IMPACTS OF PLASTIC POLLUTION ON FRESHWATER AQUATIC, TERRESTRIAL AND AVIAN MIGRATORY SPECIES IN THE ASIA AND PACIFIC REGION

UN environment programme

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COVER IMAGE

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Table of Contents

Foreword

An estimated 8.3 billion tonnes of plastics have been produced since industrial production began. Much is still in existence as waste. Plastic pollution is now ubiquitous and is found all over the earth, from the heights of Mt. Everest to the depths of the oceans.

While plastic provides undisputed benefits such as in the medical field, the ability to safely manage plastic pollution is not keeping pace with projected growth in the plastics market over the coming decades. A 2020 study in the journal Science estimated that by 2030, even with ambitious efforts to reduce and manage plastic waste globally, up to 53 million metric tonnes per year will enter the aquatic environment (including fresh and saltwater), and as much as 90 million metric tonnes per year with no improvements in waste management (Borrelle et al. 2020*). These figures do not include all sources of plastic pollution, such as lost or discarded fishing gear - found to be a considerable problem in the present CMS report.

Over the past few decades, concern has grown regarding the negative impacts of plastic pollution. Yet actions to address this global issue have fallen far short of what is needed. The potential adverse impacts of plastic pollution on the natural environment, food web and human health are still not fully known. Much of the effort to address plastic pollution has focused only on the marine environment and has emphasized removal rather than prevention.

Since the vast majority of plastic pollution is generated on land, there is an urgent need to better understand the likely impacts on animals that live in terrestrial and freshwater ecosystems, including mammals, birds and fish. Recognizing this, CMS Parties called for a review of the impact of plastic pollution on terrestrial and freshwater CMS species, at their most recent Conference of the Parties (COP 13, 2020).

This report is the result of a collaboration between the Convention on Migratory Species and the UN Environment Programme as part of the CounterMEASURE II plastic pollution programme, generously funded by the Government of Japan, to assess the impact of plastic pollution in the Asia-Pacific region. It was prepared for the CMS Secretariat by the National Oceanography Centre, UK. This report is an important addition to knowledge on the threat of plastic pollution on CMS-listed species in terrestrial and freshwater ecosystems in the region.

Among its findings, the report concludes that species that are protected under the Convention on Migratory Species, including freshwater species, land animals and birds, are impacted by plastic pollution. It finds that migratory species are likely to be especially vulnerable, as they have an increased chance of encountering and interacting with plastics at some point in their migration. Within the Asia-Pacific region, it cites discarded fishing gear as a major threat, with entanglement a widely reported problem. The report recommends that understanding the negative effects on organisms and ecosystems as a result of plastic pollution should be a research priority, and calls for more effective waste management, recycling, and design of products, ideally preventing plastic pollution at the source.

This report is an important first step towards filling the gap in our knowledge regarding the impact of plastic pollution on CMS-listed species in terrestrial and freshwater ecosystems. More work clearly needs to be done to better understand the scale and nature of the potential negative impacts, and to take the necessary measures to address them.

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Executive Secretary
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**S. B. Borrelle, J. Ringma, K. L. Law, C. C. Monnahan, L. Lebreton, A. McGivern, E. Murphy, J. Jambeck, G. H. Leonard, M. A. Hilleary (2020) Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution.* Science *369(6510), 1515-1518.*

Executive Summary

Plastic pollution is widespread globally. Plastic is inexpensive and widely available, meaning that is commonly used and often carelessly discarded. However, the characteristics of plastics: strong and durable, means that plastics discarded into the environment have the capacity to persist for decades or hundreds of years. Plastic pollution is a particular problem in the region of Asia and the Pacific (hereafter ‘the region of interest’), where plastic production and consumption has been increasing, waste management infrastructure is often insufficient, and environmental education is not universal. The two case study rivers within this study, the Mekong and the Ganges, sit among the most polluted rivers globally. Combined, they have an estimated contribution of over 200,000 tonnes of plastic to oceans annually.

The Convention on the Conservation of Migratory Species of Wild Animals (CMS) is an environmental treaty of the United Nations, in place to promote cooperation and action for species and habitat conservation. Species of conservation need are listed within Appendices I and II: Appendix I species are those that are threatened with extinction (taking or killing is prohibited), while Appendix II species are those that would benefit from international cooperation for their conservation (conservation agreements should be adhered to). Across ecosystems in general, and including many species listed in the CMS appendices I and II, there is ample evidence of animal interactions with plastics in the environment, including nest building, entanglement and ingestion. At different levels, these interactions all have the capacity to alter animal behaviours, health, and in some cases, survival.

While not all species have been found to interact with plastics, in some cases this lack of evidence is likely due to insufficient research and available information, rather than a real lack of interactions. This is particularly the case for infrequently observed animals such as Snow Leopards, Gobi Bears (also known as Himalayan Brown Bears) and Mekong Giant Catfish (to name only a few). Where evidence is not available for a species in the region of interest, data can sometimes be found for the same species in another region. In this case, inferences can be made as to likely behaviours and traits of the species that would lead to similar interactions in the region of interest, especially given the likely scenario of heavy pollution in this region. Alternatively, where data on certain species are not available, related or comparable species can give an indication of likely interactions and effects.

Of the species considered in the region of interest, some are particularly vulnerable to the effects of plastic pollution. For example, the Ganges River Dolphin and the Irrawaddy Dolphin are both endangered, and both susceptible to entanglement in discarded fishing gear, leading often to entanglement and drowning. For mammals in general, the greatest amount of evidence for plastic interactions and ingestion are found for aquatic, rather than terrestrial mammals. Over 80% of the species in Appendices I and II in the region of interest are birds, with a correspondingly large amount of evidence available for bird interactions with plastics. Despite plenty of reports of direct harm or mortality as a result of plastic entanglement or ingestion across a wide range of aquatic and terrestrial species, as yet there is little evidence available on long-term population-level impacts resulting from plastic pollution alone.

It is important to note that plastic pollution is not the only issue negatively affecting species in the region of interest. Other factors leading to declines in health, survival and populations as a whole can result from engineering projects (such as hydropower dams, leading to population fragmentation and habitat destruction), overfishing, water abstraction, domestic and industrial pollution, and climate change. Even if plastic pollution is not the most significant of these stressors, it can add an additional stress to already vulnerable populations.

Community engagement and education are key to reducing day-to-day plastic use and improper disposal, in addition to debris-collection campaigns. A number of grassroots community initiatives are already making a difference through education and clean-up operations throughout the Mekong and Ganges river basins. However, real change must come from the top down, and government and industry action towards reducing the volume of plastic that enters the stream of commerce and becomes waste, more effective waste management, recycling, and designing products for a more circular economy will be among the most effective solutions to plastic pollution in the environment.

1. Rationale for this Study

Plastic pollution is a globally recognised problem, with some regions acknowledged as being more heavily impacted than others. It has often been stated that countries in Asia are the most significant polluters globally, in terms of plastic pollution inputs to the environment. The reasons for these inputs are numerous, but include factors such as insufficient waste management infrastructure, lack of education around waste management, economic reasons leading to greater use of single use plastics (such as single-portion sachets) and global imports[1]. Additionally, population growth and increasing urbanisation are leading to increased volumes of plastics utilised; for example in Association of Southeast Asian Nations (ASEAN) countries this is currently estimated at 1.14 kg/capita/day[2]. Where waste management is insufficient or ineffective for controlling the large volumes of plastics used and discarded, these end up becoming distributed on land, and within rivers. Here they may accumulate or be transported to the oceans, depending on local and seasonal environmental conditions. It has been suggested that even with ambitious efforts to reduce and manage plastic waste, millions of tonnes will continue to enter the environment. It is estimated that up to 53 million tonnes will be introduced to environment annually by 2030[3].

Plastics in the oceans have been a focus of study for many years, yet far less research has been carried out on plastics on land and within freshwater systems such as rivers, despite the knowledge that plastics will enter and accumulate in these environments[4]. Land-based sources are estimated to account for 80% of plastic in the oceans, with the remainder input directly from marine sources such as shipping and fishing activities[5]. In 2017 it was estimated that the top 10 most polluted rivers transport 88-95% of the global riverine plastic load into the sea, with eight out of 10 located in Asia (the other two being located in Africa). Within this analysis, the Ganges and the Mekong were ranked 6th and 10th respectively in terms of plastic inputs[6], and are estimated to contribute an estimated 200,000 tonnes of plastics the the ocean annually[7]. Other estimates put the Ganges at number two and the Mekong at number 11[7]. A more recent study, also acknowledges the importance of the contribution of small urban rivers, although still within the region of interest[8]. Though the numerical estimates provide an indication of the extent of riverine plastic leakage, the uncertainty associated with estimations of plastic debris abundance is currently quite high. This can largely be attributed to the difficulty in plastic debris monitoring and the lack of a robust system for monitoring macro and microplastic debris abundance. It should therefore be noted that different analyses give different outcomes in terms of volume of input and proportional significance of specific rivers, based on the data input to the models. However, despite these differences, rivers in Asia are consistently found to be significant contributors of plastic to the ocean[7,9]. For this reason, this study considers the Mekong River and the Ganges River as case study systems.

While the aforementioned studies focus on rivers as a pathway to the oceans, not all plastics follow this complete route from land to sea and many will be sequestered on their journey, accumulating on land or in freshwaters, for example in soils and sediments[4]. Given the importance of soil and freshwater resources for life on earth, understanding the contamination of these systems is equally as important as understanding the oceans. Modelling studies do not always consider this retention and therefore much of what is predicted to reach the oceans, based on waste mismanagement, may in fact be retained within soils, river waters and sediments. For example it has been predicted that 65% of inputs to rivers may be retained within the rivers as a result of artificial barriers such as dams[7].

It is known that wildlife is vulnerable to the effects of plastic pollution, primarily as a result of ingestion or entanglement. This report focusses specifically on species listed within the Convention on the Conservation of Migratory Species of Wild Animals (CMS, also known as the Bonn Convention). CMS is an international environmental treaty of the United Nations that was signed in 1979 for the purpose of conserving migratory species and their habitats. CMS listed species are defined as being endangered, or having an unfavourable conservation status, and migrate across or outside national jurisdictional boundaries. As at 1st January 2021, 132 countries were party to the CMS convention. Parties are obliged to recognise the value of wild animals for the environment and mankind, recognise their role as protectors of species that live within, or cross, their jurisdictional boundaries, and remain conscious and aware of the increasing importance of wild animals and the need to preserve these and the environment for future generations. Species may sit within Appendix I, appendix II, or both. Appendix I species are those that are threatened with extinction, while Appendix II species are those that would benefit from international cooperation for their conservation. CMS parties are required to provide protection for species listed within Appendix I (including habitat protection and restoration, and preventing unlawful taking or killing), and to conclude and adhere to agreements to conserve appendix II species[10]. This report considers species across appendices I and II. Within the study region (Asia and the Pacific) there are a large number of CMS-listed species, including some that are endemic, and classified as Critically Endangered (IUCN Red List[11]).

This report forms part of the UNEP CounterMEASURE II project: Promotion of action against marine plastic litter in Asia and the Pacific (phase II)[12]. This report aims to fill a gap in our knowledge on the exposure and effects of plastics to CMS-listed migratory species in freshwater and terrestrial systems, focussing on Asia and the Pacific with specific case study areas: the Mekong River and the Ganges River. Following a general introduction to the issue of plastic pollution, an overview of the region of interest is followed by specific introductions to the case study areas, including knowledge of plastics within these areas. As some species span the case study areas, species are then considered broadly by class for the region of interest as a whole, with comparisons made to related species globally where appropriate. Finally, some examples of activities and initiatives being undertaken are given, leading to an overview of the remaining challenges and recommendations.

2. Introduction to Plastic Pollution

No known environment, from populated to pristine, is nowadays untouched by plastics. This widespread contamination has wide-ranging economic, health, social, environmental and ecological consequences, and is likely to continue to increase with global plastic production and usage. The issue of environmental plastic contamination is exacerbated by the ubiquitous availability of plastics as practical and durable materials for a wide range of applications. Because plastic is so cheap and widely available, there is often little incentive to salvage and repurpose plastic materials from waste products, and waste materials often bypass proper waste management systems.

Since the invention of plastics in the 1950s, it is estimated that 8.3 billion tonnes of plastics have been produced, with only 9% of this having been recycled. The remainder has been incinerated (12%), leading to the loss of valuable materials, or sits within landfills or the natural environment (79%)[13]. It has been estimated that by 2050, even with ambitious reduction measures, up to 53 million tonnes of plastics could be released into the environment annually. If no measures are taken to reduce plastic input, by 2050 this figure could increase to 90 million tonnes released annually[3]. This, combined with the longevity of plastics, means that global environmental contamination is likely to continue to increase dramatically for some years to come.

Plastics are comprised of a wide variety of polymers and composites, all with different properties. They may be soft and flexible or hard and brittle, different colours, shapes and sizes (Fig. 1). Part of what gives plastics their properties are incorporated chemicals, for example plasticisers, dyes, and flame retardant chemicals. These chemicals vary between products and are not chemically bound to the polymer structure so can leach out of the product over time. This leaching leads items to become brittle, leading to fragmentation, ultimately forming microplastics. It has been shown that plastics exposed to solar UV radiation can even release greenhouse gases, including methane and ethylene[14].

To enable distinction between different types of plastic pollution, items recovered from the environment are broadly categorised by size. It should be noted that there is considerable debate over the distinctions between different particle size classes, with no single consensus on the definitions. Nonetheless, there are commonly agreed definitions as follows:

- Macroplastics: >2.5 cm
- Mesoplastics: 5 mm – 2.5 cm
- Microplastics: 1 µm – 5 mm (further distinction can be made between large microplastics, 1 mm - 5 mm; and small microplastics, 1 µm – 1 mm)
- Nanoplastics: 1 – 1000 nm (0.001 – 1 µm)

These definitions correspond with wide current opinion from the research community[15,16], NOAA[17], GESAMP[18] and also with UNEP's own published definitions[19]. This report focuses on macroplastics and microplastics, although is relevant across the size spectrum of plastic items.

One of the key challenges in plastics research, largely related to item size, is determining the best methods for quantifying plastics of specific types in any given environment. Techniques for gathering data on plastics will vary depending on item size (e.g. macroplastic vs microplastic), environmental matrix (e.g. water, sediment, soil) and the research question being asked. For macroplastics, surveys range from quantitative transect-based surveys, to ad-hoc debris collection with associated (qualitative) data collection. For some studies, only a total plastic weight is recorded, whereas other studies categorise items by application, size, polymer type and more[20]. For microplastics, due to their small size, even the extraction of plastic particles from the environment can be challenging. Visible analysis is subject to bias, and can lead to the identification of false postives whereby natural particles are incorrectly categorised as plastics, based on physical characteristics (e.g. spherical, fibrous, brightly coloured, characteristics which are common to plastics but may also be seen in natural particles)[21]. Polymer analysis is therefore important to verify the chemical identity of particles.

This is commonly carried out using spectroscopic techniques (FTIR and Raman spectroscopy), however these methods are unable to detect the smallest micro and nanoplastics (e.g. < 10 µm), therefore some of the most biologically relevant particles are often missed from analyses[22,23]. Even quatitative analyses are thus subject to uncertainties relating to particles which could not be analysed. With respect to global models of plastic contamination, the data that is input to models can sigificantly influence the output, leading to large uncertainties and different outcomes between studies. This is crucial to consider when using data to parameterise models, bearing in mind that such data may be incomplete, or may rely on assumptions. For this reason, there are calls across the research community to standardise or harmonise methods for plastic quantification and analysis, to ensure accurate reporting of data, reduce uncertainty, and enable comparison between studies[24].

Plastics can cause a variety of environmental issues. It is evident that plastic poses an aesthetic issue within the natural environment, and their durability leads them to persist in the environment. Animals purposely or accidentally interact with plastics, leading to entanglement or ingestion. This can lead to both physical harm and chemical toxicity. A report published in 2020 showed that up to May 2019, 914 marine megafauna species were affected by plastic litter through ingestion or entanglement[25], a huge increase from the 267 reported in 1997[26]. This is likely a combined result of greater plastic contamination in the oceans since 1997, in addition to increased effort in recent years in carrying out surveys and reporting observations. However, considering that these figures do not include terrestrial or freshwater species, and these are just the reports that have been published in the academic literature (not including informal or unrecorded observations), the real number of species affected by plastics worldwide is undoubtedly far higher.

2.1. Macroplastics

Due to the nature of our use and manufacture of plastics, the majority of plastic debris starts its life on land, as macroplastics. While many macroplastic (and mesoplastic) sized items have purposes that are fundamental in today's society, for example in packaging, healthcare, the automotive industry and technology, very few are designed with end-of-life in mind, and so cannot be easily reused or recycled[27]. Instead, plastics are carelessly discarded and new materials used for new products. Plastic items easily enter the environment following their use, either deliberately through littering or accidentally via mismanagement. A common example is that of packaging, which is a common sight across both urban and rural areas. While in some cases plastic waste is effectively landfilled or incinerated, in many instances they are accidentally lost from waste management systems, or intentionally discarded directly to the environment where disposal facilities do not exist or are difficult to access[9].

Macroplastics within the environment are a concern due to their longevity and ability to accumulate. For example, macroplastics in the form of discarded fishing gear, 'ghost nets', can continue to capture organisms long after the loss of nets to the ocean or river, leading to fatal injury or drowning[28]. Macroplastics can also be ingested by large organisms, leading to gut blockage and eventual starvation. Well-known examples of such include whales, dolphins and porpoises washing up dead on beaches with stomachs full of plastics, believed to have died as a result of starvation[29]. In addition to outright mortality, such ingestion can lead to the transfer of plasticiser chemicals to organisms, leading to accumulation in tissues, toxic effects, and trophic transfer, depending on the chemical and the concentration[30,31]. Macroplastics also provide a large surface area for the colonisation of organisms, leading to the transport of non-native and potentially invasive or pathogenic species to new regions[32].

While plastics are highly durable, they are not indestructible, and so items break and become useless for their original purpose. These processes are accelerated by abrasion or heavy use (mechanical degradation), high temperatures (thermal degradation) and exposure to UV (photodegradation), all processes that lead to further breakdown of plastic items once they reach the environment[33,34]. In certain circumstances, biodegradation via microbial action can also occur[35]. The extent to which each of these mechanisms are significant depends on the environment in which the plastic is found. The deterioration and degradation of materials leads to fragmentation into smaller and smaller pieces, ultimately becoming microplastics, and thus hindering the identification and removal of these items from the environment. These aging processes also lead to the release of plasticiser chemicals, which may be toxic in themselves, thus plastics can pose both a physical and a chemical threat.

2.2. Microplastics

The term 'microplastics' was coined in 2004[36] and research in this field has flourished since then, especially in the last 10 years[37]. Microplastic surveys have been carried out in locations globally, with microplastics discovered widely across marine, freshwater, terrestrial and atmospheric environments[4,38]. Microplastics are now present even in remote areas including the deep sea[39], in remote mountainous areas[40], within Arctic sea ice[41] and in Antarctic freshwaters[42]. These studies highlight the extent and spread of microplastics dispersed as a result of human activities, weather, currents and winds. Microplastics are comprised of a huge variety of polymer types, composites and particle shapes, in addition to a wide range in particle sizes (1 μm – 5 mm, Section 2.1, Fig. 1). These may be either 'primary' i.e. specifically designed to be of a very small size for domestic, cosmetic or industrial purposes, or 'secondary' i.e. unintentionally derived from the breakdown of larger plastic items while in use, or once in the environment.

To date, the greatest research effort on plastics has focused on marine systems, with freshwater and terrestrial systems lagging behind. It is known that the majority of plastics are manufactured and used on land, and when discarded, are likely to enter rivers before they reach the sea. Therefore, research on plastics and microplastics on land and in rivers is crucial to understanding their impacts across the whole environment. This research has been developing across the last few years, primarily focussing on rivers throughout Europe and North America[4,43], but more recently broadening out to rivers across Asia, Australasia and South America[44-46].

Concentrations of microplastics in river water and sediments are highly dependent on local environmental conditions, and in the majority of locations, concentrations

Figure 1. Plastic items of various sizes on a beach. Image credit: Alice A. Horton.

will continually change. These varying environmental concentrations will significantly influence exposure of organisms to microplastics over time[47]. For example, some areas will be natural accumulation zones, and many will also be seasonal in relation to rainfall and flow conditions. For example, in the UK, microplastic concentrations in river sediments were found to be much reduced following flooding, leading to resuspension of microplastics from sediments and subsequent flushing of microplastics downstream[48]. In the Ganges, the concentration of microplastics was found to increase with increasing distance from the source of the river, with the highest concentrations found towards the estuary, although in a similar concentration range to other freshwater studies[4,49]. With respect to seasonality, it would be expected that the monsoon would have a significant influence on microplastics transport and mobilisation and thus water concentrations; the same study found that surface water concentrations of microplastics were higher pre-monsoon, likely due to monsoon rains diluting and flushing out microplastics[49].

As plastics and microplastics are a relatively new contaminant, having only been in use for a few decades, the long-term implications of these for organisms and ecosystems are as yet unclear. The key concerns surrounding microplastics relate to their ubiquity and small size, and thus bioavailability to a wide range of organisms. It has been shown that microplastics can be ingested by organisms spanning the trophic web, from primary consumers to higher predators. Ingestion can lead to particle toxicity, whereby the physical form of the microplastic particle(s) leads to gut blockage, abrasion, translocation into tissues, and inflammation, thus reducing the fitness of organisms, or leading to mortality[50]. Entanglement is also possible (e.g. for invertebrates) and it has been shown that particle shape (i.e. fibre, fragment, bead) can significantly influence its potential to do harm[51]. In terms of chemical toxicity, concerns stem from microplastics' ability to adsorb, accumulate and transport hydrophobic chemicals. Microplastics have been found to accumulate greater concentrations of POPs than surrounding media or co-located organisms[52]. For example, a study in Japan found that microplastics accumulated higher concentrations of POPs than did zooplankton, suggesting that ingestion of microplastics would lead to a greater chemical exposure compared to ingestion of zooplankton from the same location[53]. Studies have also shown that gut fluids can facilitate POP desorption, making POPs more bioavailable if microplastics are ingested[54,55]. Nonetheless, other studies have suggested microplastics to be a negligible vector of POPs compared to natural organic and inorganic particles within the environment, which are far more abundant, can comparably sorb and transport POPs[56-58], and similarly desorb contaminants into organisms upon ingestion. Another chemical consideration is that microplastics have the propensity to leach potentially toxic incorporated plasticisers into the environment as they age. In contast to POP adsorption, this will lead to the presence of chemicals that would not otherwise have been present within the environment, and the subsequent bioavailability of these.

While studies investigating the toxicity of microplastics do not always show negative effects, nonetheless microplastics can impact growth, reproduction, hormone production and ultimately survival[59]. The actual effects depend on a number of factors including the route of exposure, the sensitivity of the organism and the concentration and characteristics of the microplastics themselves. While studies on the ecotoxicological effects of microplastics are numerous, covering a wide range of trophic guilds, the effects of microplastics on human health are not yet well-understood. Nonetheless, recent research suggests that microplastics will continually and irreversibly accumulate in adult humans to a concentration of 50,000 particles by the age of 70[60]. Furthermore, in vitro tesing of human cells has shown that microplastics and nanoplastics can induce pro-inflammatory cytokines and cause oxidative stress, with effects being polymer and particle size-specific[61,62]. Effects of microplastics on human health are a concern given our day-to-day use of plastic and thus high exposure, and such research is ongoing.

3. Introduction to Migratory Species and Plastics

Migration is a costly activity in terms of energy expenditure, exposure to threats, and potential to encounter unfavourable or extreme weather events. Migration must therefore provide significant benefits in order for species to undertake it. These benefits might take the form of access to seasonal food supplies, finding sufficient water, or following favourable climatic conditions. Migratory behaviours are being increasingly lost or changed as a result of a number of factors including habitat loss, anthropogenic disturbance and climate change, among others[63]. In discussions about migration loss, it is not specifically mentioned that this is related to plastic exposure or environmental pollution in general. Nonetheless ingestion of plastics, or entanglement, can have negative consequences, including mortality, for individuals or populations. Thus, it should be considered as a stressor that may influence survival, fitness and behaviour of migratory species, from invertebrates through to birds and mammals[47,64,65].

Non-migratory species are only exposed to local levels of contamination and therefore body burden of any plastics (or indeed, any contaminants) can usually be attributed to local exposure, unless these species prey on migratory species. Migratory species, however, may be exposed to pollutants at any stage throughout their migration. For this reason, migratory species found in remote regions have been shown to accumulate far higher concentrations of pollutants than species which remain local, due to their tendency to travel to less remote (and therefore more highly populated and industrialised) regions. An example is the migratory South Polar Skua, which accumulates far higher concentrations of PBDEs (flame-retardant chemicals) than its Antarctic neighbours, chinstrap and gentoo penguins[66]. Because migratory species pass through multiple different regions and environments, it can be very difficult to pinpoint the origin of any internalised contaminants.

With respect to plastic, it is difficult to determine whether plastics were recently ingested, or have been previously ingested but retained within the gut. If microplastics or nanoplastics are observed within tissues, this would imply migration of ingested particles from the gut to the tissues, and therefore a longer retention time[67]. It has been suggested that biota, especially seabirds, may act as a significant reservoir for plastic waste within the environment[68,69]. There is also therefore the potential for migratory species to act as carriers, transporting plastics between regions. Given that migratory species will encounter a wider range of different environments, this leads to the possibility of higher exposure to plastics and associated contaminants. Many of the CMS-listed species in the region of interest are also classified as endangered[11]. Given these facts, migratory species are likely among the most vulnerable to plastic pollution, combined with other anthropogenic pressures. It is therefore essential that conservation plans are developed to protect these vulnerable species and that unnecessary plastic pollution is cleaned up, and ideally stopped at source.

4. Literature Review Methodology

This report focusses on freshwater and terrestrial systems in the Asia and Pacific regions, including two case study systems: the Mekong and Ganges River basins. Specifically, this includes the countries through which the Mekong and Ganges Rivers flow, including China, Myanmar, Thailand, Laos, Cambodia, Viet Nam, India and Bangladesh, while Sri Lanka is also included as a separate country of interest.

Within the countries making up the region of interest, there are 605 migratory species listed with CMS appendices I and II[70]. To ensure all CMS species within the region of interest were covered, the CMS Appendix I and II lists were downloaded for the countries of interest using the website https://speciesplus.net/ on 16th November 2020[70]. To determine any evidence of species interactions with, or ingestion of, plastics both the species' common names and Latin names were searched on both Google and Google Scholar alongside the phrase '*plastic*' to find grey literature, news reports and peer-reviewed articles. The asterisks (*) on either side of the word plastic enable any permutation of the word 'plastic' to be found, e.g. plastics, microplastic etc. Where many species exist within related groups, a broader search term was used (e.g. bats, buzzards) prior to searching species. If no relevant records were found for the wider group it was determined not necessary to search each species within this group individually. Marine species were also considered more broadly (for example whales) rather than searching all species individually, as they are not the key focus of this report. All relevant CMS-listed species for which observations were documented are listed in Table 1.

Where data are sparse in the case study locations, we consider data from the same species in habitats more widely across countries surrounding the Bay of Bengal and Western Indian Ocean including Malaysia, Singapore and Indonesia. Further, where data do not exist and where appropriate, comparisons are made to global parallels and phylogenetically related species in other regions, or co-located species with similar traits.

5. Asia Pacific and Case Study River Systems

As mentioned above, Asia is known to be one of the most heavily plastic-polluted continental regions globally[9,71]. In terms of oceans, the Pacific Ocean has been stated to be the most polluted: in 2015 an estimated > 1,000,000 microplastics/km^2 were present in some areas[72]. In the Great Pacific Garbage Patch (an area spanning 1.6 million km^2) a study in 2018 estimated that there were 1.8 trillion plastic items (of which microplastics accounted for 1.7 trillion, 94%), weighing an estimated 79 thousand tonnes. In this study, microplastics were by far the most numerous at ~680,000 microplastic/km^2, although by mass only accounted for 8% of the total[73]. The main sources of plastics to the Pacific Ocean are believed to be from Asian countries[73].

While the majority of plastics are manufactured and used on land, and the oceans are the ultimate sink for many plastics, rivers are recognised as a major transport corridor of plastics. The following subsections detail the case study river systems contributing plastics to the Indian Ocean and the Pacific Ocean: the Mekong and the Ganges.

5.1. Mekong

5.1.1. Overview of the Mekong

The Mekong River is the world's tenth longest river, flowing for 4600 km through six countries: China, Myanmar, Thailand, Laos, Cambodia and Vietnam. The Mekong supplies critical domains such as food, water and energy security to over 70 million people. Reliance on the Mekong river basin is predicted to increase, as the population is expected to grow over 100 million by 2025[74]. In addition to its importance as a freshwater resource, the Mekong feeds directly into the marine area comprising the Coral Triangle, recognised as the most diverse marine area globally. As a vulnerable marine ecosystem, any contamination here could have detrimental and irreversible ecological implications.

The Mekong River is the second most biodiverse river in the world after the Amazon, and supports the largest riverine fishery in the world. The annual value of the fishery is $11 billion and provides 17% of the global inland fisheries harvest[75]. Examples of key edible species include the migratory Siamese Mud Carp (also known as trey riel, *Henicorhynchus siamensis*), the Boeseman Croaker (*Boesemania microlepis*) and the Giant River Prawn (*Macrobrachium rosenbergii*). The Mekong boasts over 1100 freshwater species and hosts some of the largest freshwater fish in the world: both the Mekong Giant Catfish (*Pangasianodon gigas*) and the Giant Barb (*Catlocarpio siamensis*) grow to 3 m in length, while the Giant Freshwater Stingray (*Himantura chaophrya*) can reach weights of 600 kg[76].

Social and economic development of the river basin has resulted in deleterious effects to species' numbers in the catchment area, including the endangered Mekong Giant Catfish and the Irrawaddy Dolphin (*Orcaella brevirostris*). For example, hydropower development in the form of dams is increasing rapidly, affecting critical migration routes for fish, and leading to habitat fragmentation. Additionally, climate change, habitat destruction, pollution and overfishing are all significant issues in the Mekong (and many rivers globally) with the potential to lead to catastrophic population declines if not properly managed[77]. It is known that multiple stressors can lead to greater synergistic effects on species than the predicted combined effects, meaning that the implications of exposure of animals to multiple stressors simultaneously can be difficult to predict.

5.1.2. Plastics in the Mekong

The Mekong is among the top 20 most polluted rivers in the world when considering contribution of plastic inputs to the oceans, estimated to transport up to 40,000 tonnes of plastic into the South China Sea each year[7]. While rivers are known to act as conduits for pollutants including plastics to the oceans, many of these will be retained within the river, its sediments and its biota. Despite this knowledge, and the economic and ecological importance of the Mekong, very little information is available on the sources, abundance and distribution of plastics in the Mekong. The CounterMEASURE phase I project was among the first research efforts to collect data on macroplastic and microplastics in the Mekong River Basin, including the main stem of the river and a number of its tributaries especially around large cities: Vientiane (Laos), Chiang Rai (Thailand), Phnom Penh (Cambodia) and Can Tho (Viet Nam). This included both environmental surveys and collection of data on waste production and management. This research revealed that river water from 30 out of 33 sites analysed in the Mekong basin contained microplastics, with concentrations up to 18 microplastics/m^3. The most common polymer was polypropylene, determined to be possibly derived from artificial turf or plastic sheeting. A trend of increasing microplastic concentration was observed as the river flowed towards the sea (unpublished, CounterMEASURE phase I reports). Some preliminary research by the University of Hull (UK) has also shown the presence of microplastics at three sampled sites in the Mekong, with wider sampling and analysis to follow[78]. However far more research is needed if we are to understand the extent and implications of this contamination.

5.2. Ganges

5.2.1. Overview of the Ganges

The Ganges River is 2500 km in length, starting in the Indian Himalaya and ending at the Ganges-Brahmaputra-Meghna (GBM) delta in Bangladesh, where the combined flow of these rivers flows into the Bay of Bengal. The river supports 655 million people, providing key nutrition, water and employment opportunities in the form of fisheries[79]. The Ganges River bears immense religious, cultural, socioeconomic and ecological significance. The river is regarded as a sacred entity, and is worshipped by Hindus. As such, the river plays a pivotal role in the lives of many in India and Bangladesh.

Fisheries in the GBM delta are responsible for the maintenance of the national economy, employment and food security. The overall economic turnover of these inland fisheries is vital for the country's economy and security, contributing 4-5% of Gross Domestic Product (GDP). The fisheries produce 50-60% of animal protein to surrounding regions, where fish are a key part of the local diet[80]. Bangladesh is the fourth highest producer of inland fisheries globally, with India being the third largest inland capture and aquaculture producer in the world[78]. It is therefore crucial that anthropogenic pollution does not contaminate and potentially reduce the fisheries yield.

As in the Mekong, an increasing number of dams and barrages for hydropower and flow management is an issue that could contribute to habitat destruction and possible changes in population dynamics and food web structure, leading to negative impacts on populations[81].

5.2.2. Plastics in the Ganges

One of the most polluted rivers in the world, the Ganges has been identified as the second most significant contributor of plastics to the ocean after the Yangtze river in China, and is estimated to transport and discharge up 172,000 tonnes of plastic into the Indian Ocean per year[7]. Considering microplastics alone, this could equate to up to 1-3 billion (10^9) microplastic particles into the northern Indian Ocean (Bay of Bengal) every day[49]. This is not considering the large plastic items that are also abundant and for which quantitative estimates by number of items have not been made. While the Ganges exports large volumes of plastic to the ocean, there is some evidence to suggest that dams can act as accumulation zones of pollutants including plastics and microplastics[82], thus changing the distribution and accumulation of plastic within the river.

As mentioned above, fisheries are a key industry in the Ganges, supporting food security and employment. Although undoubtedly not the only source of plastics, a recent study within the Ganges by Nelms et al. (2021) showed that fishing activities are a significant contributor of plastic waste to the Ganges River. Fishing activities lead to the accidental loss, or intentional discard, of large quantities of plastic-based fishing gear. This includes nets, ropes and floats, constituting a wide range of different plastic types, but predominantly nylon, polypropylene and polyethylene respectively[83]. Accidental loss of gear is also an issue, and is more difficult to control. Anecdotal evidence from interviewed fishers also indicated that non-target animal interactions and entanglement with fishing gear is common, and sometimes fatal[83]. This study also showed that the abundance and volume of fishing debris on the riverbanks increased significantly as the river flowed from its source towards the ocean, with the highest amounts of waste recorded nearest to the delta. In the marine environment, this issue stems partly from the fact that ships less than 400 GT are not obliged to adhere to Annex V of the International Convention for the Prevention of Pollution from Ships (MARPOL 37/78) and can therefore legitimately discard plastic waste to the ocean[84].

A similar trend of increasing concentrations from river source to sea has also been observed for microplastics, whereby concentrations in surface waters were seen to generally increase downriver (average concentration 38 microplastics/m^3)[49]. This has been observed in other studies and is likely due to the increased population pressures on rivers as they flow towards the sea. The most common polymers found were rayon and acrylic, therefore assumed primarily to derive from textiles and fishing gear. These limited studies suggest that the polymer composition and thus sources in the Ganges are different to those observed in the Mekong (where polypropylene appears to dominate), however a greater number of studies would be needed to further assess this difference. In the Ganges, significantly higher concentrations were found pre-monsoon compared to post-monsoon, highlighting the importance of considering seasonal variability when conducting surveys[49]. Along coastal beaches in the Hooghly estuary, within the Ganges river delta, litter abundance was found to be higher by number of items during the monsoon, compared to post-monsoon[85].

Other sources of plastics to the Ganges include the mismanagement of everyday plastics, for example packaging and carrier bags, in addition to religious offerings of flowers and nondegradable materials, including plastics (Fig. 2). In some places along the Ganges, for example in Bangladesh, there is no dedicated waste management system and little public awareness of the problems caused by plastic pollution. This is despite the fact that Bangladesh was the first country globally to ban plastic bags. However this ban has proven ultimately unsuccessful to date, due to the lack of enforcement and insufficient suitable alternatives[86]. Nonetheless, a corresponding reduction in plastic bag usage did occur

Figure 2. Litter floating in the Ganges River at Varanasi. Image credit: Kandhal Keshvala, obtained from iStock.

following the ban in 2002 which, in the first few years after the ban, was suggested to lead to reduced severity of flooding in the capital city Dhaka, due to reduced clogging of waterways with plastic litter[87].

Specific animal interactions with plastics in the case study river systems are discussed in the following sections. These will consider the region of interest as whole, relating to these two river basins and the countries of interest. Species within countries through which these rivers flow, plus Sri Lanka, are also included where appropriate. The species discussed in the following section are all those for which published literature or observations could be found, including related species in some instances when data relating to the CMS-listed species of interest were unavailable.

6. Freshwater Species

6.1. Invertebrates

There are no aquatic invertebrates listed within CMS appendices I and II, nonetheless as a key food source for many aquatic species, wider invertebrate interactions with plastics do have the potential to affect higher trophic organisms including CMS-listed species. Due to their size and feeding habits, invertebrates are more likely to ingest microplastics than macroplastics. Interactions with these larger plastics may still occur, however as macroplastics form a novel habitat for invertebrates, and may provide a food source in the form of associated biofilms (consisting of bacteria and microorganisms). However, when considering negative impacts, it is at the microplastic scale that effects on invertebrates, in addition to bioaccumulation and trophic transfer, are most likely to be observed[88].

It is has been widely shown that aquatic invertebrates will ingest microplastics, and that the extent of ingestion is affected by habitat and feeding type[89]. For example, the highest environmental concentrations of microplastics recorded to date are within freshwater and marine sediments[39,90,91], leading benthic organisms to be particularly vulnerable to exposure, thus having a higher chance of ingesting microplastics. Studies have also shown that filterfeeders are particularly susceptible to the ingestion of microplastics given their indiscriminate feeding strategy, harvesting particles from the water column[92]. A relevant example here is the non CMS-listed Asian Clam (*Corbicula fluminea*). While it is native to Eastern Asia and some areas of Africa, the Asian Clam is an invasive species and not native to the Mekong and Ganges rivers. Nonetheless, Asian Clams have been found in the Lower Mekong Basin[93]. Further, they can now also be found within freshwater systems throughout Europe and the Americas. It has been shown that Asian Clams ingest and retain large numbers of microplastics, for example individuals from Lake Taihu and the Yangtze River in China were found to contain in the range 0.2-12.5 particles per gram of clam tissue[94,95]. Due to its wide geographical distribution, tolerance to pollution, ease of laboratory culturing and propensity to bioaccumulate pollutants including microplastics, it has been suggested that the Asian clam is an ideal bioindicator species[94,96].

Invertebrates, including bivalves, form an important food source for a vast array of animals including fish, mammals (such as otters and cetaceans) and birds. Ingestion of microplastics by these key lower trophic organisms can therefore lead to trophic transfer within the food web. This has been demonstrated both within laboratory experiments[97,98], and within the environment[99-101]. Effects of microplastics on invertebrates vary depending on species sensitivity and level of exposure. However, negative effects including reduced growth and fecundity may result from chronic exposure and may therefore lead to long-term population effects, with implications for the species that rely on them as a food source.

6.2. Fish

There are 35 fish species listed in the CMS which have ranges within the countries of interest, and only 12 if considering freshwater species alone. Those that are present include the classes Actinopterygii (ray-finned fish) and Elasmobranchii (cartilaginous fish, including sharks and rays).

6.2.1 Actinopterygii (ray-finned fish)

Examples in the class Actinopterygii include various species of sturgeon (*Acipenser spp.*) and the Mekong giant catfish (*Pangasianodon gigas*). To our knowledge, there are no reports of plastic or microplastic ingestion by the Mekong Giant Catfish Pangasianodon gigas. Although historically eaten as a food fish, they are now critically endangered and infrequently sighted[11]. They are protected by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix I[102] meaning that international trade in this species is prohibited.

The Chinese Sturgeon (*Acipenser sinensis*) is a critically endangered species found only within the Yangtze River. Chinese Sturgeon populations are shown to be in continual decline due to a number of anthropogenic factors, including construction of hydroelectric dams, overfishing and pollution[103]. While construction is a great hindrance to Chinese Sturgeon as dams, for example, obstruct access to spawning grounds[103], it is known that pollution also has damaging impacts. For example, Chinese Sturgeon have been shown to accumulate triphenyltin (TPT, a fungicide and pesticide), polybrominated diphenyl ethers (PBDEs, used as flame retardants), poly- and perfluorinated compounds (PFCs, used as flame retardants and water-repellents) among other persistent organic compounds[104-106]. This exposure and bioaccumulation to contaminants can lead to potential reproductive effects such as malformation of larvae[104]. Given that plastic is known to contain and transport a range of organic chemicals, in addition to metals, exposure to plastic pollution may lead to further exposure to, and accumulation of, anthropogenically-derived contaminants[107,108].

While not within the region of interest, the closest species within the same genus with direct reported research on microplastic ingestion and effects is White Sturgeon (*Acipenser transmontanus*). An experimental study was carried out by feeding a range of environmentally relevant microplastics to the prey species Asian Clam (*Corbicula fluminea*), and subsequently feeding the

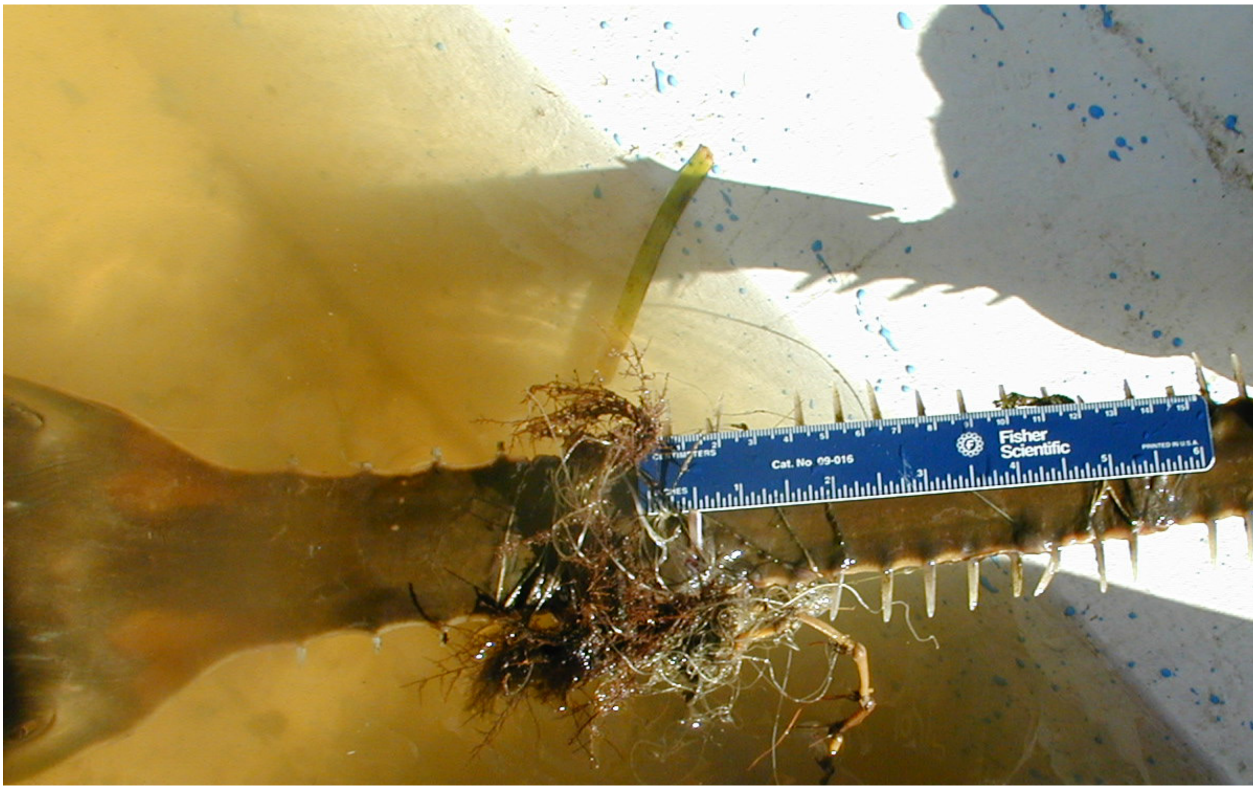

Figure 3. Smalltooth Sawfish entangled in fishing line. Image credit: Gregg Poulakis, Ph.D., Florida Fish and Wildlife Conservation Commission. Reproduced with permission.

clams to their natural predator, White Sturgeon. It was observed that feeding behaviour was altered in the sturgeon exposed to clams that had ingested microplastics, with exposed sturgeon ingesting more food overall. However, the effects seen were subtle, and it is not clear what the implications are for feeding and for ecosystem responses in the long term[109]. Asian Clams are a key food source for a range of Acipenser species and therefore it is a reasonable assumption that other species of sturgeon within the region of interest will also ingest microplastics through their prey, and may show similar responses.

A recent study in the Chi River in Thailand, a large tributary of the Mekong, showed that of eight different freshwater fish species studied, 73% of all individuals collected had microplastics within their guts[110]. However, no significant differences were seen between species, despite differences in feeding strategies. This highlights the widespread ingestion of microplastics by freshwater fish species within this region. Fishing nets and cages were deemed to be the greatest source of ingested microplastics.

6.2.2 Elasmobranchii (cartilaginous fish)

Sawfish are euryhaline, found in marine, estuarine and freshwater systems. Species of Sawfish within the region of interest are the Narrow or Knifetooth Sawfish *(Anoxypristis cuspidata),* Smalltooth Sawfish (*Pristis pectinata*), Largetooth Sawfish (*Pristis pristis*) and Longcomb Sawfish (*Pristis zijsron*). Due to their sharp protruding teeth placed along a long rostrum, Sawfish are highly susceptible to entanglement with debris (Fig. 3)[111,112]. The Smalltooth Sawfish has been reported to be in severe decline as a result of fisheries bycatch (reported in the United States, but likely to be the case globally)[113] and, as also with the Largetooth Sawfish, is listed on the IUCN Red List as critically endangered[11]. Fourteen records exist for Smalltooth Sawfish entanglement in plastic debris, although in the Atlantic Ocean rather than the region of interest, and yet fewer records in the Indian Ocean (2 records for *Pristidae* sp.)[112]. Little evidence of plastic ingestion or interactions exists for the other sawfish species.

Another similarly Critically Endangered CMS-listed freshwater elasmobranch species, the White-spotted Wedgefish (*Rhynchobatus australiae*) is commonly accidentally caught as bycatch (in addition to intentional capture for the harvesting of their fins, which are among the most valuable in the shark fin trade)[11,114]. While evidence of ingestion of plastics and microplastics is not available for the White-spotted Wedgefish, many other marine shark and ray species globally have been observed to ingest microplastics, with filter feeders including CMS-listed Whale Sharks (*Rhincodon typus*) and Basking Sharks (*Cetorhinus maximus*) likely to be the most susceptible to ingestion[115]. However, carnivorous sharks are also likely to ingest microplastics, primarily via trophic transfer from their prey, many species of which are known to ingest microplastics[115]. Entanglement in fishing gear is similarly common for a range marine shark and ray species globally, with especially higher numbers of entanglement records for CMS-listed species including Silky Shark (*Carcharhinus falciformis*, 52 records across the Pacific and Indian Oceans) and Spiny Dogfish (*Squalus acanthias*, 106 records in the Pacific Ocean). In the Atlantic, 29 records are available for the Dusky shark (*Carcharhinus obscurus*)[112].

6.3. Mammals (aquatic)

Compared to other aquatic organisms such as fish and aquatic invertebrates, air-breathing aquatic mammals may be particularly badly affected by entanglement in plastic waste, as entanglement can prevent animals from reaching the surface for air, leading to drowning. There are a number of dolphin species in CMS appendices I and II believed to be negatively affected by plastic waste, in addition to other threats. The Ganges River Dolphin (*Platanista gangetica gangetica*, a subspecies of the South Asian River Dolphin *Platanista gangetica*) is a freshwater mammal with a wide distribution throughout the Ganges River system in Bangladesh, Bhutan, India and Nepal. It is currently classified as Endangered on the IUCN Red List[11], with an estimated 3500 individuals remaining in the wild[116]. The Irrawaddy Dolphin (*Orcaella brevirostris*) thrives in brackish and saline waters and can be found more widely including within the Ganges and Mekong rivers. It has been suggested that rising salinity, as a result of increasing abstraction and therefore decreased freshwater flow, is one factor contributing to the decline of Ganges River Dolphin in the Sundarbans (located in the GMB delta)[117], evidence correlating with a reported increased range of the Irrawaddy Dolphin further upstream[118]. In the Sundarbans, Ganges River Dolphins have a greater habitat range than the Irrawaddy Dolphin and it has been suggested that they face a higher number and range of threats than the Irrawaddy Dolphin, with habitat loss and degradation being a major threat, in addition to plastic waste, primarily in the form of fishing gear[118]. A report by the Government of Bangladesh states that between 2007 and 2013 approximately 90 cetaceans were killed by gillnets in Bangladesh, of which 63 were Ganges River Dolphins and 16 were Irrawaddy Dolphins[115]. One study reported entanglement of Ganges River Dolphins with discarded fishing gear, once in the form of fine gillnet thread wrapped around the rostrum and between the teeth, and another incidence of an individual entangled in long-line fishing gear[119].

According to a recent study, the Ganges River Dolphin was rated as the second most vulnerable species at risk of entanglement and negative effects from discarded fishing gear in the Ganges (the first most vulnerable species being a non CMS-listed species but on the priority species list in India: the Three-striped Roofed Turtle, *Batagur dhongoka*)[83]. This vulnerability classification was based on a combination of IUCN Red List status, evidence of interactions of the species with plastics, and abundance of plastic in the species' local habitat.

There is also evidence to show that river dolphins from other regions (e.g. the Amazon River Dolphin, *Inia geoffrensis* and the Tucuxi, *Sotalia fluviatilis*, both in Brazil) have experienced interactions leading to injury or mortality of individuals[83].

In the Mekong, drowning as a result of entanglement in nets is considered to be the key threat to Irrawaddy Dolphins[120] and there is plenty of evidence to show that plastics are widespread within their habitat, with specific examples of direct co-location including Chilika Lake (India)[121], Halda River (Bangladesh)[118], and the wider Ganges and Mekong Rivers. In fact, Irrawaddy Dolphins in the Mekong are estimated to number less than 100 individuals, therefore conservation efforts are crucial. Given that both the Ganges River Dolphin and the Irrawaddy Dolphin are considered Endangered according the IUCN Red List[11], these numbers are cause for concern.

Porpoises are also threatened as a result of human activities. Populations of the CMS-listed Narrow-ridged Finless Porpoise (*Neophocaena asiaeorientalis*) in the Yangtze River have declined by more than 80% since 1991 alone as a result of fishing, habitat degradation, pollution and water development projects[122]. Illegal fishing leading to porpoise by-catch is increasing as fishing activities intensify. Water development projects such as the Three Gorges Dam have disrupted the Yangtze river, blocking porpoise movements through the system and affecting migrations of their prey. Ingestion of microplastics has been observed in the subspecies Neophocaena asiaeorientalis sunameri, with all eight individuals studied having ingested microplastics, including both neonates and adults[123]. It is not clear whether this was a result of direct ingestion or trophic transfer from prey. Anecdotal evidence of macroplastic ingestion by the Finless Porpoise (*Neophocaena phocaenoides*) has also been reported, leading to blockage of the gut and subsequent mortality[124].

Ingestion of plastics by the CMS-listed marine Harbour porpoise (*Phocoena phocoena*), a coastal and estuarine species, is more widely-documented outside the region of interest, although this is likely due to its much wider distribution globally. Little information is available on Harbour Porpoise interactions with plastics in the region of interest. Elsewhere, in the North Sea, a Harbour Porpoise was found to have ingested fishing line and a plastic bag, leading to emaciation and death[125].

Figure 4. Dead Humpback Whale (Megaptera novaeangliae) (CMS-listed species found globally, including Pacific and Indian Oceans) entangled in fishing lines. Image credit: Scottish Marine Animal Stranding Scheme. Reproduced with permission.

Evidence relates not only to the physical presence of ingested plastics but also indirect evidence of ingestion. In Norway, Harbour porpoises were found to contain phthalate chemical derivatives (resulting from plastic additives, thus acting as an indicator of plastic exposure) within their livers. These chemicals were shown to lead to a reduced body size. These studies therefore show both direct and indirect consequences of plastics and associated chemical contaminants to this CMS-listed species in the wider environment[126]. Another marine mammal on the CMS list in the region of interest is the dugong (*Dugong dugon*), which have been shown to become entangled in fishing nets and drown[127], in addition to ingesting plastics, leading to death[128]. In general, interactions of cetaceans (including whales, dolphins and seals) with plastics are much more widely reported within marine systems than freshwaters (Fig. 4)[129-131].

As well as direct ingestion, mammals are also vulnerable to plastic and microplastic exposure as a result of trophic transfer. For example, in freshwater systems, Eurasian otters (*Lutra lutra*, not on the CMS list but considered a priority species in India) have been found to ingest microplastics, likely as a result of trophic transfer from fish prey. This prey includes the European Catfish (*Silurus glanis*) which, in a study in Italy, was found to make up 25% of *L. lutra* diet[132]. As catfish are higher predators themselves, they also likely to accumulate large amounts of contaminants, with microplastics potentially one of these[132,133]. While little evidence exists for ingestion of microplastics by other otter species, this is likely to occur in the same way in related otter species throughout the region of interest, for example the Hairynosed Otter (*Lutra sumatrana*) in the Mekong, the Smooth-coated Otter (*Lutrogale perspicillata*) and the Asian Small-clawed Otter (*Aonyx cinereus*). While not CMS-listed species, these species are listed on the IUCN red list as Endangered (*L. sumatrana* and *L. perspicillata*) or Vulnerable (*A. cinereus*)[11].

6.4. Reptiles

There are six reptile species listed in the CMS appendices I and II within the regions of interest, only one of which is exclusively found within inland freshwaters: Gharial (*Gavialis gangeticus*). This species is classified as Critically Endangered by the IUCN Red List, with an estimated 650 individuals remaining in the wild in 2017[11]. The other species found within river systems in the region of interest is the Saltwater crocodile (*Crocodylus porosus*) which inhabits saline and brackish waters within estuaries and deltas. Both Gharial and Saltwater Crocodile are on the priority species list of India. The Gharial is limited to a small region in the GMB delta and associated rivers within India, Bangladesh and

Nepal, and does not inhabit the Mekong River. Although the Saltwater Crocodile historically used to inhabit the Mekong, it is thought that no viable populations remain in this region, as a result of habitat degradation and poaching[134]. Direct observations of plastic interactions by these two river-dwelling species within the region of interest have not been reported, although some evidence of Saltwater crocodile entanglement in plastics has been observed in Australia[111], and the false Gharial (*Tomistoma schlegelii*, in the same family as the Gharial: Gavialidae) has previously been observed to be injured by fishing gear in the Ganges River[83]. Where species such as Gharial are Critically Endangered and exist only in small populations in the wild, on top of habitat degradation and anthropogenic pressure the additional widespread hazard posed by plastics may have serious population-level consequences.

All five other reptile species on the CMS appendices I and II within the region of interest are marine turtles, for which there are multiple reports of interactions with plastics. Entanglement has been reported for all five turtle species on the CMS list in the region of interest: Loggerhead turtles (*Caretta caretta*), Green-sea turtles (*Chelonia mydas*), Hawksbill sea turtles (*Eretmochelys imbricata*), Olive Ridley sea turtles (*Lepidochelys olivacea*) and Leatherback sea turtles (*Dermochelys coricea*)[135]. Ingestion is also commonly observed. These interactions can lead to injury such as amputation and infection, inhibited growth, or mortality as a result of drowning or starvation[136], consequences which are also common to aquatic mammals.

7. Terrestrial Species

7.1. Invertebrates

There is only one invertebrate listed within the CMS appendices I and II, globally; the Monarch Butterfly (*Danaus plexippus*). This species is native to North America, however populations are nowadays widespread across Europe, Asia and the Americas, although not specifically within the region of interest. They are famous for their two-way seasonal migration between North America and Mexico, travelling Southwards for the winter months. However, not all Monarch Butterfly populations migrate, and outside of the Americas, monarch butterfly migration is limited[137]. There is no published evidence to date on the interactions of monarch butterflies with plastics or microplastics, although limited evidence does exist for interaction of other lepidoptera species with microplastics, including the Silkworm Moth (*Bombyx mori*)[138]. Given this limited information, no inferences can be made about Monarch Butterfly interaction with plastics of any potential effects.

As with aquatic invertebrates, terrestrial invertebrates provide the food source for a vast array of higher trophic organisms and therefore interactions and ingestion of microplastics by invertebrates may lead to ingestion, accumulation and potential impacts for the birds, reptiles and mammals that rely on invertebrates. It is therefore recommended that research on possible Monarch Butterfly ingestion of microplastics is considered going forwards.

7.2. Mammals

With respect to terrestrial mammals, both in Asia and globally, the available evidence of ingestion of plastics and subsequent harm is predominantly anecdotal. Only six peer-reviewed publications relevant to CMS-listed or related species were found for this report. Especially with respect to wild mammals, this is partly due to the practical and ethical constraints of working with large, sentient animals, especially where they are endangered or protected. In such instances it is not possible to intentionally sacrifice animals for research. Such observations are therefore a result of opportunistic analysis from animals that have died as a result of natural or unnatural causes, including plastic exposure, and can be subsequently dissected. Alternatively, faeces can be examined to investigate components of diet, including any ingested plastics. In the marine environment, common examples of such observations include marine mammals such as whales, dolphins and seals, which beach due to poor health and are thus found dead or near death, or from which faeces are analysed[101,129].

An example of land mammals in Asia (and elsewhere) affected by plastic ingestion are ruminants such as cows,

Figure 5. A cow feeding amongst waste on the banks of the Bagmati River, Kathmandu, Nepal. Image credit: Asiafoto, obtained from iStock

sheep and goats which feed indiscriminately on waste sites (Fig. 5), incidentally ingesting plastics[139,140]. As plastics cannot be easily egested, these can accumulate within the stomach, causing impaction and leading ultimately to death[141]. Another example of such a ruminant is the camel. While no data can be found for the Bactrian Camel (*Camelus bactrianus*, listed in CMS Appendix I), the relative Dromedary Camels (*Camelus dromedaries*) in the United Arab Emirates have been found dead with large accumulations of plastics within their guts, leading to an estimated mortality rate of 1% of the population as a result of plastic ingestion alone[142]. This result suggests that indiscriminate feeding leads to large-scale ingestion of plastics by *Camelus spp*.

A CMS-listed animal for which anecdotal evidence exists is the Indian Elephant (*Elephas maximus indicus*, also known as the Asian Elephant). The Indian Elephant is endemic to the region of interest, using both the Ganges and the Mekong Rivers as resources for water and bathing. In some areas, elephant sanctuaries directly flank the Ganges, for example the Shivalik Elephant Reserve in Uttarakhand, northern India. However, even within reserves elephant populations are not immune to human activities and related disturbances[143]. A wild elephant was recently found to have died in Thailand as a result of plastic ingestion, with multiple plastic bags found within its stomach[144]. Further, there have been many reported sightings of elephants scavenging on rubbish dumps, including in Sri Lanka (Fig. 6)[145].

Another terrestrial mammal of interest is the Gobi bear (*Ursus arctos isabellinus*, CMS Appendix I), a subspecies of the Brown bear (*Ursus arctos*). While there does not appear to be any information available on Gobi bear interactions with plastics, the Brown bear in North America has been observed to feed from rubbish dumps, including in Alaska and Yellowstone National Park. These studies did not investigate plastic interaction or ingestion, but the results of this and other studies suggest that foraging on waste dumps is, in fact, beneficial to brown bear populations, as a result of increased availability of food. This leads to increased body weight, earlier maturation and increased litter size [146,147]. This positive, rather than negative, effect may be because bears are selective enough in their feeding to avoid eating indigestible items such as plastics.

There are no concrete reports of plastic ingestion by big cats on the CMS list: Lions (*Panthera leo*), Cheetahs (*Acinonyx jubatus*), Leopards (*Panthera pardus*) and Snow Leopards (*Uncia uncia*). Nonetheless interactions have been observed, for example a leopard was photographed carrying a plastic bottle in its mouth in the Masai-Mara game reserve, Kenya (Fig. 7). With respect to the more elusive Snow Leopard, and the other big cat species, no sightings of plastic interactions have been reported. Many other terrestrial mammals are listed within CMS appendices I and II, including bats, horses and ruminants such as mountain sheep and yaks, however no documented evidence of interactions with plastics can be found for most of these species.

Figure 6. A group of Indian Elephants foraging on a rubbish dump in Oluvil, Sri Lanka. Photo credit: Tharmapalan Tilaxan © Reproduced with permission.

Figure 7. A leopard carrying a plastic bottle in its mouth, in the Masai-Mara game reserve, Kenya. Photo credit: Denis-Huot ©, obtained from Alamy.

8. Avian Species

Over 80% of CMS-listed species in the region of interest are birds, representing nearly 500 species. Due to this abundance of migratory bird species, it is unsurprising that, as a class, birds have the greatest number of reported observations with respect to the different types of plastic interactions.

8.1. Plastics Used in Nest Constructions

Birds making nests out of plastics is a relatively common sight. For example, migratory species within the Sulidae family, gannets and boobies, have been found to build nests using fishing and shipping debris. This has also been observed with the CMS-listed Long-Legged Buzzard (*Buteo rufinus*), whereby a nest constructed with plastic bags, fibres and string was observed to lead to brood failure (due to inability to properly incubate the eggs) and nest abandonment[148]. If hatching is successful, juveniles can become entangled and ingest plastics. This entanglement of juveniles has been observed with another CMS-listed species, the Blackfaced Spoonbill (*Platalea minor*); in South Korea, a juvenile was found in its nest entangled with plastic rope round its legs, which may have been a result of this rope being used as a nesting material[149].

Black Kites (*Milvus migrans*) have also been observed to build their nests using artificial materials, such as white plastic debris (Fig. 8). In contrast to the negative effects of plastics reported by most studies, behavioural studies have observed that decorating nests with white plastic bags increases the visibility of the nests, thus improving the likelihood and success of courtship[150]. Using plastics as nest-building materials may also be a consequence of the lack of other suitable materials locally. Entanglement and mortality of nestlings also appears to be low in this species, likely because plastic bags rather than twine are the preferred debris type[150]. Other bird species globally have also been shown to intentionally collect plastics based on their colour, for example the non-CMS listed Satin Bowerbird (*Ptilonorhynchus violaceus*), the male of which collects blue items (including plastics) with which to attract a female mate to its nest. Other species of raptors are more susceptible to entanglement than Black Kites, especially those that choose to build their nests from fishing lines, baling twine and wire, for example the Osprey (*Pandion haliaetus*). Osprey chicks have a high risk of becoming entangled in items with a string-like appearance, such as fishing line or balloons[151].

Fishing line also poses a threat for other waterbirds and land birds, when incorporated in nest construction and when birds forage in habitats near wetlands. Kite strings are especially an issue for land birds, and have been estimated as the second most frequent source of plastic interaction after fishing line[151]. Regarding entanglement of coastal and river-dependent birds, the CMS-listed coastal

Figure 8. Black Kite with plastic in its beak, possibly being collected for nest construction. Image credit: Volodymyr Kucherenko, obtained from iStock.

seabird Lesser Crested Tern (*Thalasseus bengalensis*) has specifically fallen victim to fishing gear becoming entangled in gill nets, leading to injury[152]. A number of Common Terns (*Sterna hirundo*, not a CMS-listed species but related to CMS-listed Sterna species) in the Ganges river basin have also been found with nylon fishing line entangling their legs, obstructing blood supply and causing permanent damage. This entanglement can prevent normal feeding behaviour and obstruct flight[83].

The CMS-listed Long-tailed Tit (*Aegithalos caudatus*) have also been shown to build nests out of plastic, which has been suggested to provide nest camouflage as a result of light reflectance, provide insulation, and requires low energetic cost to acquire[153]. Using plastics for nest construction does not appear to have a negative effect on breeding success, and may in some cases be beneficial in terms of nest visibility and energetic cost of acquiring building materials[150,153]. Nonetheless, entanglement and ingestion are common and still pose a threat, while plastics used in construction can promote nest abandonment or lower breeding success[153].

8.2. Plastic Ingestion

White Storks (*Ciconia ciconia*) are commonly observed foraging on rubbish dumps, interacting with debris and building nests out of litter[154,155] (Fig. 9). An item that is uncommonly noted in general with respect to plastic impacts on wildlife is rubber bands, however White Storks ingest these in abundance. This is likely because rubber bands resemble earthworms, their favoured prey[156]. In a study in Spain, ingestion of plastics was higher in juveniles than adults (63% of individuals analysed, compared to 35%). This is likely because juveniles are less able to discriminate between edible and chance of accidents, for example collision inedible items and less able to regurgitate these if ingested. This can lead to a lack of energy, impaired orientation, and a greater with power lines[154]. There are fewer reports on the Oriental Stork (*Ciconia boyciana*), although one study found that an individual reintroduced to the wild in Japan died shortly after release, due to ingestion of plastic foam[157]. Also vulnerable are species that utilise the abandoned nests of other birds, including Eurasian eagle owls (*Bubo bubo*) which use White Stork nests[158].

The Cinerous Vulture (*Aegypius monachus*) and Griffon Vulture (*Gyps fulvus*) are interesting avian examples as they have a different feeding strategy compared to most birds. Given that they are scavengers that feed off carrion, they regularly ingest indigestible material such as hair, claws and hooves. As such, mechanisms have evolved in their digestive system to remove such materials from the gut to prevent accumulation, through the formation of pellets which are regurgitated. These pellets consist mainly of ingested hair and skin, in which smaller indigestible items can become embedded. For Cinerous Vultures this is easier as they have a diet rich in skin, facilitating pellet formation. However, Griffon Vultures ingest less indigestible material and produce pellets less frequently. In order to ensure sufficient material for pellet formation, this species may in fact purposely take up indigestible material with which to form these pellets. If this consists of anthropogenic debris including plastics, as opposed to their usual materials of grass, twigs and hair, these may not be easily egested due to sharp edges and may remain lodged in the gut where they can accumulate and cause internal damage[159].

Black-footed Albatrosses (*Phoebastria nigripes*) and Laysan Albatrosses (*Phoebastria immutabilis*), both listed in CMS Appendix II, appear to be particularly vulnerable to plastic ingestion. This is likely due to their feeding strategy, selecting floating items from the ocean surface. In the time before the abundance of plastics, these items would have been dominated by organic matter and neustonic (floating) organisms. However, the growing prevalence of plastics in some areas means these can be difficult for albatrosses to distinguish, leading to accidental ingestion[160]. These may then accumulate in the gut or be passed to offspring through regurgitates. Plastics from degraded post-consumer products have been observed in the digestive contents of albatross chicks in the Midway Atoll (North Pacific). In the study, Black-footed Albatrosses tended to ingest more fishing line, while Laysan Albatrosses ingested more fragments. A greater incidence of fishing line appeared to correlate with an abundance of fish eggs in their digestive contents[161]. This preference of Black-footed

Figure 9. White Stork on a rubbish dump. Image credit: Volodymyr Shevchuk, obtained from iStock

Albatrosses for fishing gear seems to be a common trend, as evidenced by other studies[162].

An earlier study carried out in 1986-1987 found that a greater proportion of Laysan Albatross chicks in the North Pacific had ingested plastics than Black-footed Albatross chicks, leading to a significant reduction in fledgling weight. Black-footed Albatross chick weight was not affected. It can be inferred that reduced weight would have implications for survival, although direct mortality as a result of plastic ingestion was not widely evident across either species[163]. As well as indirect effects from toxic chemicals and direct physical damage such as internal lesions, mortality may be increased as increased mass of plastic in chicks' stomachs. This reduces the amount of food and water a chick can accept, leading to starvation and/or dehydration[163]. A small-scale study of six Short-tailed Albatross (*Phoebastria albatrus*, CMS Appendix I) found that four out of the six birds, including both adults and juveniles, had ingested plastics, predominantly fragments. The health effects of these were not investigated[164].

Evidence of microplastic ingestion has been observed in a range of other CMS-listed birds which have different feeding habits, including Mallard (*Anas platyrhynchos*)[165] and Osprey (*Pandion haliaetus*)[166], although these observations were not made specifically within the region of interest. Nonetheless it is likely that these species will ingest plastics in the same way in the region of interest, and this is likely also the case across a wider range of land and river-dependent birds where plastics and microplastics are abundant. It is also commonly observed that predators of seabirds ingest high quantities of plastics via trophic transfer. For example, the Bald Eagle (*Haliaeetus leucocephalus*) ingests plastic via trophic transfer from prey that has ingested plastics, including Parakeet Auklets (*Aethia psittacula*) in the North Pacific[167]. This can lead to accumulation of plastics within the gut, in addition to impacts from plastic-associated chemicals or heavy metals[168]. While not a CMS-listed species itself, this suggests that the related CMS-listed Haliaeetus species could ingest plastics via the same mechanisms. Across birds in general, trophic transfer has been reported little to date, but this is likely simply due to a lack of research in this area. Trophic transfer to birds as a result of invertebrate or fish ingestion is highly likely across a range of species.

From the above studies it is clear that birds are particularly susceptible to interactions with plastics due to their specific behaviours. This relates to intentional handling of plastics as building materials, unintentional contact and entanglement, and ingestion by adults and juveniles. While many of the studies presented here relate to geographically widespread observations, nonetheless they relate to CMS-listed species that are also present in the region of interest, and thus inferences can be made as to similar behaviours and interactions occurring in the region of interest. Despite this knowledge, many species, including those on the CMS appendices I and II, remain uninvestigated. While evidence of resulting mortality or long-term effects is not always available, we should be aware that these interactions have great potential to be detrimental to health and survival.

Table 1. CMS-listed freshwater and terrestrial species for which observations of interactions with plastics were found for this report. Marine species which also utilise estuarine or delta environments are included, but purely marine species are excluded. Species distributions were determined using information from CMS list (Speciesplus.net) and IUCN Red List. *Region is broadly specified by continent/ocean of interest unless the species has a more specific and limited habitat range ^Indicates that recorded observations for these species were not within the region of interest (see text for details).

Class	Species Latin Name	Species Common Name	CMS Appendix	Region Inhabiting*
Terrestrial				
Mammalia	*Elephas maximus indicus*	Indian Elephant	I	Asia
Mammalia	*Panthera pardus*	Leopard	II	Asia^
Mammalia	*Ursus arctos isabellinus*	Gobi Bear	I	China
Freshwater/Estuarine				
Mammalia	*Dugong dugon*	Dugong	II	Pacific
Mammalia	*Neophocaena asiaeorientalis*	Narrow-ridged Finless Porpoise	II	Yangtze river
Mammalia	*Neophocaena phocaenoides*	Finless Porpoise	II	Asia
Mammalia	*Orcaella brevirostris*	Irrawaddy Dolphin	I/II	Ganges and Mekong
Mammalia	*Phocoena phocoena*	Harbour Porpoise	II	North Pacific^
Mammalia	*Platanista gangetica gangetica*	Ganges River Dolphin	I/II	Ganges
Reptilia	*Crocodylus porosus*	Saltwater Crocodile	II	Asia^
Reptilia	*Gavialis gangeticus*	Gharial	I	Ganges
Elasmobranchii	*Pristis pectinata*	Smalltooth Sawfish	I/II	Asia^
Elasmobranchii	*Rhynchobatus australiae*	White-spotted Wedgefish	II	Mekong^
Elasmobranchii	*Squalus acanthias*	Spiny Dogfish	II	North Pacific^
Actinopterygii	*Acipenser sinensis*	Chinese Sturgeon	II	China
Actinopterygii	*Pangasianodon gigas*	Mekong Giant Catfish	I	Mekong
Avian				
Aves	*Aegithalos caudatus*	Long-tailed Tit	II	Asia and North Pacific^
Aves	*Aegypius monachus*	Cinereous Vulture	II	Asia
Aves	*Anas platyrhynchos*	Mallard	II	Asia^
Aves	*Buteo rufinus*	Long-legged Buzzard	II	Asia
Aves	*Ciconia boyciana*	Oriental Stork	I	Asia
Aves	*Ciconia ciconia*	White Stork	II	Asia^
Aves	*Milvus migrans*	Black Kite	II	Asia

Aves	*Pandion haliaetus*	Osprey	II	Asia and Pacific^
Aves	*Phoebastria albatrus*	Short-tailed albatross	II	North Pacific
Aves	*Phoebastria immutabilis*	Laysan Albatross	II	North Pacific
Aves	*Phoebastria nigripes*	Black-footed Albatross	II	North Pacific
Aves	*Platalea minor*	Black-faced Spoonbill	I	Mekong
Aves	*Thalasseus bengalensis*	Lesser-crested Tern	II	Ganges and Mekong

9. The Future

9.1. Ongoing Challenges

Plastics are cheap, widely available, lightweight and adaptable. Among their benefits they reduce food wastage and improve sanitation and healthcare, and enable access to clean drinking water. Plastics are therefore practical materials for a wide variety of purposes. The key challenge globally is therefore to retain the benefits of plastics, while reducing the volume of waste, and preventing environmental harm caused as a result of mismanagement. Reducing the introduction into the stream of commerce of plastic products likely to become waste is also an important aspect of this effort. While alternatives are being developed and encouraged, such as biodegradable or compostable plastics, or natural materials such as paper, these all have economic and environmental consequences associated with the manufacture of these materials, their handling and disposal. These are therefore not always a better or more sustainable option, and life cycle assessments should be carried out when designing products[169].

A major challenge in Asia and the Pacific is the lack of understanding of plastic leakage to land and rivers, including uncertainties around the transport pathways, dynamics and hotspots of released plastics. Data collection across a range of scales (e.g. social, industrial, spatial, temporal) is essential to address this knowledge gap. Global imports of plastic waste from Western countries can pose a particular challenge for Asian countries. While imports can have a financial incentive as the materials themselves have value and can usually be recycled into new products, the volume of imports is often unmanageable, and can occur illegally or in an unregulated manner[170]. Furthermore, much of the waste sold as ‘recyclable’ cannot actually be recycled. This may, for example, be due to unclear labelling, miseducation or apathy, leading non-recyclable materials to enter the recycling stream. This leads to an uncontrollable build-up of unrecyclable waste which cannot be suitably contained and inevitably ends up within the environment[171,172]. This problem amplified in 2017 when China, previously the world’s largest importer of Western plastics, halted imports, thus forcing smaller nations with less infrastructure to accept this waste. According to Greenpeace Southeast Asia, plastic imports to ASEAN countries increased 171% between 2016 and 2018, from 836,529 tonnes to 2,231,127 annually[173]. This is in addition to the 57 million tonnes of plastic waste produced annually within East Asia and the Pacific (greater than all of Europe and Central Asia combined (45 million tonnes), and greater than North America (35 million tonnes))[174]. Multiple barriers exist for waste recycling in developing countries (and globally), including energetic cost of recycling, material complexity, low demand due to downcycled products, lack of public awareness, and lack of financial support, meaning that landfill can often be the most economic and energy-efficient means of waste management[175]. It should be noted, however, that where waste management in the importing countries is effective, recycling can be beneficial with respect to promoting sustainability, reducing the negative environmental consequences of plastics, and can be positive economically due to material recovery[176].

Many of the countries in the region of interest are on the Organisation for Economic Cooperation and Development (OECD) Development Assistance Committee (DAC) list and most are considered either Least Developed (Bangladesh, Cambodia, Lao People's Democratic Republic, Myanmar), or Lower Middle Income Countries (India, Viet Nam, Sri Lanka). With limited financial resources, waste management may not be a priority for all DAC countries, where other income-related social and healthcare issues are prevalent. Such schemes must therefore either be incentivised, or must provide some tangible economic and societal benefit, such as through increased employment or recouping value from waste materials through recycling.

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9.2. Mitigation and Management

Despite the challenges, there are many ways in which plastic pollution can be, and is being, tackled, both from the top down (i.e. government) and from the bottom up (i.e. society). The CounterMEASURE phase I project identified a number of diverse strategies which should be applied, to contribute towards mitigating and reducing plastic leakage. These include scientific data collection to identify leakage and accumulation hotspots, citizen engagement, and sector and product-specific management policies and strategies. This also requires investigation of industrial and commercial activities, in addition to assessing societal perceptions of plastic waste. Importantly, investment in waste management infrastructure is vital. Many additional factors are crucial to consider when designing strategies across different countries and localities, as there will not be a one-size-fits-all approach. This requires accounting for socioeconomics, climate, cultural factors, topography and more. Based on the geographical scale of the challenge, these measures rely on the cooperation, input and support of local stakeholders.

At the societal level, education is key to ensure consumers know how to make sustainable choices (where possible), how to manage their waste, and the societal and environmental implications of plastic waste mismanagement i.e. are aware of their responsibilities as citizens. However, while society has a large role to play in determining how plastics are purchased, utilised and disposed of, many of these decisions lie first and foremost with manufacturers and retailers who develop, market and sell products, thus determining what is available for consumers. These stakeholders need to be pushed to design and engineer products that reduce plastic waste, can be easily reused, separated into different materials and recycled as appropriate, overall reducing plastic waste. Nonetheless, significant practical and economic challenges exist for industries with respect to dramatically changing their materials and processes, and such challenges should not be underestimated.

Policies such as local or government bans on specific items can be effective, but only if effectively regulated. There are many governments worldwide that have now imposed legislations relating to plastic sale and use. This includes taxes or bans on plastic bags and single-use packaging. In the region of interest, India has set an intention to eliminate singleuse plastic items by 2022, with some states already being at the forefront of bans: plastic bags have been banned in Himachal Pradesh since 2009, while in Delhi, specific uses of plastics such as bags, plates and cutlery were banned in 2017. Many other countries such as Thailand have roadmaps for reducing non-recyclable plastic waste. While these are good first steps, bans are not always strictly enforced; as mentioned above, Bangladesh was the first country to ban plastic bags, however the limited success of this ban highlights the significant challenges in controlling plastic production, availability, and public behaviour. At the microplastic scale, bans of microbeads in wash-off personal care products are now widespread globally. In Europe, the European Chemicals Agency (ECHA) has gone a step further, proposing a ban on intentionally added microplastics in any products[177].

Assuming that plastic usage is not likely to reduce any time soon and is, in fact, highly likely to increase, the issue of plastic waste in the environment is likely to continue. This is exacerbated by the longevity of plastics, meaning that what is already within the environment will remain, although may degrade from larger items into smaller microplastics. There is therefore a strong argument for firstly preventing the release of plastics to the environment, and secondly removing existing macroplastic litter, to reduce the risk of ecological harm, and the likelihood of it breaking down to a form that cannot be removed. Waste management is one of the key challenges being faced in the region of interest. In many places within Asia, there are no formal solid waste management systems. As such, large quantities of waste are dumped on land or intentionally into rivers where it gets ‘taken away’ by the flow and instead becomes a problem for downstream communities. To resolve this issue, local or government funded schemes are required to ensure that solid waste can be collected and processed within communities. There is growing recognition of the importance of removing waste from the environment and measures are being taken, for example a number of national, regional and grassroots initiatives exist to remove (and often repurpose) plastic litter from the environment. In India for example, significant effort and investment is being put into waste management through the Swacch Bharat Mission (since 2014), a government initiative to improve sanitation, by eliminating open defecation and improving solid and liquid waste management[178]. Nonetheless, such actions can be costly and logistically difficult to implement and are therefore medium-long term rather than immediate solutions. In the Mekong Basin is the Mekong BasinWide Fisheries Management and Development Strategy, funded by the Mekong River Commission (MRC) for Sustainable Development. This strategy recognises the need for coordinated communication and action across the MRC member countries, to ensure effective and sustainable inland fisheries management. While plastic pollution is not specifically mentioned, conservation of habitats and protecting the Mekong from pollution resulting from human activities are both key pillars of the strategy[74]. Further examples of a range of initiatives across the region of interest are displayed in Table 2.

One key requirement in ameliorating this issue is education. Where individuals or communities are not aware of the issues around plastic waste, they are unlikely to change their behaviours. This is an especially important consideration within the fishing community, given the prevalence of discarded fishing gear in the region of interest (Fig. 10) and the hazard these materials can pose for wildlife. Careless disposal may change if people are made aware of the potential implications of plastic (and wider) pollution for ecosystems, but also their food supply, livelihood and health. Both globally and locally, community-based citizen science projects can be an excellent way to provide education, raise local awareness and gather data on the types, abundance and condition of plastic litter. Smartphone apps can be simple and effective ways to collect data for use by scientists. Example apps include Litterati, Planet Patrol or the Ocean Cleanup River Survey, all of which are being used to gather data globally. The data gathered can, for example, help contribute towards identifying hotspots and predicting future plastic pollution trends. Smaller-scale local surveys and clean-up operations can be valuable for understanding local pollution levels and temporal variability. Identifying which items are the most abundant, for example plastic bags or plastic bottles, can help to guide strategies for targeting specific sources of plastic pollution. However, such efforts require significant coordination to ensure data can be gathered and utilised effectively. Further, with Asia and the Pacific being a major fishing region, strengthening measures and raising local awareness on shore-based waste management and recovery facilities, especially for abandoned, lost and discarded fishing gear can help reduce the abundance of fishing related plastic litter.

Figure 10. Discarded fishing gear on the banks of the Ganges River. Photo credit: Emily Duncan. Reproduced with permission.

9.3. Moving Forward - Future Research Needs and Actions

It is clear that plastic is a widespread problem across the region of interest, with substantial evidence of animal interactions with, and ingestion of, plastics. Fishing gear has been observed to be a particular threat in the region of interest. Despite this, there is insufficient data to conclude whether there are long-term harm or ecosystem-scale effects. Understanding the extent and drivers of negative effects on organisms and ecosystems as a result of plastic exposure and ingestion should be a research priority, given the ubiquity of plastics. For example, where observations have been made of CMS-listed species' interactions with plastics in places outside of the region of interest, especially where harm has occurred as a result, it is highly recommended that monitoring is implemented for these species in the region of interest due to the likelihood that individuals in this area will also interact with plastics in the same way as conspecifics elsewhere.

It is important to understand the abundance, fate and behaviour of plastics in order to understand the likely exposure of species across different systems. Accurate temporal and spatially-distributed monitoring data, across different systems and organisms, are therefore essential. These data, combined with an understanding of the hazard posed to different organisms by plastics, will enable predictions of the short and long-term risks posed, with a view to predicting future scenarios and informing mitation strategies. As such, harmonisation of methods for surveying and identifying plastics and/or data reporting will be a crucial requirement going forwards.

Given the lack of spatial data on plastics in the region of interest with respect to freshwater and terrestrial systems, it is not yet possible to map accumulation zones and hotspots, although the current UNEP CounterMEASURE phase II project will collect data to address some of these knowledge gaps, using both on-the-ground and aerial surveys. Identifying plastic hotspots within the environment will further enable the targeting of areas where flows to the environment can be stopped, reduced, or where localised clean-up efforts may be necessary. Terrestrial environments are particularly under-represented in plastic research globally, yet should be a priority environment given that the health of soils directly impacts on food security. The development of standardised protocols for monitoring and reporting of plastic litter can help to track and manage leakages of marine litter.

Table 2. A range of initiatives that exist to reduce, manage or mitigate plastic pollution within the region of interest. Note this list provides some examples and is not exhaustive.

Name of Initiative	Location/Region	Type of Initiative	Action
National ban on single-use plastic bags	Bangladesh	National policy	Ban on plastic carrier bags since 2002
Ban on Imported Waste	China	Government policy	Ban on any imported waste to reduce the plastic trade flow and improve environmental quality
Ganga Action Parivar	Ganges	Community project	Removing plastic waste from the environment, and educating local citizens on behaviours and plastic alternatives
National Geographic Sea to Source expedition	Ganges	Science expedition	Document and understand how plastic travels from source to sea
Break Free From Plastic	Global	Cross-sector initiative	Prevent the use of single-use plastics and find a solution to plastic pollution
Global Ghost Gear Initiative	Global	Cross-sector initiative	Create solutions to lost and discarded fishing gear (ghost gear) through a range of projects
International Solid Waste Association	Global	Cross-sector initiative	Promote and develop sustainable and professional waste management
Litterati	Global	Digital app	Using litter data to inspire positive environmental change
Ocean Cleanup river survey	Global	Digital app	Record river plastic and transport around the world to identify hotspot locations
Planet patrol	Global	Digital app	Clean up, research, educate and promote involvement to waste removal
National ban on single-use plastics by 2022	India	National policy	Three-phased ban on manufacture, sale, import and handling single-use plastic
Rethink+	India	Digital waste management platform	Prevent postconsumer plastic from entering landfill
Swachh Bharat Mission	India	Government initiative	Eliminate open defecation and improve solid waste management
Plastic Waste Control Plan	Korea	Government initiative	Comprehensive management of plastic waste
Make the Planet Green Again	Mekong	Community project	Improve household waste management and recycling to clean the Mekong river
Mekong Basin-Wide Fisheries Management and Development Strategy	Mekong	Regional strategy	Ensure effective sustainable inland fisheries management
The Interceptor - the Ocean Cleanup	Mekong	Extracting technology	Remove plastic waste from polluting rivers to prevent the input of ocean plastic
CounterMEASURE II (this project)	Mekong and Ganges	National/local scientific project	Detecting plastic leakages to land and rivers and impacts, assess impacts, contribute towards policy
Net Free Seas	Thailand	Community project	Remove discarded fishing nets from the ocean and repurpose the plastic

Name of Initiative	Location/Region	Type of Initiative	Action
Terracycle global foundation	Thailand	Community project	Created the 'River Trap' to capture riverine plastic before it enters the ocean
Thailand Public-Private Partnership for Plastic and Waste Management	Thailand	Public-private partnership	Reduce plastic marine debris by 50% by 2027
The Wongpanit Company	Thailand	Business	Buys recyclable materials from communities
Trash Trap	Viet Nam	Community Project	Trash trap made from locally sourced materials removes plastic debris from the oceans
National Action Plan for Management of Marine Plastic Litter by 2030	Viet Nam	National strategy	Reduce the flow of plastics into the ocean by 75% by 2030

Based on existing knowledge of other systems globally, inferences can be made as to the factors that will influence plastic transport and abundance in specific locations and this can be applied to the region of interest. For example, it is understood in wider riverine systems that seasonal flooding can remobilise plastics, reducing concentrations in sediments and diluting concentrations in surface waters[48]. This reduced water concentration has also been observed in the Ganges, linked to monsoon floods[49]. However, it should be noted that despite apparent concentration declines, these conditions often actually contribute to greater inputs of plastics to the system via surface runoff, ultimately leading to greater numbers of items transported to the oceans. A recent modelling study suggests that remobilisation of plastics as a result of flooding (for example particles previously deposited in sediments, or plastics sitting on surrounding riverbanks and floodplains) is particularly significant in the Mekong delta, with flooding events leading to a four-fold increase in plastic transport[179]. Seasonality is therefore essential to consider when designing monitoring surveys.

The wide-ranging existing data contribute to our fundamental understanding of the factors influencing plastic transport and accumulation in different river systems under variable conditions. However, insufficient evidence exists yet to fully understand how this can be translated to whole river basins, to inform management and conservation plans. In the case of migratory species, the situation is even more complex as these animals are not stationary and thus will encounter a range of different environments during their migrations. In order to protect these species from pollution hotspots, coordinated regional, national and international efforts in research and conservation will be needed. Further research to identify the species most at risk as a result of plastic pollution, through exposure or due to specific species sensitivity, will be crucial for understanding the measures required to prevent this harm. This report has highlighted that there are many CMS-listed species for which no observations have been recorded. With coordinated efforts, formal and informal data gathering should be made a priority for these many species for which no knowledge of plastic interactions exists. Efforts should also focus on those species that are known to be particularly vulnerable to ingestion or entanglement in plastic pollution, in addition to suffering the effects of other anthropogenic pressures, including the Ganges River Dolphin, Gharial, Largetooth Sawfish, Smalltooth Sawfish, White-spotted Wedgefish, Black-footed Albatross and Laysan Albatross.

10. Conclusions

Plastic pollution is a well-known global issue, particularly prevalent in the region of interest, comprising Asia and the Pacific. This has led to numerous interactions of animals with plastics, leading from nest construction to entanglement and ingestion. These interactions can have severe effects on individuals including injury, starvation and death. Animals listed within CMS Appendices I and II may be particularly vulnerable to habitat disturbance and pollution in general, due to special habitat requirements, the need for undisturbed and connected migratory routes and, often, limited population numbers (especially Appendix I species). Plastic pollution is therefore adding to this growing list of stressors.

Within the region of interest, discarded fishing gear (including nets, ropes and lines) poses a particular threat, with entanglement a particularly widely-reported problem. This is especially the case for aquatic species, but also by terrestrial and avian species who encounter these discarded materials on land. Greater incentives therefore need to be introduced for retaining and repairing fishing gear that may be intentionally discarded, while also attempting to recover accidentally lost or discarded fishing gear from the environment where possible.

The potential for plastics to cause harm is a result of a combination of species sensitivity, susceptibility to ingestion, and exposure. Due to the ubiquitous nature of plastics and the wide ranges of migratory species, it is likely that migratory species will encounter and interact with plastics at some point throughout their migration. Whether they will then ingest these plastics depends on feeding habits. While negative effects on individuals as a result of plastic pollution have been observed on multiple occasions, population-level impacts are less prominent and long-term implications are not clear. Where species are Critically Endangered and a small number die as a result of plastic contact, this may still be a significant proportion of the population, thus plastic is significantly detrimental. Where populations are larger, populations are stable and/or interactions are infrequent, negative impacts of plastics on the population as a whole are less likely. It should be noted, however, that plastic pollution is likely to increase in coming years, leading to more frequent exposure of species to plastics at increasing environmental concentrations. It is therefore not yet possible to say whether plastics are causing (or will cause in the future) ecological failures in the region of interest. Continued research will help to identify hotspots and key sources of plastics which can be targeted for reduction and mitigation strategies, in addition to the hazard posed to different species.

With respect to reducing possible harm from plastics, particular conservation attention should be paid to species which are known to be especially vulnerable to harm caused by plastic pollution as a result of ingestion or entanglement. This includes a number of Critically Endangered species, which are already under severe pressure, and for which plastics may pose an unacceptable additional threat. These conservation efforts should involve addressing plastic pollution in selected habitats in which target species live, through development of local wildlife reserves, clean-up efforts, and local governmental or societal initiatives surrounding waste management and collection. Importantly, efforts should be made to prevent the loss of plastic materials to the environment, both in these unique habitats and globally, including education programmes to inform citizens, thus encouraging reuse and proper disposal of plastics.

Industry and government both have a significant role to play in controlling the plastic pollution issue. Industry have a responsibility to ensure their products are developed and designed in such a way that they minimize plastics and can be effectively reused and recycled in the countries and locations in which they will be sold. This requires an innovative approach to product design, which is currently lacking across many consumer goods. In many instances, government policies and regulations will be the only option to enact industrial and behavioural change, for example bans, taxes or controls on the manufacture or sale of specific items. However, as evidenced in the case of Bangladesh banning plastic bags, active government enforcement is then essential to ensure that such policies are adhered to.

It is clear that a single approach alone will not be sufficient to prevent plastic waste reaching the environment, or to reduce the amount that is already there. Coordinated action and collaboration is therefore essential between local communities, academics, industry, governments and NGOs to tackle the issue from a range of different angles and perspectives.

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