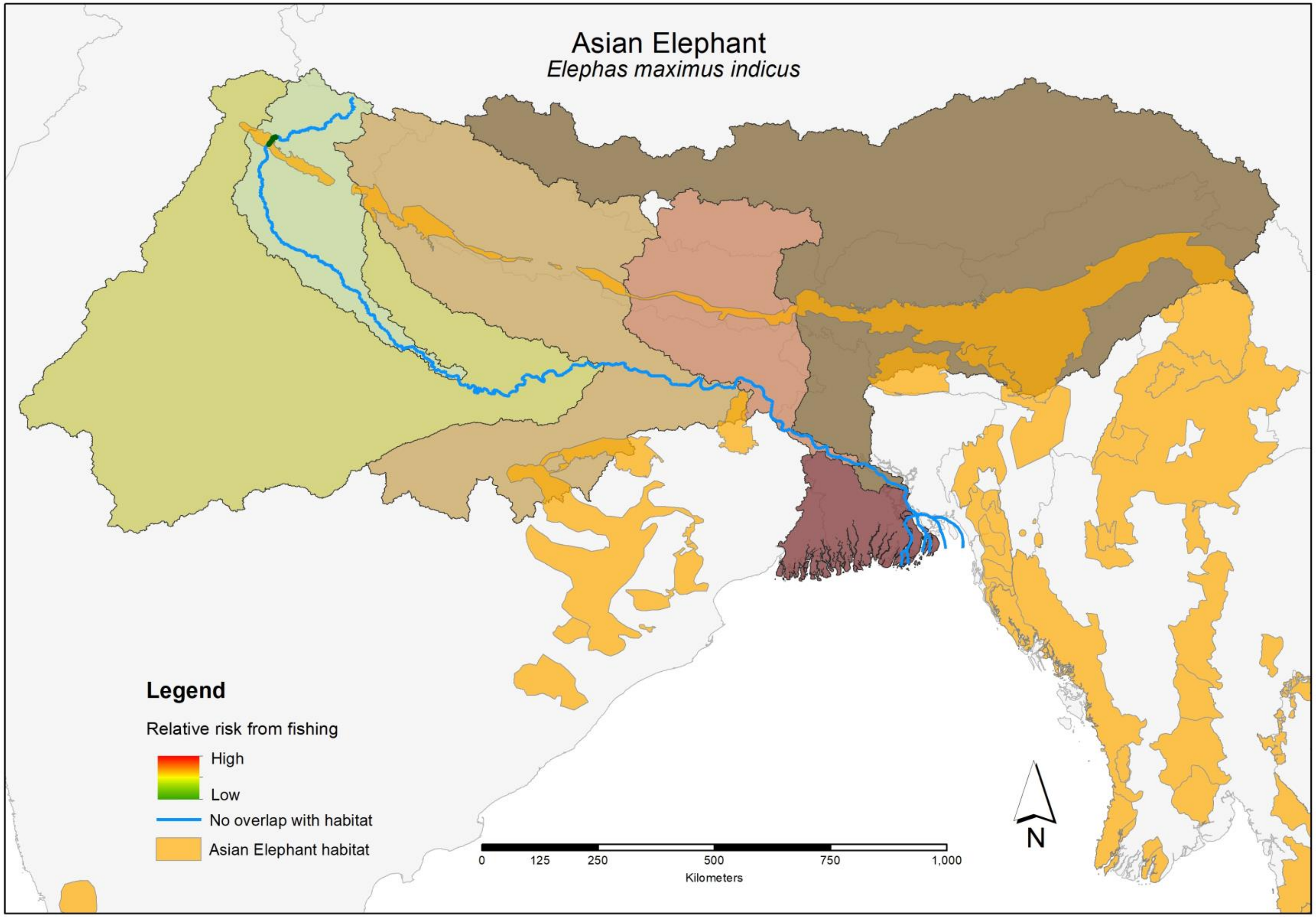

Temminck's Stint
Calidris temminckii
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Temminck's Stint habitat
0
125
250
500
750
1,000
Kilometers
N

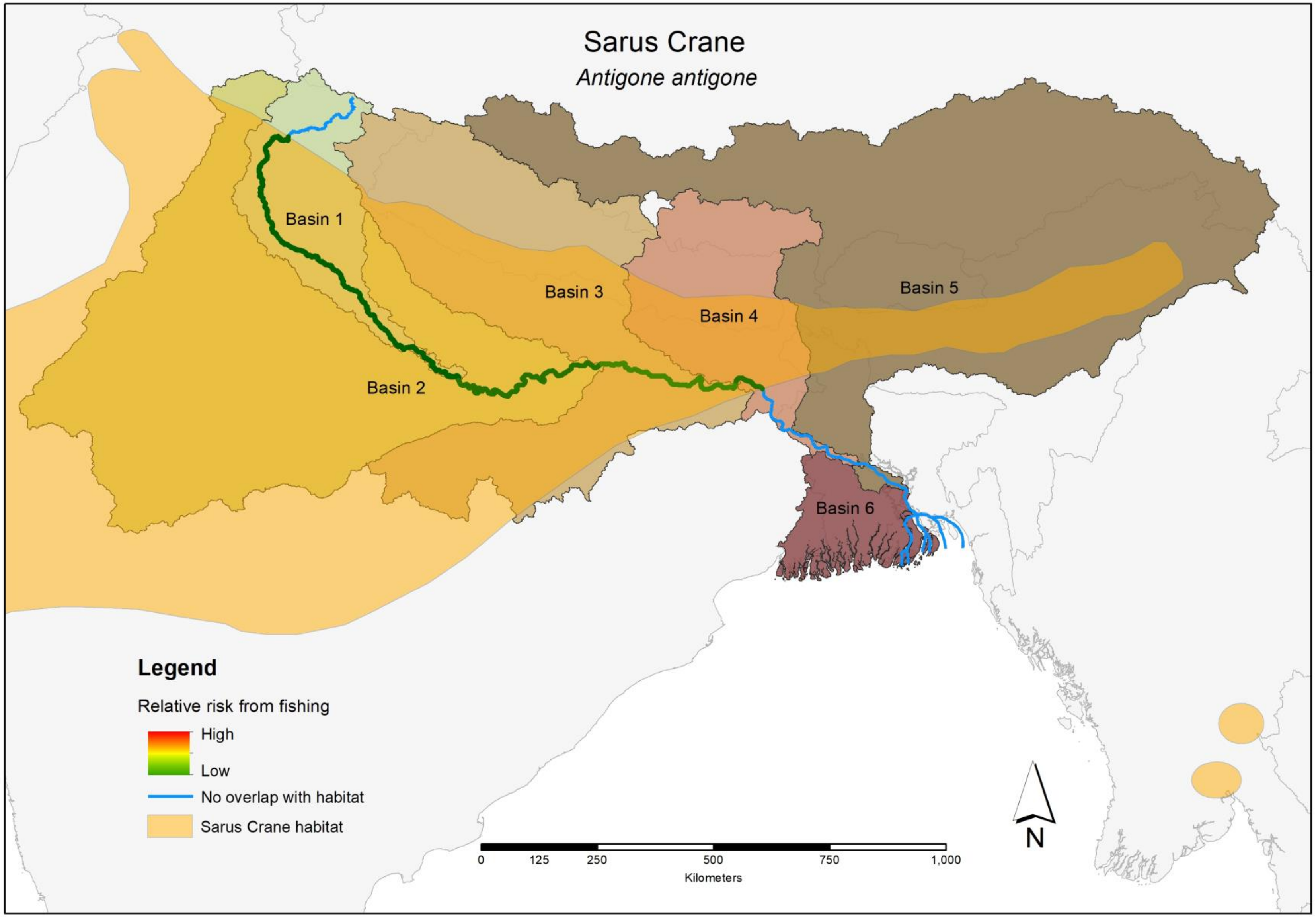
14.5 Ganga River CMS species relative risk from fishing debris

The following maps present the relative risk to CMS-listed species from entanglement with fishing debris across 6 sectors of the Ganga River. Note that the maximum level of risk would occur in a species with a high likelihood of interacting with debris, and an expected lethal outcome from that debris, in the section of the river with the highest expected fishing pressure.

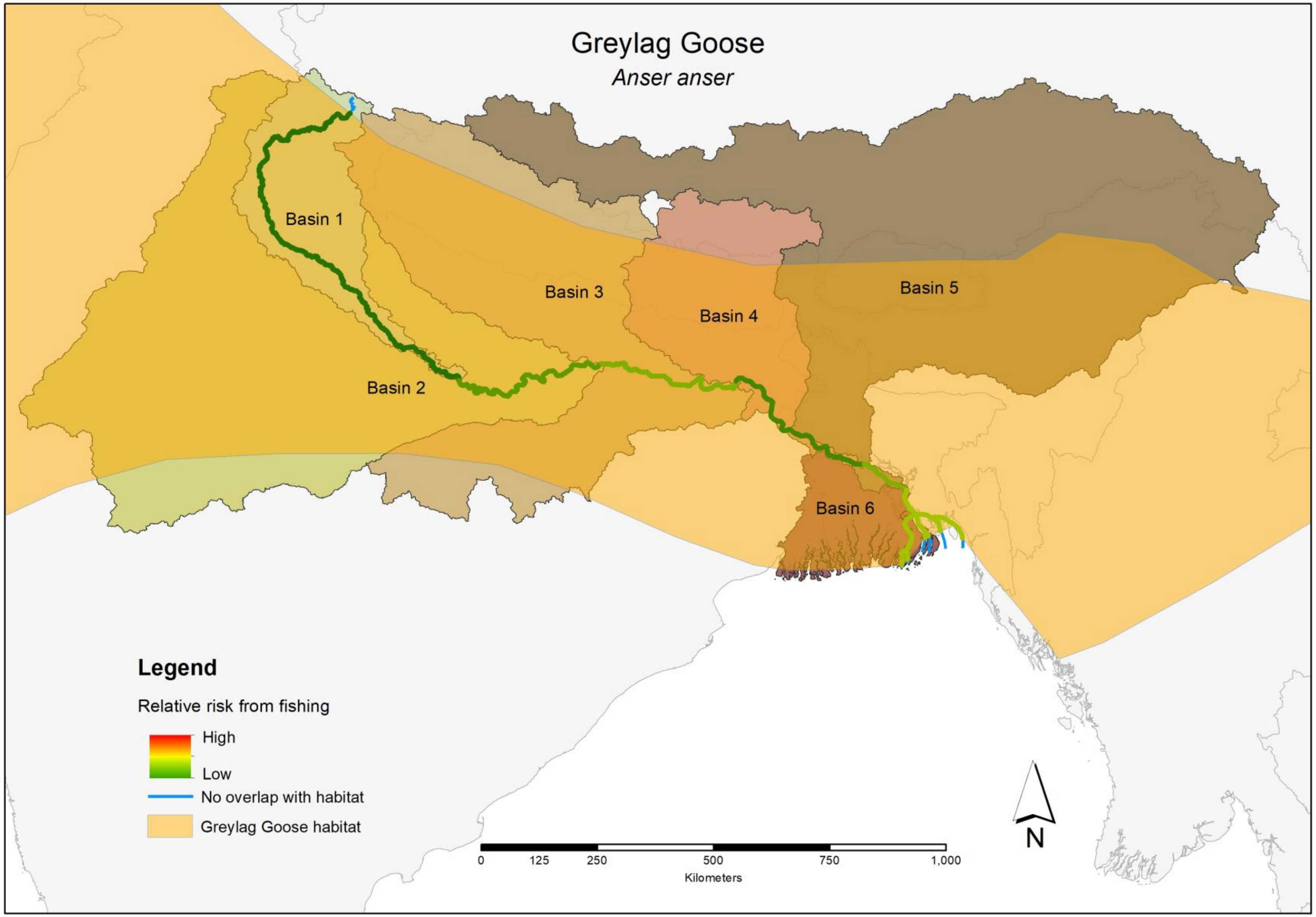

Ganges River Dolphin
Platanista gangetica gangetica
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Ganges River Dolphin habitat
0
125
250
500
750
1,000
Kilometers
N

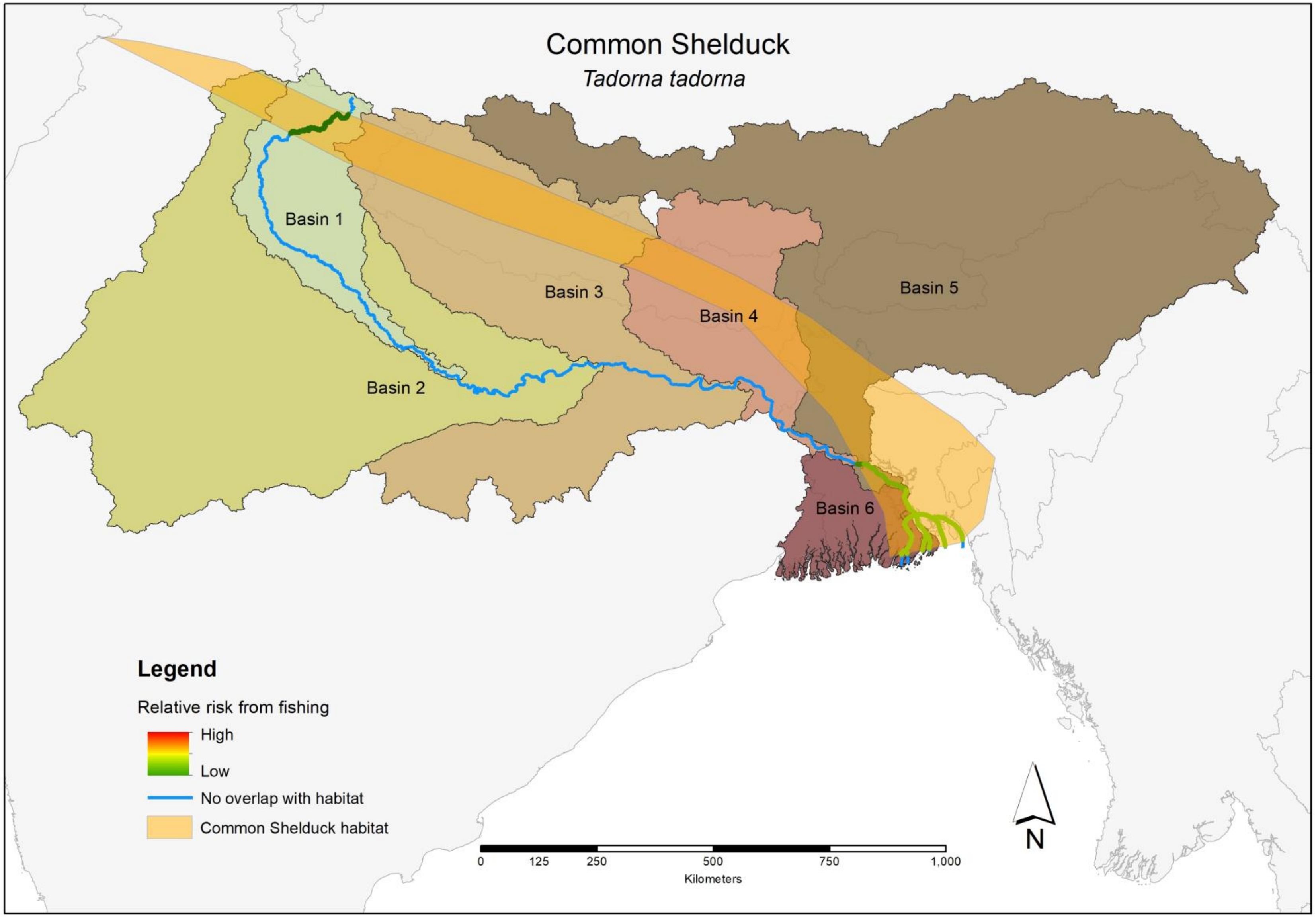

Gharial
Gavialis gangeticus
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Gharial habitat
0
125
250
500
750
1,000
Kilometers
N

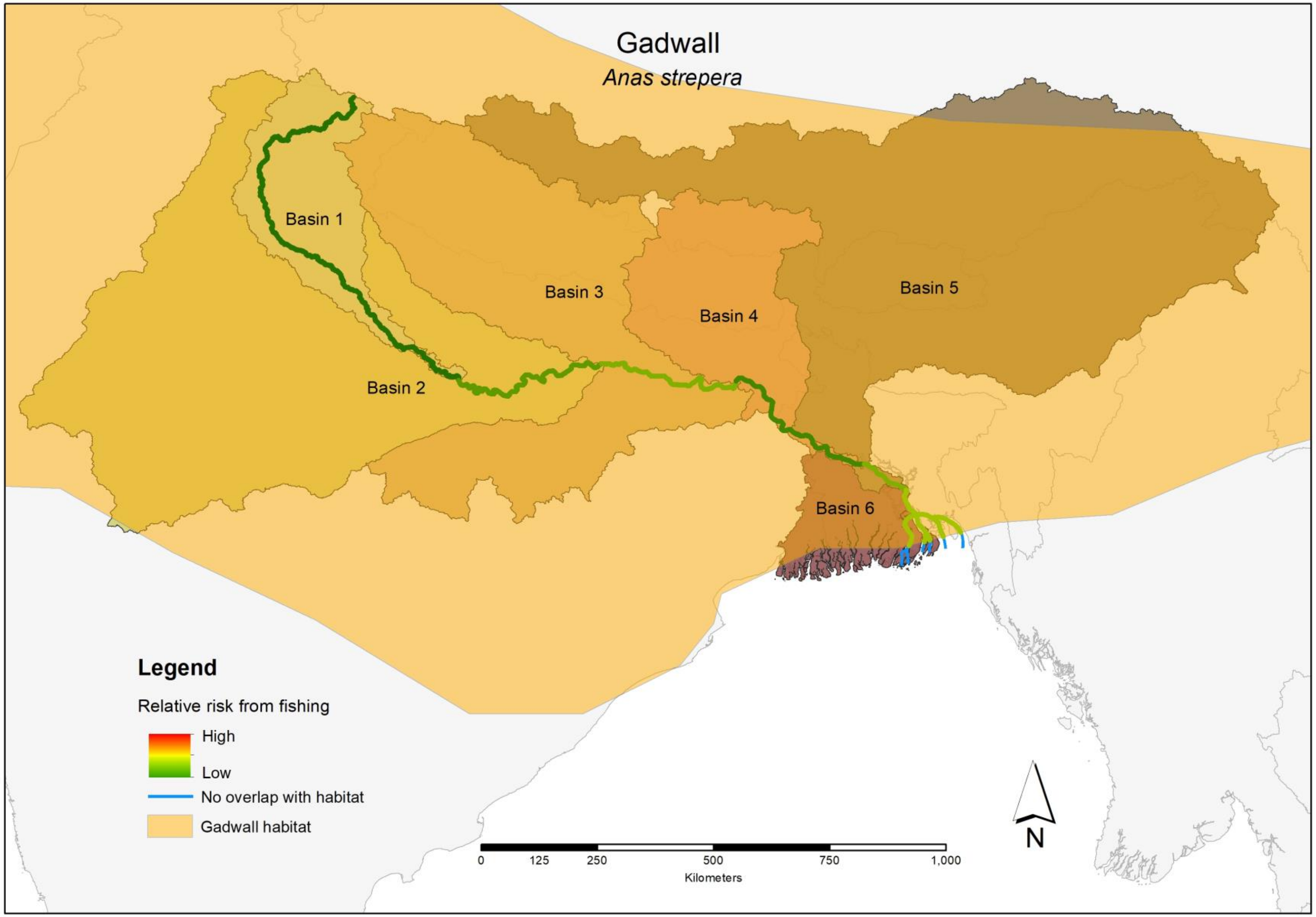

Asian Elephant
Elephas maximus indicus
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Asian Elephant habitat
0
125
250
500
750
1,000
Kilometers
N

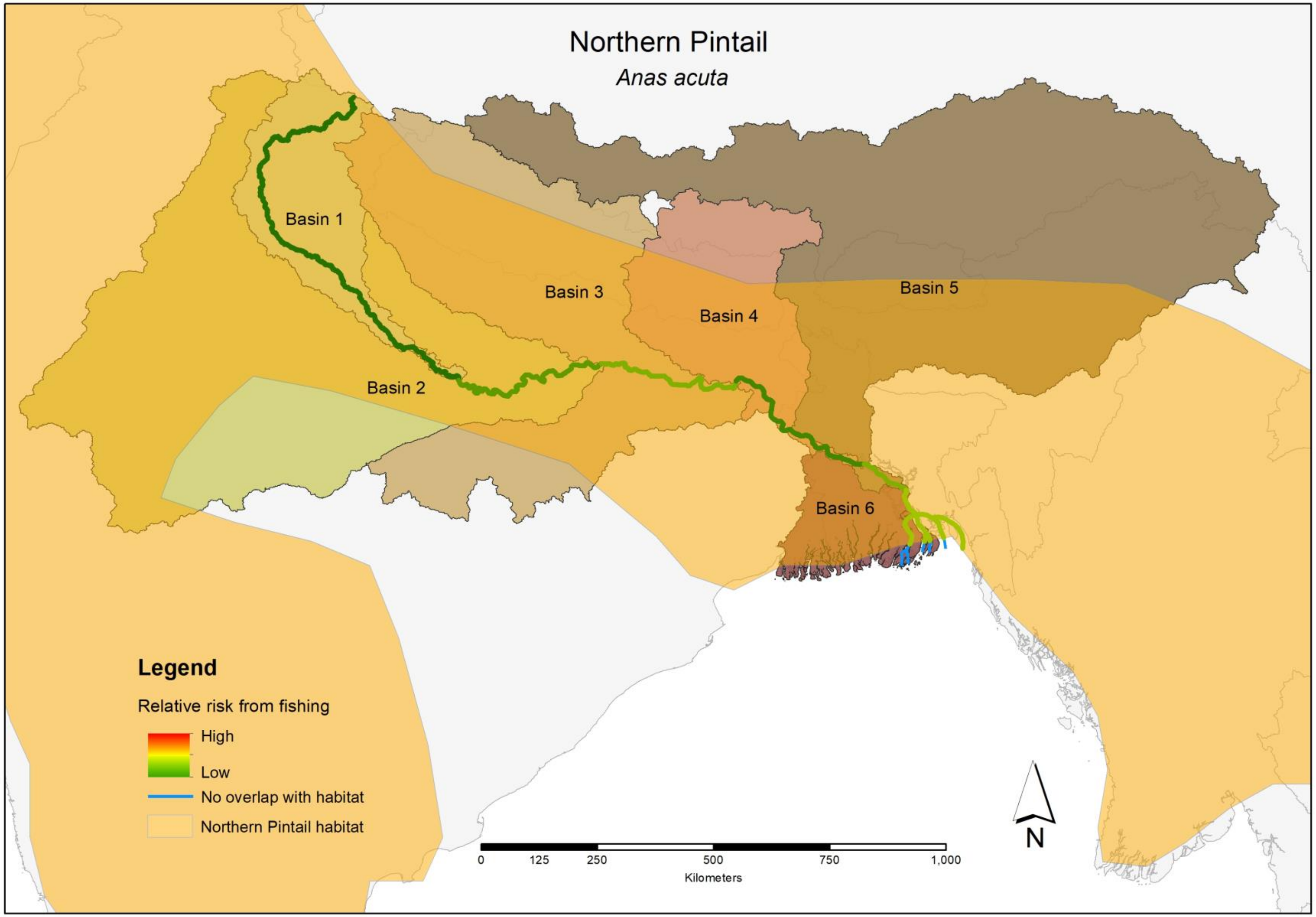


Sarus Crane
Antigone antigone
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Sarus Crane habitat
0
125
250
500
750
1,000
Kilometers
N

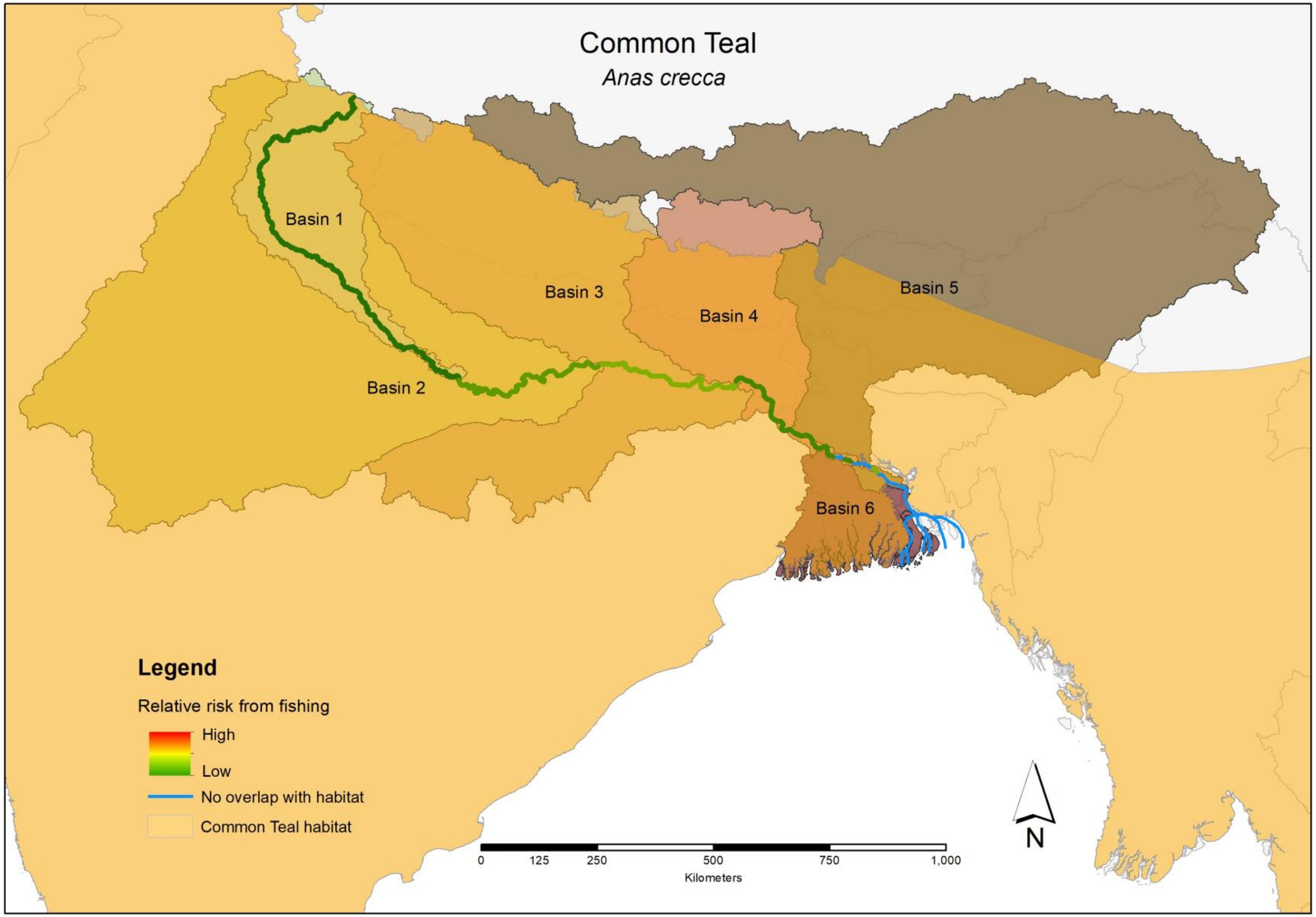

Greylag Goose
Anser anser
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Greylag Goose habitat
0
125
250
500
750
1,000
Kilometers
N

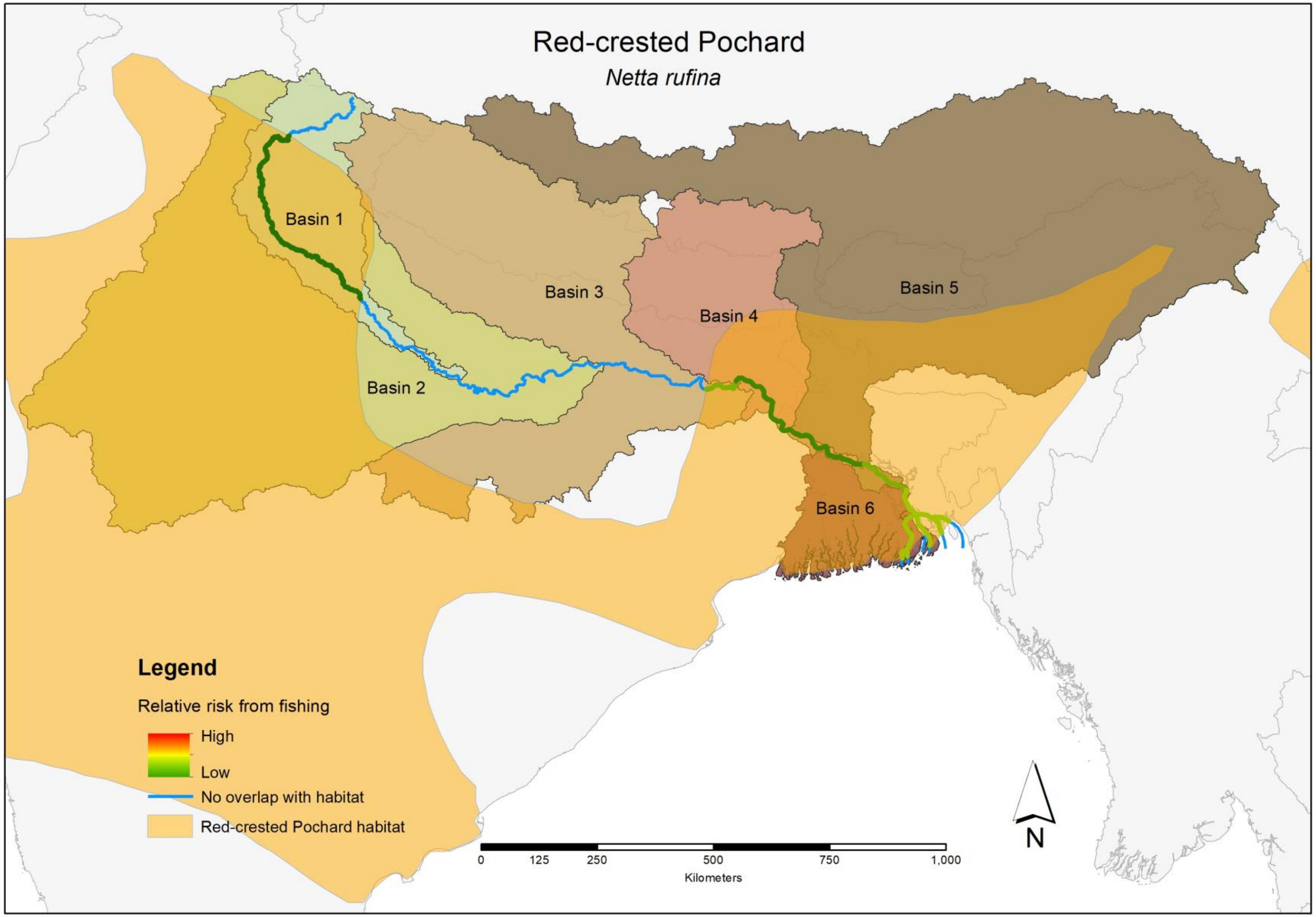

Common Shelduck
Tadorna tadorna
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Common Shelduck habitat
0
125
250
500
750
1,000
Kilometers
N


Gadwall
Anas strepera
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Gadwall habitat
0
125
250
500
750
1,000
Kilometers
N

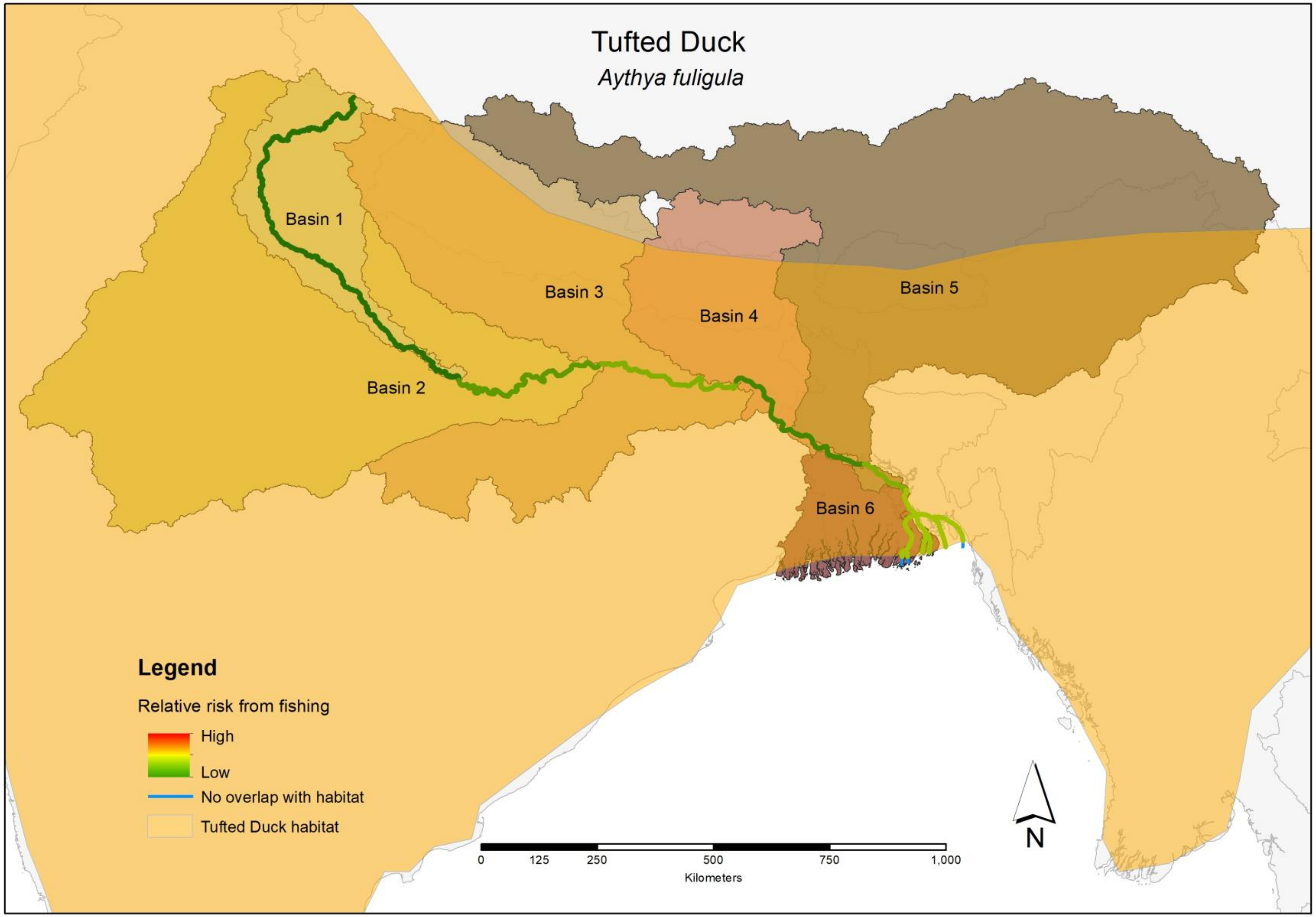


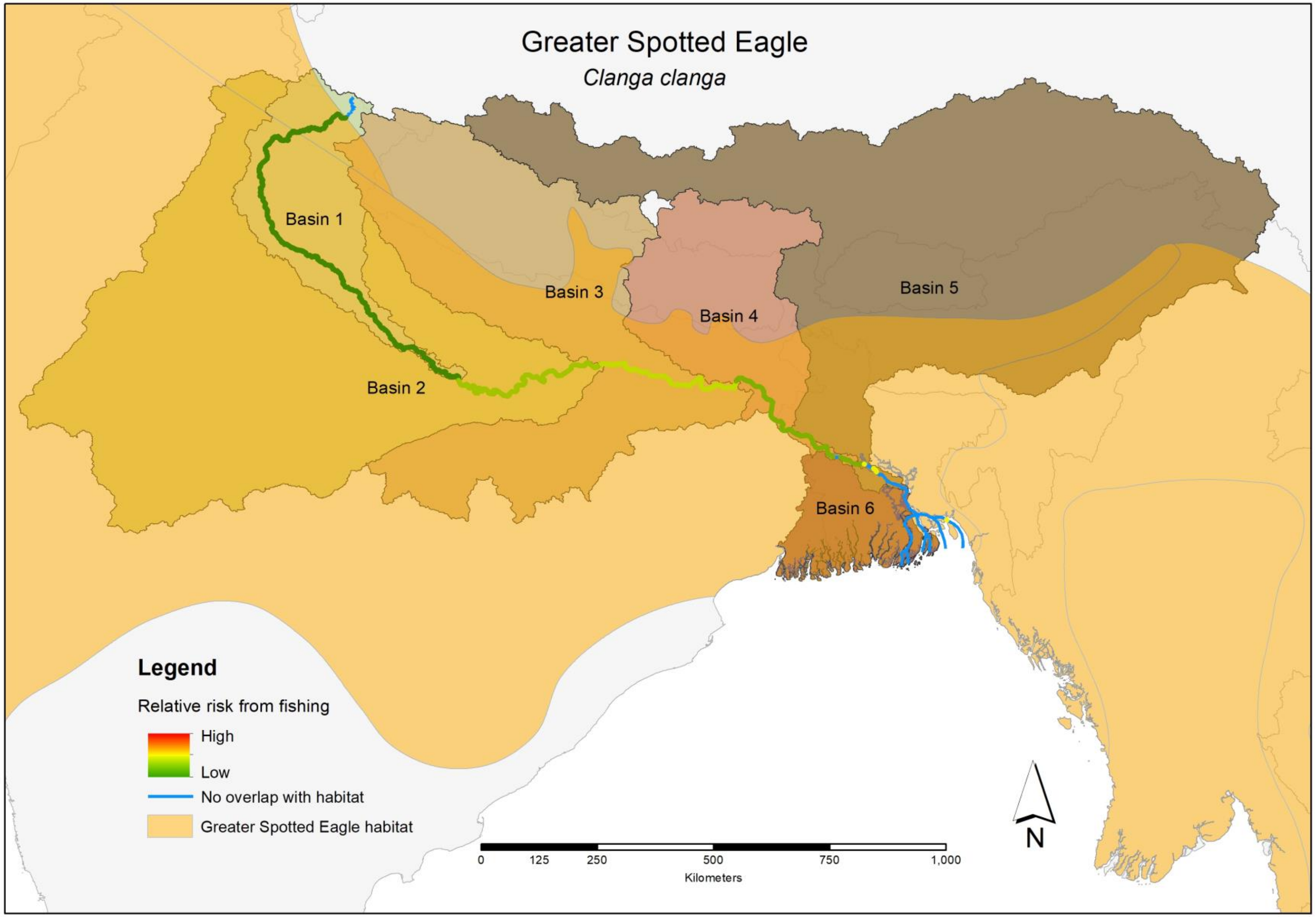
Northern Pintail
Anas acuta
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Northern Pintail habitat
0
125
250
500
750
1,000
Kilometers
N

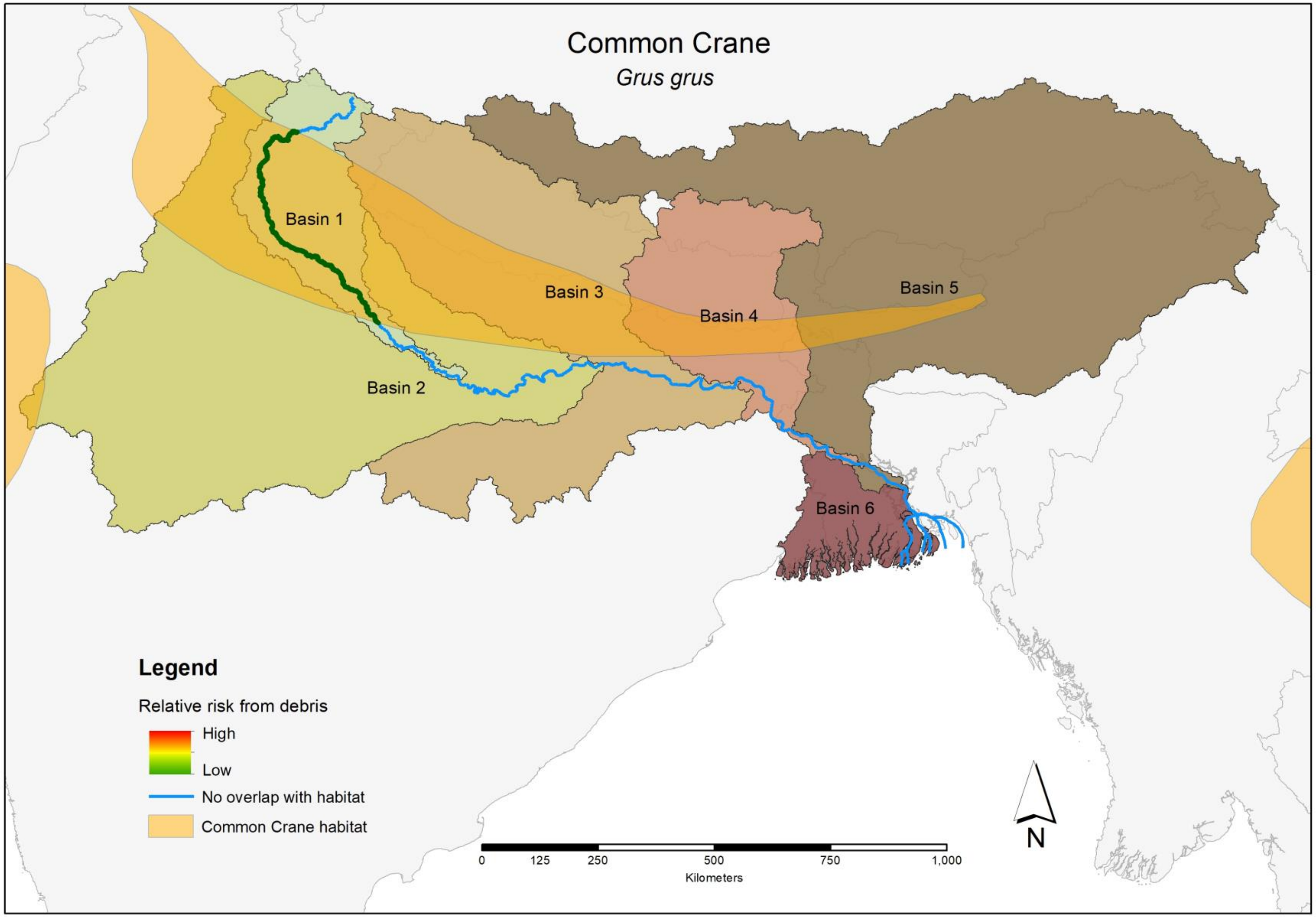

Common Teal
Anas crecca
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Common Teal habitat
0
125
250
500
750
1,000
Kilometers
N

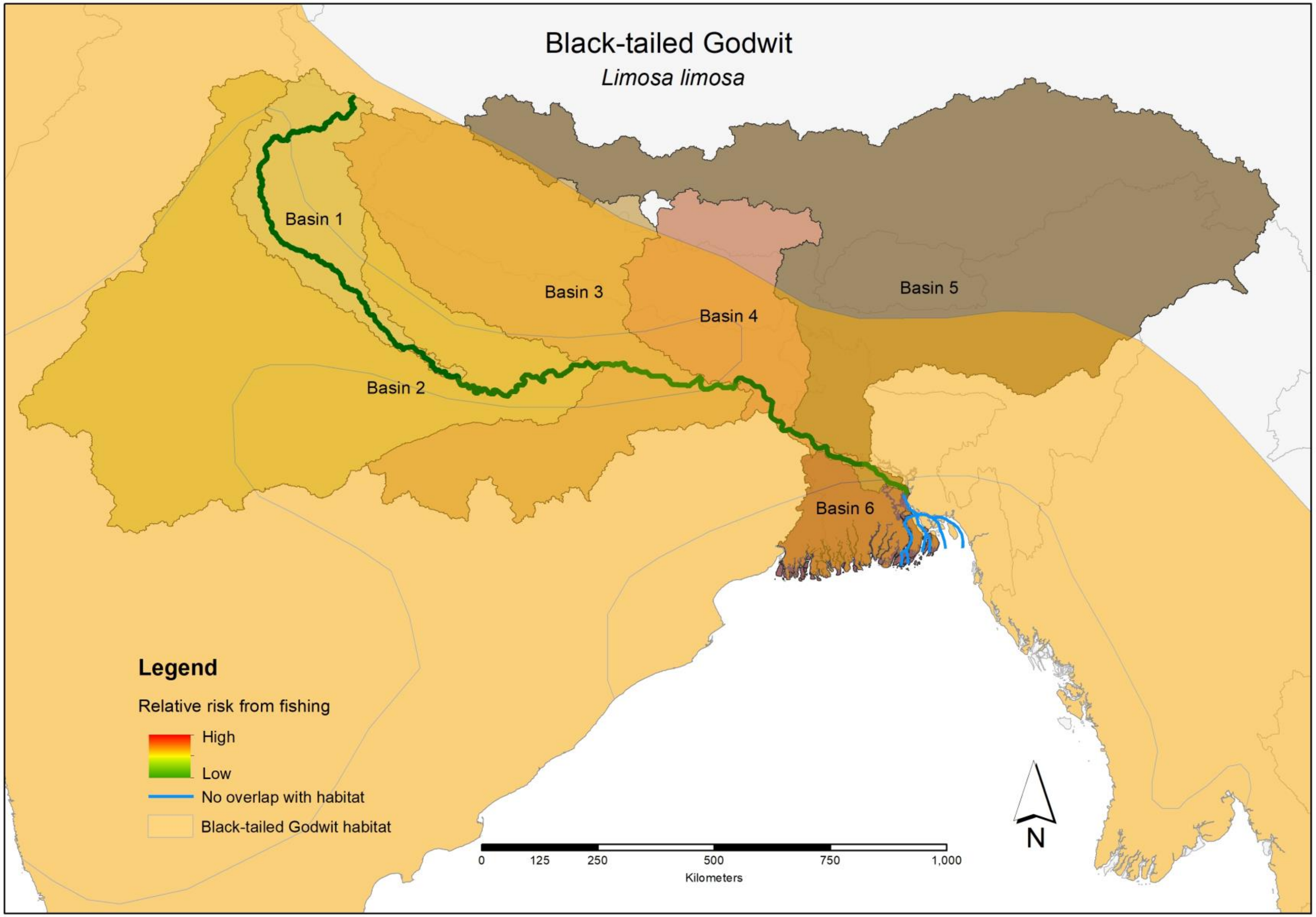


Red-crested Pochard
Netta rufina
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Red-crested Pochard habitat
0
125
250
500
750
1,000
Kilometers
N

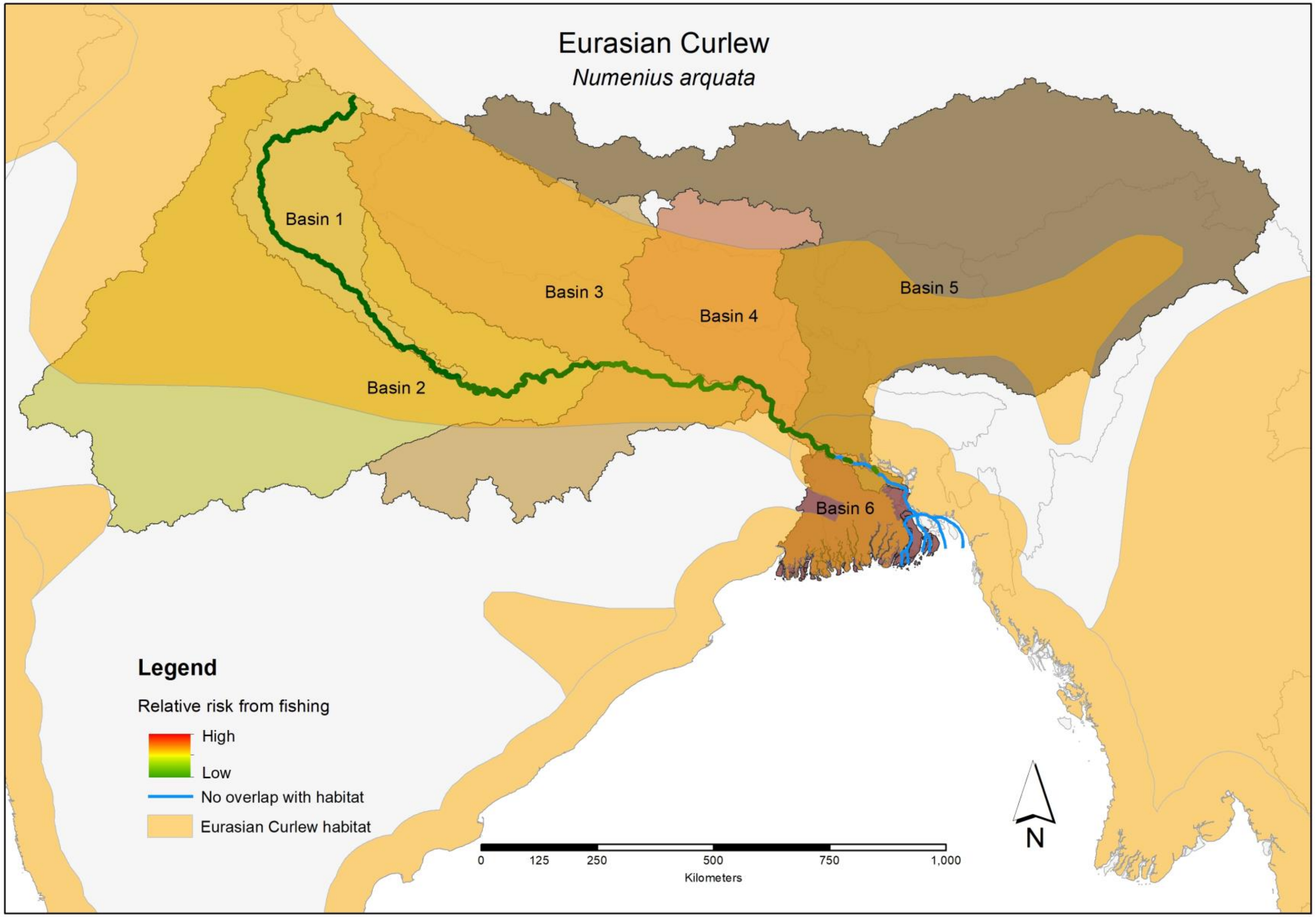

Tufted Duck
Aythya fuligula
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Tufted Duck habitat
0
125
250
500
750
1,000
Kilometers
N


Greater Spotted Eagle
Clanga clanga
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Greater Spotted Eagle habitat
0 125 250 500 750 1,000
Kilometers
N

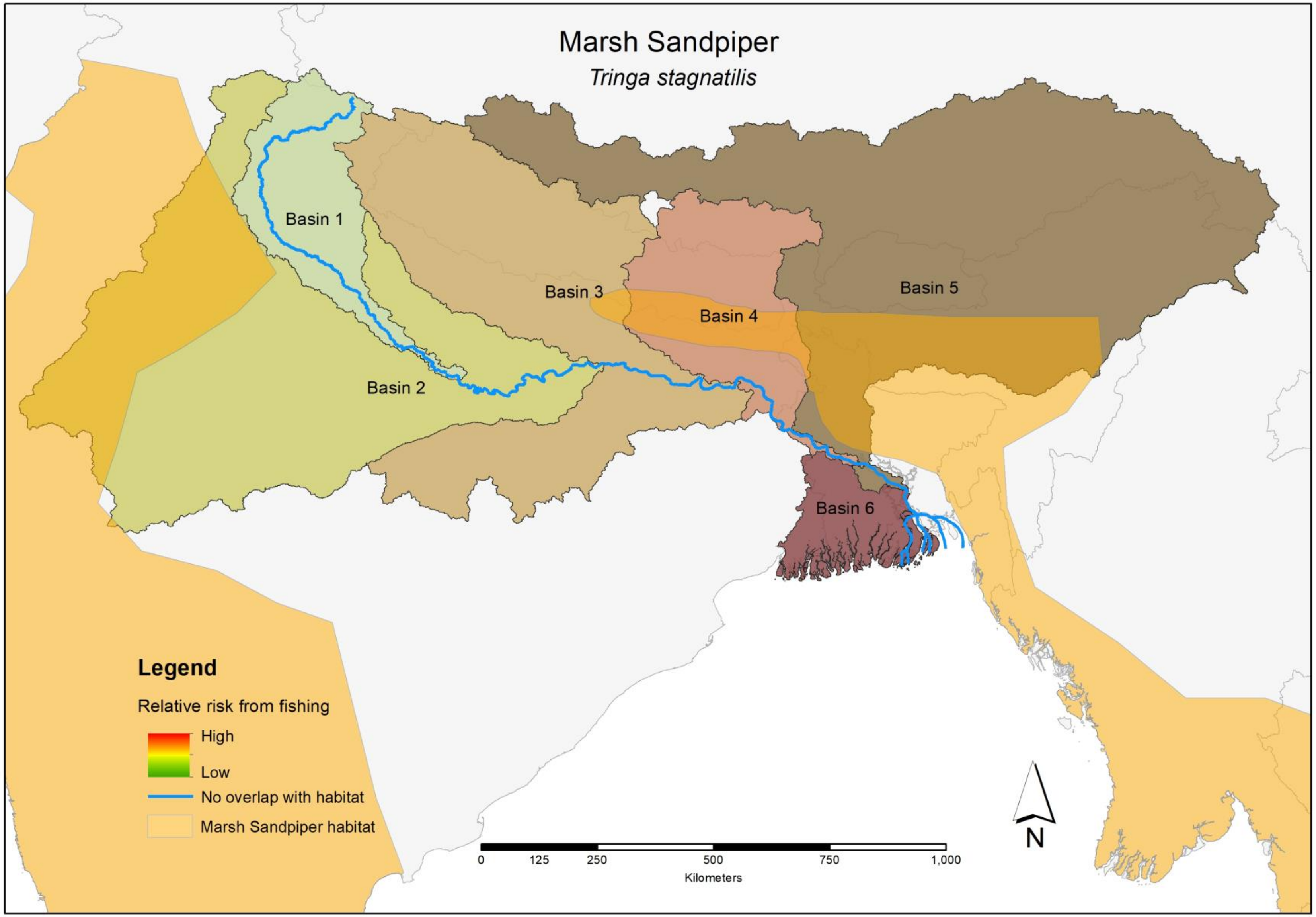

Common Crane
Grus grus
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from debris
High
Low
No overlap with habitat
Common Crane habitat
0
125
250
500
750
1,000
Kilometers
N



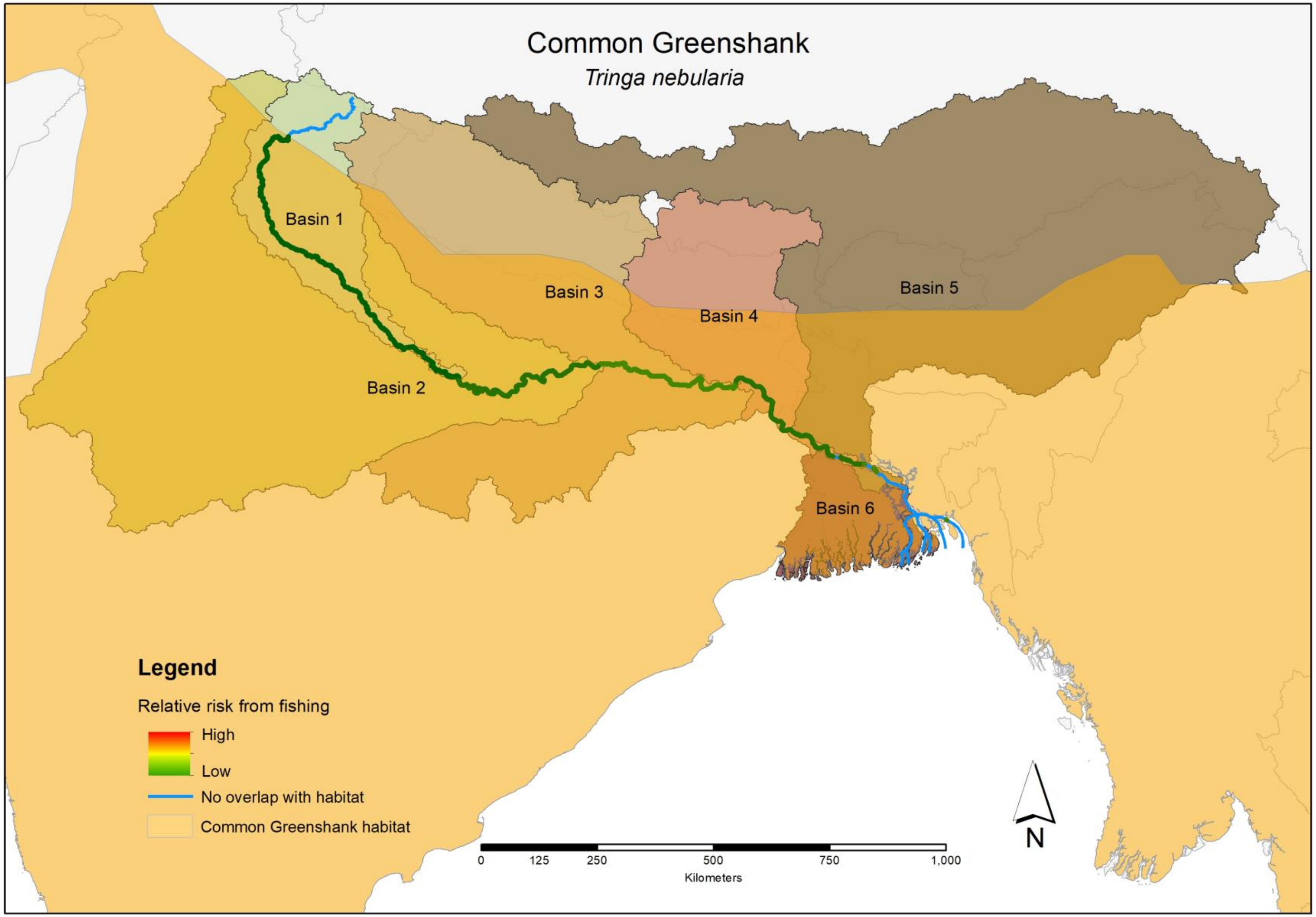
Black-tailed Godwit
Limosa limosa
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Black-tailed Godwit habitat
0
125
250
500
750
1,000
Kilometers
N



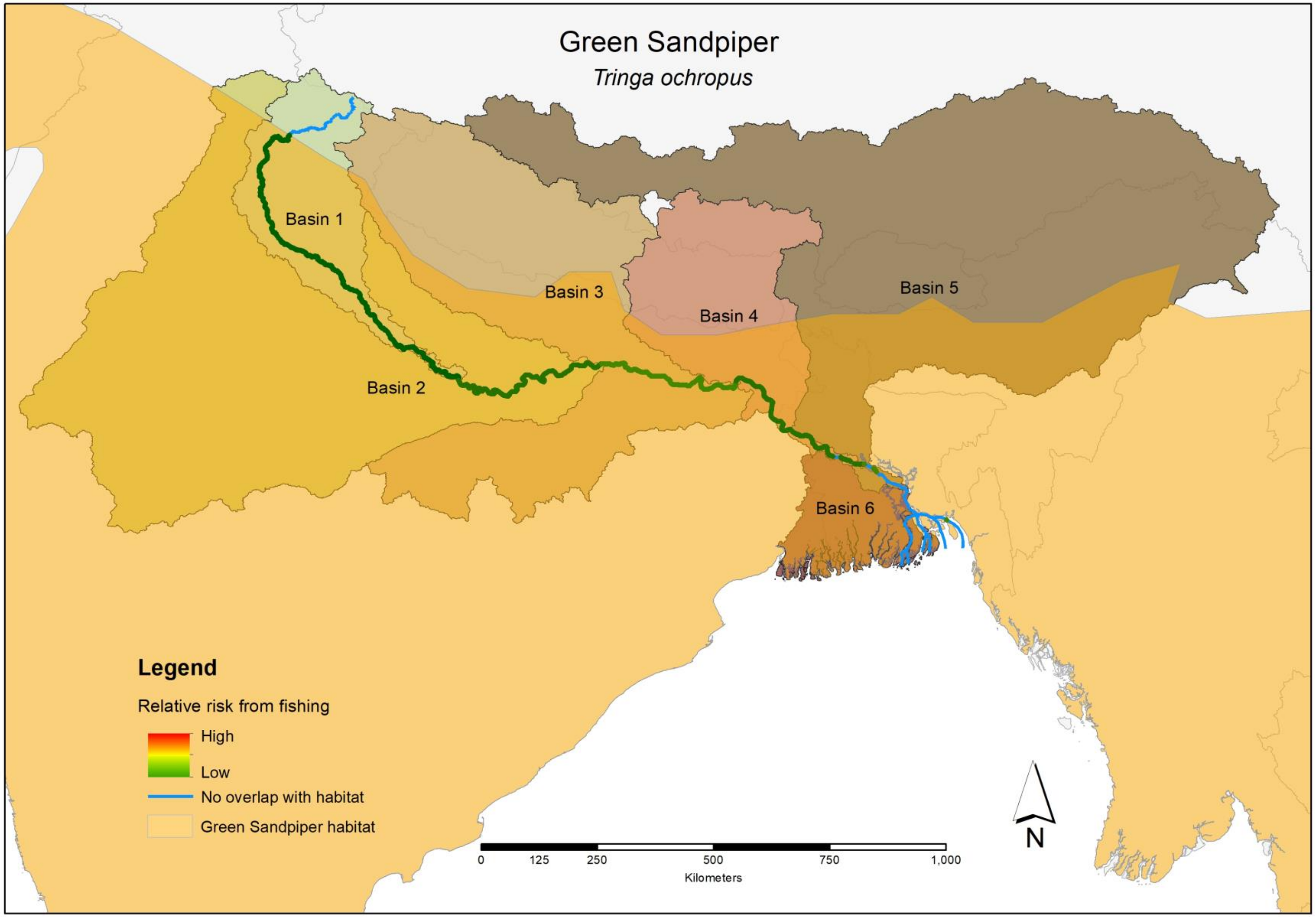
Eurasian Curlew
Numenius arquata
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Eurasian Curlew habitat
0
125
250
500
750
1,000
Kilometers
N

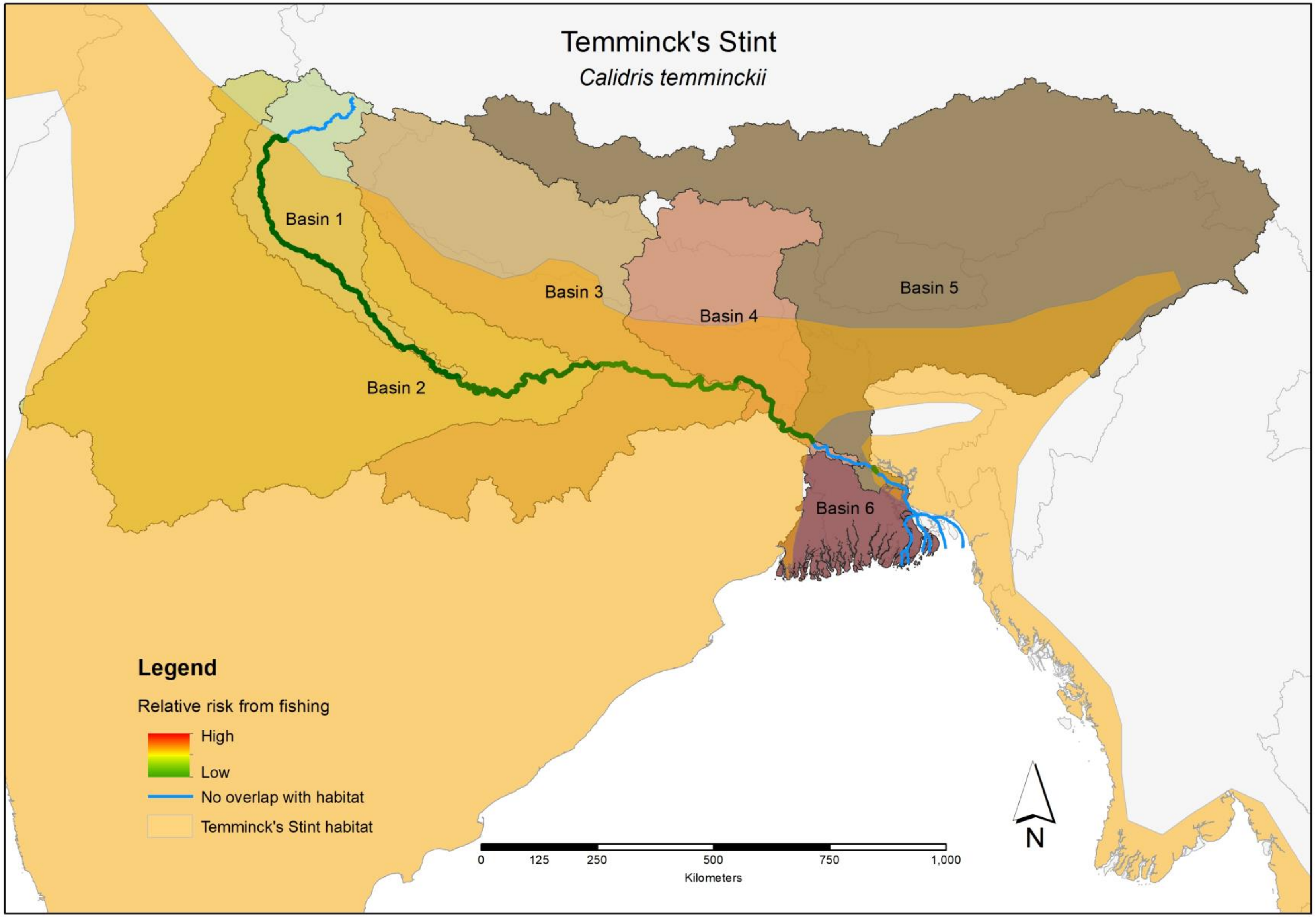


Marsh Sandpiper
Tringa stagnatilis
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Marsh Sandpiper habitat
0
125
250
500
750
1,000
Kilometers
N



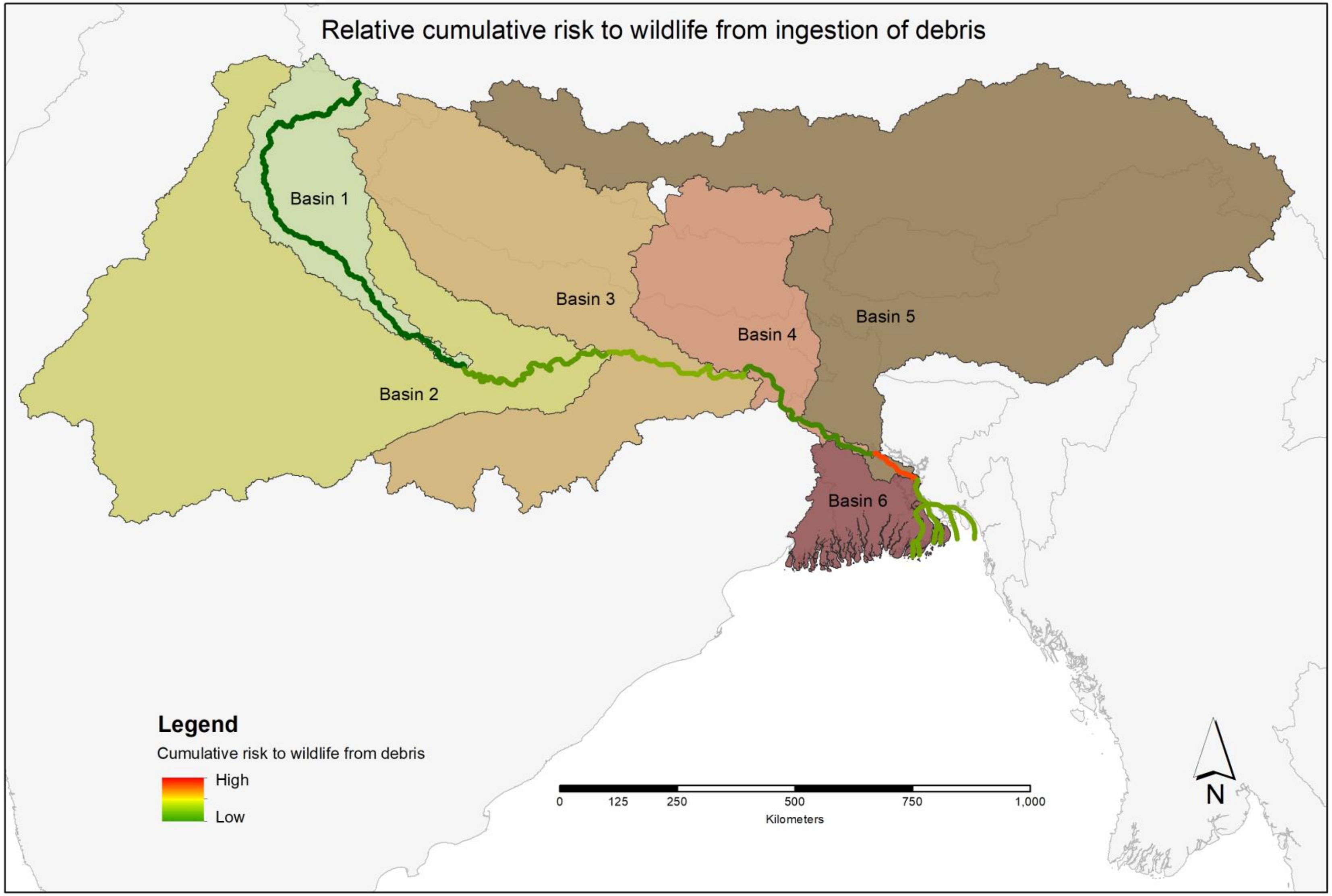
Common Greenshank
Tringa nebularia
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Common Greenshank habitat
0
125
250
500
750
1,000
Kilometers
N

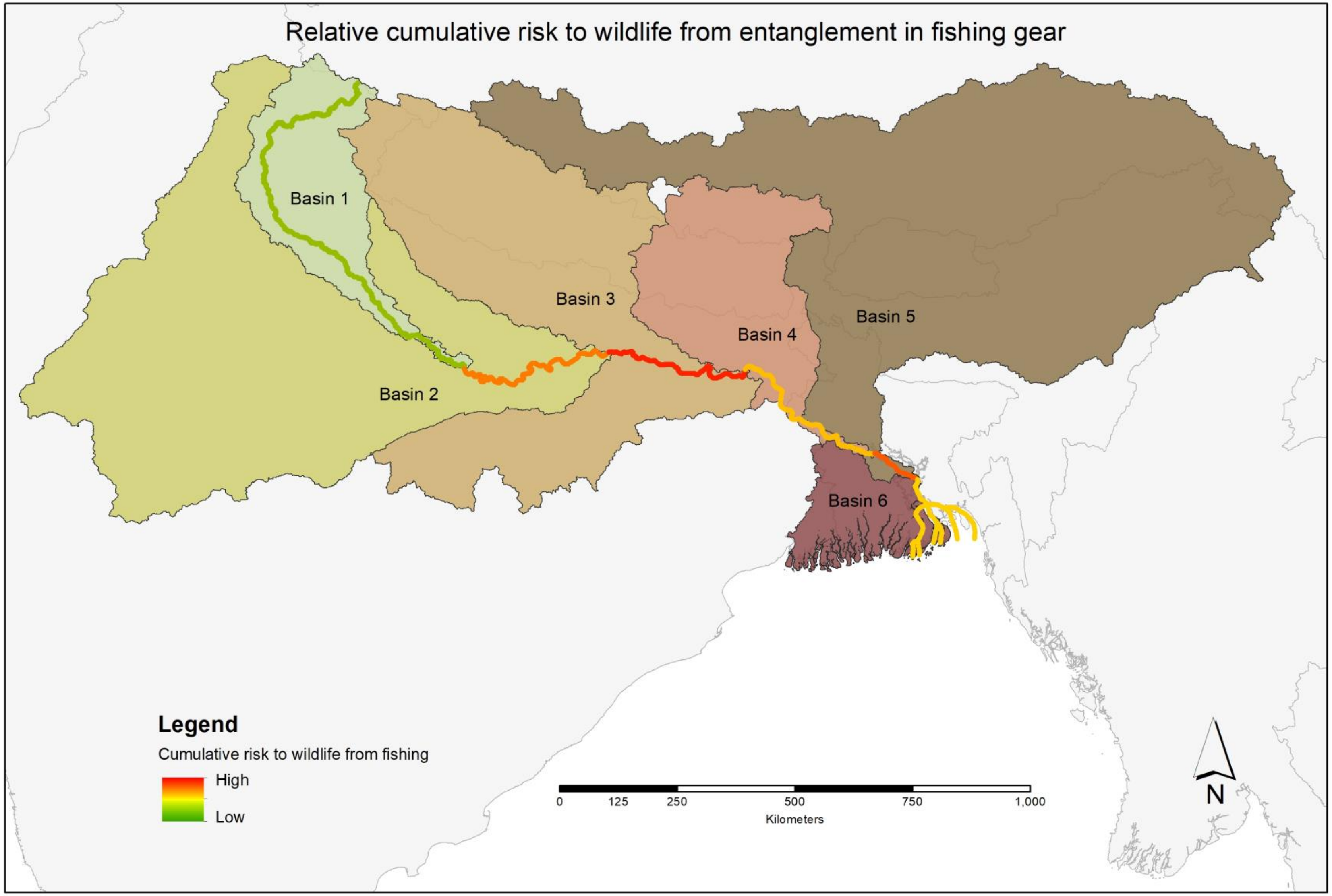

Green Sandpiper
Tringa ochropus
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Green Sandpiper habitat
0
125
250
500
750
1,000
Kilometers
N


Temminck's Stint
Calidris temminckii
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Relative risk from fishing
High
Low
No overlap with habitat
Temminck's Stint habitat
0
125
250
500
750
1,000
Kilometers
N

14.6 Ganga River CMS species cumulative risk

The following maps present the cumulative risk to CMS-listed species from ingesting litter and from entanglement in fishing debris across 6 sectors of the Ganga River. Note that the risk is scaled to the maximum cumulative risk for any section of the river, across both ingestion and entanglement risk, so as to provide a comparative risk score.


Relative cumulative risk to wildlife from ingestion of debris
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Cumulative risk to wildlife from debris
High
Low
0
125
250
500
750
1,000
Kilometers
N



Relative cumulative risk to wildlife from entanglement in fishing gear
Basin 1
Basin 2
Basin 3
Basin 4
Basin 5
Basin 6
Legend
Cumulative risk to wildlife from fishing
High
Low
0
125
250
500
750
1,000
Kilometers
N

Part V Discussion and Future Directions

15 Risk matrix, model results and litter predictions

15.1 What do the risk scores mean in context of severity?

The risk matrix provides an estimate of the potential risk to an animal when it encounters litter in its environment. The actual outcome for the individual depends in no small part on the likelihood that the animal encounters litter in the first place. For both fishing (entanglement risk) and macrolitter encounters (ingestion risk), the below risk scores are based on a presumption that the pressure from either fishing or litter density is high enough that the animal will come in contact with litter. The maps and risk scores present, in effect, a worst-case scenario.

Table 27 Risk scores (Interaction x Impact)

HIGH RISK	Common interaction and/or lethal impacts. We expect that numerous deaths would occur by this threat where litter is present in the environment. May be relevant at the population scale.
MEDIUM RISK	Common interaction and/or potentially lethal impacts. Deaths may occur where litter is present in the environment. We do not expect the number of deaths to be relevant at the population scale, except perhaps in species that are highly threatened and the population cannot afford to lose additional members.
LOW RISK	Infrequent interaction and/or low to moderate impact. Deaths may occur but are expected to be infrequent where litter is present in the environment.
NEGLIGIBLE RISK	Unlikely interaction and or with no or low impact. Deaths from plastic litter are very unlikely.

Even with this worst-case scenario, it is clear that there are only a handful of species in the Mekong (Mekong catfish, the Irrawaddy dolphin, and the Eastern Imperial Eagle), and a few species in the Ganga (Ganges River dolphin and the gharial) that are at medium or high risk from litter ingestion or entanglement.

15.2 Litter model results

Human development index (HDI), mismanaged waste, and certain land uses/land covers were statistically significant in both the best fit models. Each of the numeric variables (HDI, and mismanaged waste), were positively correlated with litter, meaning that the higher the values, the more litter was likely to be found at a site.

The term with the strongest effect size in the model was HDI, meaning that HDI explains a greater proportion of the variability in the data than the other terms. The positive direction of this correlation indicates that the higher the HDI, the more waste in the environment. HDI incorporates several measures, including education, life expectancy, and a modified measure of income (Kummu et al., 2018) . Other studies have found a positive correlation between GDP and per capita waste generation, but conversely, a negative correlation between GDP and the proportion of mismanaged waste (L. Lebreton & Andrady, 2019) . It is difficult to disentangle these factors, but the results in this instance may indicate that the net effect tends towards overall higher amounts of litter in more affluent areas. This is perhaps a surprising result, given both the negative correlation between litter and the total value of the built environment, one of our socio-economic proxies. This may be due in part to the complex relationships between the covariates in the model, but may also result from the bulk of the empirical data being collected in countries with lower overall HDI. As individuals increase their socio-economic status, they tend to increase consumption (and waste volumes). However, as the country as a whole increases its wealth, there are ancillary benefits such as improved waste management solutions that mitigate the increase in per capita waste generation (Panel, Consumption, & Branch, 2011). Additionally, many poorer countries are recipients of waste generated in more affluent countries. We would therefore expect to see a decrease in correlation between HDI and waste, or even a negative correlation in countries with a higher overall HDI.

Although population density is commonly used as a proxy for mismanaged waste (L. C. M. Lebreton et al., 2017; van Sebille et al., 2015) , it did not have a very high effect size in the best fit models, and was not significant in the Mekong model. This result is similar to what we have seen in other large scale empirical studies (Schuyler et al, Environmental context and economic status drive plastic pollution in the environment, in prep). While population density does certainly influence litter density, it is not in itself the best explanatory variable. This is due in part to the fact that population is proxied by other covariates, including nightlights and mismanaged waste, and partly due to the fact that the relationship between population density and litter is complex.

At low population densities there may be a more linear relationship, but as populations become denser, in many regions this is accompanied by enhanced waste infrastructure, thereby leading to a decline in the amount of waste per person. Therefore, other factors such as socio-economic variables may better explain the variability in the observed litter densities.

Because we did not have a comprehensive data set of observations of plastic waste along the river to use for quantifying litter loads in the risk analysis, using the best-fit models to predict these loads allows us to calculate the relative risk at a sub-river basin scale. Future iterations of the model would ideally incorporate more empirical data, or hydrological modelling to improve litter predictions.

We did have access to a limited set of measurements of microplastics at 5 locations along the Mekong River (in four of the twelve segments of the river) (Nelms et al, 2021), and 10 locations along the Ganga River (at least one in each of the six sections of the river)(Toxics link, 2020). While we have reported the ranks from each of these studies, the density of macroplastics is unlikely to be correlated with microplastics density, so it is not feasible to use these results as a validation for the litter model (Blettler et al., 2017; Jeyasanta, Sathish, Patterson, & Edward, 2020). Additionally, plastics densities are likely to be very patchy, and without samples spread across the full length of the river, determining the measured relative densities is quite challenging.

We have predicted relative litter loads at one particular moment in time, and do not have a component of seasonality built into the model. As the results from the Sea to Source expedition demonstrate, the relative litter levels along the river (and likely the absolute litter densities) may change across the year. Future models could incorporate seasonal variability (Sarah E Nelms et al., 2021) .

16 Risks of plastic litter in the Mekong River as compared to listed threats for CMS listed species

16.1 Species at Risk from Plastic Litter in the Mekong

Our risk analysis has identified three species at risk overall from plastic litter in the Mekong Basin. The Irrawaddy dolphin is at medium risk from litter ingestion. The Irrawaddy dolphin and Mekong catfish are at high risk from entanglement, and the eastern imperial eagle may be at medium risk from entanglement.

All other species were either at negligible or low risk from these threats, which we do not expect would cause significant mortality, and have not discussed further in this section.

Table 28. Mekong river CMS listed species risk scores for entanglement.

Species	Interaction	Impact	Risk score
Ingestion			
Irrawaddy dolphin	3 (Moderate)	3 (Potentially lethal)	**9 MEDIUM RISK**
Entanglement			
Mekong catfish	4 (High)	4 (Lethal)	**16 HIGH RISK**
Irrawaddy dolphin	3 (Moderate)	4 (Lethal)	**12 HIGH RISK**
Eastern Imperial Eagle	3 (Moderate)	3 (Potentially lethal)	**9 MEDIUM RISK**

16.2 Mekong Catfish

Our risk analysis identified the Mekong Catfish at high risk of entanglement by plastic litter, especially fishing related debris. Overfishing of the Mekong Catfish is recognised as the main threat to this species. While we expect some mortality to this species from entanglement in derelict fishing gear, as Mekong Catfish is not intentionally targeted, we expect that the mortality from entanglement in derelict would be less of a threat than overfishing.

Table 29 Classification of threats from IUCN Red List of Threatened species (Mekong Catfish).

Threats			Timing	Stresses		Scope	Severity	Impact score
5. Biological resource use	5.3. Logging & wood harvesting	5.3.5. Motivation Unknown/Unrecorded	Ongoing	1. Ecosystem stresses	1.2. Ecosystem degradation			Low Impact: 3
	5.4. Fishing & harvesting aquatic resources	5.4.6. Motivation Unknown/Unrecorded	Ongoing	1. Ecosystem stresses	1.2. Ecosystem degradation			Low Impact: 3
7. Natural system modifications	7.2. Dams & water management/use	7.2.11. Dams (size unknown)	Ongoing	1. Ecosystem stresses	1.1. Ecosystem conversion 1.2. Ecosystem degradation			Low Impact: 3
9. Pollution	9.3. Agricultural & forestry effluents	9.3.2. Soil erosion, sedimentation	Ongoing	1. Ecosystem stresses	1.2. Ecosystem degradation			Low Impact: 3

16.3 Irrawaddy Dolphin

Our risk analysis identified the Irrawaddy at high risk of entanglement by plastic litter, especially fishing related debris, and medium risk of litter ingestion. High mortality due to entanglement in fishing gear is already recognised as a cause of high mortality to the Irrawaddy dolphin in the Mekong River, both historically and an ongoing threat. Ingestion of plastic litter is not currently recognised among the threats to the Irrawaddy dolphin, but we propose that ingestion of litter is likely to lead to Irrawaddy dolphin mortalities. However, we expect the number of these ingestion deaths to be low, and considerably fewer than entanglement mortalities.

Table 30 Classification of threats from IUCN Red List of Threatened species (*Orcaella brevirostris* Mekong River subpopulation).

Threats			Timing	Stresses		Impact score
4. Transportation & service corridors	4.3. Shipping lanes		Ongoing	2. Species Stresses	2.1. Species mortality 2.2. Species disturbance	Low Impact: 3
5. Biological resource use	5.4. Fishing & harvesting aquatic resources	5.4.2. Intentional use: (large scale) [harvest]	Past, Unlikely to Return	2. Species Stresses	2.1. Species mortality	Past Impact
		5.4.4. Unintentional effects: (large scale) [harvest]	Ongoing	2. Species Stresses	2.1. Species mortality 2.2. Species disturbance	Low Impact: 3
		5.4.5. Persecution/control	Past, Unlikely to Return	2. Species Stresses	2.1. Species mortality	Past Impact
6. Human intrusions & disturbance	6.1. Recreational activities		Ongoing	2. Species Stresses	2.2. Species disturbance	Low Impact: 3
7. Natural system modifications	7.2. Dams & water management/use	7.2.11. Dams (size unknown)	Future	1. Ecosystem stresses	1.1. Ecosystem conversion 1.2. Ecosystem degradation	No/Negligible Impact: 1

(Scope and severity columns removed as blank)

16.4 Eastern Imperial Eagle

Our risk analysis identified the Eastern Imperial eagle to be at medium risk of entanglement in derelict fishing gear, especially in locations where line fishing occurs from the riverbank. We consider the risk posed by other net types, including those set underwater, to be a much lower risk of entangling eagles. Entanglements are not listed among known threats to this species. We expect mortality from this threat to be occasional, unlikely to cause mortality in enough numbers to be considered a population risk, and mostly limited to locations where bankside line fishing occurs.

Table 31 Classification of threats from IUCN Red List of Threatened species (Eastern Imperial Eagle).

Threats			Timing	Stresses			Scope	Severity	Impact score
2. Agriculture & aquaculture	2.2. Wood & pulp plantations	2.2.3. Scale Unknown/Unrecorded	Ongoing	1. Ecosystem stresses	1.1. Ecosystem conversion 1.2. Ecosystem degradation		Minority (<50%)	Slow, Significant Declines	
4. Transportation & service corridors	4.2. Utility & service lines		Ongoing	1. Ecosystem stresses 2. Species Stresses	1.2. Ecosystem degradation 2.1. Species mortality		Minority (<50%)	Slow, Significant Declines	
5. Biological resource use	5.1. Hunting & trapping terrestrial animals	5.1.1. Intentional use (species is the target)	Ongoing	2. Species Stresses	2.1. Species mortality 2.3. Indirect species effects	2.3.7. Reduced reproductive success	Minority (<50%)	Slow, Significant Declines	
		5.1.3. Persecution/control	Ongoing	2. Species Stresses	2.1. Species mortality		Minority (<50%)	Slow, Significant Declines	

					2.3. Indirect species effects	2.3.7. Reduced reproductive success		
	5.3. Logging & wood harvesting	5.3.4. Unintentional effects: (large scale) [harvest]	Ongoing	1. Ecosystem stresses	1.2. Ecosystem degradation		Minority (<50%)	Slow, Significant Declines
6. Human intrusions & disturbance	6.3. Work & other activities		Ongoing	2. Species Stresses	2.2. Species disturbance 2.3. Indirect species effects	2.3.7. Reduced reproductive success	Minority (<50%)	Slow, Significant Declines

17 Risks of plastic litter in the Ganga River compared to listed threats for CMS listed species

17.1 Species at Risk from Plastic Litter in the Ganga

Our risk analysis has identified three species at risk overall from plastic litter in the Ganga River Basin. The Ganges river dolphin is at medium risk from litter ingestion. The Ganges river dolphin and gharial are at high risk from entanglement, and the greater spotted eagle may be at medium risk from entanglement.

All other species were either at negligible or low risk from these threats, which we do not expect would cause significant mortality and have not discussed further in this section.

Table 32. Ganga River CMS listed species risk scores for plastic litter.

Species	Interaction	Impact	Risk Score
Ingestion			
Ganges River Dolphin	3 (Moderate)	3 (Potentially lethal)	**9 MEDIUM RISK**
Entanglement			
Ganges River Dolphin	3 (Moderate)	4 (Lethal)	**12 HIGH RISK**
Gharial	4 (High)	4 (Lethal)	**16 HIGH RISK**
Greater Spotted Eagle	3 (Moderate)	3 (Potentially lethal)	**9 MEDIUM RISK**

17.2 Ganges River Dolphin

Our risk analysis identified the Ganges River Dolphin at high risk of entanglement by plastic litter, especially fishing related debris, and moderate risk of litter ingestion. High mortality due to entanglement in fishing gear (especially gillnets) is already recognised as a cause of high mortality to the Ganges River dolphin in the Ganga River, though it has been described only in the context of active fishing gear. We propose that entanglement in derelict fishing gear is also likely to be a very high threat to this species. Ingestion of plastic litter is not currently recognised among the threats to the Ganges River dolphin, but we propose that ingestion of litter is likely to lead to dolphin mortalities. However, we expect the number of these ingestion deaths to be low, and considerably fewer than entanglement mortalities.

Table 33 Classification of threats from IUCN Red List of Threatened species (Ganges River Dolphin).

Threats			Timing	Stresses		Impact score
5. Biological resource use	5.4. Fishing & harvesting aquatic resources	5.4.1. Intentional use: (subsistence/small scale) [harvest]	Ongoing	2. Species Stresses	2.1. Species mortality	Low Impact: 3
		5.4.4. Unintentional effects: (large scale) [harvest]	Ongoing	2. Species Stresses	2.1. Species mortality	Low Impact: 3
7. Natural system modifications	7.2. Dams & water management/use	7.2.8. Abstraction of ground water (unknown use)	Ongoing	1. Ecosystem stresses	1.2. Ecosystem degradation	Low Impact: 3
		7.2.11. Dams (size unknown)	Ongoing	1. Ecosystem stresses	1.1. Ecosystem conversion 1.2. Ecosystem degradation	Low Impact: 3
9. Pollution	9.1. Domestic & urban waste water	9.1.3. Type Unknown/Unrecorded	Ongoing	1. Ecosystem stresses	1.2. Ecosystem degradation	Low Impact: 3
	9.2. Industrial & military effluents	9.2.3. Type Unknown/Unrecorded	Ongoing	1. Ecosystem stresses	1.2. Ecosystem degradation	Low Impact: 3
	9.3. Agricultural & forestry effluents	9.3.4. Type Unknown/Unrecorded	Ongoing	1. Ecosystem stresses	1.2. Ecosystem degradation	Low Impact: 3

(Scope and severity columns removed as blank)

17.3 Gharial

Our risk analysis identified the gharial at high risk of entanglement by plastic litter, especially fishing related debris. High mortality due to entanglement in fishing gear (especially gillnets) is already recognised as a cause of high mortality to the gharial. We propose that entanglement in derelict fishing gear is likely to be a very high threat to this species.

Table 34 Classification of threats from IUCN Red List of Threatened species (gharial).

Threats			Timing	Stresses			Scope	Severity	Impact score
2. Agriculture & aquaculture	2.1. Annual & perennial non-timber crops	2.1.1. Shifting agriculture	Ongoing	1. Ecosystem stresses	1.2. Ecosystem degradation		Majority (50-90%)	Slow, Significant Declines	Medium Impact: 6
				2. Species Stresses	2.2. Species disturbance				
3. Energy production & mining	3.2. Mining & quarrying		Ongoing	1. Ecosystem stresses	1.1. Ecosystem conversion		Majority (50-90%)	Slow, Significant Declines	Medium Impact: 6
					1.2. Ecosystem degradation				
				2. Species Stresses	2.2. Species disturbance				
					2.3. Indirect species effects	2.3.7. Reduced reproductive success			
5. Biological resource use	5.4. Fishing & harvesting aquatic resources	5.4.3. Unintentional effects:	Ongoing	2. Species Stresses	2.1. Species mortality		Majority (50-90%)	Slow, Significant Declines	Medium Impact: 6

		(subsistence/small scale) [harvest]						
6. Human intrusions & disturbance	6.3. Work & other activities		Ongoing	2. Species Stresses	2.2. Species disturbance	Whole (>90%)	Slow, Significant Declines	Medium Impact: 7
7. Natural system modifications	7.2. Dams & water management/use	7.2.11. Dams (size unknown)	Ongoing	1. Ecosystem stresses	1.1. Ecosystem conversion 1.2. Ecosystem degradation	Whole (>90%)	Slow, Significant Declines	Medium Impact: 7

17.4 Greater Spotted Eagle

Our risk analysis identified the greater spotted eagle to be at moderate risk of entanglement in derelict fishing gear, especially in locations where line fishing occurs from the riverbank. We consider the risk posed by other net types, including those set underwater, to be a much lower risk of entangling eagles, unless they become washed up on the riverbank or in shallow parts of an attached wetland. Entanglements are not listed among known threats to this species. We expect mortality from this threat to be occasional, unlikely to cause mortality in enough numbers to be considered a population risk, and mostly limited to locations where bankside line fishing occurs.

Table 35 Classification of threats from IUCN Red List of Threatened species (Greater Spotted Eagle).

Threats			Timing	Stresses		Scope	Severity	Impact score
1. Residential & commercial development	1.1. Housing & urban areas		Ongoing	1. Ecosystem stresses	1.1. Ecosystem conversion 1.2. Ecosystem degradation	Minority (<50%)	Slow, Significant Declines	Low Impact: 5
	1.2. Commercial & industrial areas		Ongoing	1. Ecosystem stresses	1.1. Ecosystem conversion 1.2. Ecosystem degradation	Minority (<50%)	Slow, Significant Declines	Low Impact: 5
2. Agriculture & aquaculture	2.1. Annual & perennial non-timber crops	2.1.2. Small-holder farming	Ongoing	1. Ecosystem stresses 2. Species Stresses	1.1. Ecosystem conversion 1.2. Ecosystem degradation 2.2. Species disturbance	Minority (<50%)	Slow, Significant Declines	Low Impact: 5
		2.1.3. Agro-industry farming	Ongoing	1. Ecosystem stresses 2. Species Stresses	1.1. Ecosystem conversion 1.2. Ecosystem degradation 2.2. Species disturbance	Minority (<50%)	Slow, Significant Declines	Low Impact: 5
	2.2. Wood & pulp plantations	2.2.2. Agro-industry plantations	Ongoing	1. Ecosystem stresses 2. Species Stresses	1.2. Ecosystem degradation 2.2. Species disturbance	Minority (<50%)	Slow, Significant Declines	Low Impact: 5

5. Biological resource use	5.1. Hunting & trapping terrestrial animals	5.1.2. Unintentional effects (species is not the target)	Ongoing	2. Species Stresses	2.1. Species mortality 2.2. Species disturbance 2.3. Indirect species effects	2.3.7. Reduced reproductive success	Unknown	Unknown	Unknown
		5.1.3. Persecution/ control	Ongoing	2. Species Stresses	2.1. Species mortality 2.2. Species disturbance 2.3. Indirect species effects	2.3.7. Reduced reproductive success	Majority (50-90%)	Slow, Significant Declines	Medium Impact: 6
	5.3. Logging & wood harvesting	5.3.4. Unintentional effects: (large scale) [harvest]	Ongoing	1. Ecosystem stresses 2. Species Stresses	1.2. Ecosystem degradation 2.2. Species disturbance		Majority (50-90%)	Slow, Significant Declines	Medium Impact: 6
7. Natural system modifications	7.2. Dams & water management/use	7.2.3. Abstraction of surface water (agricultural use)	Ongoing	1. Ecosystem stresses 2. Species Stresses	1.2. Ecosystem degradation 1.3. Indirect ecosystem effects 2.3. Indirect species effects	2.3.7. Reduce reproductive success	Majority (50-90%)	Slow, Significant Declines	Medium Impact: 6
	7.3. Other ecosystem modifications		Ongoing	1. Ecosystem stresses	1.2. Ecosystem degradation		Minority (<50%)	Slow, Significant Declines	Low Impact: 5

					1.3. Indirect ecosystem effects				
8. Invasive and other problematic species, genes & diseases	8.1. Invasive non-native/alien species/diseases	8.1.2. Named species	Ongoing	1. Ecosystem stresses	1.3. Indirect ecosystem effects		Minority (<50%)	Unknown	Unknown
				2. Species Stresses	2.3. Indirect species effects	2.3.2. Competition			
	8.2. Problematic native species/diseases	8.2.2. Named species	Ongoing	2. Species Stresses	2.3. Indirect species effects	2.3.1. Hybridisation	Minority (<50%)	Unknown	Unknown

18 Future directions – potential adaptations to steps in risk model framework

While we have incorporated the most current and complete data sets that we could access which covered the entire range of the Ganga and Mekong rivers, we recognise that the accuracy and resolution of the risk assessment could be improved as additional information is gathered and analysed. This risk framework is designed to be able to accommodate a range of inputs, and can be adapted as and when additional data are available. We suggest a range of potential data and analyses that could enhance these analyses in the future.

Step 1: Risk Matrix

Current method: Literature review, scale the potential for interaction and for impact for each species from 1-4. Currently this is with a focus on macro litter and fishing interactions, but it would be different for microplastics.

Potential future adaptations: With additional quantitative data on encounter rates (e.g., in a study of 50 individuals, 5 of them ingested litter, and 3 of them died from it), the interaction and impact figures could become numeric probabilities, rather than a qualitative measure given a numeric ranking.

Step 2: Litter load in river sections

Current method: We used global modelling based on surveys from 10 countries, which relates litter loads on land to globally available covariates. We summed the predicted litter within each watershed to obtain a relative litter density for each river section. The predictions incorporated a simple model of downstream flow between river sections.

Potential future adaptations:

The most accurate modelling would be based on empirical data gathered along the length of each river basin, in order to determine the actual load. In the absence of empirical data on litter densities along the entire length of the river at fine scale resolution, litter predictions are the next best option, but it is critical to recognise that they provide only a relative measure of litter loading. The litter predictions we used are based on modelling of litter loads from nearly 1500 transects across a range of global covariates. There are several adaptations to this methodology that could be employed to further enhance the accuracy and resolution of the assessment.

- Use hydrology to predict flows of litter from upland areas to the river.
- Incorporate seasonal variability into the estimates of litter densities.
- Incorporate barriers and dams into modelling.

- Determine boundaries of smaller scale watersheds in order to divide rivers into smaller sections.
- Use empirical data to determine load in river sections.

Step 3: Determine habitat overlap

Current method: We used IUCN species distributions (where available). These are the most comprehensive maps currently available, but are likely to overestimate the range of the species. This serves to make the assessment more conservative.

Potential future adaptations: Use finer scale resolution habitat mapping if available.

Step 4: Risk calculations

With additional quantitative data across compartments, including total litter load, habitat overlaps, behaviour and impact, this figure could become a numeric probability of the likelihood of death at a given concentration of litter, rather than a qualitative measure given a numeric ranking.

Given data on mortality, the risk can be compared directly to other risks for which mortality rates are available.

Appendix A Extended literature review, including all literature review references.

A.1 Search terms and results

Mekong River – Initial literature search (all taxa)

We conducted an advanced literature search of all literature published on the Web of Science on 12 November 2020.

Search terms

Species

AB = (catfish* OR *Pangasianodon* OR dolphin* OR *Orcaella* OR Florican* OR *Houbaropsis* OR bustard* OR eagle* OR *Aquila* OR crane* OR *Antigone*)

Interaction

AB = (fishing OR tangle* OR entangle* OR ingest*)

Litter

AB = (plastic OR debris OR solid waste OR net* OR trap* OR line*)

Results

Search History:

Set	Results	Save History / Create Alert · Open Saved History	Edit Sets	Combine Sets (AND / OR, Combine)	Delete Sets (Select All, Delete)
# 11	1,100	AB = (Antigone OR grus) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 10	9,396	AB = (Crane OR Antigone) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 9	387	AB = (Sarus Crane OR Antigone Antigone) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 8	10,600	AB = (Eagle OR Aquila) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 7	71	AB = (Eastern Imperial Eagle OR Aquila heliaca) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 6	543	AB = (Florican OR Houbaropsis OR bustard) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 5	14	AB = (Bengal Florican OR Houbaropsis bengalensis) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 4	7,385	AB = (dolphin OR Orcaella) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 3	73	AB = (Irrawaddy dolphin OR Orcaella brevirostris) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 2	10,264	AB = (catfish OR Pangasianodon) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 1	154	AB = (Mekong catfish OR Pangasianodon gigas) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
				AND OR Combine	Select All Delete

Note: crane returned mostly engineering papers, so we tested Antigone or Grus instead.

Results

Search History:

Set	Results	Save History / Create Alert Open Saved History	Edit Sets	Combine Sets AND OR Combine	Delete Sets Select All Delete
# 4	1,357	#3 AND #2 AND #1 *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 3	6,183,351	AB = (plastic OR debris OR solid waste OR net* OR trap* OR line*) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 2	477,084	AB = (fishing OR tangle* OR entangle* OR ingest*) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 1	38,514	ab = (catfish* OR Pangasianodon OR dolphin* OR Orcaella OR Florican* OR Houbaropsis OR bustard* OR eagle* OR Aquila OR crane* OR Antigone) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
				AND OR Combine	Select All Delete

Mekong river secondary search

Conducted an advanced literature search of all literature published on the Web of Science on 14 December 2020.

Species

AB = (Florican* OR *Houbaropsis* OR bustard* OR crane* OR *Antigone*)

Interaction

AB = (stomach content* OR diet*)

Results

Search History:

Set	Results	Save History / Create Alert Open Saved History	Edit Sets	Combine Sets AND OR Combine	Delete Sets Select All Delete
# 3	93	#2 AND #1 *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 2	586,347	AB = (stomach content* OR diet*) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 1	10,336	AB = (Florican* OR Houbaropsis OR bustard* OR crane* OR Antigone) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
				AND OR Combine	Select All Delete

Returned 93 potentially relevant studies.

Ganga River primary search

We conducted a systematic literature review, conducting an advanced literature search of all literature published on the Web of Science on 08 June 2021.

Species

AB = (dolphin* OR *Platanista* OR gharial* OR *Gavialis* OR crocodil* OR elephant* OR *Elephas* OR eagle* OR *Clanga* OR crane* OR *Antigone* OR *Grus* OR goose OR geese OR *Anser* OR duck OR gadwall* OR pintail* OR teal* OR *Anas* OR pochard* OR *Netta* OR *Aythya* OR godwit* OR *Limosa* OR curlew* OR *Numenius* OR sandpiper* OR greenshank* OR *Tringa* OR stint OR *Calidris*)

Interaction

AB = (fishing OR tangle* OR entangle* OR ingest*)

Litter

AB = (plastic OR litter OR debris OR solid waste OR net* OR trap* OR line*)

Results

Search History:

Set	Results	Save History / Create Alert · Open Saved History	Edit Sets	Combine Sets AND OR Combine	Delete Sets Select All Delete
# 4	810	#3 AND #2 AND #1 *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 3	6,534,190	AB = (plastic OR litter OR debris OR solid waste OR net* OR trap* OR line*) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 2	498,521	AB = (fishing OR tangle* OR entangle* OR ingest*) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
# 1	75,362	AB = (dolphin* OR Platanista OR Gharial* OR Gavialis OR crocodil* OR elephant* OR Elephas OR eagle* OR Clanga OR crane* OR Antigone OR grus OR goose OR geese OR anser OR duck OR gadwall* OR pintail* OR teal* OR anas OR pochard* OR netta OR Aythya OR godwit* OR limosa OR curlew* OR Numenius OR sandpiper* OR greenshank* OR tringa OR stint OR calidris) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit		
				AND OR Combine	Select All Delete

Ganga River secondary search

We conducted a systematic literature review, conducting an advanced literature search of all literature published on the Web of Science on 09 June 2021 for elephants, cranes and waders. We conducted the search for cranes and waders separate to the search for elephants, due to different search terms used considering the size and behaviour differences.

Search terms- Cranes and waders

Species

AB = (crane* OR *Antigone* OR *Grus* OR godwit* OR limosa OR curlew* OR *Numenius* OR sandpiper* OR greenshank* OR *Tringa* OR stint OR *Calidris*)

Interaction

AB = (stomach content* OR diet*)

Results- Cranes and waders

Search History:

Set	Results	Save History / Create Alert · Open Saved History	Edit Sets	Combine Sets (AND / OR) Combine	Delete Sets (Select All) Delete
# 3	263	#2 AND #1 *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit	☐	☐
# 2	611,304	AB = (stomach content* OR diet*) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit	☐	☐
# 1	13,046	AB = (crane* OR Antigone OR grus OR godwit* OR limosa OR curlew* OR Numenius OR sandpiper* OR greenshank* OR tringa OR stint OR calidris) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit	☐	☐
				AND / OR Combine	Select All Delete

Returned 263 potentially relevant studies, of which 63 were relevant.

For elephants, we searched for studies of the species and litter, using different search terms due to the animal's size, without the interaction

Search terms- Elephants

AB = (elephant* OR *Elephas*)

Litter

AB = (plastic OR litter OR debris OR solid waste OR trash OR garbage)

Results- Elephants

Search History:

Set	Results	Save History / Create Alert · Open Saved History	Edit Sets	Combine Sets (AND / OR) Combine	Delete Sets (Select All) Delete
# 3	146	#2 AND #1 *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit	☐	☐
# 2	425,120	AB = (plastic OR litter OR debris OR solid waste OR trash OR garbage) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit	☐	☐
# 1	11,153	AB = (elephant* OR Elephas) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*	Edit	☐	☐
				AND / OR Combine	Select All Delete

Returned 146 potentially relevant studies, of which three were relevant.

Wildlife hospital search

Search terms

AB = (wildlife)

AB = (hospital OR rescue OR rehabilitation)

An advanced search for wildlife hospitals, rescue or rehabilitation facilities on 11 June 2021 returns 874 results, though only five usable relevant results.

A.2 Quality of evidence

In this section, we present the extended findings of our literature review of each the interactions and impact of interactions with plastic litter for CMS listed species.

We acknowledge that for most species, the evidence is limited due to lack of data in the target species, and for some CMS listed species, lack of evidence in similar species also. We therefore provide not only our assessment of the likelihood of interaction and the consequence of that interaction for each species, but also a qualitative score indicating how strong the support for each score is within the literature.

Table 36 Table of quality scores for the strength of the evidence within the literature for a given risk score.

Quality score	Meaning
A	Demonstrated evidence interaction/lack of interaction in the target species and/or numerous lines of evidence in a similar species*.
B	Some demonstrated evidence for interaction/lack of interaction in similar species* but not the target species.
C	Limited evidence. Score is based on the foraging behaviour (interaction) or the physiology (impact) of the target or similar species, or a suggestion in the literature, but evidence is limited/absent.

**similar species means a minimum level of taxonomic family for interaction and minimum level of taxonomic class for impact.*

A.3 Mekong species risk overview

Table 37 Risk scores for litter ingestion in Mekong species, and qualitative assessment of evidence for these scores.

Species	Interaction	Impact	Quality of evidence and qualitative impact
Mekong catfish	3 (Moderate)	2 (Sub-lethal)	B: Sublethal impacts from plastic ingestion found experimentally in other fish at high levels of exposure.
Irrawaddy dolphin	3 (Moderate)	3 (Potentially lethal)	A: Lethal impacts from litter ingestion found in wild dolphins if large or sharp item eaten, but this is not common.
Bengal Florican	1 (Unlikely)	2 (Sub-lethal)	B: Uncommon lethal impacts from ingestion found in other birds if large litter items are ingested.
Eastern Imperial Eagle	2 (Low)	3 (Potentially lethal)	B: Uncommon lethal impacts from litter and synthetic item ingestion found in other raptorial birds in captivity.

Sarus Crane	1 (Unlikely)	2 (Sub-lethal)	B: Uncommon lethal impacts from ingestion found in waterbirds, if large litter items are ingested, however no evidence from cranes.

Table 38 Mekong River CMS-listed species risk scores for entanglement in plastic litter, and qualitative assessment of evidence for these scores.

Species	Interaction	Impact	Quality of evidence and qualitative impact
Mekong catfish	4 (High)	4 (Lethal)	B: Sublethal impacts from plastic ingestion found experimentally in other fish at high levels of exposure.
Irrawaddy dolphin	3 (Moderate)	4 (Lethal)	A: Lethal impacts from entanglements, especially in gillnets, are frequent in the scientific literature.
Bengal Florican	1 (Unlikely)	3 (Potentially lethal)	B: Uncommon lethal impacts from ingestion found in other birds if large litter items are ingested.
Eastern Imperial Eagle	3 (Moderate)	3 (Potentially lethal)	B: Uncommon lethal impacts from litter and synthetic item ingestion found in other raptorial birds in captivity.
Sarus Crane	1 (Unlikely)	3 (Potentially lethal)	B: Uncommon lethal impacts from ingestion found in waterbirds, if large litter items are ingested, however no evidence from cranes.

A.4 Mekong catfish (*Pangasianodon gigas*)

A.4.1 Risk of interaction with plastic and other aquatic plastic if present in the environment

Ingestion of plastic and fishing gear

Fish vary in their behavioural response to plastic; some species target drifting plastic to eat (Carson, 2013), while others egest plastic, only swallowing small particles that are swallowed at the same time as food (Ory, Gallardo, Lenz, & Thiel, 2018). Catfish feed by suction in the sediment at the bottom of waterways, and this foraging method makes them vulnerable to the unintentional ingestion of non-target items, including plastic litter. Though plastic ingestion has not been reported in the Mekong catfish, one study shows that the gut morphometry of the Mekong catfish indicates a diet preference to indigestible materials (Medo et al., 2020). The Mekong catfish is suggested to feed on indigestible materials such as plants, algae, and sediments (Medo et al., 2020) and we suggest that this species is also likely to swallow plastic litter. The types of plastic ingested by other catfish species are mostly microplastic-sized items and include fibres and fragments of hard and soft plastic (Lubis et al., 2019; Park et al., 2020; F. E. Possatto et al., 2011; Ribeiro-Brasil et al., 2020).

Due to the large size of the Mekong catfish, we suggest that they might also be vulnerable to ingestion of larger items. The consequences of plastic ingestion in large aquatic fish are not well understood. Lethal impacts of plastic ingestion in large fish are not recorded. In other vertebrates, plastics can cause foreign body obstructions if they become trapped in the gastrointestinal tract, though microplastic ingestion rarely causes lethal impacts in large animals (Roman, Schuyler, et al., 2021) as most items swallowed pass through the gut lumen and are excreted (D'Souza, Windsor, Santillo, & Ormerod, 2020; Sarah E Nelms et al., 2019). Several sublethal impacts from plastic ingestion, including reduced growth (Critchell & Hoogenboom, 2018), hepatic stress (Rochman et al., 2013) and consequences on fish behaviour (Mattsson et al., 2017) have been recognised, though whether these have a measurable impact on fish survival or are important at the population level remains controversial (Cunningham et al., 2020).

Entanglement in fishing gear

Our literature search revealed two studies showing the vulnerability of catfish to becoming entangled or entrapped in two different types of fishing gear. First, catfish have become by-caught in gillnets (Morteza Eighani et al., 2020) and second, catfish have become trapped in pot-style traps (James West Page et al., 2013). If entangled/entrapped, the consequences are likely to be lethal for the fish. In both these studies, active fishing gear was involved, however, we suggest that there is the potential that catfish would also be vulnerable to entanglement or entrapment in both gillnets and pot traps.

A.4.2 Relevant references obtained during the literature review

Ingestion of plastic relevant references:

- Lubis, I. E. N.; Melani, W. R.; Syakti, A. D., Plastic Debris Contamination in Grey-Eel Catfish (Plotosus canius) in Tanjungpinang Water, Riau Islands-Indonesia. In 1st International Conference on Material Science and Engineering for Sustainable Rural Development, Fatoni, A.; Yusuf, Y.; Supriyanti, R.; Habe, H.; Choi, J. S.; Sulaeman, U.; Cahyanto, W. T.; Sanagi, M. M.; Widanarto, W.; Subba, J. R., Eds. Amer Inst Physics: Melville, 2019; Vol. 2094.
- Park, T. J.; Lee, S. H.; Lee, M. S.; Lee, J. K.; Lee, S. H.; Zoh, K. D., Occurrence of microplastics in the Han River and riverine fish in South Korea. Sci. Total Environ. 2020, 708, 11.
- Possatto, F. E.; Barletta, M.; Costa, M. F.; do Sul, J. A. I.; Dantas, D. V., Plastic debris ingestion by marine catfish: An unexpected fisheries impact. Mar. Pollut. Bull. 2011, 62 (5), 1098-1102.
- Ribeiro-Brasil, D. R. G.; Torres, N. R.; Picanço, A. B.; Sousa, D. S.; Ribeiro, V. S.; Brasil, L. S.; de Assis Montag, L. F., Contamination of stream fish by plastic waste in the Brazilian Amazon. Environmental Pollution 2020, 266, 115241

Ingestion of derelict fishing gear relevant references:

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- Medo, A.; Nishizawa, H.; Yokoyama, A.; Kume, M.; Mitsunaga, Y.; Arai, N.; Yamane, H.; Ikeya, K.; Viputhanumas, T.; Mitamura, H., Gut Morphometry Represents Diet Preference To Indigestible Materials in the Largest Freshwater Fish, Mekong Giant Catfish (*Pangasianodon* gigas). Zool. Sci. 2020, 37 (5), 444-449.
- Carson, H. S., The incidence of plastic ingestion by fishes: From the prey's perspective. Mar. Pollut. Bull. 2013, 74 (1), 170-174.

Entanglement in fishing gear relevant references

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A.5 Irrawaddy dolphin (*Orcaella brevirostris*)

A.5.1 Risk of interaction with plastic and other aquatic plastic if present in the environment

Ingestion of plastic and fishing gear

Ingestion of plastic and fishing gear has been recorded across dolphin taxa, including both marine species (Alexiadou et al., 2019; Byard et al., 2020; Fernandez et al., 2009) and river dolphins (Denuncio et al., 2011). The threat to cetaceans posed by litter in marine environments is serious enough that cetacean experts at the European Cetacean Society (ECS), 31st Annual Conference in Middelfart (Denmark) consider plastic litter to be one of the major threats for marine mammals (Panti, Baini, Lusher, Hernandez-Milan, Rebolledo, et al., 2019). Plastic litter in aquatic environments and its potential threat to cetaceans in rivers, however, has yet to be investigated. None of the studies examined as part of the literature search undertaken reported ingestion of plastic litter in the Irrawaddy dolphin nor in cetaceans that exclusively inhabit rivers. However, given the frequent reporting of plastic litter ingestion in other dolphin taxa, we consider it very likely that the Irrawaddy dolphin is at a high risk of ingesting items such as plastic bags and food packaging (Alexiadou et al., 2019; Panti, Baini, Lusher, Hernandez-Milan, Rebolledo, et al., 2019; Puig-Lozano et al., 2018), fishing nets and ropes (Denuncio et al., 2011; Panti, Baini, Lusher, Hernandez-Milan, Rebolledo, et al., 2019; Puig-Lozano et al., 2018), hooks and monofilament line (Byard et al., 2020).

Ingestion of plastic litter in cetaceans can cause foreign body obstructions, and may result in death due to gastric blockage, starvation, perforation or rupture of the gastro-intestinal tract, severe injury, peritonitis and septicaemia (Byard et al., 2020; Panti, Baini, Lusher, Hernandez-Milan, Rebolledo, et al., 2019). Where the specific items ingested and leading to death are reported, film-like plastics, including plastic bags, plastic sheeting and packaging as well as fishing debris including ropes and nets, account for most items causing fatal foreign body obstructions, typically in the stomach (Alexiadou et al., 2019) while fishing hooks are often responsible for perforations (Byard et al., 2020). Feeding by suction and filter feeding increases the risk of litter ingestion (Alexiadou et al., 2019; Fossi et al., 2014). Cetaceans that die from litter have been observed swimming with difficulty in the days preceding death (Alexiadou et al., 2019), which may increase the risk of being struck by boats. One study shows that half of necropsies conducted on ship-struck cetaceans in marine environments had ingested plastic before death (Alexiadou et al., 2019).

Entanglement in fishing gear

Entanglement in fishing gear is recognised as a major cause of death of cetaceans worldwide (Alexiadou et al., 2019; Duras et al., 2021; Puig-Lozano et al., 2020). Numerous studies detailing fatal cetacean entanglement, including of Irrawaddy dolphins (Coram, Abreo, Ellis, & Thompson) and dolphins in rivers (Kelkar & Dey, 2020), were encountered during the literature search. In one study of the contribution of social media to cetacean research in Southeast Asia, the Irrawaddy dolphin was the most frequent species to experience litter-related strandings, with each stranding involving entanglement in fishing gear (Coram et al.). In this study, all Irrawaddy dolphin strandings in the Philippines (n=2) were postulated to result from entanglement in discarded fishing nets, while others were presumed to be bycatch (Coram et al.). The authors suggest that freshwater populations of Irrawaddy dolphins are more vulnerable to entanglement than those in marine environments (Coram et al.).

Studies reviewed for this report that reported fatal encounters between cetaceans and fishing gear often did not report whether active or derelict fishing gear was involved in the encounter. In most cases, whether active or derelict gear was involved was probably not known by the studies' authors (note: our search methodology excluded reports of dolphin entanglement in active fishing gear). Among gear types, gill nets were frequently singled out as a gear type frequently associated with dolphin mortality (Bordino, Mackay, Werner, Northridge, & Read, 2013; Dawson, 1991; Kastelein et al., 2000; Kelkar & Dey, 2020; Mooney, Au, Nachtigall, & Trippel, 2007; A. J. Read, D. M. Waples, K. W. Urian, & D. Swanner, 2003) as dolphins have difficulty detecting gillnets with echolocations, especially in quiet conditions (Kastelein et al., 2000).

A.5.2 Relevant references obtained during the literature review

Ingestion of plastic relevant references

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Ingestion of fishing gear relevant references

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A.6 Bengal Florican (*Houbaropsis bengalensis bengalensis*)

A.6.1 Risk of interaction with plastic and other aquatic plastic if present in the environment

Our initial literature search did not return any results for the Bengal florican, floricans or bustards interaction with plastic litter through ingestion or entanglement. There is no significant evidence that terrestrial birds that forage visually for small, mobile prey such as insects and small aquatic animals are at risk of ingesting plastic and other types of plastic litter. Based on this lack of behavioural predisposition for intentionally or accidentally eating large plastic and plastic litter, we consider the Bengal florican at low risk of litter ingestion.

We conducted a literature search for records of diet, faecal analysis and stomach contents for bustards. None of these reviewed dietary studies made any mention of plastic litter encountered.

A.6.2 Relevant references obtained during the literature review

- 519 great bustards (*Otis tarda*) feces samples collected, no plastic mentioned. (Bravo, Bautista, Ponce, & Alonso, 2019)
- 619 great bustards (*Otis tarda*) feces samples collected, no plastic mentioned (Bravo, Ponce, Bautista, & Alonso, 2016)

- 357 droppings of Little Bustard (*Tetrax tetrax*) with no plastic mentioned (Bravo, Cuscó, Morales, & Mañosa, 2017)
- Contents from 74 stomachs of North African houbara bustard (*Chlamydotis undulata undulata*) (Bourass & Hingrat, 2015)
- 110 fecal samples of Great Bustards (*Otis tarda*), no plastic mentioned (Gooch, Ashbrook, Taylor, & Székely, 2015)
- 49 stomachs of young Great Bustards (*Otis tarda*) in Spain, no plastic mentioned (Bravo, Ponce, Palacín, & Carlos Alonso, 2012)
- 388 feces and three stomachs of Little Bustards (*Tetrax tetrax*) (Jiguet, 2002)
- Fecal analysis of great bustards (*Otis t. tarda*) in north-west Spain, no plastic mentioned (Lane, Alonso, Alonso, & Naveso, 1999)

While this evidence does not rule out the presence or ingestion of plastics (especially microplastics), given the high frequency of their presence in aquatic environments, the lack of evidence suggests that it is unlikely that plastics pose a notable threat to the Bengal florican.

A.7 Eastern Imperial Eagle (*Aquila heliaca*)

A.7.1 Risk of interaction with plastic and other aquatic plastic if present in the environment

Our literature search revealed an isolated cases of the ingestion of a plastic materials in captive raptors (Applegate et al., 2017), numerous cases of lead shot ingestion in wild raptors (Cochrane et al., 2015; Descalzo et al., 2021; Franson & Russell, 2014; Franzen-Klein et al., 2018; Mateo et al., 2007; Miller et al., 2000; Rattner & McGowan, 2007), and cases of entanglement in derelict fishing gear (Rattner & McGowan, 2007). The only plastic ingestion cases occurred when plastic cage substrates were eaten by captive animals leading to anorexia and death, though the reason for this was not known (Applegate et al., 2017). As these interactions occurred in captive animals, the cases may not be relevant to wild raptors. Ingestion of lead shot, resulting from raptors preying on waterbirds that were either embedded with shot or had ingested shot, was a recurring finding in the literature review, and can lead to debilitation and death from lead poisoning (Cochrane et al., 2015; Franson & Russell, 2014; Franzen-Klein et al., 2018; Mateo et al., 2007; Miller et al., 2000; Rattner & McGowan, 2007). The source of lead shots was from hunting of waterfowl, a recreational activity which is restricted to specific locations where hunting is permitted, and is probably not relevant to this report. Our literature review revealed that entanglement in fishing gear, especially monofilament line, is threat to raptors that hunt in areas where fishing occurs (Rattner & McGowan, 2007). Entanglement in monofilament line can cause serious debilitation and death in raptors.

Wildlife hospital admissions

Though entanglement was listed in just one study (Rattner & McGowan, 2007) as a potential threat in our primary literature search for raptors, entanglements of raptors are noted among the wildlife hospital admission literature. Wildlife hospital admissions of Australian coastal raptors show that fishing equipment entanglement is an important threat, fishing equipment entanglement, accounting for 21% of raptors for which we could determine the cause of admission (Thomson et al., 2020). Fishing line ingestion and entanglement reported in another study of raptors in Australia (Taylor-Brown et al., 2019). The wildlife hospital admission literature further reiterates the threat of lead poisoning to raptors Relevant references obtained during the literature review (Kenntner, Crettenand, Fünfstück, Janovsky, & Tataruch, 2007; Pérez-López, de Mendoza, Beceiro, & Rodríguez, 2008).

Plastic ingestion relevant references

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Metal ingestion relevant references

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Entanglement relevant references

- Rattner, B. A.; McGowan, P. C., Potential hazards of environmental contaminants to avifauna residing in the Chesapeake Bay estuary. Waterbirds 2007, 30, 63-81.

A.8 Sarus Crane (*Antigone antigone*).

A.8.1 Risk of interaction with plastic and other aquatic plastic if present in the environment

Our initial literature search did not return any results for the cranes or species of the genera *Antigone* or *Grus* interaction with plastic litter through ingestion nor entanglement. There is no significant evidence that terrestrial birds that forage visually for small, mobile prey such as insects and small aquatic animals are at risk of ingesting plastic and other types of plastic litter. Based on this lack of behavioural predisposition for intentionally or accidentally eating large plastic and plastic litter, we consider the sarus crane at low risk of litter ingestion.

A.8.2 Relevant references obtained during the literature review

We conducted a literature search for records of diet, faecal analysis and stomach contents for cranes. None of these reviewed dietary studies made any mention of plastic litter encountered.

- 1,055 red-crowned crane (*Grus japonensis*) faeces samples, no plastic mentioned. (Li, Zhang, Chen, Lloyd, & Zhang, 2020)
- 505 good quality, 5-min videos were recorded of Black-necked Crane (*Grus nigricollis*) foraging, no plastic mentioned (Dong, Lu, Zhong, & Yang, 2016)
- Eight dead red-crowned cranes, stomach and faecal samples, plastic not mentioned (Luo, Ye, Gao, & Wang, 2015)
- 135 faecal samples collected from Red-crowned Crane (*Grus japonensis*), no plastic mentioned (Li, Ding, Yuan, Lloyd, & Zhang, 2014)
- 16 gizzards and 35 fecal samples of Demoiselle Crane (*Anthropoides virgo*), no plastic mentioned (Sarwar, Hussain, Khan, & Anwar, 2013)
- 136 stomach contents of Sandhill Cranes (*Grus canadensis*), diet contents collected by shooting, no plastic mentioned (Ballard & Thompson, 2000)

While this evidence does not rule out the presence or ingestion of plastics (especially microplastics), given the high frequency of their presence in aquatic environments, the lack of evidence suggests that it is unlikely that plastics pose a notable threat to the sarus crane.

A.9 Ganga River Species

In this section, we present the findings of our extended literature review of each interactions and impact of interactions with plastic litter for CMS listed species.

Table 39 Ganga River CMS listed species risk scores for ingestion of plastic litter.

Species	Interaction	Impact	Quality of evidence and qualitative impact
Ganges River Dolphin	3 (Moderate)	3 (Potentially lethal)	A: Lethal impacts from litter ingestion found in wild dolphins if large or sharp item eaten, but this is not common.
Gharial	2 (Low)	1 (Unlikely)	C: No evidence of lethal impacts from ingestion found in other crocodilians.
Asian Elephant	2 (Low)	1 (Unlikely)	C: Unlikely to be lethal. One reputable example of a lethal impact despite high and regular exposure at dump sites.
Sarus Crane	1 (Unlikely)	2 (Sub-lethal)	B: Uncommon lethal impacts from ingestion found in waterbirds, if large litter items are ingested, however no evidence from cranes.
Common Crane	1 (Unlikely)	2 (Sub-lethal)	
Greylag Goose	3 (Moderate)	2 (Sub-lethal)	B: Evidence for frequent plastic litter ingestion in numerous waterfowl species. Limited evidence for lethal impacts from litter ingestion found in waterbirds, despite common ingestion.
Common Shelduck	3 (Moderate)	2 (Sub-lethal)	
Gadwall	3 (Moderate)	2 (Sub-lethal)	
Northern Pintail	3 (Moderate)	2 (Sub-lethal)	
Common Teal	3 (Moderate)	2 (Sub-lethal)	
Red-crested Pochard	3 (Moderate)	2 (Sub-lethal)	
Tufted Duck	3 (Moderate)	2 (Sub-lethal)	
Greater Spotted Eagle	2 (Low)	3 (Potentially lethal)	B: Uncommon lethal impacts from rare synthetic item ingestion in captive raptors.
Black-tailed Godwit	1 (Unlikely)	2 (Sub-lethal)	B: No evidence of litter ingestion nor of lethal impacts in wading birds. However, sub-lethal impacts are possible if litter is ingested, as for other birds.
Eurasian Curlew	1 (Unlikely)	2 (Sub-lethal)	
Marsh Sandpiper	1 (Unlikely)	2 (Sub-lethal)	
Common Greenshank	1 (Unlikely)	2 (Sub-lethal)	

Species	Interaction	Impact	Quality of evidence and qualitative impact
Green Sandpiper	1 (Unlikely)	2 (Sub-lethal)	
Temminck's Stint	1 (Unlikely)	2 (Sub-lethal)	

Table 40. Ganga River CMS listed species risk scores for entanglement in plastic litter.

Species	Interaction	Impact	Quality of evidence and qualitative impact
Ganges River Dolphin	3 (Moderate)	4 (Lethal)	A: Lethal impacts from entanglements, especially in gillnets, are frequent in the scientific literature.
Gharial	4 (High)	4 (Lethal)	A: Abundant evidence of frequent entanglements and lethal outcomes.
Asian Elephant	1 (Unlikely)	1 (Unlikely)	C: Asian elephants are unlikely to become entangled and if they are, it is unlikely to be lethal due to large size
Sarus Crane	1 (Unlikely)	3 (Potentially lethal)	B: Uncommon lethal impacts from ingestion found in waterbirds, if large litter items are ingested, however no evidence from cranes.
Common Crane	1 (Unlikely)	3 (Potentially lethal)	
Greylag Goose	2 (Low)	3 (Potentially lethal)	A: Abundant evidence that entanglements occur with waterfowl, especially in fishing line, though infrequent as fishing line is not common in aquatic environments. Lethal outcomes without treatment proposed in wildlife hospital reports from the scientific literature.
Common Shelduck	2 (Low)	3 (Potentially lethal)	
Gadwall	2 (Low)	3 (Potentially lethal)	
Northern Pintail	2 (Low)	3 (Potentially lethal)	
Common Teal	2 (Low)	3 (Potentially lethal)	
Red-crested Pochard	2 (Low)	3 (Potentially lethal)	
Tufted Duck	2 (Low)	3	

Species	Interaction	Impact	Quality of evidence and qualitative impact
		(Potentially lethal)	
Greater Spotted Eagle	3 (Moderate)	3 (Potentially lethal)	A: Evidence of common entanglements and lethal outcomes of raptors from the scientific literature.
Black-tailed Godwit	1 (Unlikely)	3 (Potentially lethal)	B: No evidence of entanglement of migratory waders from the literature, but if a wader became entangled, there would likely be a potentially lethal consequence.
Eurasian Curlew	1 (Unlikely)	3 (Potentially lethal)	
Marsh Sandpiper	1 (Unlikely)	3 (Potentially lethal)	
Common Greenshank	1 (Unlikely)	3 (Potentially lethal)	
Green Sandpiper	1 (Unlikely)	3 (Potentially lethal)	
Temminck's Stint	1 (Unlikely)	3 (Potentially lethal)	

A.10 Ganges River Dolphin (*Platanista gangetica gangetica*)

A.10.1 Risk of interaction with plastic and other aquatic plastic if present in the environment

Ingestion of plastic and fishing gear

Ingestion of plastic and fishing gear has been recorded across dolphin taxa, including both marine species (Alexiadou et al., 2019; Byard et al., 2020; Fernandez et al., 2009) and river dolphins (Denuncio et al., 2011). The threat to cetaceans posed by litter in marine environments is serious enough that cetacean experts at the European Cetacean Society (ECS), 31st Annual Conference in Middelfart (Denmark) consider plastic litter to be one of the major threats for marine mammals (Panti, Baini, Lusher, Hernandez-Milan, Rebolledo, et al., 2019). Plastic litter in aquatic environments and its potential threat to cetaceans in rivers, however, has yet to be investigated. None of the studies examined as part of the literature search undertaken reported ingestion of plastic litter in the Irrawaddy dolphin nor in cetaceans that exclusively inhabit rivers. However, given the frequent reporting of plastic litter ingestion in other dolphin taxa, we consider it very likely that the Ganges River dolphin is at a high risk of ingesting items such as plastic bags and food packaging (Alexiadou et al., 2019; Panti, Baini, Lusher, Hernandez-Milan, Rebolledo, et al., 2019; Puig-Lozano et al., 2018), fishing nets and ropes (Denuncio et al., 2011; Panti, Baini, Lusher, Hernandez-Milan, Rebolledo, et al., 2019; Puig-Lozano et al., 2018), hooks and monofilament line (Byard et al., 2020).

Ingestion of plastic litter in cetaceans can cause foreign body obstructions, and may result in death due to gastric blockage, starvation, perforation or rupture of the gastro-intestinal tract, severe injury, peritonitis and septicaemia (Byard et al., 2020; Panti, Baini, Lusher, Hernandez-Milan, Rebolledo, et al., 2019). Where the specific items ingested and leading to death are reported, film-like plastics, including plastic bags, plastic sheeting and packaging as well as fishing debris including ropes and nets, account for most items causing fatal foreign body obstructions, typically in the stomach (Alexiadou et al., 2019) while fishing hooks are often responsible for perforations (Byard et al., 2020). Feeding by suction and filter feeding increases the risk of litter ingestion (Alexiadou et al., 2019; Fossi et al., 2014). Cetaceans that die from litter have been observed swimming with difficulty in the days preceding death (Alexiadou et al., 2019), which may increase the risk of being struck by boats. Boat strikes may result from difficulty swimming due to ingested plastic. One study shows that half of necropsies conducted on ship-struck cetaceans in marine environments had ingested plastic before death (Alexiadou et al., 2019).

Entanglement in fishing gear

Entanglement in fishing gear is recognised as a major cause of death of cetaceans worldwide (Alexiadou et al., 2019; Duras et al., 2021; Puig-Lozano et al., 2020). Numerous studies detailing fatal cetacean entanglement, including dolphins in rivers (Kelkar & Dey, 2020), was encountered during the literature search. Studies reviewed for this report that reported fatal encounters between cetaceans and fishing gear often did not report whether active or derelict fishing gear was involved in the encounter. In most cases, whether active or derelict gear was involved was probably not known by the studies' authors (note: our search methodology excluded reports of dolphin entanglement in active fishing gear). Among gear types, gill nets were frequently singled out as a gear type frequently associated with dolphin mortality (Bordino et al., 2013; Dawson, 1991; Kastelein et al., 2000; Kelkar & Dey, 2020; Mooney et al., 2007; A. J. Read et al., 2003) as dolphins have difficulty detecting gillnets with echolocations, especially in quiet conditions(Kastelein et al., 2000).

A.10.2 Relevant references obtained during the literature review

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Ingestion of fishing gear relevant references

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A.11 Gharial (*Gavialis gangeticus*)

A.11.1 Risk of interaction with plastic and other aquatic plastic if present in the environment

Ingestion of plastic and fishing gear

Ingestion of lead sinkers from recreational line and tackle fishing in Nile crocodiles, *Crocodylus niloticus*, from South Africa is the only evidence of litter ingestion in a crocodilian (Warner et al., 2016). As ingestion of litter is not recorded in other studies (Staffieri et al., 2019), we suggest that it seldom occurs, probably due to the predatory foraging method of crocodilians. Secondary ingestion of microplastics (a crocodilian has eaten an animal containing plastic) may feasibly take place, but we suggest that this would be infrequent, and the size of the items involved would be unlikely to harm the crocodilian.

Entanglement in fishing gear

Entanglement in fishing gear is recognised as a cause of mortality across several crocodilian taxa (Aust et al., 2009; Hussain, 2009; Kyle, 1999; Platt & Van Tri, 2000; Shaney et al., 2019; H. Singh & Rao, 2017; Thorbjarnarson et al., 2000), including the gharial (Hussain, 2009), though there is mixed evidence about the magnitude of this threat. A review on impact of plastic litter on marine and estuarine reptiles describes the evidence of entanglement as 'scanty', which they suggest may be due to the lack of entangling litter present in the habitat of many crocodilians (Staffieri et al., 2019). However, other manuscripts describe fishing-net mortality as a probable population-level threat to the gharial, though without providing quantitative evidence to support the claim (Hussain, 2009; H. Singh & Rao, 2017). We suggest that given the evidence for fishing net mortality of gharial, derelict fishing gear mortality is likely where fisheries overlap with gharial habitat.

A.11.2 Relevant references obtained during the literature review

Ingestion of plastic and fishing gear relevant references

- Staffieri E, de Lucia GA, Camedda A, Poeta G, Battisti C. Pressure and impact of anthropogenic litter on marine and estuarine reptiles: an updated "blacklist" highlighting gaps of evidence. Environmental Science and Pollution Research. 2019;26(2):1238-49.
- Warner JK, Combrink X, Myburgh JG, Downs CT. Blood lead concentrations in free-ranging Nile crocodiles (Crocodylus niloticus) from South Africa. Ecotoxicology. 2016;25(5):950-8.

Fishing gear entanglement relevant references

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- Hussain SA. Basking site and water depth selection by gharial *Gavialis* gangeticus Gmelin 1789 (Crocodylia, Reptilia) in National Chambal Sanctuary, India and its implication for river conservation. Aquatic Conservation-Marine and Freshwater Ecosystems. 2009;19(2):127-33.
- Kyle R. Gillnetting in nature reserves: a case study from the Kosi Lakes, South Africa. Biological Conservation. 1999;88(2):183-92.
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- Singh H, Rao RJ. Status, threats and conservation challenges to key aquatic fauna (Crocodile and Dolphin) in National Chambal Sanctuary, India. Aquatic Ecosystem Health & Management. 2017;20(1-2):59-70.
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A.12 Asian Elephant (*Elephas maximus indicus*)

A.12.1 Risk of interaction with plastic and other aquatic plastic if present in the environment

Ingestion of plastic and fishing gear

There were no studies that related to elephants and their ingestion or entanglement of plastic litter or fishing debris in an aquatic environment context, such as would be expected with respect to the Ganga River. However, there is the ingestion risk at dump sites while elephants target food inside packaging, especially by bull elephants, during raiding of dump sites for food (Le Breton, 2019; Liyanage, Fernando, Dayawansa, Janaka, & Pastorini, 2021). Plastic is not mentioned as eaten in other contexts (such as aquatic litter) and is probably not likely to be eaten unless there is food inside plastic or other packaging or garbage dumped by the river. One study mentioned elephants refusal to eat small plastics when offered as part of a gut passage experiment (Beirne et al., 2019).

The ingestion of plastic is unlikely to be fatal to elephants, given their large size. One study mentioned that consumed plastic items were regularly excreted, retention and obstruction of the alimentary tract are unlikely in elephants. Another linked to a news article saying elephant deaths were linked to plastic consumption at a dump site, but the cause of these deaths was not confirmed. We suggest that plastic litter in the Ganga is unlikely to be a threat to the Asian elephant.

A.12.2 Relevant references obtained during the literature review

Ingestion of plastic relevant references

- Beirne C, Nuñez CL, Baldino M, Kim S, Knorr J, Minich T, et al. Estimation of gut passage time of wild, free roaming forest elephants. Wildlife Biology. 2019;2019(1):1-7.
- Liyanage DJ, Fernando P, Dayawansa PN, Janaka H, Pastorini J. The elephant at the dump: how does garbage consumption impact Asian elephants? Mammalian Biology. 2021:1-9.
- Le Breton J. Visitation patterns of African elephants (Loxodonta africana) to a rubbish dumpsite in Victoria Falls, Zimbabwe. Pachyderm. 2019;60:45-54.

A.13 Greater Spotted Eagle (*Clanga clanga*)

A.13.1 Risk of interaction with plastic and other aquatic plastic if present in the environment

Ingestion of plastic and fishing gear

Our literature search revealed an isolated case of the ingestion of a plastic materials in captive raptors (Applegate et al., 2017), numerous cases of lead shot ingestion in wild raptors (Cochrane et al., 2015; Descalzo et al., 2021; Franson & Russell, 2014; Franzen-Klein et al., 2018; Mateo et al., 2007; Miller et al., 2000; Rattner & McGowan, 2007), and cases of entanglement in derelict fishing gear (Rattner & McGowan, 2007). The only plastic ingestion case occurred when plastic cage substrates were eaten by captive animals leading to anorexia and death, though the reason for this was not known (Applegate et al., 2017). As these interactions occurred in captive animals, the cases may not be relevant to wild raptors. Ingestion of lead shot, resulting from raptors preying on waterbirds that were either embedded with or had ingested shot, was a recurring finding in the literature review, and can lead to debilitation and death from lead poisoning (Cochrane et al., 2015; Franson & Russell, 2014; Franzen-Klein et al., 2018; Mateo et al., 2007; Miller et al., 2000; Rattner & McGowan, 2007). The source of lead shots was from hunting of waterfowl, a recreational activity which is restricted to specific locations where hunting is permitted and is probably not relevant to the Ganga River. Our literature review revealed that entanglement in fishing gear, especially monofilament line, is threat to raptors that hunt in areas where fishing occurs (Rattner & McGowan, 2007). Entanglement in monofilament line can cause serious debilitation and death in raptors.

Wildlife hospital admissions

Though entanglement was listed in just one study (Rattner & McGowan, 2007) as a potential threat in our primary literature search for raptors, entanglements of raptors are noted among the wildlife hospital admission literature. Wildlife hospital admissions of Australian coastal raptors show that fishing equipment entanglement is an important threat, fishing equipment entanglement, accounting for 21% of raptors for which we could determine the cause of admission (Thomson et al., 2020). Fishing line ingestion and entanglement reported in another study of raptors in Australia (Taylor-Brown et al., 2019). The wildlife hospital admission literature further reiterates the threat of lead poisoning to raptors (Kenntner et al., 2007; Pérez-López et al., 2008).

A.13.2 Relevant references obtained during the literature review

Plastic ingestion relevant references

- Applegate, J. R.; Van Wettere, A.; Christiansen, E. F.; Degernes, L. A., Management and Case Outcome of Gastric Impaction in Four Raptors: A Case Series. J. Avian Med. Surg. 2017, 31 (1), 62-69.

Metal ingestion relevant references

- Cochrane, J. F.; Lonsdorf, E.; Allison, T. D.; Sanders-Reed, C. A., Modeling with uncertain science: estimating mitigation credits from abating lead poisoning in Golden Eagles. Ecol. Appl. 2015, 25 (6), 1518-1533.
- Franson, J. C.; Russell, R. E., Lead and eagles: demographic and pathological characteristics of poisoning, and exposure levels associated with other causes of mortality. Ecotoxicology 2014, 23 (9), 1722-1731.
- Franzen-Klein, D.; McRuer, D.; Slabe, V. A.; Katzner, T., The Use of Lead Isotope Analysis to Identify Potential Sources of Lead Toxicosis in a Juvenile Bald Eagle (Haliaeetus leucocephalus) With Ventricular Foreign Bodies. J. Avian Med. Surg. 2018, 32 (1), 34-39.
- Mateo, R.; Green, A. J.; Lefranc, H.; Baos, R.; Figuerola, J., Lead poisoning in wild birds from southern Spain: A comparative study of wetland areas and species affected, and trends over time. Ecotox. Environ. Safe. 2007, 66 (1), 119-126.
- Miller, M. J. R.; Wayland, M. E.; Dzus, E. H.; Bortolotti, G. R., Availability and ingestion of lead shotshell pellets by migrant Bald Eagles in Saskatchewan. J. Raptor Res. 2000, 34 (3), 167-174.
- Rattner, B. A.; McGowan, P. C., Potential hazards of environmental contaminants to avifauna residing in the Chesapeake Bay estuary. Waterbirds 2007, 30, 63-81.

Entanglement relevant references

- Rattner, B. A.; McGowan, P. C., Potential hazards of environmental contaminants to avifauna residing in the Chesapeake Bay estuary. Waterbirds 2007, 30, 63-81.

A.14 Sarus Crane (*Antigone antigone*) and Common Crane (*Grus Grus*)

A.14.1 Risk of interaction with plastic and other aquatic plastic if present in the environment

Our initial literature search did not return any results for the cranes or species of the genera *Antigone* or *Grus* interaction with plastic litter through ingestion nor entanglement. There is no significant evidence that terrestrial birds that forage visually for small, mobile prey such as insects and small aquatic animals are at risk of ingesting plastic and other types of plastic litter. Based on this lack of behavioural predisposition for intentionally or accidentally eating large plastic and plastic litter, we consider the sarus and common crane to be at a low risk of litter ingestion.

A.14.2 Relevant references obtained during the literature review

We conducted a literature search for records of diet, fecal analysis and stomach contents for cranes. None of these reviewed dietary studies made any mention of plastic litter encountered.

- 1,055 red-crowned crane (*Grus japonensis*) faeces samples, no plastic mentioned. (Li et al., 2020)
- 505 good quality, 5-min videos were recorded of Black-necked Crane (*Grus nigricollis*) foraging, no plastic mentioned (Dong et al., 2016)

- Eight dead red-crowned cranes, stomach and faecal samples, plastic not mentioned (Luo et al., 2015)
- 135 faecal samples collected from Red-crowned Crane (*Grus japonensis*), no plastic mentioned (Li et al., 2014)
- 16 gizzards and 35 faecal samples of Demoiselle Crane (*Anthropoides virgo*), no plastic mentioned (Sarwar et al., 2013)
- 136 stomach contents of Sandhill Cranes (*Grus canadensis*), diet contents collected by shooting, no plastic mentioned (Ballard & Thompson, 2000)

While this evidence does not rule out the presence or ingestion of plastics (especially microplastics), given the high frequency of their presence in aquatic environments, the lack of evidence suggests that it is unlikely that plastics pose a notable threat to the saurus or common crane.

A.15 Waterfowl: Greylag Goose (*Anser anser*), Common Shelduck (*Tadorna tadorna*), Gadwall (*Anas strepera*), Northern Pintail (*Anas acuta*), Common Teal (*Anas crecca*), Red-crested Pochard (*Netta rufina*) and Tufted Duck (*Aythya fuligula*)

A.15.1 Risk of interaction with plastic and other aquatic plastic if present in the environment

Our literature search retrieved results for the ingestion of plastic (English et al., 2015; Gil-Delgado et al., 2017; Reynolds & Ryan, 2018; Susanti, Yuniastuti, & Fibriana, 2021), metal (lead shot) (English et al., 2015; Ferreyra et al., 2014; Ferreyra, Romano, & Uhart, 2009; Havera, Whitton, & Shealy, 1992; Mateo et al., 2007; J. L. Moore, Hohman, Stark, & Weisbrich, 1998), and fishing gear (Goulart et al., 2019) as well as entanglement in fishing gear (Bellebaum, Schirmeister, Sonntag, & Garthe, 2013; Zydelis et al., 2009). The wildlife hospital literature search revealed more evidence of the threat of fishing gear entanglement for waterfowl (Kelly & Kelly, 2004; Taylor-Brown et al., 2019).

Ingestion of plastic and fishing gear

The literature search indicated several case of the ingestion of plastic litter across waterbird taxa, including ingestion of plastics and microplastic (English et al., 2015; Gil-Delgado et al., 2017; Reynolds & Ryan, 2018; Susanti et al., 2021), many involving the ingestion of lead shot (English et al., 2015; Ferreyra et al., 2014; Ferreyra et al., 2009; Havera et al., 1992; Mateo et al., 2007; J. L. Moore et al., 1998) and a single case of the ingestion of fishing gear (Goulart et al., 2019). This study shows that ducks are vulnerable to ingestion of small pieces of plastic, probably due to their dabbling foraging method, but little evidence of harm resulting from the ingestion of this litter, which is probably ground to a small size in the strong muscular gizzard which has evolved to grind vegetation. Ducks also commonly swallow lead shot, mostly likely as a gastrolith, when present in the environment. There was one case of foreign body obstruction caused by the ingestion of nylon monofilament fishing line from a domesticated waterbird, muscovy duck, *Cairina moschata* (Goulart et al., 2019). We propose that there is a reasonably high probability of the ingestion of plastic litter ingestion by waterfowl when feeding in the Ganga, however, a low probability that foreign body obstructions or other harm would result as most ingested plastic will likely be ground in the gizzard to a small enough size to pass the digestive tract. Occasional foreign body obstructions may result from the ingestion of wear resistant litter, for example, nylon monofilament line.

Entanglement in fishing gear

Entanglement of waterbirds in fishing-related debris, particularly derelict gillnets, is a probable risk to waterbirds in the Ganga. The risk is probably higher to diving species compared to those that forage at the water's surface. We consider that waterbirds are at risk of fatal entanglement in derelict fishing gear where their habitat overlaps with fishing activity.

Wildlife hospital admissions and entanglements

Though entanglement was mentioned only twice as a potential threat in our primary literature search for waterfowl, entanglements of birds, especially in fishing related debris, are noted in the wildlife hospital admission literature. For example, fishing line entanglement and ingestion are commonly reported in waterbird hospital admissions in Australia (Taylor-Brown et al., 2019). Another study investigated the incidence of injuries caused by lost or discarded fishing tackle on the Mute Swan (*Cygnus olor*) admitted to a wildlife hospital in the English Midlands between January 2000 and December 2002. Injuries caused by lost or discarded fishing tackle was the largest single attributable cause of admission over this period, accounting for 17% of a total of 1,491 swans admitted over the three-year period. The authors note that the majority of these birds would probably have died without treatment.

Most publications that list relevant threat categories do not report which species were affected. Two publications report the affected numbers of birds, but not the species. For example, 1.4% of all birds (n= 6058) submitted to wildlife hospitals in Portugal over ten years were due to fishing gear entanglement and ingestion, for example, hooks, lines and nets (Garcês et al., 2019) and interaction with fishing gears (5.3%) of seabird (similar physiology and swimming behaviour as waterbirds) admissions in Bay of Biscay (Garcia-Baron et al., 2019). We consider that though the chance of entanglement to waterfowl in the Ganga is low, though if an animal does become entangled, the chance of mortality is high.

A.15.2 Relevant references obtained during the literature review

Ingestion of plastic and fishing gear relevant references

- English, M. D.; Robertson, G. J.; Avery-Gomm, S.; Pine-Hay, D.; Roul, S.; Ryan, P. C.; Wilhelm, S. I.; Mallory, M. L., Plastic and metal ingestion in three species of coastal waterfowl wintering in Atlantic Canada. Marine Pollution Bulletin 2015, 98 (1-2), 349-353.
- Gil-Delgado, J. A.; Guijarro, D.; Gosalvez, R. U.; Lopez-Iborra, G.; Ponz, A.; Velasco, A., Presence of plastic particles in waterbirds faeces collected in Spanish lakes. Environmental Pollution 2017, 220, 732-736
- Reynolds, C.; Ryan, P. G., Micro-plastic ingestion by waterbirds from contaminated wetlands in South Africa. Marine Pollution Bulletin 2018, 126, 330-333.

- Susanti, R.; Yuniastuti, A.; Fibriana, F., The Evidence of Microplastic Contamination in Central Javanese Local Ducks from Intensive Animal Husbandry. Water Air and Soil Pollution 2021, 232 (5).
- Mateo, R.; Green, A. J.; Lefranc, H.; Baos, R.; Figuerola, J., Lead poisoning in wild birds from southern Spain: A comparative study of wetland areas and species affected, and trends over time. Ecotoxicology and Environmental Safety 2007, 66 (1), 119-126.
- Ferreyra, H.; Romano, M.; Beldomenico, P.; Caselli, A.; Correa, A.; Uhart, M., Lead gunshot pellet ingestion and tissue lead levels in wild ducks from Argentine hunting hotspots. Ecotoxicology and Environmental Safety 2014, 103, 74-81.
- Ferreyra, H.; Romano, M.; Uhart, M., Recent and Chronic Exposure of Wild Ducks to Lead in Human-modified Wetlands in Santa Fe Province, Argentina. Journal of Wildlife Diseases 2009, 45 (3), 823-827.
- Havera, S. P.; Whitton, R. M.; Shealy, R. T., BLOOD LEAD AND INGESTED AND EMBEDDED SHOT IN DIVING DUCKS DURING SPRING. Journal of Wildlife Management 1992, 56 (3), 539-545.
- Moore, J. L.; Hohman, W. L.; Stark, T. M.; Weisbrich, G. A., Shot prevalences and diets of diving ducks five years after ban on use of lead shotshells at Catahoula Lake, Louisiana. Journal of Wildlife Management 1998, 62 (2), 564-569.
- Goulart, M. A.; Braga, C. S.; Lira, C.; Amorim, D. B.; Macedo, A. S.; Alievi, M. M., Intercostal celiotomy for removal of proventriculus foreign body in muscovy duck (Cairina moschata): case report. Arquivo Brasileiro De Medicina Veterinaria E Zootecnia 2019, 71 (3), 805-810.

Fishing gear entanglement relevant references

- Bellebaum, J.; Schirmeister, B.; Sonntag, N.; Garthe, S., Decreasing but still high: bycatch of seabirds in gillnet fisheries along the German Baltic coast. Aquatic Conservation-Marine and Freshwater Ecosystems 2013, 23 (2), 210-221.
- Zydelis, R.; Bellebaum, J.; Osterblom, H.; Vetemaa, M.; Schirmeister, B.; Stipniece, A.; Dagys, M.; van Eerden, M.; Garthe, S., Bycatch in gillnet fisheries - An overlooked threat to waterbird populations. Biological Conservation 2009, 142 (7), 1269-1281.

Wildlife hospital relevant references

- Taylor-Brown, A.; Booth, R.; Gillett, A.; Mealy, E.; Ogbourne, S. M.; Polkinghorne, A.; Conroy, G. C., The impact of human activities on Australian wildlife. PloS one 2019, 14 (1), e0206958.
- Kelly, A.; Kelly, S., Fishing tackle injury and blood lead levels in mute swans. Waterbirds 2004, 27 (1), 60-68.
- Garcês A, Pires I, Pacheco F, Fernandes LS, Soeiro V, Lóio S, et al. Natural and anthropogenic causes of mortality in wild birds in a wildlife rehabilitation centre in Northern Portugal: a ten-year study. Bird Study. 2019;66(4):484-93.
- Garcia-Baron I, Santos MB, Uriarte A, Inchausti JI, Escribano JM, Albisu J, et al. Which are the main threats affecting the marine megafauna in the Bay of Biscay? Continental Shelf Research. 2019;186:1-12.

A.16 Wader birds: Black-tailed Godwit (*Limosa limosa*), Eurasian Curlew (*Numenius arquata*), Marsh Sandpiper (*Tringa stagnatilis*), Common Greenshank (*Tringa nebularia*), Green Sandpiper (*Tringa ochropus*) and Temminck's Stint (*Calidris temminckii*)

A.16.1 Risk of interaction with plastic and other aquatic plastic if present in the environment

Our initial literature search did not return any results for the wader birds or species of the genera *Limosa* , *Numenius, Tringa* or *Calidris* interaction with plastic litter through ingestion nor entanglement. While there was no evidence for ingestion of plastic litter, the methodology of one study reviewed reveals that waders may be vulnerable to entrapment in derelict debris under certain circumstances which may be relevant to the Ganga. One study mentioned 118 great knots (fishing by-catch) entrapped accidentally in nets and drowned. We do not know whether this entrapment was an entanglement or an entrapment in a tent style pot trap.

There was no significant evidence that terrestrial wading birds that forage visually for small, mobile prey such as insects and small aquatic animals are at risk of ingesting plastic and other types of plastic litter. Many wading birds also feed on invertebrates that live under the mud, silt or sediment, with many waders highly specialized on particular prey. Based on this lack of behavioural predisposition for intentionally or accidentally eating large plastic and plastic litter, including the specialized feeding on particular prey for some species, we consider the listed wader birds to be at a low risk of litter ingestion.

A.16.2 Relevant references obtained during the literature review

We conducted a review into the diet of wading birds, of which there is a considerable literature, including the CMS listed Black-tailed Godwit, Eurasian Curlew and Common Greenshank. None of the observational, stomach content, pellet or faecal analysis studies of wading birds from multiple taxa surveyed found evidence of ingestion of plastic or other plastic items. None of these reviewed dietary studies made any mention of plastic litter encountered. Due to the very large number of diet studies, the zeros in the initial literature search probably reflect a true lack of (significant) plastic litter interaction/ingestion by these taxa rather than a lack of study.

- 118 dead great knots (fishing by-catch) entrapped accidentally in nets. Stomach contents dissected and plastic not mentioned. (Zhang et al., 2019)
- Collected 108 droppings of Semipalmated Sandpipers, from each of two sites (produced by 80-90 birds/site) and manually searched via microscope. Plastic not mentioned. (C. D. Santos, Rocha, Nascimento, Oliveira, & Martinez, 2019)
- A total of 112 droppings were collected from the three selected shorebird species: the resident southern lapwing Vanellus chilensis (n = 27), migratory American golden-plover *Pluvialis dominica* (n = 30) and buff-breasted sandpiper (n = 55). Plastic not mentioned. (Faria, Albertoni, & Bugoni, 2018)

- Using dropping analysis and video recordings we compared the diet of eight shorebird species, obtaining a total of 353 droppings from eight shorebird species, 304 of which were later found to contain identifiable prey remains. Curlew sandpiper, bar-tailed godwit, red knot, sanderling, whimbrel, ringed plover, redshank and grey plover. No plastic mentioned. (Lourenco, Catry, & Granadeiro, 2017)
- Observations of Bar-tailed Godwit, Great Knot, and Eurasian Oystercatcher. No plastic mentioned (Choi et al., 2017)
- We used droppings and video recordings to compare the diet and foraging behaviour of six shorebird species at Banc d'Arguin: dunlin, sanderling, red knot, ringed plover, grey plover and bar-tailed godwit. No plastic mentioned (Lourenço, Catry, Piersma, & Granadeiro, 2016)
- We caught 50 individuals Least Sandpipers (*Calidris minutilla*) using mist netting and obtained regurgitates induced with saline solution. No plastic mentioned (Cifuentes-Sarmiento & Renjifo, 2016)
- Sanderling Calidris alba, we collected a total of 127 sanderling droppings. No plastic mentioned. (Lourenço, Alves, Catry, & Granadeiro, 2015)
- Dietary composition was determined by analysis of faecal samples collected Hudsonian Godwits, White-rumped Sandpipers and Two-banded Plovers and Red Knots. No plastic mentioned (Martínez-Curci, Azpiroz, Isacch, & Elías, 2015)
- Upland Sandpiper we collected 67 feces. Plant remains and stones were also recorded in feces, no plastic mentioned. (Alfaro, Sandercock, Liguori, & Arim, 2015)
- Eastern Curlews *Numenius* madagascariensis Diet was determined from direct feeding observations, examination of pellets collected at high-tide roosts (during daytime and night-time) (Dann, 2014)
- Black-tailed Godwits (*Limosa limosa islandica*) diet observations, no plastic mentioned (Catry, Alves, Gill, Gunnarsson, & Granadeiro, 2014)
- Trapped birds were fed an emetic (1.5% [weight : volume] potassium antimony tartrate solution. Regurgitated stomach contents were collected, stored in 70% ethanol and identified. For the 12 remaining individuals (of Pacific golden, common redshank, common sandpiper and lesser sand plover) from which stomach contents were obtained, no plastic mentioned. (Lim & Posa, 2014)
- Fifty individual droppings of bar-tailed godwits were collected at each 5 sites (40 at one site), plastic not mentioned (Duijns, Hidayati, & Piersma, 2013)
- 25 dropping at three sites of Red Knot *Calidris canutus islandica* wintering in three estuarine bays on the French Channel coast. (Gwenaël Quaintenne, Bocher, Ponsero, Caillot, & Feunteun, 2014)
- We collected a total of 575 individual droppings of **black-tailed godwit** at 14 different feeding sites from September 2004 to February 2005, no plastic mentioned (F. Robin, Piersma, Meunier, & Bocher, 2013)
- We collected foraging Killdeer, Least and Pectoral Sandpipers, and Lesser Yellowlegs with shotguns (hundreds). No plastic mentioned.(Smith et al., 2012)

- Observation of feeding **black-tailed godwits**. No plastic recorded. (Catry, Alves, Gill, Gunnarsson, & Granadeiro, 2012)
- A total of 18 western sandpipers were sampled using a shotgun at the Roberts Bank stopover. No plastic mentioned. (Beninger, Elner, Morançais, & Decottignies, 2011)
- Observations and droppings of **black-tailed godwit**. No plastic mentioned. (Estrella & Masero, 2010)
- Stomach contents, the stomachs of 89 Western Sandpipers and 56 Dunlin collected during breeding migration through the Fraser River delta, British Columbia, Canada. No plastic mentioned. (Mathot, Lund, & Elner, 2010)
- In total, 204 dropping samples from red knots (*Calidris canutus*), were collected across all study sites. Plastic not mentioned (Gwenael Quaintenne, Van Gils, Bocher, Dekinga, & Piersma, 2010).
- We studied Hudsonian godwit diet in the Costanera site by using faecal analysis (Fig. 1). Droppings were collected at low tide in March 2003 (n = 149) and March 2007 (n = 72), no plastic mentioned. (Lizarralde, Ferrari, Pittaluga, & Albrieu, 2010)
- Fresh faecal samples were collected during the spring and autumn migrations of 2002 and in the winter of 2002 - 03 at the high tide. 65 from Kentish plover, 114 from ringed plover, and 125 from dunlin. No plastic mentioned (Pedro & Ramos, 2009)
- Diet samples were obtained from 13 American avocets, 19 Ruddy ducks, and 18 western sandpipers from November 1999 to March 2000. Birds were collected with 12-gauge shotguns and #6 steel shot from flocks that were observed actively foraging. No plastic mentioned. (Takekawa et al., 2009)
- One hundred American Avocets from eleven lakes, 100 Least Sandpipers from eleven lakes, 100 Wilson's Phalaropes from nine lakes, and 25 Lesser Yellowlegs from four lakes were collected by shooting during spring. No plastic mentioned. (Andrei, Smith, Haukos, Surles, & Johnson, 2009)
- We quantified feeding eastern curlews' diet across 12 sites (different tidal flats, each re-visited at least eight times), through 970 focal observations. (Finn, Catterall, & Driscoll, 2008)
- **Black-tailed Godwits** limosa limosa in Portuguese rice fields. Fifty-eight of the 79 faecal samples contained noticeable food remains. No plastic mentioned. (Lourenço & Piersma, 2008)
- Red Knots (*Calidris canutus rufa*), White-rumped Sandpipers (*Calidris fuscicollis*), and Hudsonian Godwits (*Limosa haemastica*). No plastic mentioned. (de los Angeles Hernandez, Oscar Bala, & Raquel Musmeci, 2008)
- The dietary items of five migratory shorebirds, Dunlin (*Calidris alpina*), Red-necked Stint (*C. ruficollis*), Grey Plover (*Pluvialis squatarola*), Whimbrel (Numenius phaeopus) and Black-headed Gull (*Larus ridibundus*), were examined by analyses of faecal droppings during the birds' migration. No plastic mentioned (Iwamatsu, Suzuki, & Sato, 2007)
- A total of 140 faecal samples and 220 pellets were collected in 2001 and 2002 from waders in the Aragonesas-Bacuta saltworks of the Odiel marshes in Huelva province. Faeces and regurgitated pellets of redshank *Tringa totanus*, pellets of spotted redshank T. erythropus,

and faeces of **black-tailed godwit** *Limosa limosa***.** No plastic mentioned. (Sánchez, Green, Amat, & Castellanos, 2007)

- Faecal samples of Grey Plover Pluvialis squaturola and Redshank *Tringa totanus* from the Tagus estuary, Portugal. No plastic mentioned (Lourenço, 2007)
- The diet and feeding patterns of White-rumped Sandpipers (*Calidris fuscicollis*) were studied during migratory stopover at Fracasso Beach, Península Valdés, Argentina, fecal samples. No plastic mentioned (Hernández & Bala, 2007)
- Diet of Dunlin was investigated using dropping analysis. No plastic mentioned (Carlos D Santos, Granadeiro, & Palmeirim, 2005)
- Rufous-chested Dotterel (*Charadrius modestus*), Tawny-throated Dotterel (*Oreopholus ruficollis*), American Golden Plover (*Pluvialis dominica*) and Buff-breasted Sandpiper (*Tryngites subruficollis*).No plastic mentioned (Isacch, Darrieu, & Martínez, 2005)
- Diet of the Red Knot (*Calidris canutus*). Gizzard content and fecal analysis. No plastic mentioned (Ieno, Alemany, Blanco, & Bastida, 2004)
- Information from the analysis of 343 droppings of Common Sandpiper. No plastic mentioned (Arcas, 2004)
- We evaluated prey selection through faecal analysis related to the feeding strategies of Two-banded Plovers (*Charadrius falklandicus*) and White-rumped Sandpipers (*Calidris fuscicollis*). No plastic mentioned. (D'Amico, Hernandez, & Bala, 2004)
- Seeds in the diet of the White-rumped Sandpiper in Argentina. The stomach contents of 23 adults were investigated. No plastic mentioned. (Montalti, Arambarri, Soave, Darrieu, & Camperi, 2003)
- The diet of the Sanderling (*Calidris alba*) was studied using 105 droppings, 34 pellets and direct observations of feeding behavior. No plastic mentioned.(Petracci, 2002)
- We documented differences in diet composition of territorial Long-billed Curlews (Numenius americanus) feeding in different locations within the Elk River Estuary, Humboldt Bay. California. We used direct observations to measure diet. No plastic mentioned.(Leeman, Colwell, Leeman, & Mathis, 2001)
- We studied foraging strategies and niche dynamics of American Avocets (*Recurvirostra arnericana*), Long-billed Dowitchers (*Limnodrornus scolopaceus*), Least Sandpipers (*Calidris minutilla*), and Western Sandpipers (*C. mauri*). No plastic mentioned. (Davis & Smith, 2001)
- Estimating diet composition of Bar-tailed Godwits *Limosa lapponica* by visual observations was hampered by large amounts of unidentified prey items. Therefore, additional analyses of faeces were conducted. No plastic mentioned (Scheiffarth, 2001).
- Diet and feeding behaviour of red-necked stints (*Calidris ruficollis*) and curlew sandpipers (*Calidris ferruginea*) feeding in mixed flocks during the non-breeding season were investigated in Western Port in Victoria, south-eastern Australia.(Dann, 2000)
- Gut samples collected by stomach flushing. Red Knots (*Calidris canutus*), Ruddy Turnstones (*Arenaria interpres*), Sanderlings (*C alba*), and Semi-palmated Sandpipers (*C. pusilla*)(Tsipoura & Burger, 1999)

- A total of 3199 flocks containing 118,648 individuals of 36 different waterbird species were examined during October-November 1994. No plastic mentioned (Ntiamoa-Baidu et al., 1998)
- Gut contents of seven Lesser Yellowlegs (*Tringa flavipes*) and seven Short-billed Dowitchers (*Limnodromus griseus*) were examined. No plastic mentioned (Weber & Haig, 1997)
- Between-site variation in the diet and foraging behaviour of a fixed-method forager, the Grey Plover *Pluvialis squatarola*, and a versatile forager, the Whimbrel Numenius phaeopus, was examined. No plastic mentioned (Turpie & Hockey, 1997)
- The diets of Redshank *Tringa tetanus*, Grey Plover *Pluvialis squatarola*, **Curlew** Numenius arquata, **Black-tailed Godwit** *Limosa limosa*, Bar-tailed Godwit *Limosa lapponica*, Ringed Plover *Charadrius hiaticula*, Kentish Plover *Charadrius alexandrinus*, Black-winged Stilt *Himantopus himantopus*, Dunlin *Calidris alpina*, Little Stint *Calidris minuta* and Sanderling *Calidris alba* were investigated in this way (direct observation, pellets and feces). No plastic mentioned.(Perez-Hurtado, Goss-Custard, & Garcia, 1997)
- Both dietary techniques suggested that Long-billed Dowitchers (*Limnodromus scolopaceus*) and Stilt Sandpipers (*Calidris himantopus*) ate mostly invertebrates, whereas Hudsonian (*Limosa haemastica*) and Marbled godwits (*Limosa fedoa*) ate mainly *Potamogeton pectinatus* tubers. No plastic mentioned. (Alexander, Hobson, Gratto-Trevor, & Diamond, 1996)
- Observation and faecal analysis of two subspecies of knots *Calidris canutus* (*Islandica* wintering in Europe and breeding in the Nearctic, and *Canutus* wintering in west Africa and breeding in Siberia), stage in the international Wadden Sea before. No plastic mentioned, (Piersma, Verkuil, & Tulp, 1994)
- A study of the diet of **Blacktailed Godwits** *Limosa Limosa* and Ruffs *Philomachus pugnax* by direct examination of stomach contents emphasizes the importance of rice, which accounted for over 80% of the items eaten.(Tréca, 1994)
- This paper describes aspects of the winter feeding ecology **of Black-tailed Godwits** *Limosa limosa* on an intertidal mudflat in the Tagus estuary, Portugal. Observation and faecal analysis. (Moreira, 1994)
- We studied the diet and foraging behaviour of the Great Knot *Calidris tenuirostris* and to lesser extent of the Red Knot *Calidris canutus rogersi* and other waders at Roebuck Bay, Broome, Western Australia, through observation and faecal analysis. (Tulp & Degoeij, 1994)
- Day and night feeding in Dunlins *Calidris alpina* choice of habitat, foraging technique and prey by faecal analysis (Mouritsen, 1994)
- The diets of three common migrant waders; Curlew Sandpiper *Calidris ferruginea*, Grey Plover *Pluvialis squatarola* and Greenshank *Tringa nebularia* and three resident species, Blacksmith *Vanellus armatus*, Kittlitz's *Charadrius pecuarius* and Whitefronted Plovers *C. marginatus*, were studied at the Berg River estuary, South Africa from December 1987 to April 1989. Direct observations of feeding were combined with analyses of stomach contents, pellets and droppings.(Kalejta, 1993)

While this evidence does not rule out the presence or ingestion of plastics (especially microplastics), given the high frequency of their presence in aquatic environments, the lack of evidence suggests that it is unlikely that plastics pose a notable threat to the above species of wader birds.

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Introduction References

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