Decades of

Mangrove forest change

What does it mean for nature, people and the climate?

UN environment programme

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Glossary

Biodiversity Significance of Mangrove Areas: The significance of an area of mangrove based upon the number of mangroves associated species found there and the rarity of those species.

Climate change adaptation: The process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities

Climate change mitigation: Efforts to reduce emissions and enhance carbon sinks and stocks

Carbon sequestration and stock: Carbon sequestration is the process in which carbon from the land, sea and sky is stored in the carbon pools of specific habitats, such as above ground biomass, roots and soil. The quantity of carbon held in a habitat pool at any specified time is the carbon stock.

Species at risk of extinction: Species defined as Critically Endangered, Endangered and Vulnerable according to the Red List categories of the International Union for the Conservation of Nature (IUCN).

Global Mangrove Watch (GMW): A initiative developed as part of the JAXA Kyoto & Carbon Initiative in 2011, which in collaboration with a range of partners, provides geospatial information about mangrove extent and changes

Mangrove associated species: Species that occur in mangroves according to IUCN habitat categories - subtropical/tropical mangrove vegetation above high tide level and mangrove submerged roots/

Mangrove extent: The spatial extent / area of a mangrove forest

Mangrove forest and mangrove ecosystem: Mangrove Forest refers to “true mangrove species” which typically form a forest, whilst mangrove ecosystem includes the “associated” community which forms the ecosystem, such as microbes, fungi, plants and animals

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Foreword

In order to address the triple planetary crisis of climate change, biodiversity and nature loss, and pollution and waste, humanity needs to manage Earth's critical marine and coastal ecosystems more effectively. Mangrove forests are one such habitat. Mangroves create a protective green wall between land and sea, which reduces the impact of storms and erosion. They also provide a wide range of goods and services that support the economic and social wellbeing of millions of people who live in coastal communities.

For example, my country, Brazil, has the second-largest area of mangrove cover in the world and the planet's largest continuous mangrove forest. The trees are a haven for threatened animals, like manatees and sea turtles, nurture fish populations that underpin local economies and are resting spots for birds found only in Brazil. Unfortunately, the mangroves are under increasing human pressure and the knowledge about what's at stake remains limited. Worryingly, this is not a problem unique to Brazil. For 44 per cent of the species associated with mangroves, the risk of extinction is increasing, and for 89 per cent of those species already identified as at risk, the situation is deteriorating.

Using maps released in 2022 by the Global Mangrove Watch, this report contains the results from a series of novel analyses which describe global, regional and national estimates of mangrove change. For the first time, the report explores the impact of mangrove loss on biodiversity, small-scale fishers and climate change. In doing so, it demonstrates what we stand to lose from the continuing destruction of mangrove forests and the benefits we can receive from effective, evidence-based conservation and restoration.

To confront the triple planetary crisis, we urgently need to transform our relationship with nature and make a transition towards a more equitable and sustainable future in which ecosystem loss and degradation are a thing of the past. I hope that this publication will serve to inspire governments around the world to embrace mangroves as a nature-based solution and to take action to protect, restore, and sustainably manage the magical mangrove forests that provide vast ecosystem services for nature, people and the planet.

Leticia Carvalho

Head of Marine and Freshwater Branch

UN Environment Programme

Key recommendations

1 Harmonise knowledge relating to mangrove health, use and management at local, national, regional and global scales, including:

- **Investing in capacity building, knowledge management and local data collection to supplement and improve remotely sensed data and support adaptive management.** This requires a strengthening of existing in situ mangrove monitoring networks and investment in capacity building, data management and the long-term maintenance of national, regional and global mangrove databases. The data collected should be disaggregated by factors such as gender, age and socio-economic status to ensure inclusivity and to guide the management of mangroves.

- **Developing and collecting standardised metrics of mangrove condition.** Whilst our understanding of where mangroves are found and how their extent is changing has improved considerably, we know relatively little about their health and condition.

- **Identifying local drivers of change in mangrove extent and condition and evaluating the effectiveness of policy and management measures.** The drivers of mangrove change are relatively well understood at a global scale; however, we often do not have the data required to determine the drivers of mangrove change at specific locations and evaluate the effectiveness of our management responses which seek to reduce them.

- **Refining our knowledge of how, where and which species benefit from mangroves and are impacted by their degradation and loss.** Whilst it is evident that mangrove forests enhance local biodiversity, we often don't know which species benefit from and are dependent upon mangroves. Such knowledge is fundamental to understand what mangrove change means for local biodiversity and to develop effective species conservation and recovery plans.

2 **Stop thinking in silos. Look beyond the forest and consider mangroves as vital components in socio-ecological systems; accounting for the people they support and their interdependency with adjacent ecosystems. This requires:**

- **Monitoring, analysing and managing mangrove forests as locations of human activity.** Mangroves provide numerous monetary and non-monetary benefits to people yet our understanding of their role in maintaining and enhancing socio-economic wellbeing is relatively superficial and qualitative. Furthermore, it is biased towards specific monetary benefits (e.g., fisheries and tourism) with little consideration is given to who benefits (e.g., by gender, race) and who is most vulnerable to changes in mangrove systems. A gender responsive and right-based management approach is essential to deliver ecological and economic benefits in a way that supports and empowers often vulnerable groups including indigenous peoples, local communities, youth and women.

- **Integrated "seascape" thinking.** Mangroves are much more than trees or forests; they are often part of a mosaic of habitats which are interdependent upon one another. Yet our knowledge of the relationship and dependencies between mangroves and adjacent habitats such as coral reefs and seagrass beds is poor, and our management responses, such as the use of Area Based Management Tools such as Marine Protected Areas, are rarely designed to deliver integrated solutions.

3 **Appreciate that there is not a silver bullet or a single approach that fits all situations – multiple joined up actions are required.**

- **Whilst there is often talk of "win-wins", the reality can be different. Conservation and restoration are hard, often expensive and often require people to make sacrifices.** Aiming to undertake conservation and restoration actions which deliver broad societal, economic and/or nature positive outcomes are helpful for framing and fundraising, but local context is key to what can be achieved.

- **Ensure coherent management and governance.** Coastal and ocean governance is often fragmented into policies addressing specific species, sectors, activities or "land" and "ocean" based issues. If policies and governance are not coherent in moving towards a unified outcome, then the management and conservation of coastal habitats such as mangroves can be undermined.

- **Coordinate global action.** Whilst progress has been made, international mechanisms to coordinate and fund conservation and restoration of mangroves are lacking, which prevents joined up planning, fundraising and prioritisation, resulting in inefficient, siloed and duplicative action.

Summary

In 2020, there was an estimated 147,359 km^2 of mangrove forest globally, 51% of which occurred in the Asia-Pacific, with 29% in the Americas and 20% in Africa. Indonesia had by far the largest area of mangrove forest – totalling 20% of the global total – followed by Brazil, Australia, Mexico and Nigeria, which together contain almost half of the world's mangroves.

Using 1996 as a baseline, this represents a net loss of 5,245 km^2 (3.4%) mangrove forest over the 24-year period. The greatest net losses occurred in the Asia Pacific, followed by the Americas and Africa; in particular, within Indonesia, Australia, Mexico and Myanmar.

Encouragingly, over recent years the global loss of mangroves has largely stabilised, and gains have occurred in and around many of the world's large rivers, estuaries and deltas. These findings are based on satellite imagery, and as such local conditions and extent may differ, it is therefore important to also utilise local knowledge and field data to have a more complete understanding of the global status of mangrove ecosystems.

Analysing the potential consequences of changes in mangrove extent for species from groups whose extinction risk has been comprehensively assessed (mammals, birds and amphibians and groups of reptiles, fish and plants) and which there is spatial information, it was found that:

- 1,533 species are associated with mangroves in some way; 15% of which are threatened with extinction.
- Nearly 50% of mangrove-associated mammals, 22% of fishes, 16% of plants, 13% of amphibians and 8% of bird and reptile species are threatened with extinction. Worryingly, for 44% of the species, their extinction risk is increasing and of those already at risk, the situation is getting worse for 89%.
- The greatest impacts on mangrove associated marine vertebrates following changes in mangrove extent are likely to have occurred in the Asia-Pacific region and the Americas (Myanmar and Indonesia, the USA, Ecuador and Cuba in particular).
- The role of mangroves in supporting terrestrial mammals is increasingly being recognised, including monkeys, sloths, tigers, hyenas, African wild dogs and rodents.
- The greatest impacts on mangrove associated terrestrial vertebrates following changes in mangrove extent are likely to have occurred in the Asia-Pacific region (Indonesia and Australia in particular) and the Americas (Mexico and Cuba).

Mangrove forests also play a vital role in mitigating and adapting to climate change and are vital to the economic prosperity and wellbeing of coastal communities across the world. Analysing the potential consequences of changes in mangrove extent on carbon storage and for small scale fishers, it was found that:

- Effective climate action requires both a reduction of emissions, as well as the removal and long-term storage of carbon. Mangroves have been widely demonstrated to aid with the latter. However, between 1996 and 2020 there was an overall reduction of 139 Mega tonnes of carbon stocks due to changes in mangrove forests. The greatest changes are likely to have occurred in the Asia-Pacific region, followed by the Americas and Africa.
- Mangroves are particularly important for fishing in West and Central Africa, South Asia and South and Central America, where fisheries associated with mangroves make up the majority of a countries small-scale fishers. In Guinea-Bissau mangrove-associated fisheries are estimated to support 96% of the total fishers, and in Guinea (95%), Nigeria (89%) and Gabon (87%).

If the benefits of mangroves to people and nature are to be maximised, more needs to be done than simply conserving what remains. The legacy of human impacts needs to be reversed and lost and degraded mangrove areas need to be proactively restored. Opportunities for mangrove restoration exist in every region of the world, and particularly in Southeast Asia.

However, whilst there have been extensive artificial restoration projects and successful outcomes, the success of mangrove restoration projects varies and is often relatively low. The success of restorative actions, and the realisation of associated benefits, requires the use of scientific evidence, best practice guidelines and local knowledge, as well as minimising the pressures that lead to loss and degradation in the first place.

Acknowledging the different roles women and men have in the ecosystem and community is essential in any conservation or restoration initiative. Positive examples show that integrating gender equality into mangrove restoration and conservation initiatives is not only key to the success and sustainability of projects but can contribute additional value to its outcomes in supporting both women and men with various benefits for their homes, communities and nations.

Due to the timescales required for effective mangrove restoration, it is also equally important to secure long-term funding, and engage with local communities and all stakeholders including the most marginalized and vulnerable to ensure there is political and societal will for the project.

Furthermore, the benefits that are achieved can take decades to be realised and may not be the same as those delivered by the original forest. For example:

- The abundance of species in restored mangroves may reach pre-disturbance levels within five years. However, it is important to consider the species used to restore degraded areas and re-create those that have been lost. If the species of mangrove used for restoration differ from the species that were there previously, the system may not function or be as productive as it previously was.

- For carbon storage, the time frames that need to be considered are much longer than those observed for biodiversity. Whilst a restored mangrove forest may have the potential to begin sequestering carbon within ~5 years, up to 25 years is necessary for the levels of carbon stored within the ecosystem to be comparable to that of natural systems.

The signs of mangrove recovery around the world are encouraging and restoration (both natural and artificial) is clearly needed. However, where possible, mangrove forests should be restored by reducing human pressures and allowing the system to recover naturally, rather than artificially restoring the area (e.g., by planting trees)

We urgently need to transform our relationship with nature and transition to a more equitable and sustainable future in which activities that result in ecosystem loss and degradation are a thing of the past.

Introduction

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For many people, tropical forests bring to mind images of rainforests full of colourful and rare species. However, "tropical forests", defined as having closed canopies that receive more than 200 cm of rainfall per year and growing within 280 north or south of the Equator, can take many forms (Waide 2018). Mangrove forests, for example, are a form of tropical forest which occur across the world's tropical and sub-tropical coastlines. Uniquely the plants that form the forest thrive in hot, muddy and salty conditions which would kill most other species.

Mangrove forests share many similarities with rainforests:

- They provide food, building materials, livelihoods, coastal protection and natural spaces for the estimated 2.4 billion people living within 100 kms of the coast (Putra, Perwitasari-Farajallah and Mulyani 2017).
- They reduce the severity of climate change and its impact on the planet by capturing and storing atmospheric carbon and reducing the impacts of coastal storms and floods (UNEP-WCMC 2014).
- They are home to numerous rare and threatened species of birds (Renjifo, Amaya-Villarreal and Butchart 2020), dolphins, sharks, turtles and crocodiles (Sievers et al. 2019), as well as the mangrove plants themselves (Akter 2020).

Unfortunately, and as with rainforests, mangrove forests have been lost at a considerable rate and scale. This not only makes the world a less rich and diverse place, but also impacts the ability of mangrove forests to support nature and people.

For decades, scientists and local communities have been aware of the loss of mangrove forests and the resultant impact on nature and people (Canestri and Ruiz 1973). So why are we still seeing loss and degradation of these vital ecosystems? As with many sustainability challenges there is no single answer. Rather multiple interacting factors, including pressures resulting from human activities, climate change and limited awareness of the importance of intact mangroves, have led us to this position.

Accurate and consistent information on where mangrove forests are found, how their extent is changing and the consequences for the species and people that depend upon them is essential to conserve, restore and sustainably manage them. It also provides an evidence base to monitor and advance progress towards national, regional and international goals, for instance, the Strategic Plan of the Convention on Biological Diversity, Sustainable Development Goals, Ramsar Convention on Wetlands, the United Nations Framework Convention on Climate Change and the Convention on Migratory Species. However, such information is often inaccessible, not comparable and is fragmented across research institutes, government departments and non-governmental organisations.

Here, we seek to address some of the knowledge issues by using the most recent and globally consistent dataset on changes in mangrove forest extent at global and national level and provide estimates of the associated impacts on nature and people.

Part **1**

Mangrove Change


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Where are mangrove forests found and how has their extent changed?

Based on global mangrove maps released by the Global Mangrove Watch (Bunting et al. 2018, 2022), in 2020 there was an estimated 147,359 km^2 of mangrove forest globally, 51% of which occurred in the Asia-Pacific, with 29% in the Americas and 20% in Africa (Table 1). Indonesia had by far the largest area of mangrove forest – totalling 20% of the global total – followed by Brazil, Australia, Mexico and Nigeria, which together contain almost half of the world's mangroves (Figure 1).

Using 1996 as a baseline, this represents a net loss of 5,245 km^2 (3.4%) mangrove forest over the 24-year period. The greatest net losses occurred in the Asia Pacific, followed by the Americas and Africa (Table 1); in particular, within Indonesia, Australia, Mexico and Myanmar (Figure 2).However, due to limitations in the available data, it is not yet possible to attribute loss and gains in mangroves to specific drivers (Thomas et al. 2017).Encouragingly, the global loss of mangroves has stabilised, and gains have occurred in and around many of the world's large rivers, estuaries and deltas, such as the Amazon in Brazil, the Indragiri River in Sumatra and the Amacura Delta in Venezuela (Leal and Spalding 2022). An annual breakdown of mangrove extent and change per country and territory is available in Annex 1).

TABLE 1: **SUMMARY STATISTICS OF MANGROVE CHANGE BETWEEN 1996 AND 2020**

			Compared to 1996	
Region	Year	Extent (km^2)	Net change (km^2)	Net change (%)
Africa	1996	29,993	0	-
	2020	29,345	-648	-2.2
Americas	1996	44,465	0	-
	2020	43,205	-1,260	-2.8
Asia-Pacific	1996	78,146	0	-
	2020	74,809	-3,338	-4.3
Global	1996	152,604	0	-
	2020	147,359	-5,245	-3.4

TABLE 1: SUMMARY STATISTICS OF MANGROVE CHANGE BETWEEN 1996 AND 2020.
SOURCE: GLOBAL MANGROVE WATCH, V3.0.

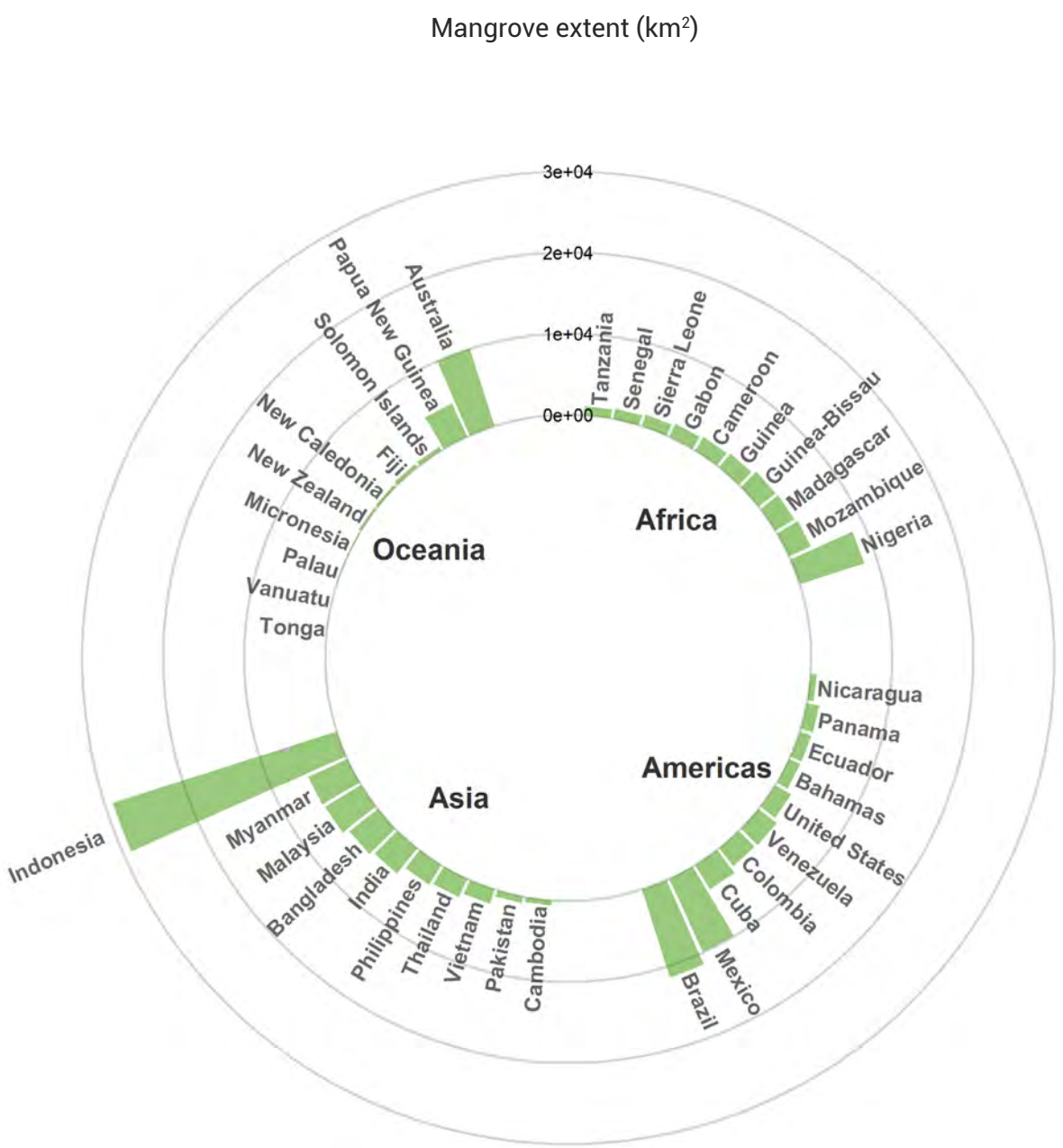


FIGURE 1: TOP 10 COUNTRIES AND TERRITORIES IN EACH REGION WITH THE LARGEST MANGROVE EXTENT.
SOURCE: GLOBAL MANGROVE WATCH, V3.0 BETA

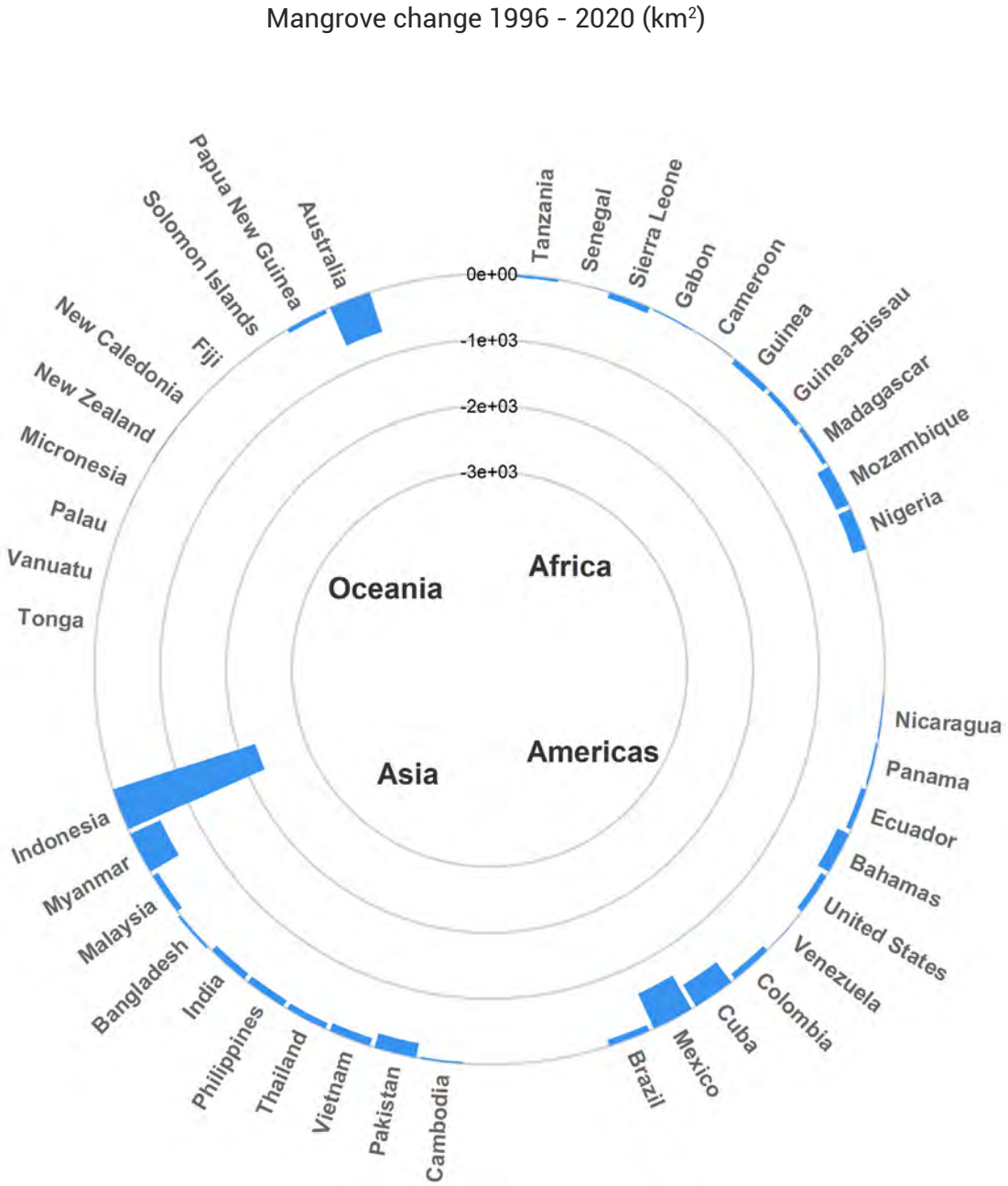


FIGURE 2: TOP 10 COUNTRIES AND TERRITORIES IN EACH REGION WITH THE LARGEST CHANGE IN MANGROVE EXTENT.
SOURCE: GLOBAL MANGROVE WATCH, V3.0 BETA

Case study 1

Mangrove change in Mexico

Mexico has one of the largest area of mangroves in the world, with much of its coastline hosting mangrove habitats. Between 1996 and 2020 there was an overall decrease in mangrove extent in the country, however, over this period gains were observed in some years and in some areas, and losses in others.

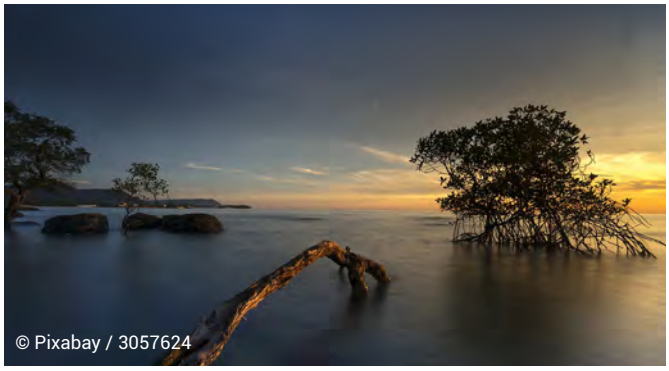
The most northernly distribution of several mangrove species occurs in Mexico, meaning that they are at the edge of their latitudinal range and are therefore sensitive to changes in the environment, resulting in high levels of variability in mangrove extent. Within the Gulf of Mexico, for example, the distribution of mangroves from south to north shifts in response to winter temperatures, whilst salinity levels, rainfall and freshwater inputs greatly influence mangrove area and distribution near the United States-Mexico border and at the tip of the Yucatán Peninsula (Comeaux, Allison and Bianchi 2012).

On top of natural variability in mangrove extent, humans have reduced mangrove area through agriculture, ranching, tourism and the development of infrastructure for ports, oil processing and cities. For example, in Mahahual (South East Mexico), from 1995-2007, 10.7 km2 of mangrove forest was cleared to build houses, hotels and infrastructure for tourism as the local population grew 89% in five years following the development of a dock for cruise ships (Hirales-Cota et al. 2010).

There are, however, success stories, with increases in mangrove coverage in the western Pacific and the Yucatán peninsula. These increases are a result of successful conservation policies over the past 18 years, under which the federal government provided land owners compensation for restoring their land back to mangrove forests (Lavieren and Spalding 2012).

Relative change in mangrove extent

Significant attention is given to regions that have lost large areas of mangroves (e.g., Indonesia), with much less consideration given to countries and regions where the amount lost is small in absolute terms, but disproportionately large in relative terms. In many areas of the world, particularly in small island developing states, the loss of even small areas of mangroves can disproportionately impact the health and wellbeing of majorly vulnerable and marginalized local people, biodiversity and resilience to climate change. For example, several small Caribbean islands lost considerable amounts of their mangrove area, including Mauritius, the Turks and Caicos Islands and Bonaire, Sint Eustatius and Saba (Annex 1). However, caution should be taken when evaluating the exact amount of mangrove change in small islands as small errors in mapping can result in large reported changes in extent.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Case study 2

Relative mangrove change on small islands

Within a number of Caribbean islands, for example, there has been considerable mangrove loss due to the extraction and use of mangrove trees for fuel wood, charcoal and timber; changes in freshwater water availability due to increasing human extraction; pollution from sewage and heavy metals; land use change; extreme weather events and sea level rise. The loss of mangroves, and the role they play in buffering storms, is particularly concerning given the vulnerability of many Caribbean islands to climate change impacts (Walcker et al. 2019)

Bonaire lies 80 km off the coast of Venezuela, with an area of 288km^2 and a population around 20,000 permanent residents. The island was colonised by the Spanish and the Dutch who cleared local vegetation for the construction of copper mines, prisons for slaves and introduced domesticated animals (e.g., cows and sheep). The flora and fauna of the island was further modified by the construction of airports and associated infrastructure by the United States during the second World War and later by the construction of hotels and an oil terminal by the Dutch. Today, the island is a Dutch municipality, and the economy is mainly based on tourism.

The island has a large flamingo population, is fringed by coral reefs and a 700-hectare shallow lagoon (LAC) surrounded by mangroves. In 1962, a national park foundation was founded to protect nature on the island, which led to the formation of various national parks including the National Marine Park which includes the conservation of mangroves. Subsequently, Lac Bay, Klein Bonaire, Pelkermeer, Slagbaai and Gotomeer have been recognized as wetlands of international significance under the Ramsar Convention.

Biodiversity on the island, including mangroves, are under pressure from pollution and unplanned urban expansion. Such problems have long been known; in the early 1980s environmental concerns were raised about developments projects within Lac Bay. For the mangroves in Lac Bay additional pressures include overgrazing from cattle which directly impacts the mangroves and erodes the soil making it less able to hold vegetation. Erosion is a significant problem in the bay, which is rapidly filling with sediment which is contributing to declines in mangroves and fish populations. However, in recent years efforts from local people and organisations have begun to help conserve and restore, mangroves, including excluding livestock from the shoreline, which resulted in the return of vegetation and a reduction in erosion, as well as restoration, conservation and educational activities by grassroots organisations such as the “mangrove maniacs”. Similarly, on other Caribbean islands, and indeed in Small Island Developing States across the world, historical legacies coupled with modern-day challenges, such as human development and climate change pressures including rising sea levels, coastal erosion and intense storms, are “squeezing” mangroves from both sides and driving declines. This problem is made worse by the limited funds available on some of these islands to support mangrove conservation and restoration, a lack of political will and legislation and the poor condition of infrastructure systems.

Part **2**

Consequences for biodiversity

Impact suggests it is only negative when it can be positive.

What does this mean for mangrove associated biodiversity?

Mangroves provide a home and safe place for numerous species, from microscopic bacteria to the largest terrestrial mammal—the elephant, to feed, grow and reproduce, The nutrients that flow from mangroves nourish nearby coral reefs and seagrass meadows (Mishra & Apte, 2019; Mumby & Arias-Gonzalez, 2003), connecting ecosystems across land, coast and the ocean. For example, in the Netherlands Antilles, the number of fish species on coral reefs in close proximity to mangroves was found to be higher than in areas where mangroves are absent (Nagelkerken et al. 2002). The loss of mangroves therefore significantly impacts biodiversity within the forest, as well as in the surrounding ecosystems (Carugati et al. 2018; Li et al. 2018)

A global review of species commonly found in mangrove forests across identified 853 vertebrate species: including 790 bird, 40 mammal, 20 reptile and 3 amphibian species. Of these, 48 species of bird, 14 reptiles, 6 mammals, and 1 amphibian species were found to be unique to mangroves (Luther and Greenberg 2009) However, these estimates are a gross underestimation, as the analysis was restricted to terrestrial vertebrate species. In addition, there are many species that do not frequently visit mangrove forests but "indirectly" benefit from their presence. At a national scale, over 4,000 species have been linked to mangrove forests in India, and the degradation and loss of mangroves in the Sundarbans region has driven the local extinction of 12 species of bird, reptile and mammal (Sandilyan and Kathiresan 2012).

Determining how dependent a species is on mangroves, and its risk of extinction following a change in mangrove extent, is an active area of research. However, it is unlikely that we will ever have a perfect understanding of the complexity of mangrove ecosystems.

The extinction risk of species occurring in mangroves

Currently there are no global estimates of the scale of impact of mangrove change on biodiversity. The following section aims to fill this gap in a globally consistent manner by exploring the potential consequence of mangrove loss on biodiversity.

Method: **Identifying species at risk from changes in mangrove extent**

Only taxonomic groups whose extinction risk has been comprehensively assessed were considered in this analysis. This includes, mammals, birds and amphibians, as well as selected groups of reptiles, fish and plants. In addition, all plant species considered to form part of the mangrove ecosystem were included. From these groups, species that occur in mangroves (hereafter called "mangrove associated" species) were identified according to the following IUCN habitat categories: subtropical/tropical mangrove vegetation above high tide level (1.7); and mangrove submerged roots (12.7)) (Jung et al. 2020).

METHOD BOX 2: The method used to identify species at risk from changes in mangrove extent

Following this method, 1,533 mangrove associated species were identified. Of these, 15% were found to be threatened with extinction (i.e., combining IUCN Red List categories Critically Endangered, Endangered and Vulnerable); representing nearly 50% of mammal, 22% of fish, 16% of plant, 13% of amphibian, and 8% of bird and reptile species found in mangroves (Figure 3). For example, the Marianne white-eye and Guam kingfisher bird species that historically occurred in mangroves are extinct and extinct in the wild, respectively.

Of the 1,553 mangrove associated species, the risk of extinction is increasing for 44%, is decreasing for 5% and is stable for 35%, with 15% having an unknown status. Worryingly, of those currently threatened with extinction, the risk is increasing for 89% and decreasing in only 1% (Annex 1).

FIGURE 3: THREAT STATUS OF COMPREHENSIVELY ASSESSED MANGROVES-ASSOCIATED SPECIES BY TAXONOMIC GROUP.

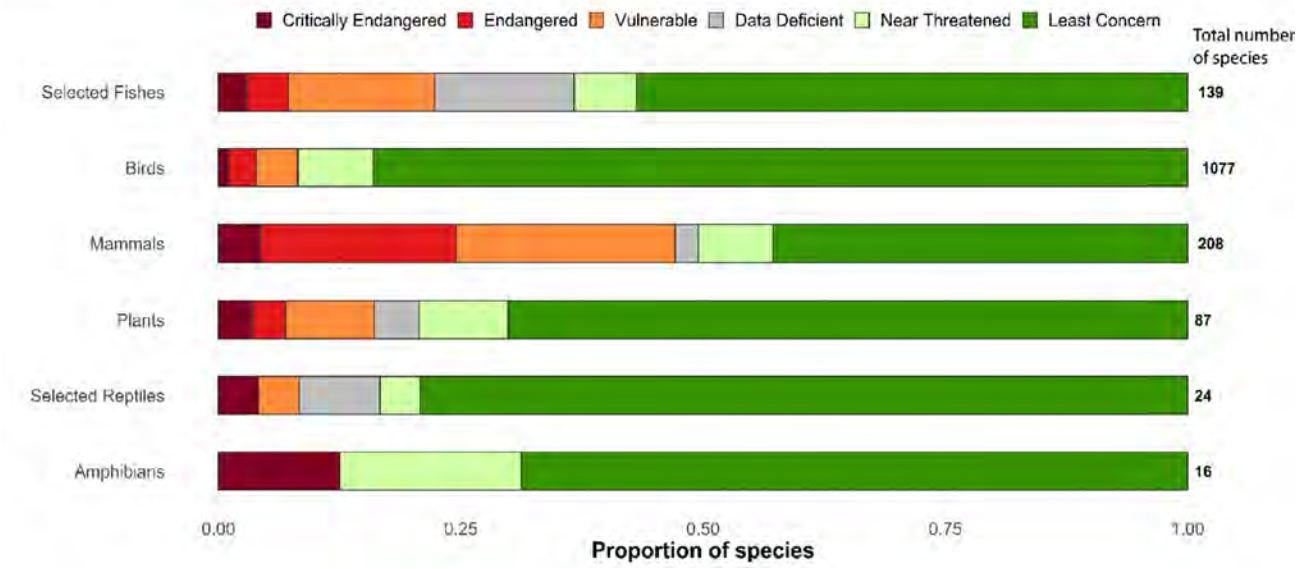
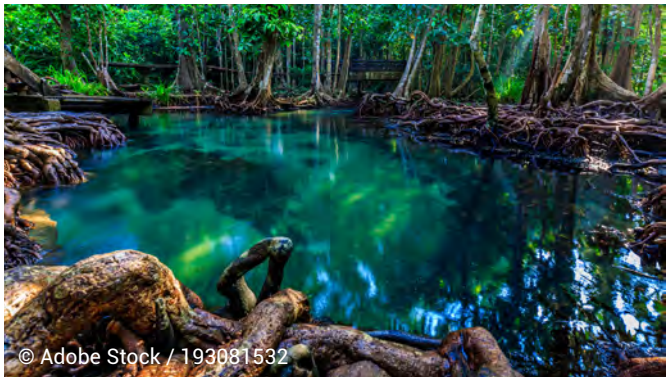


FIGURE 3: THREAT STATUS OF COMPREHENSIVELY ASSESSED MANGROVES-ASSOCIATED SPECIES BY TAXONOMIC GROUP.
SOURCE IUCN RED LIST

Where are species associated with mangroves most at risk?

Identifying areas that have high numbers of mangrove-associated species and which are also experiencing large changes in mangrove extent can help to prioritize conservation and restoration efforts (Figure 4). One such area is the Indo-Malay Philippine Archipelago, which has the highest diversity of mangrove species and one of the highest rates of mangrove area loss globally (Polidoro et al. 2010).



Method: **Determining the biodiversity significance of mangrove areas**

Of the 1,553 mangrove-associated species identified, spatial data or other information needed for the analysis were not available for 20 species, which were excluded from the analysis. Spatial data for species ranges were obtained from the IUCN Red List of Threatened Species(IUCN 2020) and refined using an updated version (v004) of a global map of IUCN habitat types and global elevation data (Danielson and Gesh 2011).

To identify areas of mangrove biodiversity value, we first generated a map of "biodiversity significance" by calculating a "weight" for each pixel (a 1km^2 square on the map used in the analysis) where mangrove-associated species occur, based on both the number of overlapping species ranges and the proportion of the global distribution (including non-mangrove habitats) that the pixel represents. This means that areas of mangrove that contain many common species, or a few globally rare species, get a high rating. The pixel weight therefore reflects the relative "significance" of each pixel for mangrove-associated species globally in 2020.

Predicted changes (loss and gain) of species for each pixel were then determined based on changes in mangrove extent between 1996 and 2020. The resulting map identifies hotpots of high biodiversity significance and high mangrove change (gain and loss) (Figure 5). This method was subsequently repeated to determine the significance of each pixel for mangrove associated plants, marine vertebrates, birds and terrestrial vertebrates excluding birds and the results used in the subsequent sections.

METHOD BOX 3: The method used to determine the biodiversity significance of mangrove areas

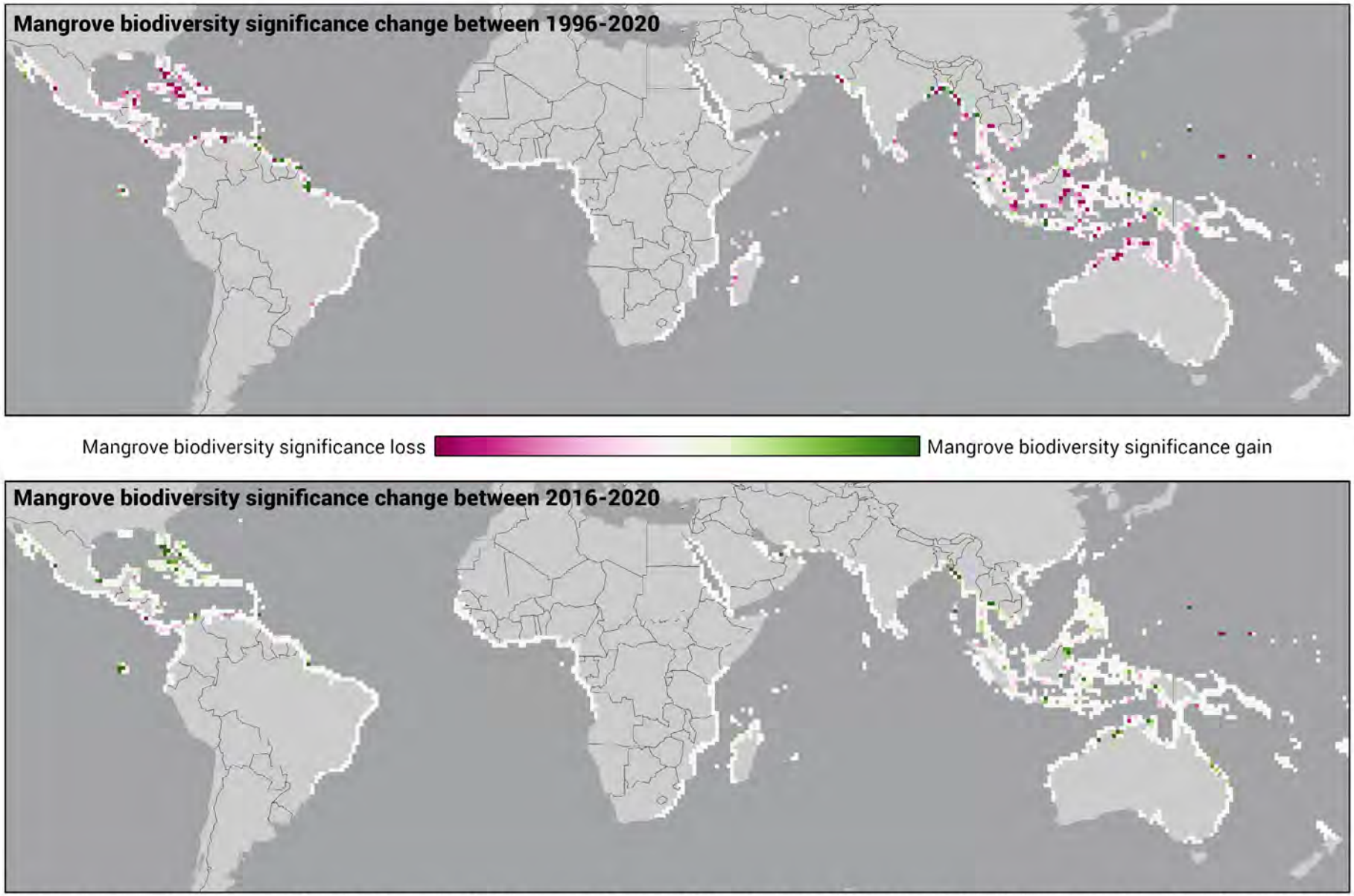


FIGURE 4: PREDICTED GAIN AND LOSS OF MANGROVE BIODIVERSITY SIGNIFICANCE BETWEEN 1996 AND 2020
SOURCE: UNEP-WCMC

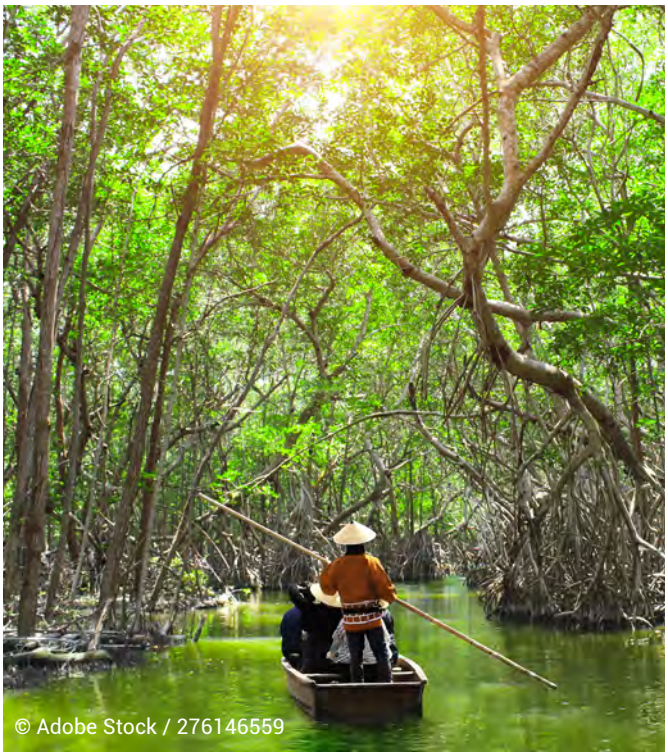
Geographic patterns of key groups associated with mangroves and their predicted response to change in mangrove extent

Plants

The word "mangrove" is often used to describe both the plants that form a mangrove forest (i.e., true mangrove species) and the "associated" community which forms the ecosystem, including microbes, fungi, plants and animals.

True mangrove species are often split into two groups: those in the Indo-West Pacific (including East Africa, India, Southeast Asia, Australia, and the Western Pacific) and those in the Atlantic Eastern Pacific (including West Africa, Atlantic South America, the Caribbean, Florida, Central America, and Pacific North and South America). Despite there being a similar area of mangrove forest in each group, the Indo-West Pacific group has three times the floristic diversity of the Atlantic Eastern Pacific (Duke 2016). The number of true mangrove species varies according to the definition used, with estimates including 54 (Feller 2018) and 73 including hybrids (Spalding, Kainuma and Collins 2010).

Associated flora includes epiphytes (e.g., orchids) and climbers (e.g., vines), as well as grasses, rushes and sedges. The number and diversity of the associated flora within a mangrove ecosystem is heavily dependent upon local contextual factors relating to environmental and ecological proprieties, and the degree of human influence on the system. The highest diversity of mangrove-associated flora is generally found furthest inland, where the cover of true mangrove species is less dense, allowing other species to become established. In many cases, the diversity of mangrove-associated flora within a mangrove ecosystem increases with disturbance, as this creates space for mangrove-associated and salt-tolerant species of herbs, shrubs and climbers to establish. The establishment of invasive, non-mangrove species of flora negatively impacts true mangrove species and the mangrove-associated faunal community due to increased competition for space and nutrients. This can adversely affect mangrove food web structures and the societal benefits derived from mangrove ecosystems, including fisheries and storm surge protection.



Analysis

Based on the IUCN Red List, 203 species of plants were found to be associated with mangrove forests. Of these, 75 species belong to comprehensively assessed groups with the necessary spatial and other information to allow for analysis using the method outlined on page 14.

For these 75 species, the Asia-Pacific (Indonesia and Australia in particular) was particularly important, although several countries and territories in the Americas (most notably Panama, Brazil and Colombia) are also of high importance. In contrast, most countries and territories in Africa had relatively low values, with Madagascar and Mozambique being the exceptions due to their relatively high levels of endemism (Figure 5). A similar geographic pattern was found in relation to predicted changes in flora diversity in response to mangrove change, largely because many of the plants considered were mangrove species (Figure 6).

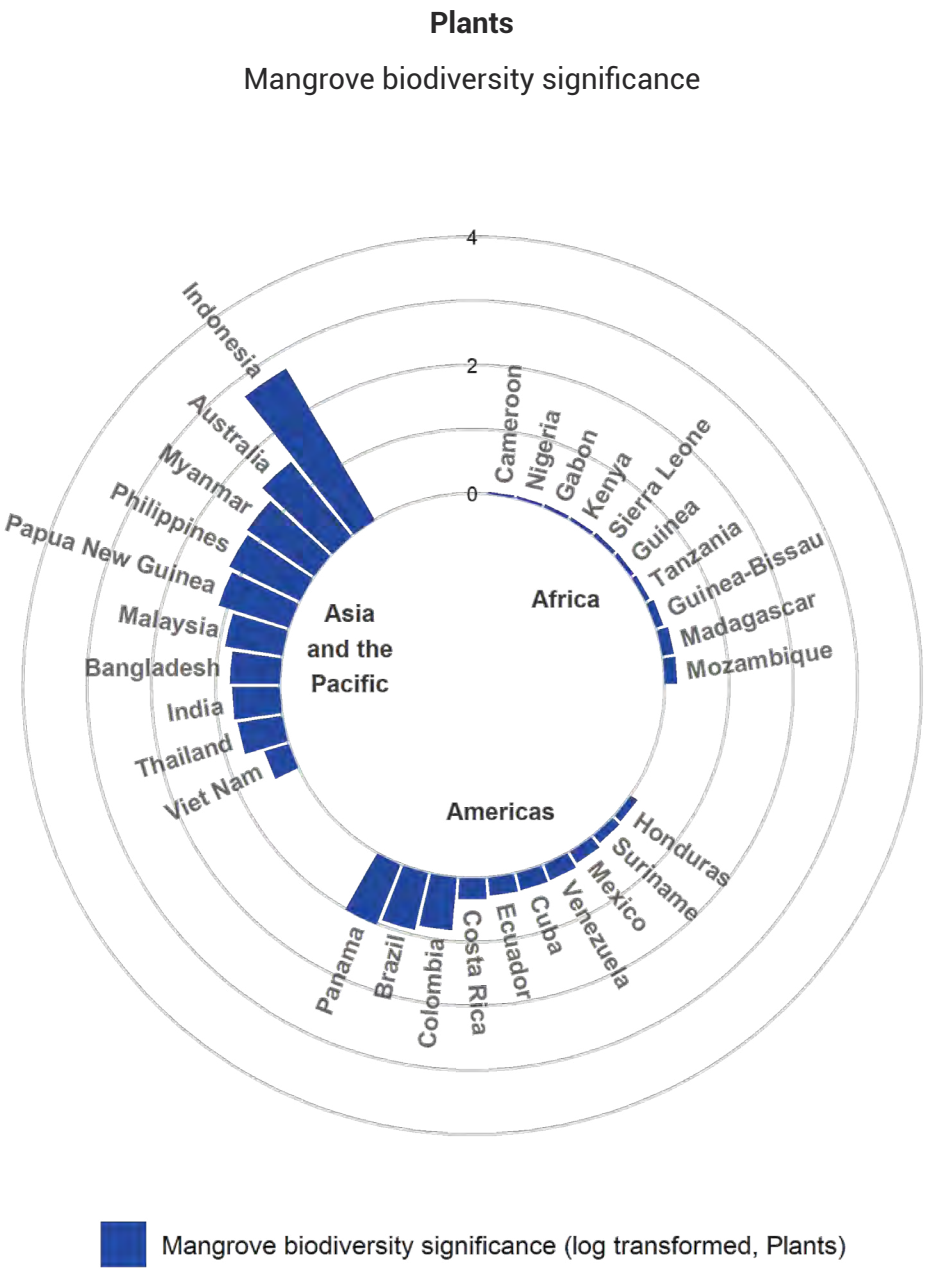


FIGURE 5: TOP 10 COUNTRIES AND TERRITORIES OF HIGHEST IMPORTANCE FOR MANGROVE-ASSOCIATED PLANTS IN EACH REGION: AFRICA, ASIA AND THE PACIFIC AND THE AMERICAS.
SOURCE: UNEP-WCMC

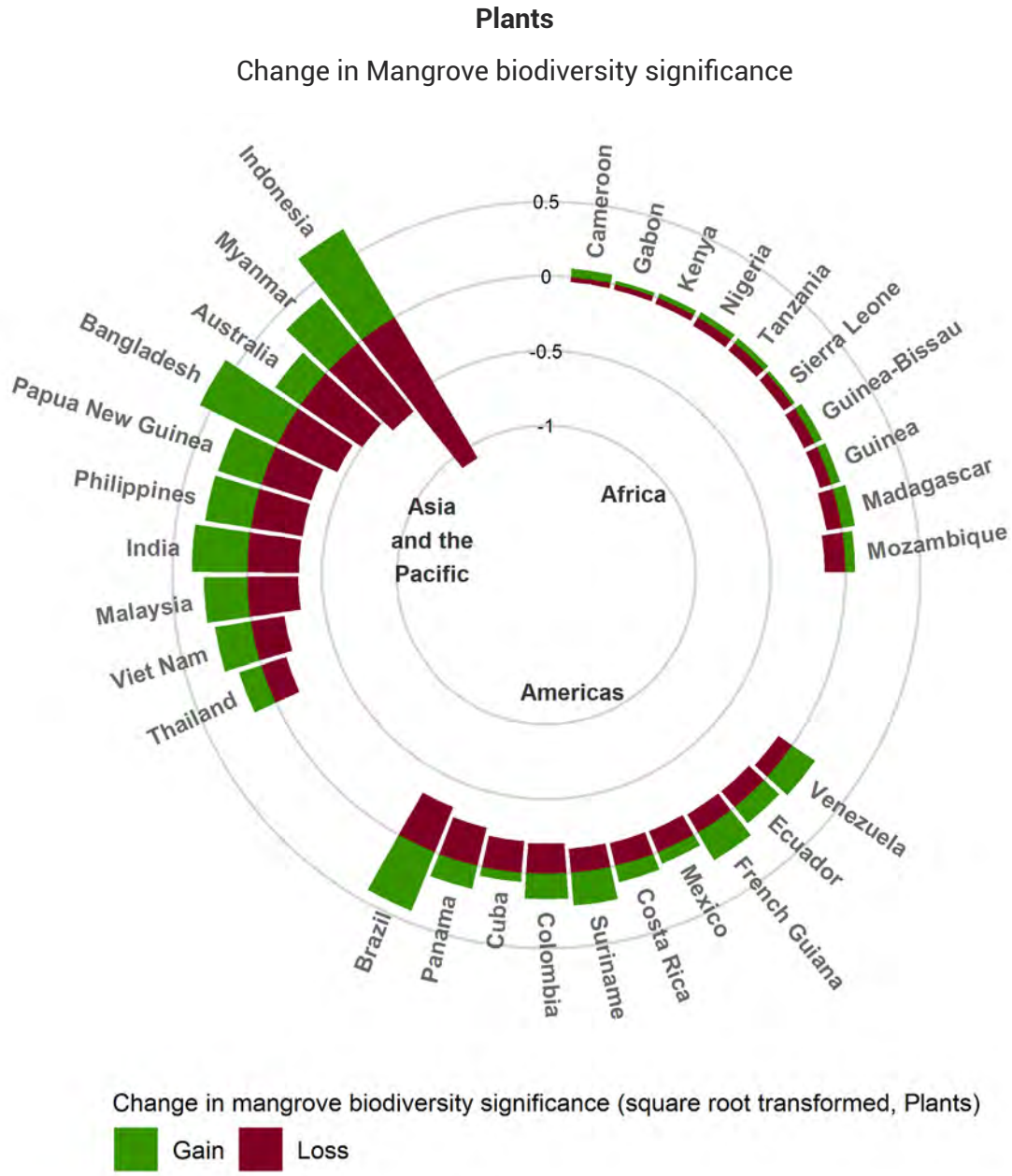


FIGURE 6: TOP 10 COUNTRIES AND TERRITORIES IN EACH REGION PREDICTED TO HAVE EXPERIENCED THE LARGEST CHANGE (GAIN AND LOSS) IN MANGROVE ASSOCIATED PLANTS BETWEEN 1996 AND 2020.
SOURCE: UNEP-WCMC

Case study 3

Mangrove flora in the Niger Delta

Nigeria has West Africa's largest concentration of mangrove forests, with a large proportion found in the Niger Delta, with the most prominent species being the red, black and white mangroves (Numbere 2018). Due to the low salinity of the soil, the delta region also contains a relatively large number of non-mangrove species, such as ferns and vines.

The delta has a high human population and extensive economic activities linked to oil, timber and fisheries industries, which have had a significant impact on the extent, health and floral diversity of the mangrove ecosystems (Duke 2016). The clearing of mangrove for fuelwood, pollution of the waterways and soils from oil extraction and urbanization are major pressures leading to degradation, opening areas of the mangrove canopy for the invasion and subsequent colonization of the forest by invasive species.

The Nipa palm is one such example: in 1901, the palm was deliberately introduced into Nigeria to stabilize the soils and sediments in the delta and remained relatively self-contained as healthy mangrove ecosystems restrict the palm to the outer fringes. However, as the mangrove ecosystem became increasingly degraded, the Nipa palm successfully invaded, colonized and outcompeted mangrove species in large areas of the delta, with a 694% increase in Nipa between 2007 and 2017 (Nwobi, Williams and Mitchard 2020). The palm has altered the hydrology and soil properties of the area, as well as increasing sedimentation rates, which have been detrimental to biodiversity in downstream regions (Numbere 2019).

Marine vertebrates

A wide range of marine vertebrates benefit from mangrove forests, including fish, turtles, whales, dolphins, porpoises, otters, seals, crocodiles, alligators and manatees. The health, diversity and abundance of marine vertebrates within a mangrove plays a fundamental role in shaping the ecosystem. Their presence influences food-web structure and stability (Nagelkerken et al. 2008); recycles nutrients within the ecosystem and transports them to adjacent waters and habitats; and they help to control pests, such as mosquitos and the associated diseases they carry (Griffin and Knight 2012).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Of all the species considered here, the use of mangroves by fish has perhaps been the most extensively researched and documented, with significant evidence demonstrating mangrove's vital role as nurseries, temporary refugia and lifelong homes, feeding grounds and breeding areas. In the Caribbean, there tend to be higher densities of juvenile fish species in mangrove ecosystems compared to seagrass beds and coral reefs, with the opposite true for the Indo-Pacific (Igulu et al. 2014). This has been attributed to differences in tidal variation (extent, duration and frequency), with Caribbean mangroves typically submerged for longer periods of time, making them more accessible to fish. At a more local level, fish abundance, diversity and taxonomic composition is influenced by factors including relative amounts of fresh and marine water; depth, width, complexity, turbidity and speed of water flow; and substrate type, amongst others. These result in differences

both between and within mangrove ecosystems (Igulu et al. 2014).

In a review of marine megafauna (Igulu et al. 2014), sharks and rays were found to be the most dominant group using mangroves (66 of the 102 species identified), including a number of threatened and severely threatened species. For example, over 70% of the elasmobranchs (cartilaginous fish, including sharks, rays, skates, and sawfish) reported from the Sundarbans mangrove system are classified as threatened (Habib et al. 2020). Perhaps the most threatened mangrove-associated shark is the Ganges shark, which after being spotted in 2006, was not seen again until 2016 at a Mumbai fish market. For some species, the loss of mangroves, irrespective of area, can have a significant impact on their life cycles and survival. For instance, lemon sharks are strongly linked to their exact place of birth within mangrove habitats, returning to the same location to give birth, even if other mangrove ecosystems are closer.

Analysis

Based on the IUCN Red List, 603 species of marine vertebrates are associated with mangrove ecosystems. Of these, 104 species belong to comprehensively assessed groups with the necessary spatial and other information to allow for analysis using the method outlined on page 14.

For these 104 species, the Asia-Pacific (most notably Indonesia) and the Americas (such as Cuba, Ecuador and the USA) were particularly important. In contrast, most African countries and territories had relatively low numbers of associated species (Figure 7). Similarly, the Asia-Pacific and Americas (Indonesia, the USA, Ecuador and Cuba in particular) are predicted to have experienced highest changes (gain and loss) in mangrove-associated marine vertebrates in response to mangrove change, with fewer changes predicted in Africa (Figure 8).

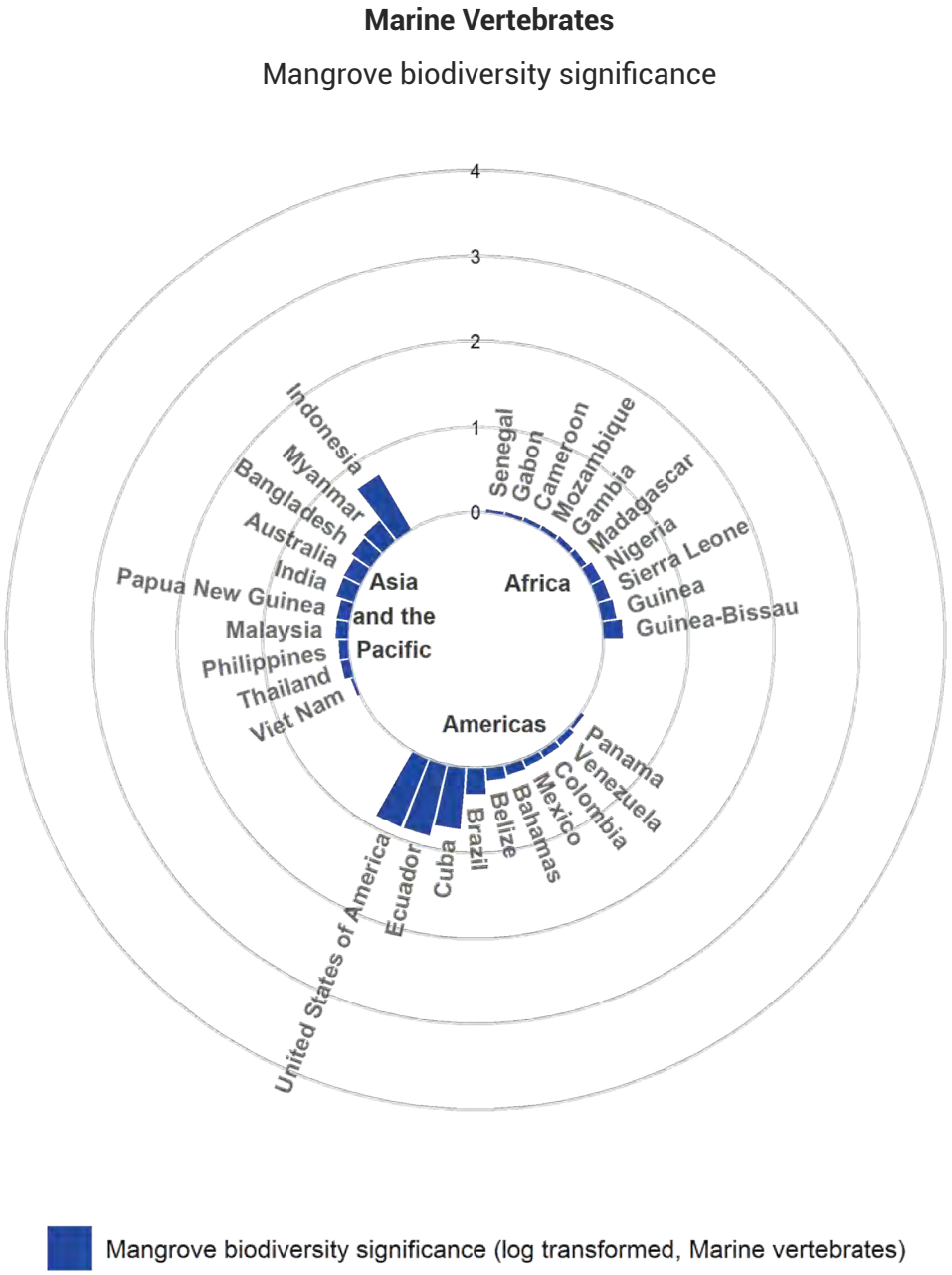

FIGURE 7: TOP 10 COUNTRIES OF HIGHEST IMPORTANCE FOR MANGROVE ASSOCIATED MARINE VERTEBRATE SPECIES IN EACH REGION: AFRICA, ASIA AND THE PACIFIC AND THE AMERICAS
SOURCE: UNEP-WCMC

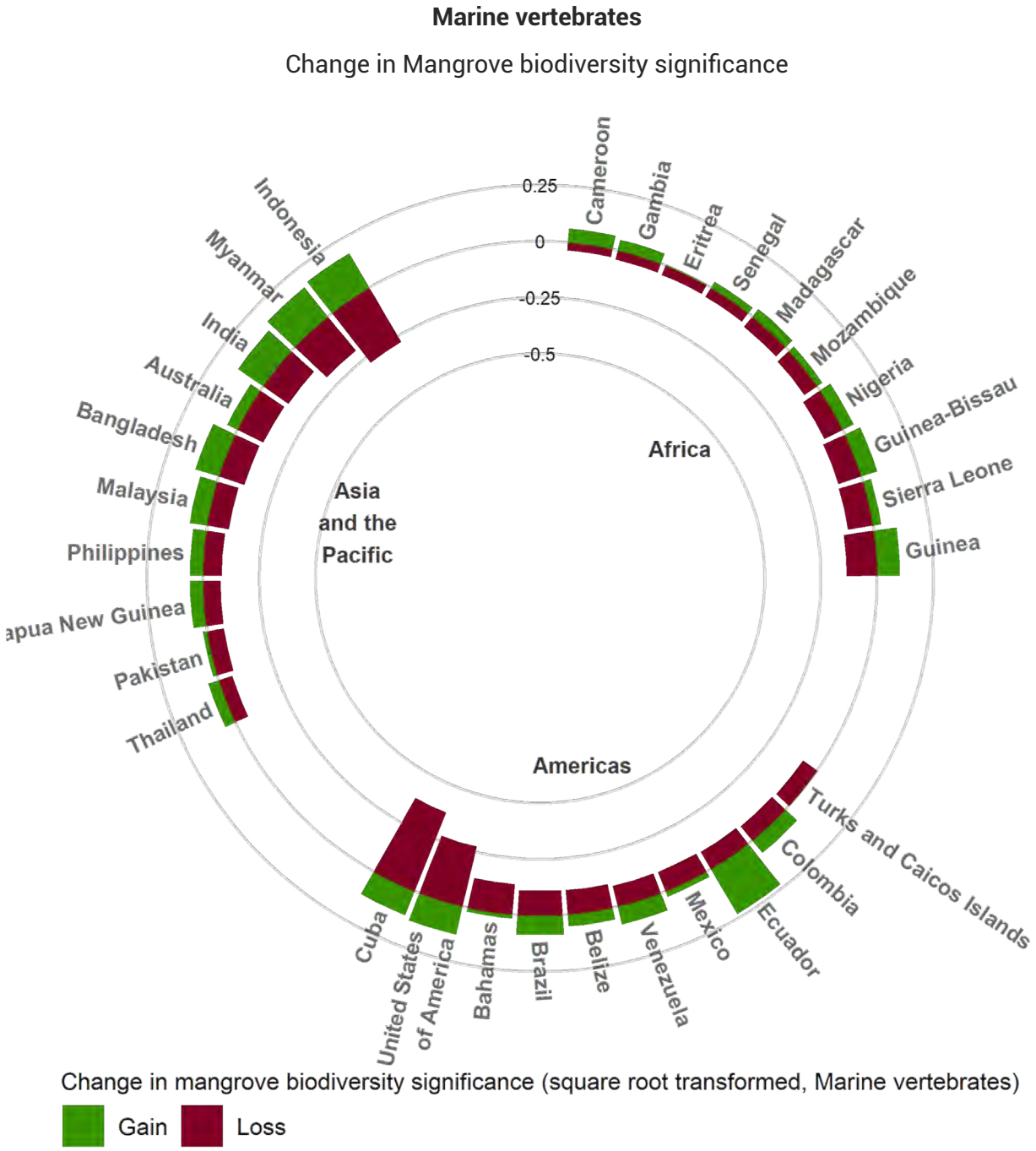

FIGURE 8: TOP 10 COUNTRIES AND TERRITORIES IN EACH REGION PREDICTED TO HAVE EXPERIENCED THE LARGEST CHANGE (GAIN AND LOSS) IN MANGROVE ASSOCIATED MARINE VERETBRATES BETWEEN 1996 AND 2020. **SOURCE:** UNEP-WCMC

Case study 4

Case study: **Marine vertebrates in Myanmar**

Myanmar has the third largest area of mangroves in Southeast Asia and the eighth largest in the world. The mangrove systems of Myanmar are of high conservation importance, containing remarkable diversity. For instance, within the Myeik Archipelago, 495 species of fish have been identified, from 62 different families(Howard 2018). However, the diversity of fish species in the country is poorly documented, with new species continuously being discovered, including the discovery of a new species of miniature fish from the carp family in 2016 (Kullander and Norén 2016) and a completely new genus and three new species of loaches in 2017 (Kottelat 2017).

Unfortunately, agriculture, aquaculture, development projects and direct exploitation have had a significant impact on the extent and health of the mangrove systems in Myanmar (Murray et al. 2020), resulting in the country experiencing the highest loss of mangroves in all South East Asian Countries. The expansion of rice production alone, primarily in Myanmar, accounted for more than 20% of the total mangrove change in Southeast Asia between 2000-2012 (Richards and Friess 2016).

The Ayeyarwady Delta in particular has been heavily impacted, losing over 64% of its mangrove cover between 1978 and 2011, restricting species that are dependent on mangrove ecosystems to small isolated areas (Richards and Friess 2016). The delta is of global significance for mangroves and contains the Meinmahla Kyun Wildlife Sanctuary, a Ramsar and ASEAN Heritage Park containing one of the largest remaining mangrove areas in the delta. The site supports a number of globally threatened marine vertebrates such as the critically endangered hawksbill turtle, the threatened green turtle and the vulnerable Pacific Ridley turtle, relatively large populations of the Ayeyarwady dolphin and one of the few remaining populations of salt water crocodiles in the region (Richards and Friess 2016).

Birds

Birds are a prominent part of most mangrove ecosystems, with the forest providing rich feeding grounds and safe nesting and breeding places. They are used by a wide range of species for a range of purposes, lengths of time and with varying degrees of dependency.

The highest diversity of mangrove-associated bird species is found in South East Asia and Australia, with considerable variability in space and time (Nagelkerken et al. 2008). For some birds, a mangrove forest presents a welcome opportunity to feed and rest, but the survival of the species is not dependent on mangroves, whilst for others, mangroves are vital for their survival (referred to as "mangrove dependent"). For example, in an assessment of mangrove use by threatened species in the Waikato region of New Zealand, the White Heron was observed using mangrove forests as well as a wide range of other coastal and freshwater habitats, and so is considered to be "non-dependent" (Boffa Miskell 2017). In contrast the Banded Rail, which is threatened due to a loss of suitable habitat and pressures from invasive species, is "dependent" on mangroves for its survival. There are of course several species whose dependency on mangroves lies in between these two examples, such as the Caspian tern, which is considered "moderately dependent" (Boffa Miskell 2017).

There appears to be relatively few mangrove-dependent bird species globally. Within north-western Australia for example, of the 104 species found in mangroves, only 16 are considered "dependent" and it is estimated that there are no mangrove-dependent African bird species (Nagelkerken et al. 2008).

Mangrove forests can hold significant numbers of individuals, especially migratory species who use mangroves as areas to overwinter, to feed before long migrations, or as stepping-stones to their destination. For example, the European Reed Warbler is a common winter visitor in West African mangrove forests, with population estimates in the region of 4-6 million individuals, accounting for 30-50% of the European population (Zwarts et al. 2014).

For some bird species, their distribution within the forest is linked to the distribution of specific mangrove species. For instance, in the Australian tropics, the Mangrove Gerygone spends over 80% of its time in the forest, whilst other species such as the Red-headed Honeyeater are more opportunistic, moving between flora zones, for example, to feed on nectar during the flowering period (Zwarts et al. 2014). In general, the highest levels of bird diversity are found further inland at the back of the mangrove forest, where mangroves form a matrix with other habitat types.

Analysis

Based on the IUCN Red List, 1,079 species of birds are associated with mangrove ecosystems. Of these, 1,075 species belong to comprehensively assessed groups with the necessary spatial and other information to allow for analysis using the method outlined on page 16.

For these 1,075 species, the Asia-Pacific (Indonesia and Australia in particular) was found to be particularly important, although several countries in the Americas and Africa (most notably Brazil, Mexico, Ecuador and Madagascar) were also of high importance (Figure 9). Based on the IUCN range data, and the assumption that an increase in mangrove area results in an increase in mangrove-associated bird species, Ecuador shows a large increase in biodiversity significance for mangrove-associated birds from 1996-2020 (Figure 10). This could be linked to the increases in mangrove area in and around the Manglares Churute Reserve, a 50,000-hectare region which is 67% mangrove forest and contains 16 globally threatened species, 28 endemic species and 26 species restricted to the Equatorial Pacific Coast (Alava et al. 2007).

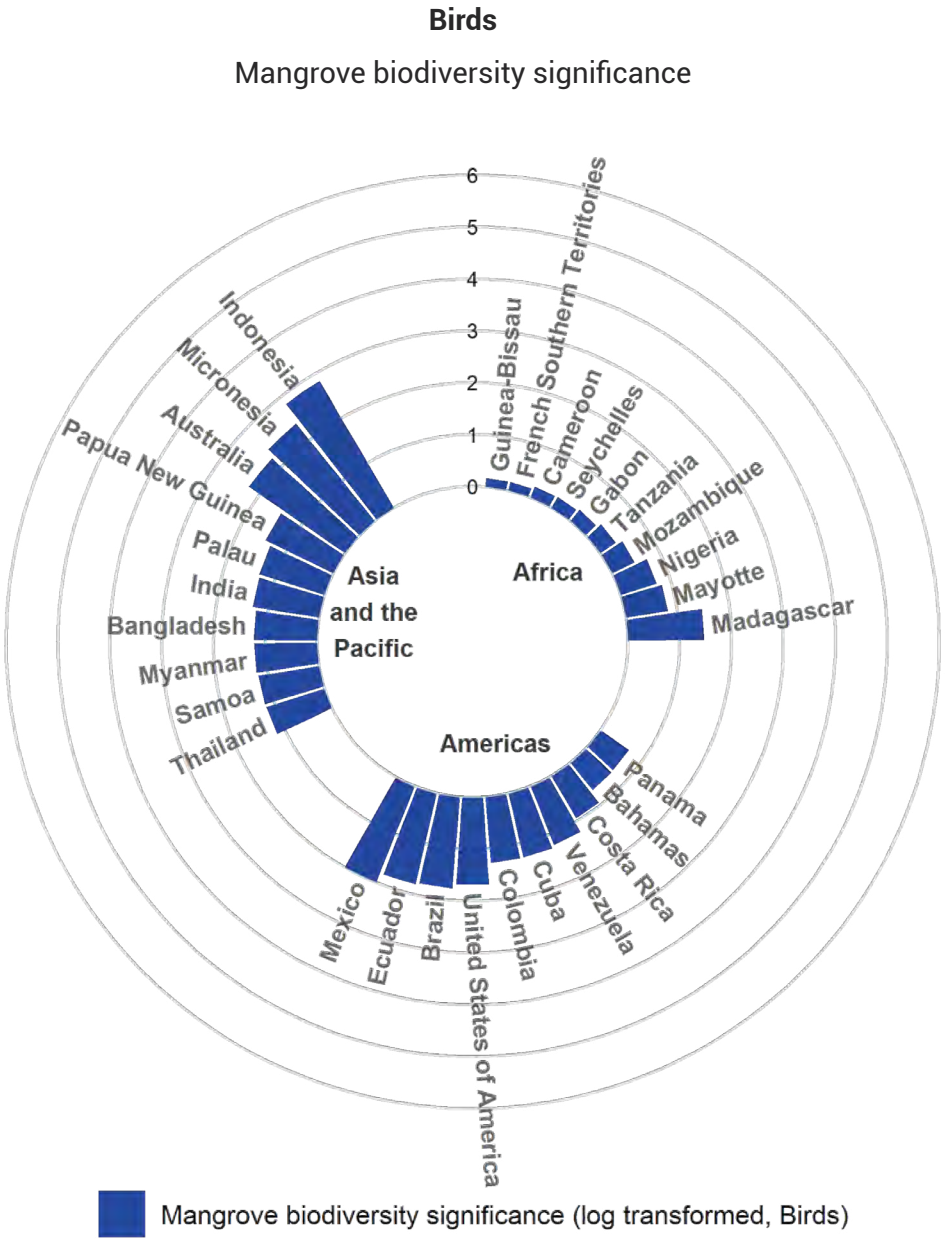

FIGURE 9: TOP 10 COUNTRIES AND TERRITORIES OF HIGHEST IMPORTANCE FOR MANGROVE-ASSOCIATED BIRD SPECIES IN EACH REGION: AFRICA, ASIA AND THE PACIFIC, AND THE AMERICAS.
SOURCE: UNEP-WCMC

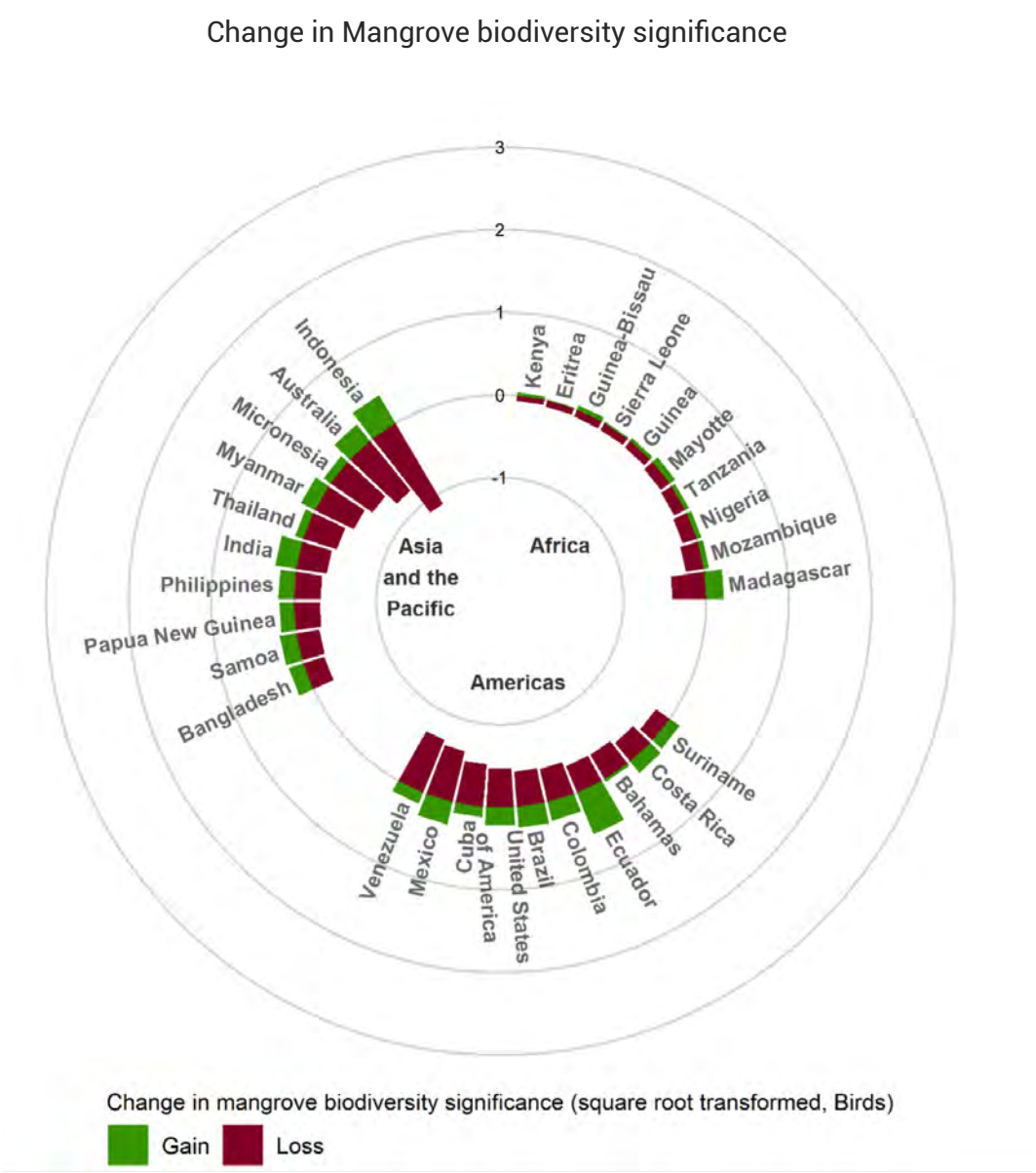

FIGURE 10: TOP 10 COUNTRIES AND TERRITORIES IN EACH REGION PREDICTED TO HAVE EXPERIENCED THE LARGEST CHANGE (GAIN AND LOSS) IN MANGROVE ASSOCIATED BIRDS BETWEEN 1996 AND 2020.
SOURCE: UNEP-WCMC

Case study 5

Bird dependence on mangroves in Indonesia

Indonesia contains a significant proportion the world's mangrove forests and has experienced, and continues to experience, considerable mangrove loss. The archipelago is a hotspot for biodiversity: 1,723 bird species have been recorded, with coastal habitats being the principal home for 106 species. An estimated 41 of these species are directly threatened by habitat modification and 24 by climate change and severe weather events (BirdLife Data Zone).

The mangroves of Indonesia are a key stopover site for many migratory shorebirds along the East Asian–Australasian Flyway, with thousands of birds recorded in the wetlands of the Deli Serdang district in North Sumatra(Putra, Perwitasari-Farajallah and Mulyani 2017). This region has experienced large-scale conversion of mangrove forests into oil palm plantations, rice fields and aquaculture, resulting in a decrease in the number of migratory shorebirds (Putra, Perwitasari-Farajallah and Mulyani 2017). Indonesia, among other countries, is yet to issue a specific regulation to conserve migratory birds, although some species are protected by a regulation on flora and fauna preservation (Gov. Reg. PP_7_1999 Preserving Flora and Fauna Species (flevin.com)).

Birds are a vital component of mangrove ecosystems, and their loss has widespread impacts on the health, productivity and resilience of the system as a whole and the numerous species, including people, who depend on it. For example, birds control the population of mangrove-associated pests such as caterpillars, beetles, bugs, and aphids that may damage plants and strip trees of their leaves. Wading birds control the numbers of fish, amphibians, reptiles and invertebrates, helping to keep the system in balance and prevent overpopulation of any one species. They also transfer pollen between flowering trees and are a source of food for animals such as snakes, eagles and falcons.

Terrestrial vertebrates

While the importance of mangroves for marine species has long been understood and documented, their importance to terrestrial mammals is also increasingly being recognized. A recent study identified 464 terrestrial vertebrate species reported to occur in mangrove forests (320 mammals, 118 reptiles and 26 amphibians) including frogs, turtles, lizards, snakes, bats, monkeys, sloths, tigers and rodents(Rog, Clarke and Cook 2017). The highest diversity was found in Asia, northern Australia, West Africa and Central America and the lowest diversity on the east coast of Africa, southern Australia, New Zealand, the Middle East, Brazil and small island developing states. As human activities degrade terrestrial systems, forcing species to shift their location, more terrestrial vertebrates have been recorded using mangrove systems(Rog, Clarke and Cook 2017).

One reason for the underappreciation of the importance of mangroves to terrestrial vertebrates is that most species are 'facultative users', meaning that they use a variety of habitats for different purposes. For instances, they use mangroves as important places to feed, reproduce, avoid predators and shelter from extreme weather events or human activities, and as corridors to move between areas (Rog, Clarke and Cook 2017).

The relationship between mangroves and terrestrial vertebrates is multi-directional, as mangroves also benefit from the presence of terrestrial vertebrates. For example, in a study of nutrient levels in two sites in Australia, higher nutrients were found in areas where bats roost and where kangaroos take shelter. This transport of nutrients is important, as mangroves are often nutrient limited, in fact growth rates of mangroves within the bat roost were nearly six times higher than trees outside, highlighting the important role of terrestrial vertebrates in supporting tree growth, productivity and the wider ecosystem (Loucks et al. 2009).


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Analysis

Based on the IUCN Red List, 376 species of terrestrial vertebrates are associated with mangrove ecosystems. Of these, 243 species belong to comprehensively assessed groups with the necessary spatial and other information to allow for analysis using the method outlined on page 16.

For these 243 species, the Asia-Pacific (in particular, Micronesia, Indonesia and Australia) was found to be of considerable importance, although several countries in the Americas and Africa are also important (including Mexico, Cuba and the Seychelles) (Figure 11). The Asia-Pacific (Indonesia and Australia in particular) and the Americas (Mexico and Cuba) are predicted to have experienced highest changes (gain and loss) in mangrove-associated terrestrial vertebrates, with much less change predicted for Africa (Figure 12).

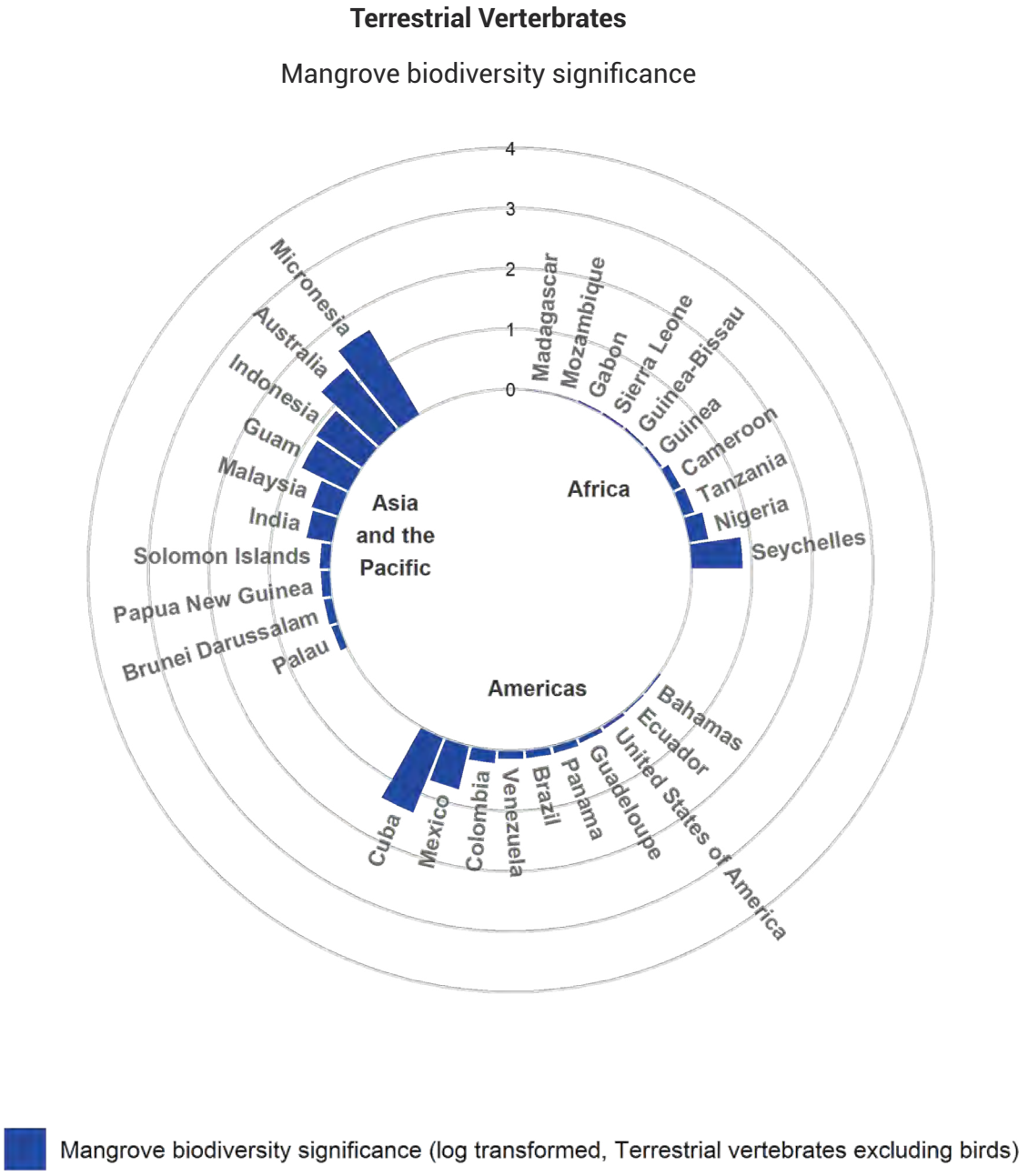

FIGURE 11: TOP 10 COUNTRIES OF HIGHEST IMPORTANCE FOR MANGROVE-ASSOCIATED TERRESTRIAL VERTEBRATES IN EACH REGION: AFRICA, ASIA AND THE PACIFIC, AND THE AMERICAS
SOURCE: UNEP-WCMC

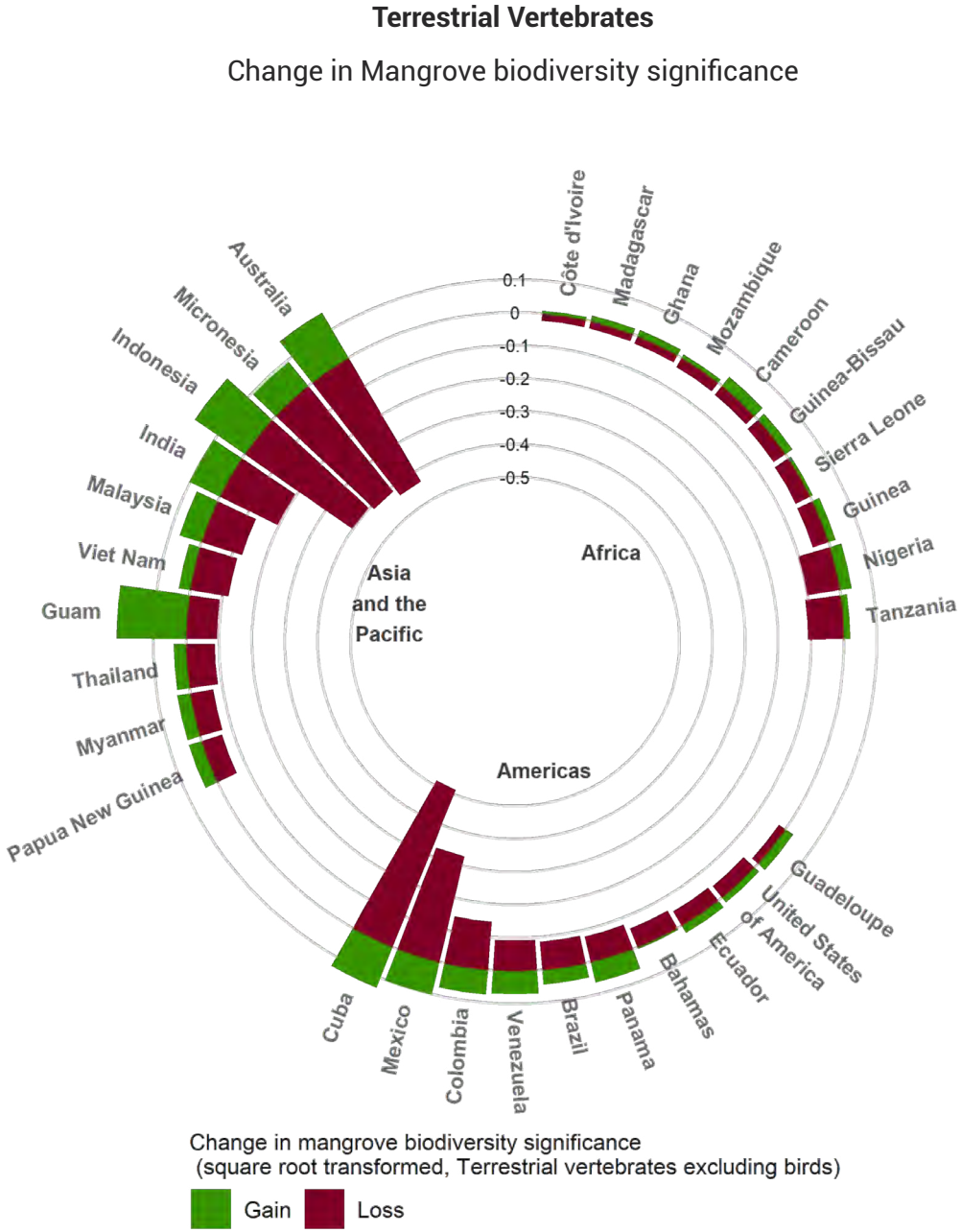

FIGURE 12: TOP 10 COUNTRIES AND TERRITORIES IN EACH REGION PREDICTED TO HAVE EXPERIENCED THE LARGEST CHANGE (GAIN AND LOSS) IN MANGROVE-ASSOCIATED TERRESTRIAL VERTEBRATE SPECIES BETWEEN 1996 AND 2020. **SOURCE**: UNEP-WCMC

Case study 6

Marine associated terrestrial vertebrates in Cuba

The Cuban archipelago is the principal centre of evolution and speciation in the Antilles and is one of the most important islands worldwide for biodiversity, containing very high levels of endemism (Goulart et al. 2018) Mangroves represent 27% of the country's forested surface and 72% of its coasts, making mangrove coverage in Cuba the highest amongst the Caribbean island countries and eleventh worldwide.

However, in many areas, mangroves have been removed to provide space for agriculture, to develop urban areas and to construct roads. The existing areas have become degraded due to overgrazing, wood extraction and pollution. This often stems from poor land-use planning for agriculture, tourism, industry, forestry and urban development, which is approached at a sectoral level with little consideration of the impacts of economic sectors or the environment (Wege et al. 2010).

The region has experienced one of the highest rates of extinction globally over the past 500 years, with Caribbean mammals representing 38% of all known modern-era extinctions (Borroto-Páez and Mancina 2017). Modern day Cuba contains relatively high levels of endemic mammals with small ranges, and despite the fact that almost all species of Cuban mammals have a portion of their habitat within protected areas, invasive species, habitat deterioration, and hunting are threatening their long-term survival (Loucks et al. 2009).

One such group of mammals are the Hutias - moderately large (30cm long) rodents that inhabit the Caribbean Islands. Twenty species of Hutia have been identified but at least one-third of these species are now extinct. Cuba is home to 10 endemic species of Hutia, representing 77% of the family, three of which are of no immediate conservation concern, one is believed to be extinct and the remaining six are facing significant threat from habitat loss, hunting and invasive rats (Loucks et al. 2009). The area of habitat that is suitable for Hutias has decreased significantly and now mangroves provide a vital refuge for many of these species (Turvey et al. 2017).

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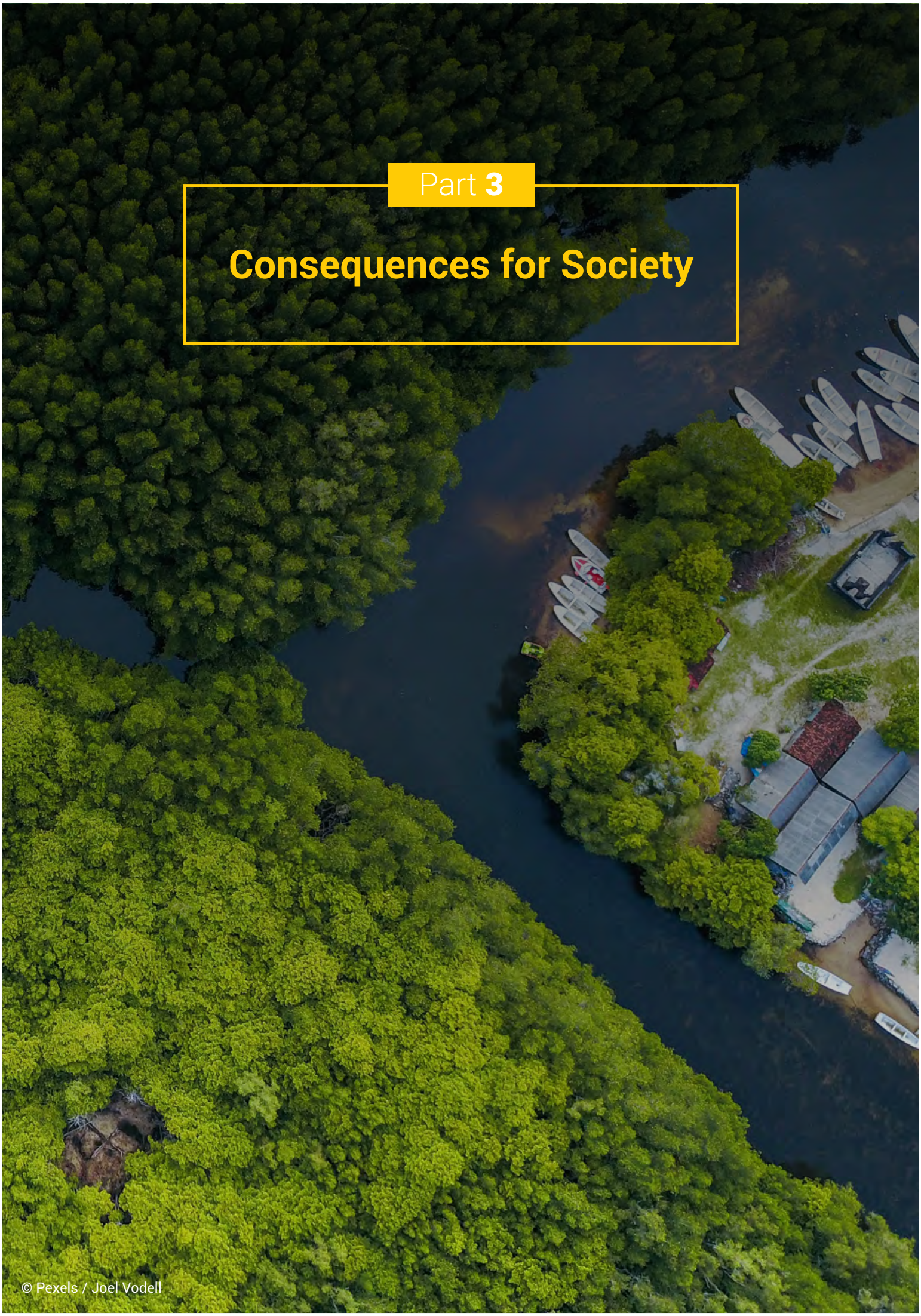


Part **3**

Consequences for Society

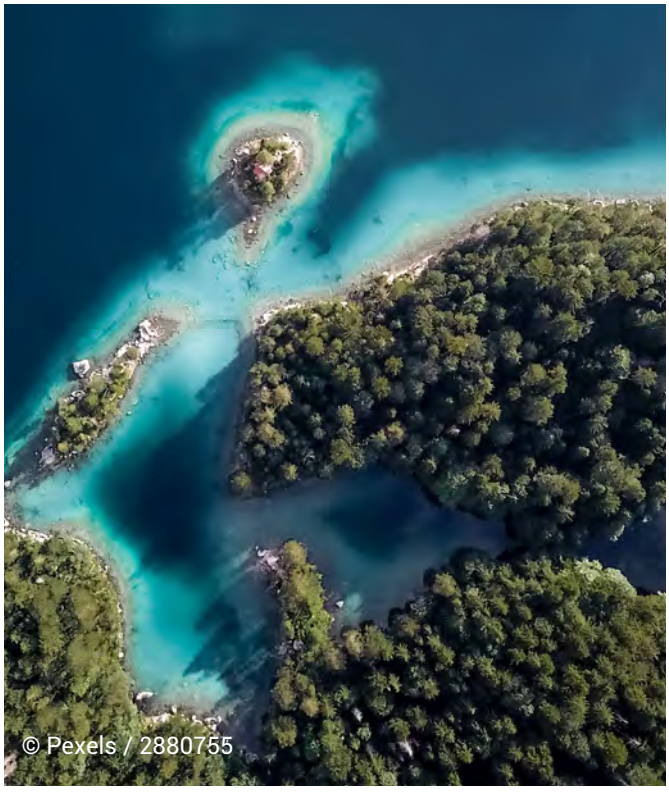
What does this mean for society?

Mangroves are not only fundamentally important for numerous marine and terrestrial species, but they are also vital to society. Mangroves help feed and shelter humans, support coastal economies and communities, help mitigate climate change by storing enormous amounts of carbon in their soil, reduce the impact of storms and coastal erosion, and provide medicines and spaces to improve mental wellbeing (UNEP-WCMC 2014). Consequently, the loss of mangroves can have significant and long-lasting impacts on the health, safety and prosperity of millions of people, as well as hampering the fight against, and ability to deal with, climate change.

At a local level, the loss of mangroves and their associated services will disproportionately impact indigenous and low-income communities that rely on a subsistence-based economy, with mangrove-dependent communities reporting negative trends in the benefits they receive (Islam et al. 2018). It will also widen gender inequalities in many forms due to gender differences in mangrove-based livelihood activities and access to resources for instance (Nguyen and Dang 2018), waterlogging and loss of mangrove forests means that women have to travel further distances to find potable water for domestic use, forage for fuel, fodder, and other forest products (UN Enviroment 2019). In addition, the loss and degradation of mangroves has the potential to impact humanity at a global level, with the clearance of mangroves releasing an estimated 24 million tonnes of CO2 per year (equivalent to the annual emissions of Myanmar) and reducing their future capacity to store carbon and mitigate greenhouse gas emissions (Hamilton and Friess 2018).

The relationship between mangroves and the benefits provided to people is poorly understood. Consequently, it is not possible to accurately determine the precise impact of mangrove loss and degradation on people, but it is safe to say that they are currently undervalued and underreported. Putting an economic value on mangrove forests provides decision-makers with the data they need to directly compare the value of mangroves with alternative uses of that land, e.g., an aquaculture site. However, our inadequate knowledge linking changes in mangrove extent and associated flora and fauna to the production of valuable goods and services at a global scale, makes it difficult to arrive at economic valuations with high degrees of confidence. Furthermore, whilst there are benefits of this approach, purely calculating the economic value of mangrove ecosystems underestimates their importance to people and society.

This analysis considers the impact of mangrove change on two services that represent very different benefits – the potential consequences for global carbon stocks and the potential impact on the fishers who use and depend upon mangroves – in relative rather than economic terms. Determining the role that mangroves play in delivering these services and the implications of their loss on people and the climate is gaining traction as an active area of research. While "perfect" data is unobtainable, scientists currently have no global estimates of the scale of the likely impact which undoubtedly has implications for how mangroves are perceived in decision-making.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Potential implications for carbon storage in mangroves

Effective climate action requires a reduction in emissions and the long-term storage of carbon. Mangroves capture and store large amounts of carbon from the land, sea and sky. While the productivity and carbon production of mangroves is equivalent to tropical humid evergreen forests, mangrove carbon stocks, mostly found in the soil, are considerably greater (Borroto-Páez and Mancina 2017). If mangrove habitats are left undisturbed, significant quantities of carbon can be stored for centuries, making them an important element in the fight against climate change. However, the loss and degradation of mangroves results in the emission of significant amounts of greenhouse gases into the atmosphere, turning mangrove ecosystems from a carbon sink into a carbon source.

Method: **Quantifying change in carbon stocks**

Approximate changes in mangrove carbon stock were estimated between 1996 and 2020 Changes in mangrove carbon stock were estimated following a modification of a previously published method (Richards, Thompson and Wijedasa 2020). From this dataset all pixels of net mangrove cover gain or loss between the start and end dates of each epoch were identified. For each pixel of change we also extracted the last year of mangrove persistence before loss, and the first year of mangrove gain recorded by GMW. Data on carbon stocks within mature mangroves at each location were extracted from global maps of biomass carbon(Hutchison et al. 2014) and carbon in mangrove soils (Sanderman et al. 2018). After mangrove loss or gain events, the stock of carbon either degrades or accumulates slowly over time (Richards, Thompson and Wijedasa 2020). We assumed that these trajectories of change followed the fitted relationships shown in Supplementary Figure 3a:c of the reference publication (Richards, Thompson and Wijedasa 2020). The reference year for which net changes in mangrove carbon stock were estimated was 2020.

Several important caveats to this approach should be understood when interpreting the following results:

- The results presented are indicative, highlighting general relative trends and patterns rather than absolute changes in carbon that accurately reflect local conditions.
- The relationship between carbon storage and mangrove loss and degradation is poorly understood
- Our knowledge of carbon stocks is spatially biased and incomplete

METHOD BOX 4: Quantifying change in carbon stocks

Change in carbon stocks

Between 1996 and 2020 there was a global net reduction in mangrove associated carbon stocks of 139 megatonnes (Mt), with 1 megatonne equalling 1,000,000 tonnes. To put this in perspective, this is over 4 times the CO2 produced globally in 2018 from the burning of fossil fuels and the manufacture of cement. The highest net change (the difference between gain and loss between 1996 and 2020) occurred in the Asia-Pacific, followed by the Americas and Africa (Figure 13 and Table 2). Regarding countries and territories, Indonesia, Australia, Mexico and Cuba had the biggest net losses, whilst Suriname Bangladesh and Brazil had the largest net gains over the period; however, the predicated gains are relatively small in comparison to the predicted net losses (Figure 14). A full breakdown per country and territory is available in Annex 1.

An estimated 308 Mt of carbon was lost between 1996 and 2020, predominately in the Asia Pacific, the Americas and Africa (Table 2), with Indonesia experiencing the greatest losses, followed by Australia, Mexico and Cuba (Figure 16). The greatest gain in mangroves associated carbon stock also occurred in the Asia Pacific, followed by the Americas and Africa (Table 2), with Indonesia, Brazil, Australia and the Philippines having the largest gains (Figure 15). A full breakdown per country and territory is available in Annex 1.

TABLE 2:

REGIONAL AND GLOBAL CHANGE IN MEGATONNES OF CARBON STOCK BETWEEN 1996 AND 2020

	Since 1996			
	Year	**Gain**	**Loss**	**Net Change**
Africa	2020	21.0	-37.7	-16.7
Americas	2020	61.7	-86.3	-24.7
Asia - Pacific	2020	86.1	-184.2	-98.1
Global	2020	168.8	-308.3	-139.4

TABLE 2: REGIONAL AND GLOBAL CHANGE IN MEGATONNES OF CARBON STOCK BETWEEN 1996 AND 2020.
SOURCE: UNEP-WCMC / DANIEL RICHARDS pers comms

It is important to put these numbers into a wider context. For example, the loss of carbon from mangrove systems between 1996 and 2016 represents only an estimated 0.6% of the total emissions from land use change, and less than 0.1% of the total global CO2 emissions (Worthington and Spalding 2018). This low percentage firstly reflects the fact that while mangroves are efficient at storing carbon, they have a relatively small global area. Second, the rate of net loss of mangrove forest has been relatively low, in comparison with other ecosystems (Worthington and Spalding 2018).

The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. Final status of the Abyei area is not yet determined.

FIGURE 13: SPATIAL VARIATION IN NET CHANGES IN MANGROVE CARBON STOCK BETWEEN 1996 AND 2020.
SOURCE: UNEP-WCMC / DANIEL RICHARDS pers comms

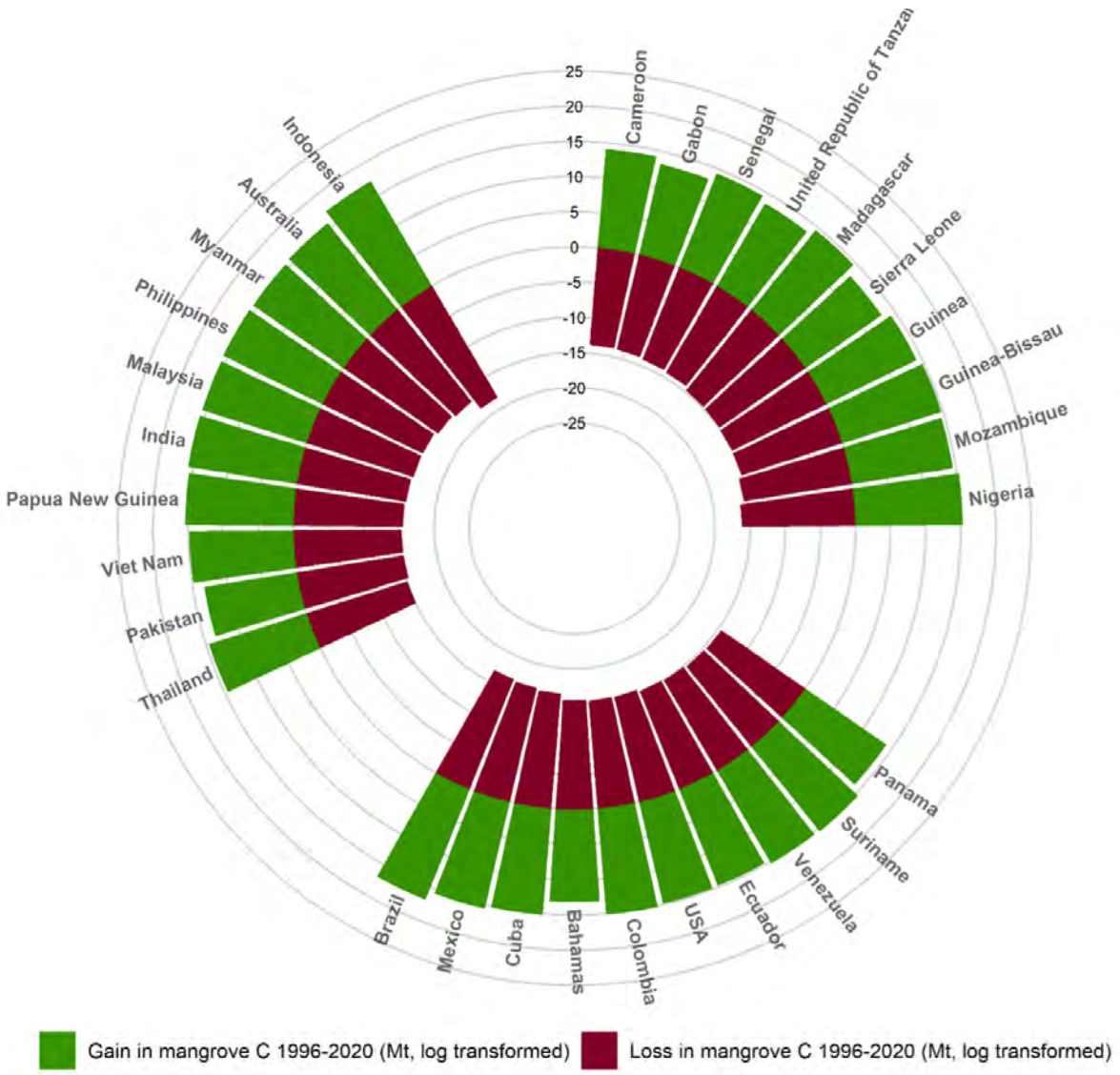

FIGURE 14: TOP 10 COUNTRIES AND TERRITORIES IN EACH REGION PREDICTED TO HAVE EXPERIENCED THE GREATEST CHANGES IN MANGROVE CARBON BETWEEN 1996 AND 2020
SOURCE: UNEP-WCMC / DANIEL RICHARDS pers comms

Assessing carbon change on the ground

Global assessments of the net change in carbon stocks following the loss or gain of mangrove forests offer a valuable overview of relative spatial and temporal patterns and provide a means of understanding the scale of the issue. However, the reality on the ground is often more complex. Variation arises for a range of reasons, including the environmental setting (e.g., the balance of fresh vs salt water; the type and water content of the sediment, light levels and temperature); ecological profile (e.g., the species and age of the forest) and the type, magnitude and duration of anthropogenic pressures (e.g., if the system is deforested, degraded or converted).

Broadly speaking, when assessing carbon stocks in mangrove systems, a distinction is made between above and below ground stocks – greater quantities of carbon are stored below ground than above (Borroto-Páez and Mancina 2017). Importantly, different types of land use change and human disturbances impact above and below ground carbon stocks in different ways, resulting in variability in the amount of carbon lost. For example, the removal of wood for fuelwood, charcoal and construction principally impacts the above ground stock, while the conversion of mangrove forests for aquaculture and salt production requires the surface soils to be excavated to depths ranging from 0.5m to 2.5m, significantly impacting the larger, below ground carbon pool (Sasmito et al. 2019).

In a review of 37 studies documenting changes in relation to four common land use changes (mangroves to aquaculture, pasture, rice fields and the removal of trees) it was found that on average human interventions resulted in an 82% (± 35% uncertainty) loss of carbon stock (Sasmito et al. 2019). The conversion of mangroves to aquaculture sites resulted in the largest total carbon losses (83% ± 37%), with the conversion of mangroves to rice fields having the highest impact on soil carbon stocks, followed by aquaculture and pastures, with no significant changes in below ground carbon stock linked to the removal of trees (Sasmito et al. 2019). However, there is considerable uncertainty in such estimates, arising from limited, but improving estimates and understanding of:

- The amount of carbon stored above and below ground;
- How and why this varies within and between mangrove forests;
- The vulnerability of specific carbon stocks to land use changes; and
- The amount of carbon released when they are disturbed.

There is an urgent need to fill these knowledge gaps to manage and conserve mangroves in a climate-smart and sensitive way.

Potential implications for mangrove associated fishers

The economic importance of mangrove-associated fisheries has been extensively demonstrated throughout the world for a variety of different fisheries. This includes annual estimates of US $106 per hector of mangrove for mixed fisheries containing finfish, molluscs and crustaceans; a crab fishery in Micronesia valued at US $423 per hector of mangrove; offshore fisheries in Indonesia and Mexico valued at 24.3 and 1394 US $ per hector of mangrove respectively and “prize game fish” in Belize valued at US $56.5 million and US $141 million to the Bahamas (Hamilton and Friess 2018).

Looking beyond economic valuations, the more mangrove-associated fisheries are studied, the greater the appreciation of their importance and complexity and the more we understand the socio-economic consequences of their degradation and loss. For example, within the Peam Krasaop Fishing Community, in Cambodia across the households studied eight different fishing-related activities were documented, including, gathering crabs by hand, fishing by boat and mariculture (the cultivation of fish or other marine life for food). Mangrove-associated fisheries were estimated to account for 90% of the total fishery landings and 85% of gross income in the village (Seary et al. 2021).

Importantly, fishery-related activities were found to be partitioned by wealth and gender (Seary et al. 2021), meaning that the loss and degradation of mangroves would disproportionately impact community members and increase inequalities. In fishing and aquaculture activities, men are usually the main fishing participants while women play secondary roles such as fish smoking and selling. However, in the case of loss of such livelihood, men often leave the village to find seasonal work elsewhere whereas women stay behind with the additional burden to provide for

the family and also increased risk of sexual harassment due to absence of their partners (UN Enviroment 2019).A recent study by zu Ermgassen et al. (zu Ermgassen et al. 2020) developed a global model of fishing intensity (as summarised below) which was used to predict the number of mangrove associated small-scale fishers per country and territory. (Table 3).

Method: **Estimating the number of mangrove associated fishers**

A global map of fishing intensity in mangroves was developed by estimating the number of mangrove fishers based on access to mangroves, modifying fishing intensity by access to markets, and down weighting the fishing intensity in response to storminess (zu Ermgassen et al. 2020). The factors included in the model were determined through an expert led process and the availability of national or global spatial datasets. The map was developed by 1) distributing national estimates of small-scale fisher numbers along the coast in proportion to the local non-urban population density, accounting for the influence of access to markets by doubling the fisher numbers relative to local population within 3h travel time of cities with >50,000 people, 2) the proportion of small-scale fishers likely to be focussing their efforts on mangrove as opposed to alternatively available habitats (shallow shelf and coral reefs) was estimated by partitioning them between these major habitat types available with in 45km. Nearby habitats were modelled to "attract" a greater proportion of the available fishers, to account for distance decay in fishing effort. Finally, a storm index was applied, resulting in a down weighting of fishing intensity in areas with storms resulting in wave heights in excess of 2m.

There are a number of factors which influence the importance of mangrove fishing, including:

- Population changes, including local non-urban populations, the number of fishers and demand from the wider population (e.g., nearby cities).
- Consumer demand for fish products may change through time (e.g., by seasonality, cultural preference and trends)
- Market accessibility may change through time (e.g., the presence of intermediaries and infrastructure to trade beyond the local area).
- The circumstances of individual fishers may also influence the intensity at which they fish. Factors such as their experience, the quality of their gear, their fishing method and the degree to which they depend on the resource for their livelihood.
- The management of mangrove protected areas, degree of protection and level of illegal fishing will also impact fishing intensity on mangroves. The condition of mangroves may also impact whether fishers' fish on them. Degraded mangrove may harbour fewer fish and crustaceans due to low habitat quality.

An important caveat to this approach is that the relationship between fishers and mangrove extent is poorly understood and is spatially biased.

METHOD BOX 5: Estimating the number of mangrove associated fishers

From the analysis, it is estimated that mangrove associated fishing is particularly high in countries and territories in West and Central Africa, South Asia and, South and Central America, where subsistence and artisanal fishing in and around mangroves are important to coastal livelihoods (zu Ermgassen et al. 2020) (Figure 15; Table 2). The importance of mangroves to fishers and coastal communities is clear in a number of African countries and territories, where the number of mangrove small-scale fishers make up the majority of the countries and territories small-scale fishers, including in Guinea-Bissau where they are estimated to account for 96%, and in Guinea (95%), Nigeria (89%) and Gabon (87%) (Table 3).

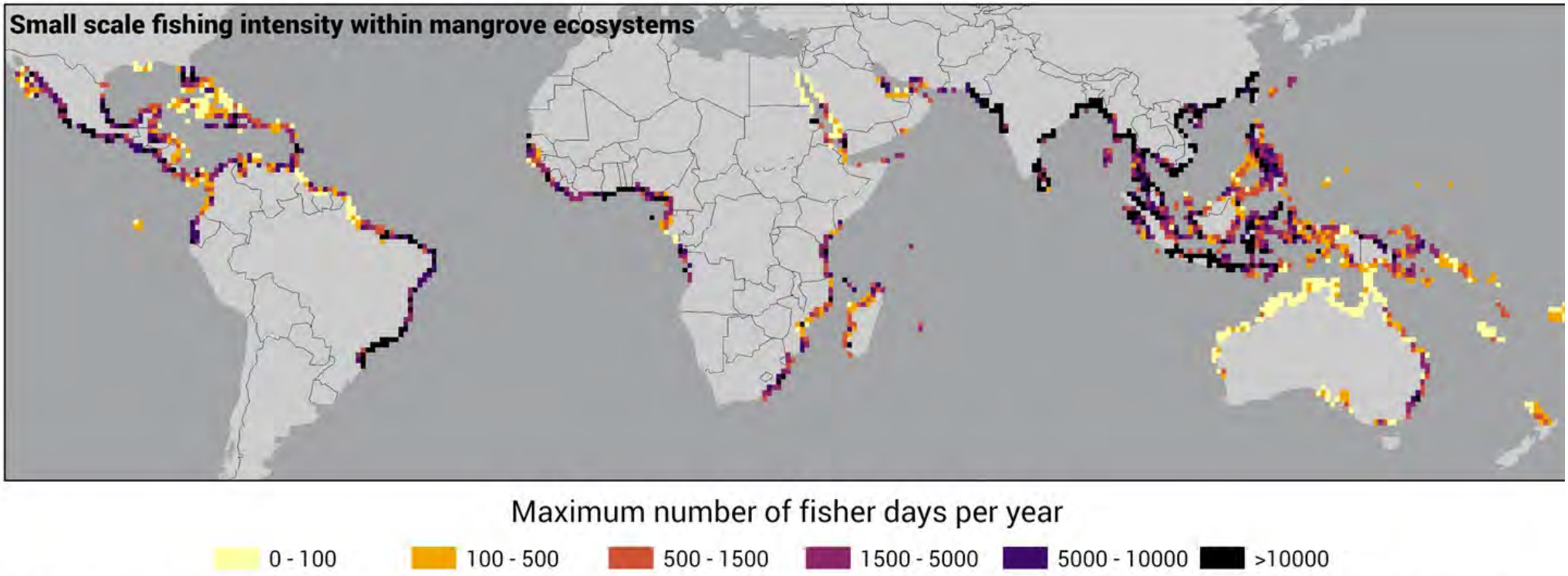

FIGURE 15: SMALL SCALE FISHING INTENSITY WITHIN MANGROVE ECOSYSTEMS. TABLE MODIFIED FROM ZU ERMGASSEN ET AL.

TABLE 3:

LEADING COUNTRIES OF SMALL FISHERS ASSOCIATED WITH MANGROVES

Country / territory	Number of small-scale fishers ('000)	Number of mangrove fishers ('000)	Small-scale fishers associated with mangroves (%)
Guinea-Bissau	6	6	96
Guinea	28	27	95
Nigeria	168	150	89
Gabon	4	4	87
Sierra Leone	35	31	87
Democratic Republic of the Congo	11	9	83
Nicaragua	16	13	83
Suriname	4	3	83
Bangladesh	352	286	82
Pakistan	100	82	82

TABLE 3: THE 10 COUNTRIES AND TERRITORIES WITH THE HIGHEST NUMBER OF SMALL-SCALE FISHERS AND THE NUMBER AND PERCENTAGE PREDICTED TO BE ASSOCIATED WITH MANGROVES- ORDERED BY THE PERCENTAGE OF MANGROVE ASSOCIATED FISHERS. TABLE ADAPTED FROM ZU ERMGASSEN ET AL. (zu Ermgassen et al. 2020)

Changes in mangrove extent have the potential to significantly impact the socio-economic wellbeing of millions of people, including by increasing resource-based conflict, increasing socio-economic inequalities and decreasing the functioning and productivity of the mangroves that remain by intensifying fishing activities. By considering both the estimates of the proportion mangrove small-scale fishers and the net change in mangrove it is possible to identify countries and territories where mangrove fisher's may have been particularly affected (Table 4).

In West Africa, small-scale fisheries and associated activities support over 5 million jobs and the decreasing extent of mangroves has been linked with reduced fish catches and increases in poverty levels (Feka and Ajonina 2011). It is therefore of potential concern that the highest proportion of small-scale fishers associated with mangroves was in Guinea-Bissau and Guinea; both of which also experienced relatively high net decreases in mangrove extent between 1996 and 2020 (Table 4).

Analyses at a national scale may of course hide the smaller scale consequences of mangrove change upon local communities. For example, whilst there has been a 0.6% net increase in mangrove extent in Bangladesh, areas within the Sundarbans have experienced significant decline in mangroves over the last three decades (Feka and Ajonina 2011), a region which has a number of small-scale fishers who are highly dependent on the mangroves. Mangrove losses have resulted in reduced fishery resources and the destruction of fish stocks. As a result of declining catches, fishers have adopted a number of strategies to cope, including, violating fisheries management

laws and regulations; placing increased responsibility on women and bartering fishery knowledge and information (Feka and Ajonina 2011).

Several countries with large proportions of small-scale fishers associated with mangroves, including French Guiana, have net gains in mangrove extent and several countries including Cambodia, Ecuador and Myanmar have shown recent gains in mangrove extent between 2016-2020, despite overall losses since 1996 (Annex 1).

The complexity of the relationship between mangrove extent, condition and fishers (Borroto-Páez and Mancina 2017) makes it almost impossible to predict the on the ground changes (positive or negative) in mangrove associated fishers following changes in mangrove extent. In reality, how, where and when people use mangroves is determined by a wide range of interlinked social, political, ecological and environmental factors including, levels of education, alternative sources of income, gender, age and socioeconomic status (Hoque Mozumder et al. 2018; Nchimbi and Lyimo 2019) as well as change in population density, demand for products and market accessibility and environmental conditions and change in mangrove extent.

Country / territory	Number of small-scale fishers ('000)	Number of mangrove fishers ('000)
Bangladesh	+0.6	82
Cambodia	-3.7	78
Ecuador	-4.5	79
El Salvador	-1.5	79
French Guiana	+7.0	81
Gabon	-1.1	87
Guinea	-4.3	95
Guinea-Bissau	-2.8	96
Honduras	-3.9	68
Myanmar	-8.7	69
Nicaragua	-2.8	83
Nigeria	-2.6	89
Pakistan	-22.8	82
Sierra Leone	-6.5	87
Suriname	+5.8	83

TABLE 4: COUNTRIES AND TERRITORIES WITH A HIGH PERCENTAGE OF SMALL-SCALE MANGROVE FISHERS AND WHERE NET CHANGE IN MANGROVE EXTENT between 1996 AND 2020 WAS RELATIVELY HIGH. NOTE: SOME COUNTRIES WITH LARGE CHANGES IN MANGROVE EXTENT DO NOT HAVE CORRESPONDING ESTIMATES FOR PROPORTIONS OF SSFS WHICH ARE MANGROVE FISHERS. **SOURCE UNEP-WCMC**

Possible outcomes may include:

- A decrease in mangrove area results in: 1) a reduction in the number of small-scale fishers; 2) no change in the number of fishers with possible consequences for the health of fish stocks and mangroves and the catch and income available to each fisher and/or 3) a diversification in the species targeted (e.g. gastropods in the Sundarbans (Hoq 2007)).

- An increase in mangrove area: 1) provides the potential for an increase in fisher numbers which is not realised in practice (e.g., due to capital costs, local or national legislation etc) or due to existing overcapacity (Pomeroy 2012); 2) increases the number of fishers in a sustainable way, resulting in increased income and food security and/or 3) creates new opportunities for diversification.

A challenge faced in responding to changes in mangrove extent and condition is the time lags before this results in changes in fisheries catch, overexploitation of the system and the outcomes of the remedial actions and policies implemented to rectify the situation. The lack of instantaneous feedback means that systems are often pushed beyond their ecological limits before those exploiting it are aware (Kettunen et al. 2010; Grizzetti et al. 2019).

Part **4**

Looking Forward

Restoring lost and degraded mangroves

If mangrove ecosystems are to be safeguarded and their associated societal benefits enhanced, more needs to be done than simply conserving what remains. The legacy of human impacts needs to be reversed by restoring lost and degraded areas.

There have been numerous projects across the world seeking to restore mangroves to create or maintain forests for use in timber and wood production, coastal protection, tourism, conservation of biodiversity, or because national law requires it as part of national economic development projects (Ellison, Felson and Friess 2020). There is considerable potential to upscale efforts and increase ambition. Over 8,000 km2 of former mangrove area lost since 1996 is considered restorable and within reach for national governments to act. Opportunities for mangrove restoration exist in every region of the world, particularly in Southeast Asia which has the largest total mangrove extent that could potentially be restored (Worthington and Spalding 2018).

The effective restoration of mangroves can increase societal wellbeing. Within the state of Gujarat in India for example, thousands of hectares of mangroves have been planted, which significantly increased catches of mangrove dependent species by artisanal and commercial fishers (Das 2017). Fisheries catch in areas with recently planted (past five to eight years) mangroves was approximately 1 kg (totalling US $ 7,00 per hectare per year) more per day per hectare than in creeks with no mangroves. However, catch levels in restored areas were only 22% of that caught within natural mangroves (Das 2017). In part this was due to how the mangroves were restored with projects planting single-species (Avicenna marina) monocultures, with little consideration for connectivity and freshwater supply (Das 2017).

For effectiveness of the restoration, it is imperative to use an equal and inclusive approach which considers the role and knowledge of local people, gender and human rights. In Mexico, an affirmative gender policy for government functions in fisheries was adopted and participatory approaches for managing coastal areas were used to improve people's livelihoods and protect the environment. This involved research on social and ecological systems focused on the division of labour and responsibilities between men and women; property rights, access to credit and resources in coastal states; resource management institutions; and ways to support the most vulnerable groups without jeopardizing resources (UN Enviroment 2019). In Kenya, women engaged in 'Mikoko Pamoja', a mangrove conservation and restoration project, maintain 'The Gazi Women Boardwalk' to promote conservation education within the mangrove forest. Through this initiative the women have proven their effectiveness in contributing to ecotourism while generating income for their community's schools as well as contributing to better health care and reliable water supply (Blum and Herr 2017).

With this in mind, it is important to undertake restoration using sound scientific evidence, local knowledge and inclusive participation and decision making whilst ensuring there is political and societal will, and long-term financing in place. To date, success rates for mangrove habitat restoration efforts have been variable, and often relatively low (Ellison, Felson and Friess 2020). There are several reasons for this, including:

- Failure to share and learn from the successes and failures of previous projects (Ellison, Felson and Friess 2020);
- A lack of engagement with, and buy-in from, local communities and all stakeholders regardless of their age, gender and socio-economic status;
- Insufficient governance and financing mechanisms to initiate and develop projects, or sustain efforts beyond the life of projects (Ellison, Felson and Friess 2020);
- Failure to reduce or stop human pressures that drive mangrove degradation and loss;
- Insufficient consideration of the ecological and environmental context of the location and mangrove species being restored (Hai et al. 2020a).

In addition to variability in success rate, there is also variability in the outcomes for nature and people. In terms of biodiversity benefits, an important factor appears to be the species used to restore degraded areas and re-create those that have been lost. There is evidence that the abundance of crabs, mollusk and shrimp species in restored mangroves may reach pre-disturbance levels within five years (Bosire et al. 2008). However, if the species of mangrove used to restore the area differ from the species that were there previously, the diversity and taxonomic profile of the restored mangrove ecosystem will be different, resembling nearby "matrix" habitats that contain both mangrove and other terrestrial species (Bosire et al. 2008). These differences can have widespread and important implications, altering how the mangrove ecosystem functions, the food-web interactions, the productivity of the ecosystem and its resilience to human disturbance and climate change. Therefore, where possible, mangrove ecosystems should be restored by reducing pressures and allowing the system to recover naturally, rather than artificially restoring the area, for example through planting of mangrove trees.

As observed for overall biodiversity health, there is evidence that restored mangroves can enhance the delivery of ecosystem services. However, as observed for biodiversity, there are also complexities and subtle differences between restored and natural mangrove ecosystems that will ultimately influence the services they supply.

In terms of carbon storage, the time frames that need to be considered are much longer than those observed for biodiversity; however, the early signs are encouraging. A study exploring differences in net primary productivity and carbon sequestration between restored aquaculture ponds in Bali and intact mangroves found that after about ten years, restored mangroves had similar rates of carbon sequestration into living biomass and soil as natural mangroves (Sidik, Fernanda Adame and Lovelock 2019). Importantly, this is not to say that the levels of carbon stored within the ecosystem are comparable to natural systems, which can take upwards of 25 years (Das 2017), but that the system has the potential to sequester carbon.

Whilst this provides encouragement for mangrove restoration efforts, there is much we still do not understand. The results observed in Bali likely reflect the ecological and environmental properties of the site and therefore may not be generable to other systems and locations(Das 2017). Furthermore, where mangroves are restored, and how the land was used before restoration, influences the capacity of the restored system to sequester and store carbon. For example, in the Philippines restoring mangroves in abandoned fishponds was found to result in greater carbon sequestration than restoring coastal areas damaged by extreme weather events (Borroto-Páez and Mancina 2017).

The above examples demonstrate the potential for mangrove restoration to deliver biodiversity and fisheries-related benefits, among others benefits not discussed here such as coastal protection (Hai et al. 2020b). These examples do not provide an extensive review of the available literature, and there is no single answer to the best way to restore degraded areas or to determine the magnitude and scale of the benefits that can be obtained.

Looking forward, countries around the world have committed to restore 1 billion hectares of degraded land and make similar commitments for marine and coastal areas. The restoration of mangroves, independently and as part of connected coastal and marine restoration efforts (i.e., those including related habitats such as corals and seagrasses), can be an important means of delivering nature-based solutions for societal challenges and ensuring healthy and sustainable ecosystems. However, it is imperative that the techniques used are based on evidence and up-to-date information, and that everyone is involved, including local communities and activists, women, youth, indigenous groups, private companies, financial investors, researchers and governments at all levels. Restoration is only one part of the answer and should be a last resort. Rather than adopting a responsive approach to habitat degradation and loss, humanity needs a proactive, preventative approach to stop the damage occurring in the first place. To do this we urgently need to transform our relationship with nature and transition to a more equitable and sustainable future in which activities that result in ecosystem loss and degradation are a thing of the past.

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