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TECHNICAL REPORT

Building Coastal Resilience with Mangroves:

The Contribution of Natural Flood Defenses to the Changing Wealth of Nations

WORLD BANK GROUP

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Acknowledgements

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This report has drawn extensively on previous World Bank valuation work, including that the development of valuation guidelines for a comprehensive assessment of the coastal protection benefits derived from these natural assets led by Michael W. Beck and Glenn-Marie Lange and the practical implementation at the national level for mangroves in the Philippines and Jamaica (Menendez et al. 2018; Ortega et al. 2019). The authors also acknowledge past support in the development of this work from The Nature Conservancy, AXA Research Fund, and the Center for Coastal Climate Resilience. The report benefited from the thoughtful guidance and input of Stefanie Onder, Borja Gonzalez Reguero, and Alexis Rivera Ballesteros of the World Bank.

This technical report was produced as input to the upcoming Changing Wealth of Nations 2024 report. The Changing Wealth of Nations flagship series is produced by the World Bank and provides the most comprehensive accounting of the wealth of nations, an in-depth analysis of the evolution of wealth, and pathways to build wealth for the future. The flagship series—and the accompanying global database—firmly establishes comprehensive wealth as a measure of sustainability and a key component of country analytics. Each iteration expands the coverage of wealth accounts and improves our understanding of the quality of all assets, notably, natural capital. In addition, each report provides a new set of tools and analysis to help policy makers mainstream wealth and its components into economic analysis and guide decision-making at the country and global scale.

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Executive summary

With the escalation of coastal risks caused by storms and climate change, the demand for coastal defenses is on the rise. Global studies using risk models (Beck et al. 2018; Menendez et al. 2020) have shown that mangroves and coral reefs can provide highly valuable coastal protection services by reducing waves and storm surges, and acting as a first line of defense against flooding and erosion. These natural coastal protection services were included for the first time in the 2021 edition of the World Bank's The Changing Wealth of Nations (CWON), which covered the changing value of mangroves as coastal protection assets from 1995–2015. Here, we have included new data for 2020 on global mangrove distribution, and assessed current flood risks and the benefits of mangroves in reducing floods. We also have re-analyzed historic flood risk and mangrove benefits (1995–2020) as there were updates to past ecological (mangrove distributions) and economic (Penn World Table (PWT)) data.

To evaluate the contribution of natural capital assets to the wealth of (sub)tropical nations, we use peer-reviewed models of flood risks and habitat benefits. Our approach uses a combination of process-based storm and hydrodynamic models, which are described in Menendez et al. 2020. Specifically, we use these models to determine the area and depth of flooding with and without mangroves for five storm frequency events (one storm in 5, 10, 25, 50, and 100 years), which are driven by local storm data. To assess the value of mangroves as natural capital assets, we overlay flood extent and depth data onto historical data on populations and asset values (PWT 10.0, (Feenstra et al. 2015)), adjusted to constant 2020 US dollars. This enables us to identify a probabilistic distribution of flood damage (risk) and the benefits of avoided damages (habitat benefits).

We assessed flood risk and mangrove benefits in 1996, 2010, 2015, and 2020 and evaluated changes in flood risks and mangrove benefits between these years. We assessed risks and mangrove benefits for 121 nations with mangroves covering about 700,000 kilometers (km) of (sub)tropical coastlines, 97 of which showed either economic or social benefits from mangroves. We summarize results by country, but these models and values can be used to understand risks and benefits within countries at the provincial and even municipal levels. These are fully quantitative risk models compared to other index-based approaches for assessing coastal vulnerability and ecosystem services.

The present value of the flood reduction benefits from mangroves (100-year assets at a 4 percent discount rate) in 2020 is $855 billion. The countries with the greatest present value of mangroves for flood reduction are China, Vietnam, Australia, the United States (US), and India (all countries here and after are listed in rank order). Annual flood risk on mangrove coastlines in 2020 is most significant in China, the US, Australia, Taiwan, and Vietnam. Each of these countries has more than 98,000 people exposed to coastal flooding yearly and more than $4.7 billion in assets at risk from flooding annually on mangrove coastlines. The increase in the wealth of mangroves for flood risk reduction from 1996–2010 was $130 billion, while from 2010–2020 the increase was $502 billion. The countries receiving the most significant increases in wealth in absolute values in 2020 (US dollars) were China, Vietnam, Australia, the US, and India, and in

relative values (percent) were South Africa, Guyana, Vanuatu, Grenada, and St Lucie.

The period from 1996–2010 covers some of the most significant losses of mangroves in recorded history from the rapid expansion of shrimp aquaculture in the 2000s and the more consistent losses from coastal development. The global loss of mangroves was 4 percent from 1996–2010, but was more than 30 percent in some countries, such as Sudan, Turks and Caicos, Oman, Djibouti, and Sri Lanka. Over this period, the total mangrove loss in hectares (absolute value) was most significant in Indonesia, Mexico, Australia, Myanmar, and Cuba. From 1996–2010 annual coastal flood risk increased dramatically to people (32 percent) and property (122 percent). Multiple factors contributed to this increase, including mangrove loss (4 percent) and population increases (21 percent), and capital stock increases (72 percent) in these countries. Despite the loss of mangrove habitats, their flood reduction benefits (i.e., their value to national wealth) increased significantly. Mangroves protected 22 percent more people and 59 percent more capital stock value in 2010 than in 1996 because of increased populations and asset values in areas protected by mangroves. The countries receiving the most significant increase in mangrove flood reduction benefits to national wealth from 1996–2015 were Vietnam, China, Puerto Rico, India, and Indonesia.

Mangrove cover declined globally from 2010–2020, but the decrease was small overall (0.66 percent). The most significant gains in mangrove habitat were observed in Oman, Turks and Caicos Islands, Mauritania, Togo, and Djibouti, with an increase in cover of more than 10 percent. However, some countries still suffered loss rates higher than 10 percent, including Saudi Arabia, Taiwan, Sudan, Pakistan, and Jamaica. From 2010–2020, the annual coastal flood risk to people and property increased by 33 percent and 104 percent globally. These national increases in risk are created by the mangrove loss (0.66 percent) and increases in population (12 percent) and capital stock (40 percent). The countries with the most significant increases in people at flood risk were China, Vietnam, India, Bangladesh, and Indonesia (more than 347,000 people flooded/year/country). The countries with the most significant increases in economic risk were China, the US, Australia, Taiwan, and Vietnam (more than $2,700 million/year/country).

However, in the period 2010–2020, for the first time, mangrove benefits increased more than flood risk. Within this decade, more than 61 percent of people received direct flood benefits, and mangroves protect more than 109 percent of capital stock from coastal flooding. Vietnam, Bangladesh, India, China, and Cameroon experienced the most significant increase in people protected by mangroves (more than 147,000 people/year/country). Some countries experienced a decline in people protected by mangroves, including Malaysia, Myanmar, Taiwan, Pakistan, and Colombia. In economic terms, China, Vietnam, Australia, the US, and Bangladesh saw the most significant increases in mangrove flood protection benefits of more than $1,170 million/year. Jamaica, Timor Leste, Belize, and Pakistan experienced decreased mangrove benefits (a decrease of $0.8 million/year/country) in annual expected flood protection benefits from mangroves.

These results indicate that mangroves can have significant and highly valuable benefits for national flood risk reduction and climate adaptation. These values can be used to inform investments in the conservation, restoration, and management of these habitats.

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ACRONYMS AND ABBREVIATIONS

CWON	Changing Wealth of Nations
EU	European Union
GDP	Gross domestic product
GHS-POP	Global Human Settlement population grid
GMW	Global Mangrove Watch
IDB	Inter-American Development Bank
JRC	Joint Research Centre
KM	Kilometer
M	Meter
PV	Present value
PWT	Penn World Table
SEEA	System of Environmental-Economic Accounting
SNA	System of National Accounts
SRTM-DTM	Shuttle Radar Topography Mission
UNDRR	United Nations Office for Disaster Risk Reduction
UNFCCC	United Nations Framework Convention on Climate Change
US	United States

1 Introduction

Rigorously evaluating flood reduction benefits and identifying where natural coastal defenses provide the most significant benefits can play an important role in informing policies for adaptation, sustainable development, and environmental restoration. Governments worldwide are investing billions of dollars in reducing the risks of flooding, erosion, and extreme weather events related to coastal development and climate change. However, most investments in coastal protection support "gray infrastructure"[1] that remains vulnerable to coastal risks and fails to adapt to changing environments. There is growing interest in nature-based defenses, as seen in significant attention from international bodies such as the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Office for Disaster Risk Reduction (UNDRR), the European Union (EU), and national and multinational agencies and organizations such as the Army Corps of Engineers, the World Bank, and the Inter-American Development Bank (IDB) (see Box 1.1).

Box 1.1: Growing interest in nature-based defenses across international bodies

There is a growing interest in nature-based defenses from multiple international bodies. The Paris Agreement, for example, adopted under the UNFCCC, emphasizes the role of ecosystems and nature-based solutions in building resilience to climate change. The UNDRR, as part of the United Nations, focuses on reducing disaster risk and promoting resilience worldwide. The Sendai Framework for Disaster Risk Reduction, adopted by UN member states in 2015, highlights the significance of nature-based solutions in disaster risk reduction efforts. It encourages the integration of ecosystem-based approaches into disaster risk management strategies. The EU has various policies and initiatives promoting nature-based solutions. Its Biodiversity Strategy for 2030 aims to protect and restore ecosystems, including using nature-based solutions. The EU's Green Deal and the European Green Infrastructure Strategy also emphasize the role of nature-based approaches in achieving environmental sustainability and resilience.

The World Bank has been actively involved in promoting nature-based solutions in its projects and initiatives. It supports initiatives such as the Global Partnership for Oceans and the Forest Carbon Partnership Facility, which incorporate nature-based approaches in their strategies for sustainable development and climate action. The IDB focuses on promoting economic and social development in Latin America and the Caribbean. While it may not have specific agreements dedicated solely to nature-based defenses, the IDB has supported numerous projects and initiatives that incorporate nature-based solutions to address environmental challenges and enhance resilience in the region.

1 Gray infrastructure refers to structures such as dams, seawalls, roads, pipes, or water treatment plants.

The wealth accounts produced by the World Bank's CWON work program can be used to inform many policy decisions, including those on risk reduction, adaptation, development and natural resource management. The measurement of wealth is enhanced with each update of the CWON database by broadening the scope and improving the quality of all assets, with particular emphasis on natural capital and human capital. The five asset categories included in the comprehensive wealth accounts are produced capital, non-renewable natural capital, renewable natural capital, human capital, and net foreign assets.

Previous wealth estimates were limited in their assessment of renewable natural capital due to data limitations, with the focus being on agricultural land, forests, and protected areas. However, CWON 2021 expanded the coverage of renewable natural capital to include marine fisheries, a pilot account for renewable energy, and additional ecosystem services from forests, especially mangroves. The upcoming CWON 2024 report will build on the findings of CWON 2021 and extend the analysis further.

Recent global studies employing integrated ecological, engineering, and economic models have highlighted the crucial coastal protection services provided by mangroves and coral reefs (Beck et al. 2018; Menendez et al. 2020). In 2016, the World Bank formulated guidelines for a comprehensive assessment of the coastal protection benefits derived from these natural assets (Beck et al. 2016). These guidelines were successfully implemented and refined at the national level for mangroves in the Philippines and Jamaica (Menendez et al. 2018; Ortega et al. 2019) and have since been extended to assess the value of reefs and mangroves worldwide (Beck et al. 2018; Losada et al. 2018; Menendez et al. 2020). In 2021, the CWON report broke new ground by quantifying the value of mangrove assets over a period of two decades (1995 to 2015; Beck et al. 2022).

Mangroves play a crucial role in safeguarding coastlines by mitigating the risk of flooding and erosion. The aerial roots of mangroves act as a barrier to retain sediments, thereby preventing erosion. Moreover, the roots, trunks, and canopy of mangroves reduce the force of oncoming wind and waves, and this, in turn, mitigates the risk of flooding. According to the World Bank (2016), a 500-meter-wide mangrove forest can reduce wave heights by 50–100 percent in general, while during cyclones the reduction can go up to 60–90 percent (Narayan et al. 2010). This reduction in wave heights can result in relatively small reductions in water levels that can prevent property damage and flooding, particularly in low-lying areas. Mangroves contribute to long-term coastal stability by promoting sedimentation, decreasing erosion, and maintaining tidal channels. They also provide resources to support fisheries, building materials, ecotourism, and trade, thus promoting sustainable livelihoods and reducing social vulnerability.

Mangroves are natural barriers that provide crucial protection to people and property from storms. However, policy makers often fail to account for these benefits, leading to the continued loss of these habitats. At present, , losses from mangroves are not factored into decision-making. In addition, the benefits of managing or restoring coastal natural capital remain unrecognized.

We use new data on historical mangrove distributions from 1996 to 2020 to assess changes in the value of coastal protection benefits over time. Overall, 19 percent of the world's mangroves was lost between 1980 and 2005 (Spalding et al. 2010). Though the rate

of loss has slowed over the past decade (according to Global Mangrove Watch data, Bunting et al. 2022), mangroves still face significant threats. When mangroves are degraded or destroyed, coastlines become more vulnerable to the destructive effects of waves and storm surges, putting more people and property at risk from storms, floods, and rising sea levels.

In this study, we applied a methodological approach to assess the value of shoreline protection services provided by mangroves. Our approach involved using global flood risk models to simulate the impact of waves and surge generated by tropical storms as they interacted with mangrove shorelines. Through this modeling, we evaluated the socioeconomic risk associated with flooding and quantified the flood protection service offered by mangroves. To capture temporal dynamics, we used mangrove extent layers from multiple time points, spanning the period from 1996–2020. By incorporating these temporal dimensions, we were able to measure how the asset value of mangroves changed over time, thus providing insights into the evolving importance of mangroves for shoreline protection.

The rest of this report is structured as follows:

The first section focuses on the methods employed in this study and provides a comprehensive description of the study domain. It outlines the specific approaches used to model the effect of waves and surge on mangrove shorelines, as well as the evaluation of the socioeconomic risk associated with flooding and the quantification of mangroves' flood protection service. It provides an overview of the main updates in data and models used in this new assessment. It highlights the advancements made in terms of data sources, methodologies, and modeling techniques, which contribute to a more robust evaluation of shoreline protection services.

The next section is dedicated to the datasets used in this assessment. It provides detailed descriptions of each dataset employed, including information on their sources, resolution, and temporal coverage. This section serves as a valuable reference for understanding the data underpinning the subsequent analyses, which is presented in the results section. The latter showcases the findings related to shoreline protection services provided by mangroves, highlighting key trends, spatial patterns, and temporal changes in asset value. The results shed light on the significance and effectiveness of mangroves as a natural defense against flooding.

Lastly, the discussion section engages in a comprehensive discussion of the results and methods employed in this assessment. It examines the implications of the findings, identifies potential limitations, and explores the strengths and weaknesses of the applied methodologies. This section facilitates a deeper understanding of the analysis and its implications. The final section concludes the report by providing key recommendations based on the findings and discussions. It offers actionable insights for policy makers, stakeholders, and practitioners involved in coastal management, disaster risk reduction, and climate adaptation. The recommendations aim to enhance the integration of shoreline protection services provided by mangroves into decision-making processes and promote sustainable practices for coastal resilience.

2 Methods

2.1 METHODS IN BRIEF

In this section we describe the methods and data sources for estimating flood risk, flood protection benefits, and the asset value of mangroves locally, nationally, and globally. The flood protection benefits provided by mangroves are assessed as the flood damages avoided to people and capital stock by keeping mangroves in place (Beck et al. 2018; Losada et al. 2017; Menendez et al. 2020; Beck et al. 2022). This section extensively relies on the findings and methodologies presented in the technical report for CWON 2021, published in 2022 by Beck et al. The detailed explanations and methodologies employed are extensively covered in Beck et al. 2022 and are reproduced here for completeness and to ensure a thorough understanding of the approach used in this study.

We couple offshore storm models with coastal process and flood models to measure the flooding that occurs: (i) with and without mangroves, (ii) under cyclonic and non-cyclonic storm conditions, (iii) by storm frequency (return period) across the globe. These flood extents and depths are used to estimate the annual expected flood damage to people and capital stock, and hence the expected benefits of mangroves in social (people protected) and economic terms (capital stock protected).

Our estimates are based on a set of global statistical models, hydrodynamic process-based models, and socioeconomic data. All these processes are grouped into five steps following the Averted Damages (Expected Damage Function) approach, commonly used in engineering and insurance sectors and recommended for the assessment of coastal protection services from habitats (Figure 2.1). This figure illustrates the process of estimating the flood protection benefits provided by mangroves. It starts with assessing offshore dynamics and sea states, then considers nearshore hydrodynamics and their impact on waves. The figure highlights the role of mangroves as habitat and their effect on reducing wave run-up. It further extends to estimating flood heights inland for different return periods, comparing scenarios with and without mangroves. Finally, the consequences of flooding, including land damage, affected population, and built capital, are evaluated. Many aspects of these models such as connections between wind, waves, run-up, and flooding have been extensively validated (Menéndez et al. 2018, 2019; Menéndez et al. 2020).

We first developed key mangrove-specific aspects of the flood models in the Philippines, a country with over 36,000km of heavily populated coastlines, high risks from cyclones, and more than 200,000 hectares of coastal mangroves. We use these models to generate a dataset of several thousand simulations to describe the physical relationships between tropical cyclones, offshore wave climate, mangrove extent and geometry, and extreme water levels (i.e., flood height) along the shoreline for five storm frequency events (one storm in 5, 10, 25, 50, and 100 years) driven by local storm data.

This dataset is then used to estimate how mangroves modify extreme water levels for every kilometer of mangrove shoreline globally. Global flood depths and extents are then estimated by intersecting the global extreme water levels with a global topography

dataset, at 90-meter (m) resolution, from the Shuttle Radar Topography Mission. Finally, we overlay the resulting maps of flood depths and extents on socioeconomic asset information downscaled to 90 x 90 meters. Flooded socioeconomic assets are then assessed by flood depth to identify flood damages (risk) and avoided damages (mangrove benefits).

The Averted Damages Approach provides a rigorous foundation for estimates of flood risk and habitat benefits (Barbier 2015; Beck & Lange 2016; Pascal et al. 2016; van Zanten et al. 2014). We have chosen this approach over others because it is (i) quantitative in contrast to other approaches, which use indicator (expert) scores to assess shoreline vulnerability (e.g., (Silver et al. 2019)), (ii) it uses process-based models and statistical tools to assess hydrodynamics, (iii) it uses the methods and tools of risk agencies, insurers and engineers (Narayan et al. 2016, 2017; Reguero et al. 2018), (iv) it is consistent with approaches for national accounting (Beck et al. 2016), and (v) it accurately captures impacts of extreme events.

The Averted Damages Approach aligns with the System of National Accounts (SNA) and the System of Environmental-Economic Accounting (SEEA) standards and guidelines in several ways. First, it recognizes the importance of valuing ecosystem services and natural assets within economic assessments, which is a fundamental principle of both the SNA and SEEA frameworks. By explicitly incorporating the estimation of averted damages and the value of flood protection provided by natural coastal habitats like mangroves, the approach ensures that the economic significance of these ecosystem services is properly accounted for.

Second, the Averted Damages Approach employs quantitative methods and tools that are consistent with the rigorous assessment and accounting practices recommended by the SNA and SEEA frameworks. By using process-based models and statistical tools, the approach adheres to the principles of accuracy, reliability, and transparency that are essential for economic and environmental accounting.

Furthermore, the Averted Damages Approach considers the impacts of extreme events, which aligns with the guidelines of the SEEA in assessing the economic consequences of natural disasters. By capturing the potential damages and costs that would occur in the absence of natural coastal habitats, the approach provides a comprehensive evaluation of the risk reduction and resilience-building benefits associated with these habitats.

By ensuring consistency with SNA and SEEA standards and guidelines, the Averted Damages Approach facilitates the integration of its findings into broader economic accounts and decision-making processes. The approach provides a robust and credible framework for valuing the ecosystem services and benefits provided by natural coastal habitats, thereby contributing to a more comprehensive understanding of their economic significance, and supporting informed policy and management decisions at the intersection of economics and the environment.

FIGURE 2.1: KEY STEPS AND DATA FOR ESTIMATING THE FLOOD PROTECTION BENEFITS PROVIDED BY MANGROVES

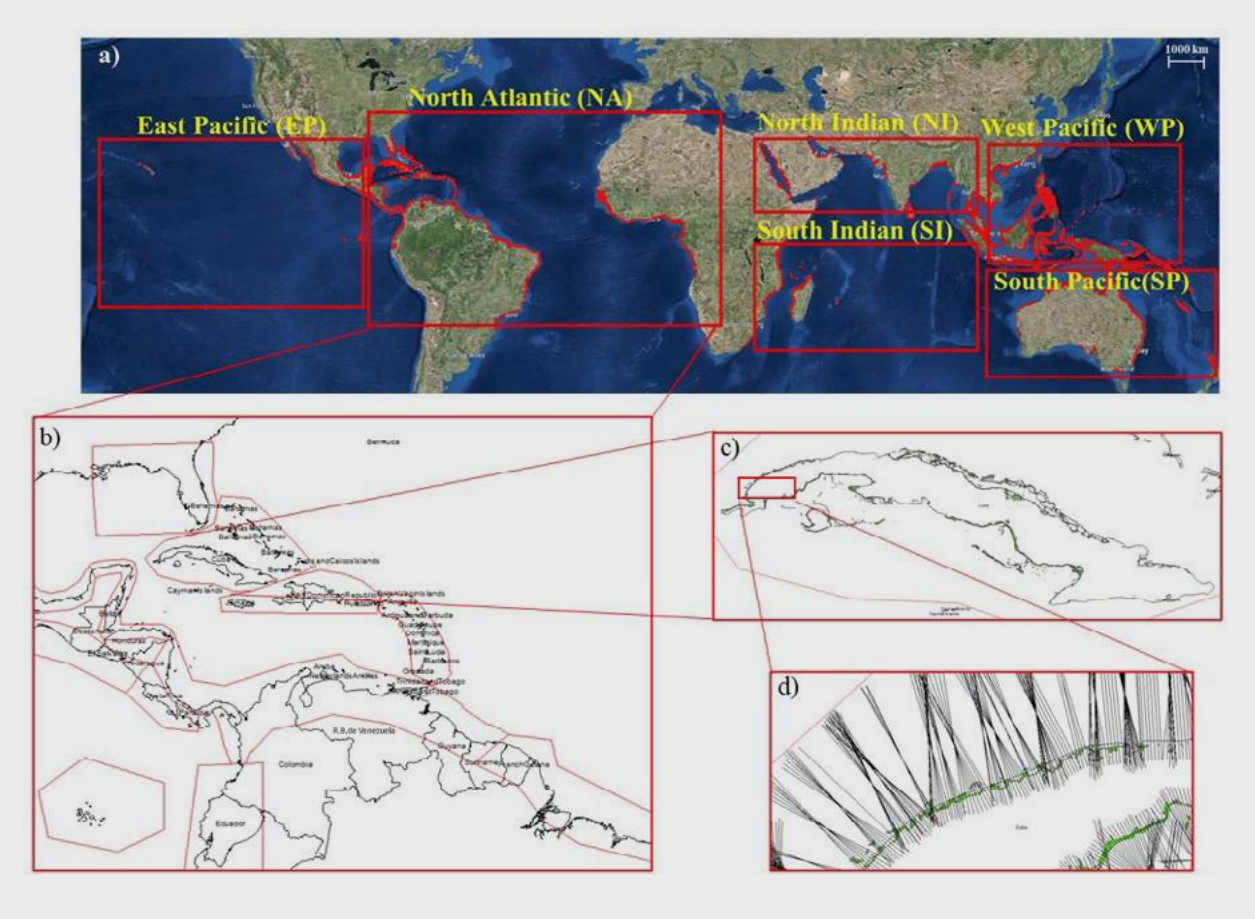
Note: Step 1, Offshore Dynamics: Oceanographic data are combined to assess offshore sea states. Step 2, Nearshore Dynamics: Waves are modified by nearshore hydrodynamics. Step 3, Habitat: Effects of mangroves on wave run-up are estimated. Step 4, Impacts: Flood heights are extended inland along profiles (every 1km) for 1 in 5, 10, 25, 50, and 100-year events with and without mangroves. Step 5, Consequences: The land, people, and built capital damaged under the flooded areas are estimated.

Source: Beck et al. 2019.

2.2 STUDY DOMAIN DESCRIPTION

This global study covers 700,000km of mangrove coastlines. For computational purposes, we divided the global domain into three levels (Figure 2.2). The first level is the division into six macro-regions, corresponding to the five ocean basins of tropical cyclone generation (Knapp et al., 2010): East Pacific, North Atlantic, North Indian, South Indian, West Pacific and South Pacific (Figure 2.2a). The second level divides the 700,000 km of coastline into 68 sub-regions considering coastline transects of similar coastal typology (e.g., islands and continental coasts) and similar ecosystem characteristics (Figure 2.2b). The third level is at the national scale, defining country-side units (Figure 2.2c). Within these nationwide units, we create cross-shore profiles perpendicular to the mangrove habitats for each kilometer of coastline, totaling 700,000 profiles (Figure 2.2d).

FIGURE 2.2: THE GEOGRAPHIC SUBDIVISIONS FOR HYDRODYNAMIC MODELS



Note: (a) Macro-regions with the global mangrove cover in red, (b) Sub-regions in the Atlantic Ocean basin, (c) Local study units every 20km of coastline in the Northern Caribbean sub-region, (d) Profiles every 1km of coastline in the North of Cuba.

Source: Beck et al. 2022.

2.3 THE PHILIPPINES: BASELINE CASE TO BUILD GLOBAL MODELS

The Philippines is the baseline case used to develop the global statistical models of the relationships between tropical cyclone parameters, oceanographic variables, and onshore flood extents and depths on mangrove coastlines. The Philippines is an excellent pilot case for valuation of the coastal protection ecosystem service provided by mangroves because:

- Almost 10 percent (548 events) of the global tropical cyclone records from the International Best Track Archive for Climate Stewardship (IBTrACS) database affected the Philippines (Knapp et al. 2010 and Knapp et al. 2018).
- The islands of the Philippines present high climatic variability and are at particularly high risk from natural hazards like typhoons and regular storms, which are the cause of 80 percent of the total losses from disasters (National Economic and Development Authority 2017).

- The Philippines ranks in the top 15 most mangrove habitat-rich countries, with 2,630km2 of mangroves (in 2010), representing 2 percent of the world total (Giri et al. 2011).
- These mangrove habitats show extensive variation in both cross-shore width (0.1km and 8km wide) and average depth (Menéndez et al. 2018).

By encompassing almost all possible geometries, the Philippines dataset provides a comprehensive basis for extrapolation. To account for variations in climate and coastal conditions, synthetic tropical cyclones were modeled beyond the specific climate patterns found in the Philippines. These synthetic cyclones cover a broad range of magnitudes, ensuring that the modeling approach captures the variability and potential scenarios that can be encountered in mangrove areas worldwide.

We valued the flood protection service of mangroves in the Philippines by using the numerical model Delft3D, considering both cyclonic and non-cyclonic storm conditions, for scenarios with and without mangroves. We used these results to build two global statistical models. The first, a "Cyclone Model", was developed to describe specific offshore and nearshore ocean dynamics produced by tropical cyclones (wave height, peak period, storm surge, and storm duration), and the second, a "Mangroves & Flood Height Model", estimated how the presence and profile of mangrove habitats influences the total water level during storm conditions on the shoreline. Further details about the Philippines-based models can be found in Menéndez et al. (2018, 2020) and the two models are summarized below.

Cyclone Model: Offshore and nearshore dynamics generated by tropical cyclones

Offshore waves and storm surge generated by tropical cyclones were numerically simulated in the Philippines by using Delft3D modules "Flow" ("Delft3D-FLOW User Manual" 2006) and "Wave" ("Delft3D-WAVE User Manual" 2000). Both modules were run simultaneously in a two-dimensional grid of 5km cell-size with a time step of 30s, forced with hourly wind data and sea level pressure fields in a model that considers the non-linear interaction processes of tide, wind setup, inverse barometers, and wave setup. The model was validated by comparing the storm surge generated by typhoon Rammasun in the bays of Legaspi and Subic. We used tidal gauge data from the Global Sea Level Observing System (GLOSS, http://www.gloss-sealevel.org) for validation.

Using the results of the numerical simulations carried out with the Delft3D model in the Philippines we looked for statistical relationships between cyclone parameters and oceanographic variables to create a new predictive model, where the key oceanographic variables that affect on-shore flooding (wave height, wave period, storm tide and duration of the storm peak) were predicted based on cyclone parameters (distance, wind speed, track velocity, wind angle of incidence). In the Philippines, we simulated 548 storm events creating a database of 58 million results. We randomly selected 90 percent of the generated results to build our predictive model and used the other 10 percent for validating the predictive models. We examined the correlation between the physical tropical cyclone parameters and the oceanographic variables for two coastal area typologies: areas directly exposed to tropical

cyclones and areas protected from the direct impact of tropical cyclones. Based on these variables, we then developed a best fit regression model to predict the oceanographic variables.

Mangroves & Flood Height Model: The role of coastal habitats in nearshore dynamics

The Mangroves & Flood Height Model predicts the effects of mangrove forest characteristics on flood heights at the shoreline. Coastal vegetation provides resistance to the energy and flow of waves and water as they come onshore, which is modeled by using a friction factor based on the Manning coefficient (n). We assigned different friction factors to sandy soil (n=0.02), mangroves (n=0.14), and coral reefs (n=0.05) (Prager 1991; Zhang et al. 2012).[2] One-dimensional numerical propagations, on cross-shore profiles perpendicular to the mangrove shoreline, were carried out using the Delft3D model to obtain flood heights along the coast. We used these numerical results to create two interpolation tables for cyclonic and non-cyclonic storm conditions that correlate the oceanographic information at the seaward side of the profile (wave height, wave period, weather storm tide, and storm peak duration) and the characteristics of the mangrove profiles (width and slope) with the flood height. These tables contain 37,500 tropical cyclone simulations (50 cyclones x 750 profiles) and 90,000 non-cyclonic climate simulations (120 sea states x 750 profiles).

2.4 METHODS IN DETAIL

Stage 1: Offshore tropical cyclone and non-cyclonic climate sea states. The offshore hydrodynamic conditions (wave height, wave period, storm surge, and astronomical tide) were subdivided into two groups: (1) those produced by less intense local climate or extreme climate generated far away from the study area (regular climate or non-cyclonic conditions) and (2) those produced by local extreme events (tropical cyclones or cyclonic conditions).

1A. Non-cyclonic climate: Deep water ocean dynamics produced by any climate condition other than tropical cyclones was analyzed as non-cyclonic climate. Non-cyclonic climate was defined by different datasets within the period 1979 to 2010: a global wave reanalysis (Reguero et al. 2012; Perez et al. 2017), a global storm surge reanalysis (Cid et al. 2017), astronomical tide (Pawlowicz et al. 2002; Egbert & Erofeeva 2002), and mean sea level compiled from historical numerical reconstruction and satellite altimetry (Church et al. 2004). Waves and sea level conditions due to tropical cyclones were excluded and studied separately to avoid double counting, resulting, finally, in 32 years' time series of only non-cyclonic climate. The 32-year long time series of wave data (1979 to 2010) included 280,000 sea states (one sea state represents one hour of wave height, peak period, and total water level). We reduced the number of sea-state propagations by considering only the 3,787 non-repeated combinations of wave height, peak period, and total water level and, then, applying the Maximum Dissimilarity Algorithm to identify 120 sea states to be propagated with the Snell law and shoaling equation across coastal profiles. All of the models and data in the non-cyclonic climate analysis, including waves and storm surge, have been globally validated (e.g., Reguero et al. 2012; Perez et al. 2017; Cid et al. 2017). The non-cyclonic climate analysis

2 Data for the three bottom types was used, but the only with/without scenario comparison was done with the mangroves.

covers most of the storm and flood risk conditions globally (including tropical depressions and storms) except for cyclone conditions, which represent comparatively small (spatio-temporally) but locally intense conditions.

1B. Tropical cyclones: Tropical cyclones were considered separately from non-cyclonic climate if the 10-minute sustained wind speeds (W10m) exceed 118km/h. Tropical depressions (W10m $\leq$ 62km/h) and tropical storms (63km/h $\leq$ W10m $\leq$ 118km/h) are included in the non-cyclonic climate models. For historical tropical cyclones, we use the IBTrACS database (Knapp et al. 2018), which provides six-hourly data for wind speed, atmospheric pressure, and track position, and contains regularly updated storm data (https://www.ncdc.noaa.gov/ibtracs/).

Stage 2: From offshore dynamics to shallow water. We obtained ocean hydrodynamics on the seaward side of each cross-shore profile cyclonic and non-cyclonic conditions. Waves interact with the bottom and other obstacles (e.g., islands) as they approach the coast and modify height and direction through shoaling, refraction, diffraction, and breaking processes.

2A. Non-cyclonic climate: For non-cyclonic climate, several thousand offshore ocean parameters representing non-extreme sea states are clustered into 120 representative sea states using a Maximum Dissimilarity Algorithm (Camus et al. 2011a; Camus et al. 2011b). Wave and water level conditions at the seaward point of each profile are then associated with the nearest non-cyclonic climate sea state. From this, a regression model was created that equates offshore non-cyclonic climate sea states with wave and water level conditions at the seaward end of a profile.

2B. Tropical cyclones: We used the Cyclone Model described above to estimate key nearshore parameters from cyclones including wave height (Hs), peak period (Tp), storm surge (SS) and the time duration of the meteorological tide (Tss).

Stage 3: Modeling the role of coastal habitats in nearshore dynamics, flood height. We used the Mangroves & Flood Height Model (described above) to estimate flood height given mangrove length and depth, significant wave height, peak period, and total water level at the head of each cross-shore profile. After calculating the historical time series of flood height (1979 to 2010), we applied an extreme value analysis to obtain 1 in 5-, 10-, 25-, 50-, and 100-year extreme sea levels at the coast. To do that, we selected maximum values over a threshold (minimum 1 event every 5 years) and then adjusted these values to a Generalized Pareto-Poisson distribution. One-dimensional wave and surge propagation model through the cross-shore profiles is commonly used even in site-based models (Beck et al. 2018). The consideration of non-linear effects is only possible using computationally expensive phase resolving models (e.g., XBeach) at local scales (e.g., bays). This modeling approach is not feasible at the global scale because of computational capacity and the lack of high-resolution bathymetric data, and especially if risk is to be evaluated probabilistically across multiple events and scenarios (Beck et al. 2018).

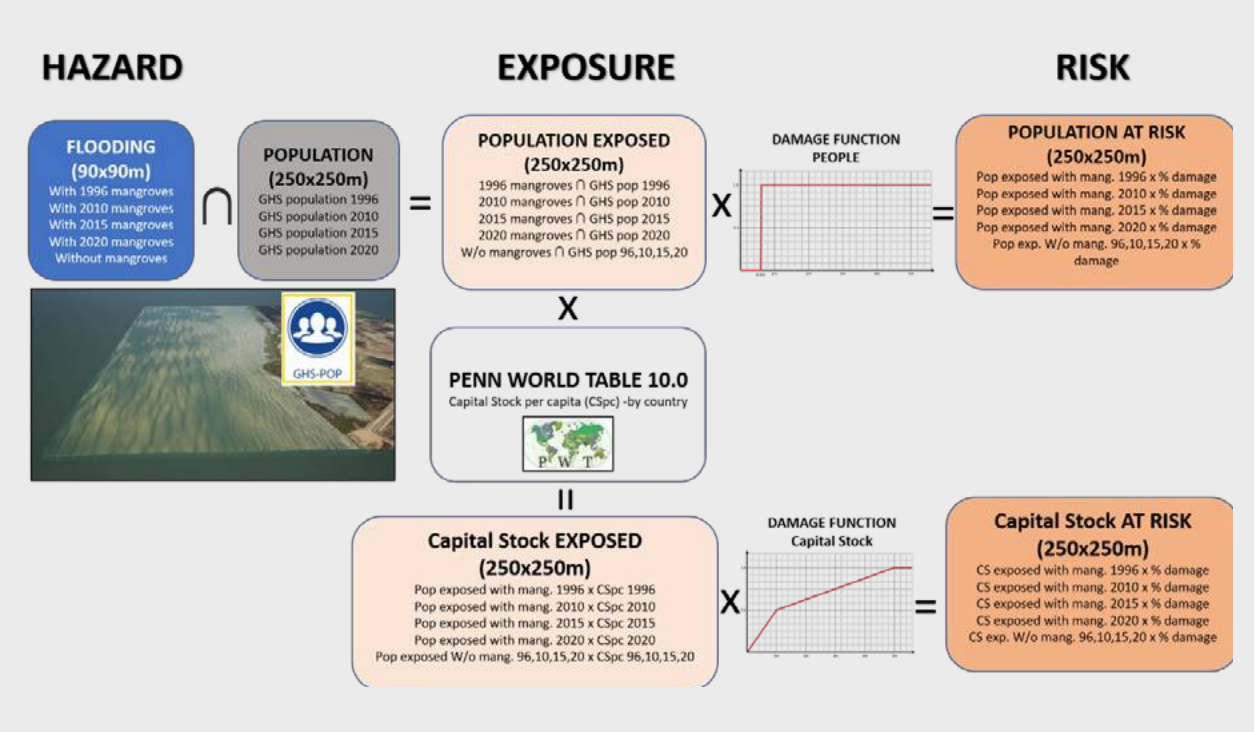
Stage 4: Calculating impacts: Flooding maps. To estimate flooding, we used a modified bathtub flooding model, which includes a hydraulic connectivity requirement for flooding connected points across the coastal topography. We used 1 in- 5-, 10-, 25-, 50- and 100-year flood heights every 1km of coastline, a global topography dataset,

20 Desalination is recorded as the abstraction of saltwater.

at 90m horizontal resolution, from the Shuttle Radar Topography Mission (Farr et al. 2007) and a bathtub method for flooding based on hydraulic connectivity between pixels. The final product of this stage were 50 global flood maps representing 5 return periods (1 in 5-, 10-, 25-, 50- and 100-year events), 2 storm conditions (cyclonic and non-cyclonic), and 5 mangrove extents (1996, 2010, 2015, 2020, and no mangroves).

Stage 5: Assessing global flood consequences in areas protected by mangroves. The expected flood risk and benefits provided by mangroves were presented in social and economic terms. In this step, we calculated the effects of flooding in terms of (1) people exposed, (2) capital stock exposed, (3) people at evacuation risk, and (4) losses of capital stock. We intersected the flood maps with population data from the new Global Human Settlement population grid (GHS-POP) released in 2022. The dataset is a spatial population raster that depicts the distribution of residential population, expressed as the number of people per cell (https://ghsl.jrc.ec.europa.eu/ghs_pop2022.php) and capital stock data from the PWT version 10.0 (https://www.rug.nl/ggdc/productivity/pwt/). The workflow of the exposure and risk assessment methodology is summarized in Figure 2.3.

FIGURE 2.3: CWON RISK ASSESSMENT METHODOLOGY



We followed a multi-step approach to obtain people and capital stock exposure and risk:

Step 1. Global population and capital stock distribution: Population distribution and density is obtained from the spatial raster GHS-POP R2022A. This dataset contains global residential population estimates at 1km resolution for 1975, 1990, 2000, 2015, and 2020. We downscaled the population rasters from 1km to 250m resolution in order to match the past GHS-POP R2019, which are available for the years 1975, 1990, 2000, and 2015 at 250m.

To obtain population estimates for the years 1996 and 2010 in our analyses, we interpolated the global data between 1990 to 2000 and 2000 to 2015, respectively. Then we calibrate both, 1996 and 2010 interpolated grids, with nationwide population statistics from the World Bank (World Bank Data). The calibration consists of adjusting the total people per country from the interpolated grids to the World Bank data. In the case of 2020, we had to reduce the population raster from 1km to 250m by equally distributing people across each 250x250m pixel, but no further adjustments were needed.

Global capital stock was calculated using PWT 10.0. This table provides information on relative levels of income, output, input, and productivity. It includes 182 countries and covers 70 years (1950 to 2019).

For our economic analyses we used the national data of capital stock ("rnna" variable) at constant 2017 national prices and transformed these into constant 2020 national prices by using country-based consumer price index data from the World Bank (https://data.worldbank.org/indicator/FP.CPI.TOTL). To derive a comprehensive understanding of the global capital stock distribution, our methodology involved several steps. Initially, we computed the capital stock per capita for each country. This step allowed us to determine the amount of capital assets available on a per-person basis in each nation. Subsequently, we integrated this country-level information with our previously calculated data, which specified the population residing within each 250x250m grid cell across the globe. By doing so, we could gauge the total capital stock associated with each grid cell, considering the population it encompasses. To create a comprehensive and highly detailed global capital stock distribution map, we applied these calculations at a fine-grained resolution of 250m. The result is a raster representation that provides an in-depth view of how capital assets are distributed across the world at this level of granularity.

Step 2. Resampling coastal flooding grids (at 90m) to population and capital stock resolution (250m): To overlay flood and assets maps, both must be at the same horizontal resolution. We upscaled the flood rasters from 90m to 250m to be consistent with the resolution of the global population and asset data. We use the ArcGIS toolbox function, "resample", for the spatial redistribution of the flooding grids. Three main reasons support this approach: (1) By upscaling flood risk to 250m we are still working with sufficiently high-resolution spatial risk to aggregate results at both national level and at any local level higher resolution; (2) working with 250m global rasters rather than 90m reduces the size of the intermediate files and therefore the computational demand of the overlying process; and (3) we do not need to re-calibrate the new rescaled rasters by adjusting the total population and total capital stock per country at 90m resolution to those at 250m.

Step 3. Exposure. People and stock in flooded areas: Here we calculate the number of people and then the capital stock exposed to coastal flooding in 1996, 2010, 2015, and 2020 with and without mangroves. We first reclassify the flooding raster into 1 and 0 values.

We assign 1 to flooded pixels with water, and 0 to dry pixels. Then we multiply population rasters by the reclassified flood raster and obtain the global distribution of people exposed to coastal flooding. The capital stock exposed to flooding is then calculated by multiplying people exposed by capital stock per capita at national level (PWT 10.0). The exposure layers will inform how many people and assets are in flooding areas, but not the real damage to people and the real economic loss (risk). Calculating flood risk requires that we estimate flood damages using damage functions, which relate flood damages at a location to the flood depth at that location.

Step 4. Damage coefficients: Flood damage depends on the water depth and the type of asset. We use different damage functions for population and capital stock. For people, the damage function assumes that, in a grid cell, people are not affected by water below 30cm in depth and all people are affected by flood water depths greater than 30cm. This a commonly used threshold in civil protection services to decide when people must be evacuated (Shao et al. 2015).

For capital stock, we combined data from JRC (Huizinga et al. 2017) and Hazus (Scawthorn et al. 2006) flood depth damage curves. The best combination of these curves globally results in a damage function that ramps up linearly from 0 to 50 percent of damage when water depth is below 1m. Then damage increases at a slower rate from 50 percent at 1m water depth to 100 percent at 5m. We use these curves to calculate a global raster of damage coefficients to people and capital stock. In prior work, we tested the use of various damage curves (including complex damage functions) for population, residential, and industrial stock from Hazus in the Philippines (Menendez et al. 2018), and we found that the results were not significantly different from approaches using simpler curves such as those in Figure 3.2.

Step 5. Risk. People evacuated and capital stock loss due to coastal flooding: To calculate risk, we multiply damage coefficient rasters by people and capital stock exposure rasters. A total of 160 risk maps for the different conditions and scenarios are generated as a combination of asset type (x2), year (x4), storm condition (x2), ecosystem presence (x2), and return period (x5) (see **Table 2.1**).

Step 6. Nationwide aggregation results: Risk to people and capital stock is aggregated at national scale. We first create a 10km external buffer for each country and find the pixels that lay into each country buffer boundary. We calculate the total number of people and the total capital stock value of each country under each scenario.

Step 7. Annual expected risk and benefits: In addition to assessing risk for specific events (such as a 100-year storm event), we also examined average annual expected damages and benefits provided by mangroves. To estimate annual risk, we integrated the values under the extreme value distribution curves that compare capital stock damaged, or people affected, by storm return period—in other words, the integration of the expected damage with the probability of the storm events.

Step 8. 100-year asset value calculation: We calculated the present value of mangrove benefits over a period of 100 years. We assumed a constant benefit flow and 4 percent discount rate to obtain the 100-year asset value (Eq. 2).

$$PV = \sum_{i=1}^{i=100} \frac{AEB}{(1+r)^i} \qquad (2)$$

Where *PV* is the present value, AEB are the annual expected benefits, *r* is the discount rate (4%) and "*i*" is each year within the life cycle period (i=1-100 years).

TABLE 2.1: RISK MAPS SUMMARY TABLE

YEARS	ASSETS	MANGROVE SCENARIO	STORM CONDITION	RETURN PERIOD
1996	People	With mangroves	Cyclonic (tropical cyclones)	1 in 5 years
2010	Capital stock	Without mangroves	Non-cyclonic (regular climate)	1 in 10 years
2015				1 in 25 years
2020				1 in 50 years
				1 in 100 years

2.5 MODEL LIMITATIONS AND ASSUMPTIONS

Our efforts represent state of the art process-based assessments of flood risk and mangrove benefits globally. For most countries with mangroves, these represent the best data and models for mangrove benefits, and for many of these countries the best national-level estimate of flood risk. For this global study, we have developed a dataset of several thousand simulations to describe how mangroves modify extreme water levels at the shoreline, for every kilometer of mangrove coastline in the world. This approach is highly efficient and allows us to estimate coastal flood risk globally for new scenarios of mangrove presence and extent.

As with all global models, there is the potential that individual countries may have better data, for example, on mangrove habitats or bathymetry (measuring the depth of water), which could be used for higher resolution analyses of risks and benefits. For mangrove coverage, we have only the extent of mangroves, for example, not the age, structure, density, species, degree of degradation, and other factors that can affect the capacity of mangroves to reduce flooding. We use mangrove length and water depth (or elevation) across each 1km cross-shore profile as input to the model.

The greatest sources of uncertainty in coastal flood risk modeling are estimates of topography and bathymetry. Given that flooding and damage from tropical storms are among the greatest risks to people and property, better elevation and depth data is urgently needed. Fortunately, in the past decade there has been a substantial increase in the availability of high-resolution coastal elevation data through the widespread use of LIDAR (light detection and ranging). Nearshore bathymetry, however, remains a major gap, though there are advances in remote sensing that could help.

Other sources of uncertainty rely on socioeconomic estimates. The changes in flood risk due to changes in the socioeconomics are more than twofold greater than the sensitivity to changes in the hydrodynamic conditions.

Our coastal flooding analyses have several significant, combined improvements over other recent global flooding analyses including:

- Generation of global flood maps at 90m resolution.
- Consideration of hydraulic connectivity in the flooding of land.
- The use of 30 years of wave, surge, tide, and sea level data.

- Reconstruction of the flooding height time series and associated flood return periods.

Our global flood risk models also include the latest datasets released of mangroves, population distribution, and economics. Remaining constraints for this global coastal flooding model include the consideration of flooding as a one-dimensional process and the difficulty in representing flooding well in smaller islands.[3]

In the previous analysis (CWON 2021, Beck et al. 2022b), we modeled 111 countries with mangroves and only 92 benefited from mangroves. In this new updated analysis, we modeled 121 countries with mangroves and 97 countries benefited from mangroves. More details about the selection of countries providing mangrove benefits are presented in Appendix 1.

We do not account for changes in sea level from 1996 to 2020; these effects would be small over this time period and would have minor impacts on flooding. We also calculate the (local) distributions of extreme sea levels across this entire time period. The statistical distributions representing extreme sea levels were kept unchanged throughout the entire time period under consideration. Keeping the extreme sea levels distribution constant simplifies the analysis by assuming homoscedasticity (variability remains constant over time). This simplification can be helpful for certain analytical purposes, especially when you want to focus on other variables or factors without the added complexity of modeling changing variances. This is the case of this analysis, where we focus on modeling the effect of changes in mangrove distribution.

We are assuming that the 30-year historical data of waves and cyclones is applicable to 1996, 2010, 2015, and 2020. Adjustments within the time period would drastically shorten the data record, which is not a standard approach for risk and flood modeling.

Caveats in the interpretation if the data is used at a subnational scale:

- Data availability and accessibility: Working with high-resolution data at a global scale can be challenging because it is based on other spatial explicit data that is at a coarse scale (e.g., population data at 1km resolution or economic data at national scale resolution), which can introduce uncertainties and gaps in the analysis.
- Data accuracy and precision: While high-resolution data provides more detailed spatial information, it is essential to assess the accuracy and precision of the data. The quality and reliability of the input data, including elevation models and socioeconomic data, can influence the accuracy of the flood risk assessment.
- Validation challenges: Validating high-resolution global data presents significant challenges due to the lack of comprehensive ground truth data at such a fine-grained resolution for the entire globe. The availability of local validation data, such as historical flood records or detailed flood damage assessments, is often limited or inconsistent across different regions. This makes it challenging to validate and verify the accuracy of the high-resolution global flood risk model. As a result, there may be uncertainties in the model's performance and limitations in assessing its reliability for specific locations or subnational areas. Rigorous validation efforts, where possible, should be conducted to assess the model's performance and ensure its suitability for subnational applications.

3 The challenges encountered in modeling are primarily attributed to the intricate nature of building a one-dimensional model for regions characterized by very small islands and highly fragmented coastlines. The resolution of the model is not the limiting factor; rather, it is the complex and geographically dispersed nature of the coastal features that pose significant difficulties in the modeling process.

3 Datasets

3.1 OVERVIEW

The dataset overview section provides a comprehensive view of the various datasets used in this study to assess coastal flood risk and the associated impacts. This section begins with a detailed table listing all the datasets employed (Table 3.1), followed by a thorough explanation of key datasets that play a crucial role in the analysis. The datasets discussed include mangrove data, population data, capital stock, consumer price index, and damage functions. Each dataset contributes essential information to our understanding of coastal vulnerability and the estimation of potential damages. By presenting these datasets and their significance, we aim to provide a transparent and comprehensive account of the data sources used in this assessment.

Several databases used in the assessment of mangrove coastal protection benefits have been updated and improved since the CWON 2021 report (World Bank 2021), in particular the mangrove cover maps and socioeconomic data. Due to these changes, the results corresponding to the previous analysis (1996 to 2015) were updated, and they changed quantitatively (slightly) but not qualitatively. The main changes in the underlying datasets are explained.

TABLE 3.1: LIST OF DATASETS USED IN THE ANALYSIS

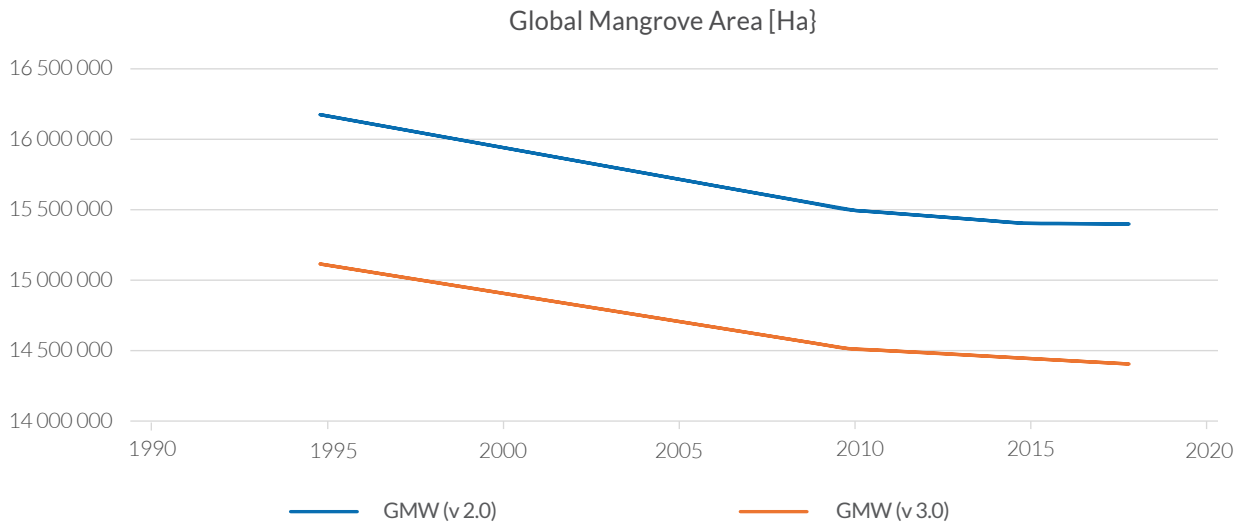
DATABASE	DATABASE NAME	INSTITUTION	VARIABLE	SPATIAL DOMAIN AND RESOLUTION	TEMPORAL DOMAIN AND RESOLUTION	WEB LINK
Tropical cyclones	IBTRrACS	NOAA	Wind speed Long, lat, time	Global (10 km)	1841-2023 (3 hours)	IBTrACS
Waves	GOW 2.0	IH Cantabria	Hs, Tp, Dm	Global (250km)	1979-2010 (1 hour)	GOW 2.0
Astronomical tide	GOT	IH Cantabria	Astronomical tide elevation	Global (4km coast, 18km open ocean)	Any (1 hour)	GOT
Storm surge	Extension of DAC	IH Cantabria	Storm surge level	Global (200km)	1871-2010 (6 hours)	Storm Surge

DATABASE	DATABASE NAME	INSTITUTION	VARIABLE	SPATIAL DOMAIN AND RESOLUTION	TEMPORAL DOMAIN AND RESOLUTION	WEB LINK
Mean sea level	Sea Level Rise	CSIRO Marine Research	Mean sea level	Global (100km)	1950-2000 (1 month)	MSL
Bathymetry	GEBCO Allen Coral Atlas	GEBCO Allen Coral Atlas	Water depth	Global (450m) Global (10m	No	GEBCO
Topography	SRTM PLUS	NASA	Land elevation	Global (90m)	No	SRTM
Mangroves	Global Mangrove Watch 3.0	UN-WCMC	Mangrove distribution	Global (1km)	1996-2020 (annual)	GMW 3.0
Population	GHS-POP – R2022A	European Commission	# of people	Global (250m and 1km)	1975-2020 (annual)	GHS-POP
Capital stock	Penn World Table 10.0	The World Bank	Capital stock at constant 2017 national prices	Global (country)	1950-2019 (annual)	PWT 10.0
Consumer price index	CPI	The World Bank	Consumer price index	Global (country)	1960-2021 (annual)	CPI
Damage function people	People damage curve	Self-produced	% damage to people	Global	No	People evacuation standard
Damage function stock	Capital stock damage curve	Self-produced from: Fema-Hazus JRC-European Commission	% damage to capital stock	Global	No	FEMA-Hazus JRC

3.2 MANGROVE DATA

Global Mangrove Watch (GMW) released an updated version (GMW 3.0) of global mangrove coverage in August 2022 (Bunting et al. 2022). This release includes new mangrove distribution maps corresponding to the 2016 to 2020 period and updates/improvements of the historical mangrove distribution data for the period 1996 to 2015. In CWON 2021, we used GMW 2.0 for the time periods 1996, 2010, and 2015. In this new report we used GMW 3.0 to update 1996 to 2015 mangrove coverage and added a new time point corresponding to 2020. The most significant difference in these datasets is that the improved GMW 3.0 shows a consistently greater global coverage than GMW 2.0 (about 7 percent greater, see Figure 3.1). To consistently assess mangrove benefits over time, all data (not just 2020) were updated, the flood models were re-run, and new assessments of risk and benefits were developed.

FIGURE 3.1: DIFFERENCES IN GLOBAL MANGROVE COVER BETWEEN GMW 2.0 AND GMW 3.0



Despite observing changes in the total area of mangroves, we discovered that these alterations had minimal impact on the results. This is due to the fact that the crucial factor driving variations in coastal flooding, which is the cross-shore width of the mangrove forest, remained relatively stable or exhibited minimal change in the new data. It is important to emphasize that modifications in the overall area of mangroves do not necessarily correspond to changes in flood risk, as the effectiveness of mangroves' protection services is primarily influenced by the cross-shore width, which exhibited limited variation.

The GMW has generated a global baseline map of mangroves for 2010 using ALOS PALSAR and Landsat (optical) data, and changes from this baseline for seven epochs between 1996 and 2020 derived from JERS-1 SAR, ALOS PALSAR, and ALOS-2 PALSAR-2. Annual maps are planned from 2018 and onwards. The primary objective of the GMW has been to provide countries with mangrove extent and change maps to help safeguard against further mangrove forest loss and degradation. The GMW aims to provide geospatial information about mangrove extent and changes to the Ramsar Convention, national wetland practitioners, decision-makers, and nongovernmental organizations.

3.3 POPULATION DATA

Global exposure data for people was obtained from GHS-POP grid dataset from the European Commission (https://ghsl.jrc.ec.europa.eu/ghs_pop2022.php).[4] This new package, released in 2022 (GHS R2022A, (Schiavina et al. 2022)) substitutes the previous version (GHS R2019) and provides estimates of global populations and their distribution for 1975, 1990, 2000, 2015, and 2020, as well as future projections to 2025 and 2030. GHS R2022A matches or outperforms other data sources for accuracy in epochs 2018 and 2020 and matches or outperforms also all the other single epochs (1975, 1990, 2000, and 2015) included in the previous release GHS R2019. The global distribution of population used for 1996, 2010, and 2015 is 250m resolution (GHS R2019), while 2020 population distribution released in 2022 (GHS R2022A) with the new version is at 1km resolution.

3.4 CAPITAL STOCK DATA

This study uses data from PWT 10.0 from the Groningen Growth and Development Center (https://www.rug.nl/ggdc/productivity/pwt/). This version is a database with information on relative levels of income, output, input, and productivity. The table covers 182 countries and 70 years (1950–2019). We used the nationwide data of capital stock at constant 2017 national prices and transformed these into constant 2020 national prices by using country-based consumer price index. Then, we calculated the stock per capita at each country and multiplied these national values by the population located at each grid cell. We then obtained the global stock distribution at 250m resolution. There were 22 tropical nations that had mangroves but were not included in the PWT; we filled most of these gaps with national data from the World Bank. There were a few remaining countries and territories that we were not able to include in the analyses due to the lack of economic data, including Eritrea, French Guiana, New Caledonia, Micronesia, Palau, Somalia, Guadeloupe, Martinique, Timor Lester, Mayotte, Samoa, US Virgin Islands, Saint Martin, and American Samoa.

The new updated version of the PWT (10.0, Feenstra et al. 2015) was released in June 2021. We used the capital stock at constant national prices ("rnna") and total population ("pop") to calculate the gross domestic product (GDP) per capita ratio at national level. Several changes have been introduced in the most recent version of PWT 10.0 relative to the version used in the previous CWON report (PWT 9.1). These differences result in changes in the economic valuation of mangroves worldwide. The main updates are described below:

- Capital stock in PWT 9.1 was in constant 2011 national prices, while capital stock in PWT 10.0 is in constant 2017 national prices.
- In PWT 9.1, the time series was 1950 to 2017. PWT 10.0 covers the period 1950 to 2019.
- Capital stock was recalculated in some countries (e.g. China, Sudan) using an outdated nominal value for GDP. Capital stock values are remarkably higher than previously estimated in some countries.

4 The Global Urban Footprint primarily focuses on urban areas and their extent, which may not accurately capture the distribution and density of human settlements in coastal regions. The Global Human Settlement dataset, on the other hand, provides more comprehensive coverage of human settlements, including both urban and rural areas. When assessing the impact of coastal storms, it is essential to consider not only the built environment but also the vulnerability and exposure of the population. The Global Human Settlement dataset incorporates population distribution and density, allowing for a more accurate estimation of the number of people at risk from coastal flooding.

3.5 CONSUMER PRICE INDEX

For this new analysis, we first transformed capital stock in constant 2017 national prices to capital stock in constant 2020 national prices using the 2021 updated country-based consumer price index from the World Bank. The index is the most widely used measure of inflation and is sometimes viewed as an indicator of the effectiveness of government economic policy.

The adjustment applied in this analysis is described by the equation below.

Where V is the capital stock value in any given year's constant national price and CPI is the consumer price index.

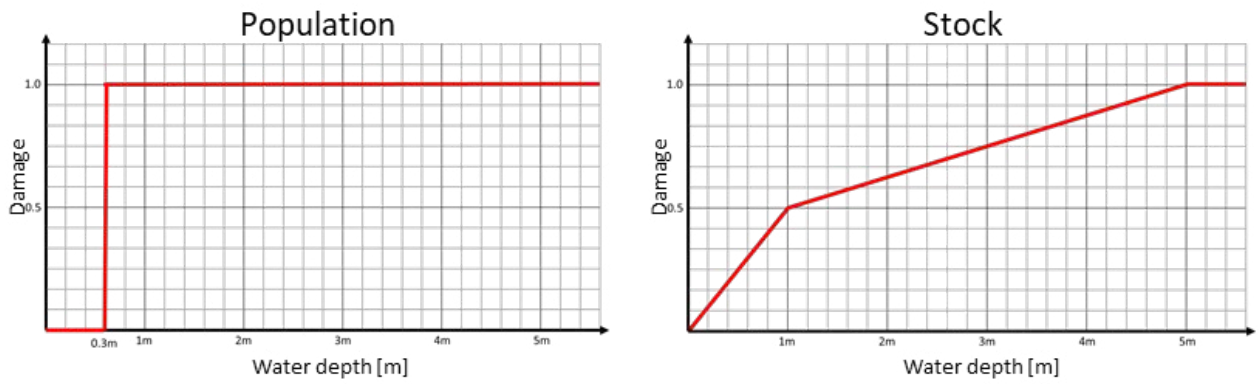
$$\frac{V_{2017}}{V_{2020}} = \frac{CPI_{2017}}{CPI_{2020}} \rightarrow V_{2020} = V_{2017} \cdot \frac{CPI_{2020}}{CPI_{2017}}$$

3.6 DAMAGE FUNCTIONS

Global flood depth damage functions are needed to evaluate the sensitivity of people and property damaged at different flood levels. The report from the EU Joint Research Centre (JRC) collected data from Africa, Asia, Oceania, North America, South America, and Central America and proposed damage functions for residential and industrial stock in each region (Huizinga et al. 2017). We refer to these as JRC damage functions. These damage functions are a better alternative to damage curves from FEMA Hazus (Scawthorn et al. 2006), which were based only on US collected data but were frequently extrapolated for use in other geographies. JRC damage functions aim to address flooding effects on property globally, developing a consistent database of depth-damage curves. We used both, JRC and Hazus to calculate capital stock damages (Figure 3.2). Capital stock damage results from the integration of global JRC damage functions, calibrated with Hazus damage curves for different building types.

The damage curve for people was built based on a commonly used threshold in civil protection services to decide when people must be evacuated. It indicates that no people are affected in areas with less than 30cm water depth, and 100 percent of people affected in areas with water depth above 30cm (Figure 3.2).

FIGURE 3.2: FLOOD DEPTH DAMAGE CURVES FOR PEOPLE AND STOCK



4 Results

4.1 MANGROVE COVER

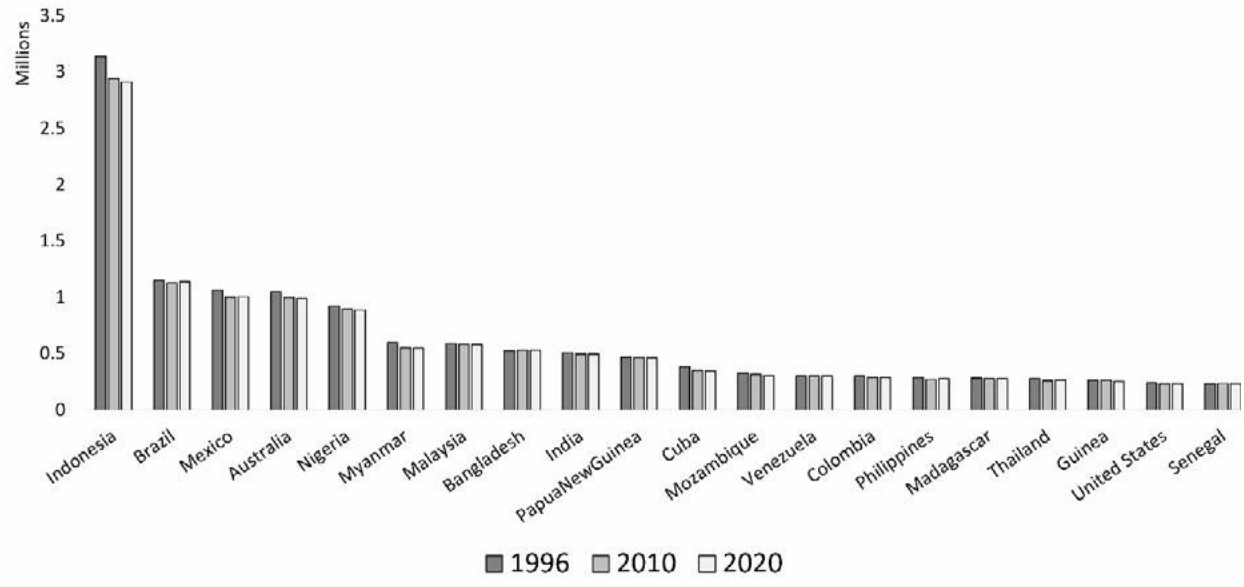
Mangrove extent declined significantly at the end of last century and the first decade of the current century. According to the GMW dataset, almost 4 percent of global mangrove cover was lost between 1996–2010, from 158,000km^2 to 151,000km^2. Countries such as Indonesia, Mexico, Australia, Myanmar, Cuba, Nigeria, Bahamas, and Brazil lost the most mangrove forest in the late 1990s and early 2000s (Figure 4.1b). In this period, a few countries saw gains in mangroves (Appendix 2, tables A4 and A6), which included countries in in Africa (Suriname, the Gambia, Guyana, Senegal, Gabon, Liberia, and Cameroon) and Central America (Nicaragua, Honduras, El Salvador, Panama, and Costa Rica).

However, from 2010 to 2020, only 0.66 percent of global mangrove cover was lost. Many countries that had previously experienced significant mangrove loss (Appendix 2, tables A5 and A7), now saw gains between 2 percent and 25 percent in mangrove area (e.g., Turks and Caicos, Oman, Djibouti, Peru, China, and Thailand). In contrast, there are still nations where mangroves experienced significantly higher losses in the last decade than within the period 1996 to 2010 (Appendix 2, tables A5 and A7): Saudi Arabia, Taiwan, Jamaica, Honduras, Nicaragua, Puerto Rico, and Costa Rica experienced an increasing mangrove loss rate between 5 percent and 25 percent.

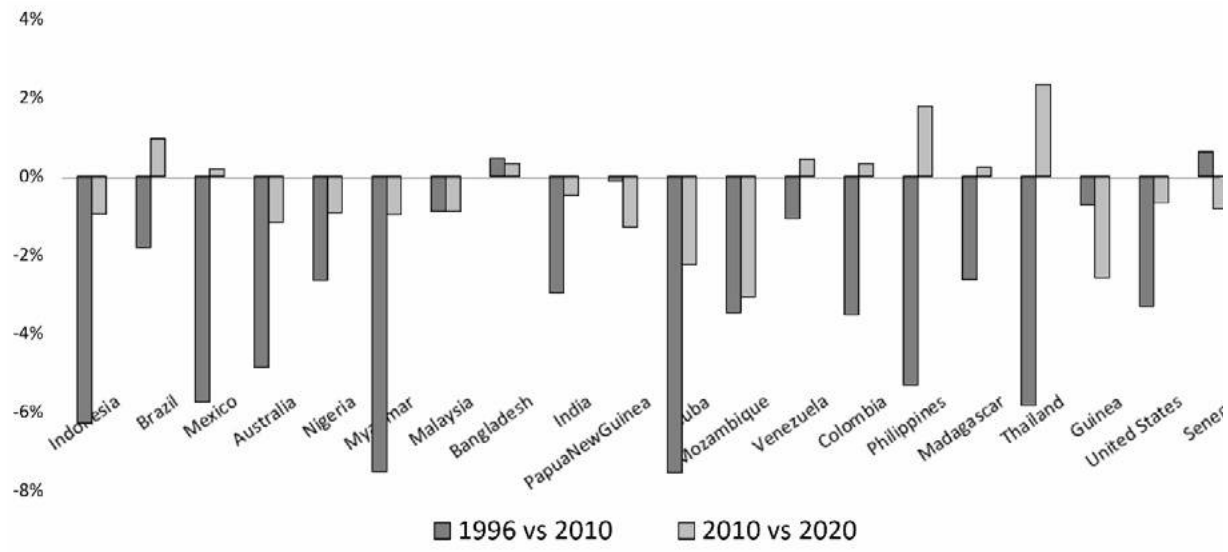
The change in the coverage of mangroves is spatially variable, which affects the protection provided by mangroves. The effect on flood height at the shore is the best way to consistently compare how mangrove loss (and gain) affects flooding.

FIGURE 4.1: MANGROVE AREA IN THE TOP 20 COUNTRIES WITH MORE MANGROVES IN 1996

a) Mangrove area [ha]



b) Changes in mangrove area [ha]

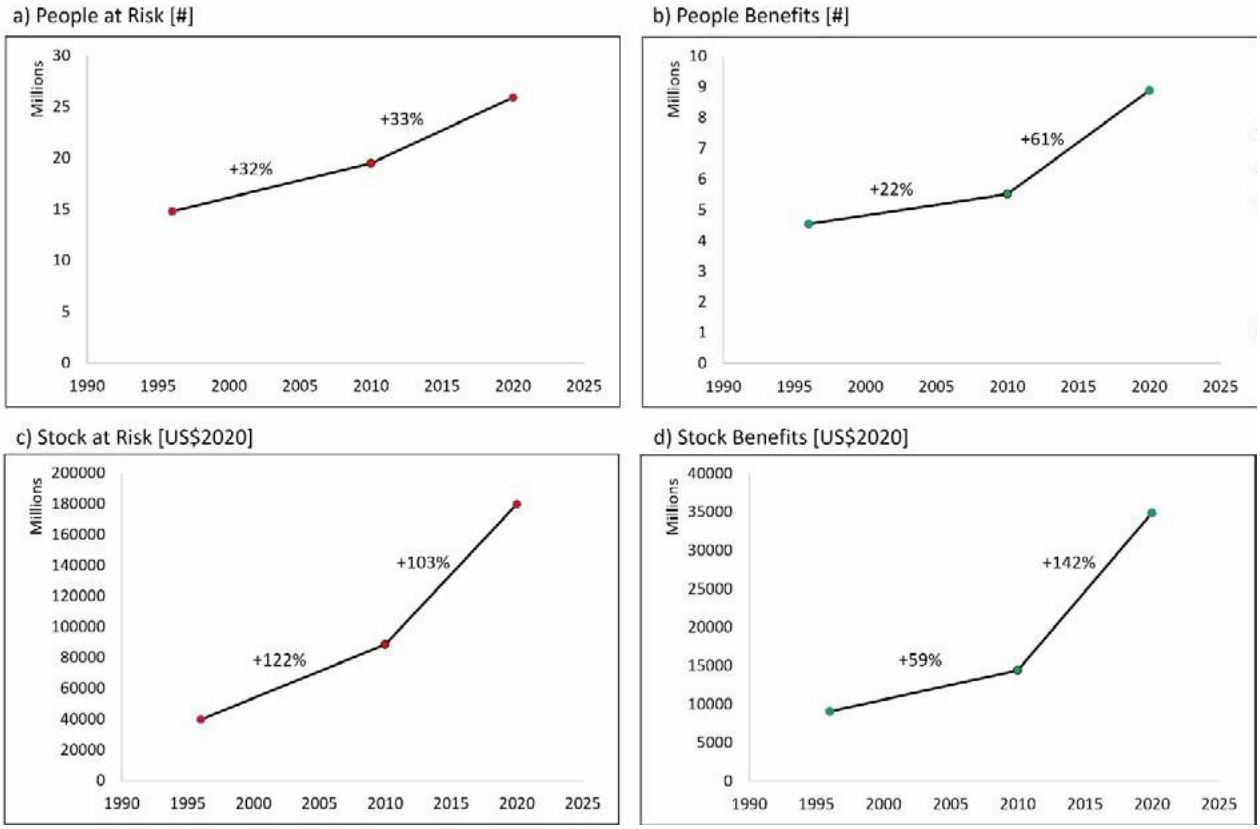


Note: Panel (a) shows the total hectares of mangrove in 1996, 2010, and 2020. Panel b) shows the percentage change in mangrove area from two-time frames: 1996 to 2010 and 2010 to 2020 (top 20 countries with the largest mangrove cover shown).

4.2 OVERALL RESULTS: FLOOD RISK AND BENEFITS

4.2.1 Flood Risk and Mangrove Benefits Globally Aggregated

FIGURE 4.2: GLOBAL FLOOD RISK AND MANGROVE FLOOD PROTECTION BENEFITS TO PEOPLE AND CAPITAL STOCK (1996– 2020)



Note: The results are divided into two periods: 1996–2010, 2010–2020

We observed different trends in flood risk and flood benefits across two different periods (1996 to 2010 and 2010 to 2020). From 1996 to 2010, when mangrove loss was more severe globally (about 4 percent), flood risk increased more than mangrove benefits (32–122 percent increase in risk versus a 22–59 percent increase in benefits, see Figure 4.2). In contrast, from 2010 to 2020, when mangrove loss slowed down (about 0.7 percent), flood risk increased less than mangrove benefits (33–103 percent increase in risk versus a 61–142 percent increase in benefits, see Figure 4.2). As coastal flooding increases slowed down, more people started living in mangrove-protected areas, resulting in high benefits and higher potential risks in the future if we experience similar losses to those experienced from 1996 to 2010.

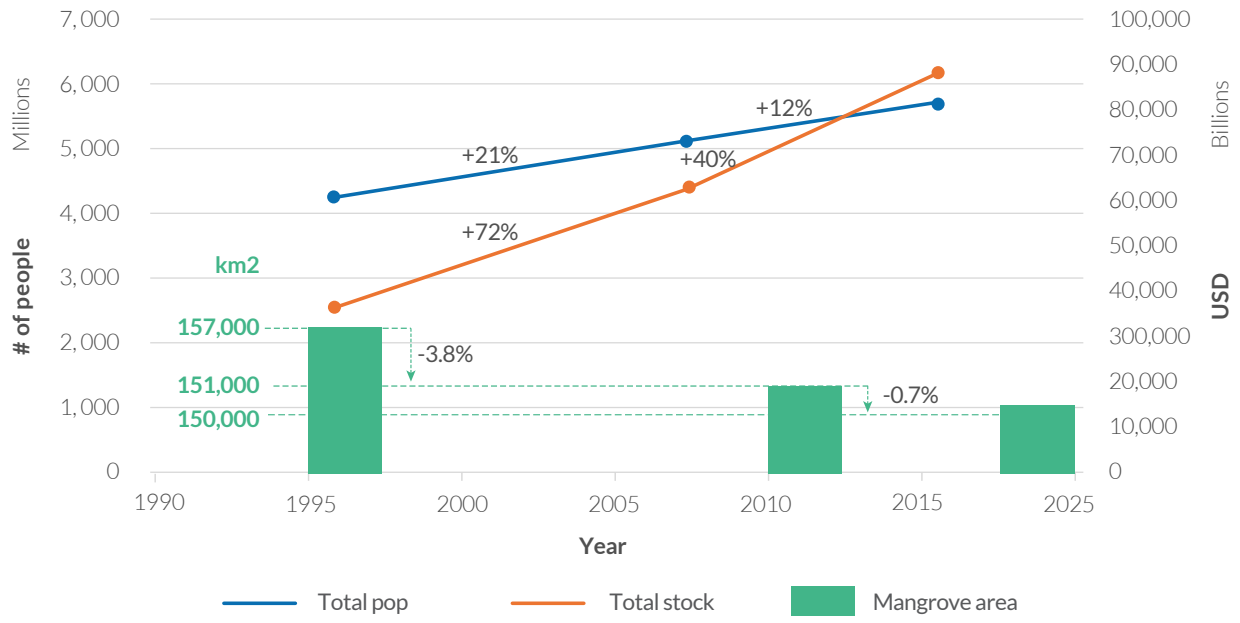
There are two reasons that explain this global pattern change:

- Flood extent in 2010 increased significantly due to the 4 percent mangrove loss, rapidly reducing the land area protected by mangroves and preventing people from settling in mangrove-protected zones.
- Flood extent did not increase significantly from 2010 to 2020, resulting in more people and economic opportunities in the mangrove-protected zones than in previous decades.

Relative contribution of the socioeconomic development and mangrove decline in flood risk:

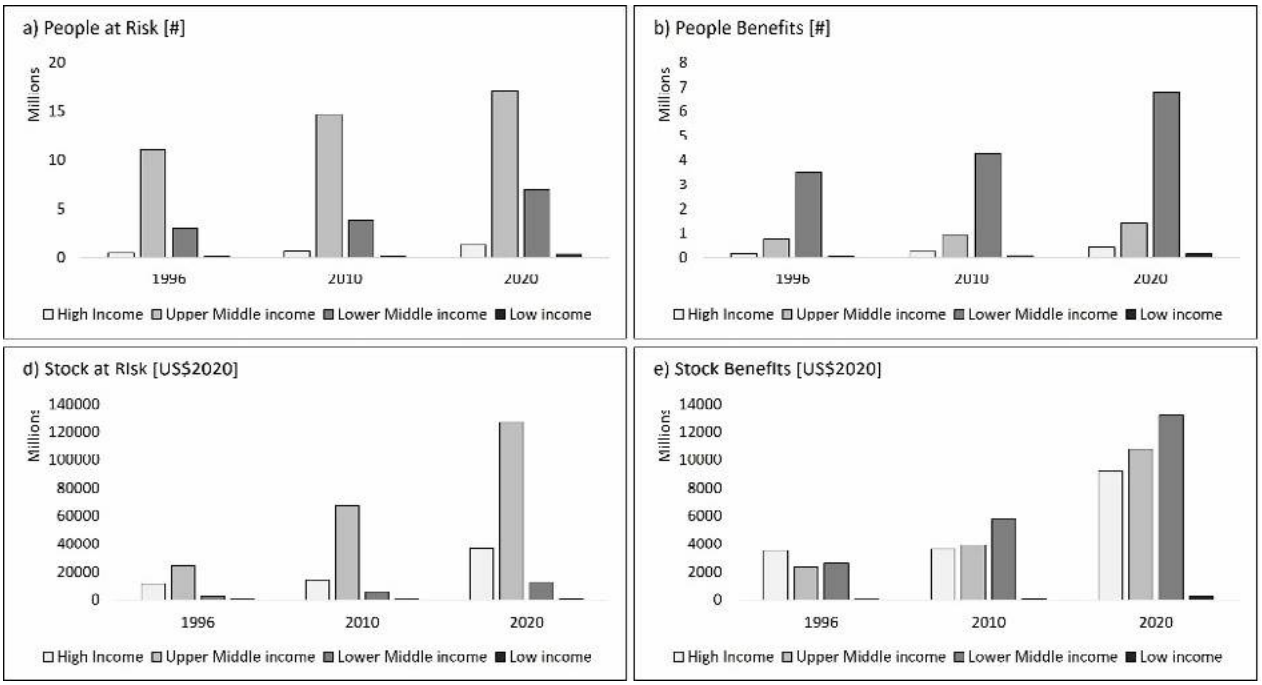
The impact of flood risk caused by a combination of economic growth and changes in mangrove forests is not straightforward. This means that we cannot simply measure how much each factor contributes to the overall increase in flood risk. For example, between 1996 and 2010, there was a 3.8 percent reduction in mangrove cover, a 21 percent increase in population, and a 72 percent rise in capital stock (Figure 4.3). These changes led to a 32 percent increase in risk to people and a 122 percent increase in losses of capital stock due to flooding. Then, from 2010 to 2020, despite a smaller mangrove loss (0.66 percent), a 12 percent growth in population, and a 40 percent increase in capital stock, there was still a 33 percent increase in the risk to people and a 103 percent rise in capital stock losses (Figure 4.3). This complex impact happens because more people and valuable assets are moving into areas that used to be protected by mangroves but are now at risk of flooding due to a larger flooded area.

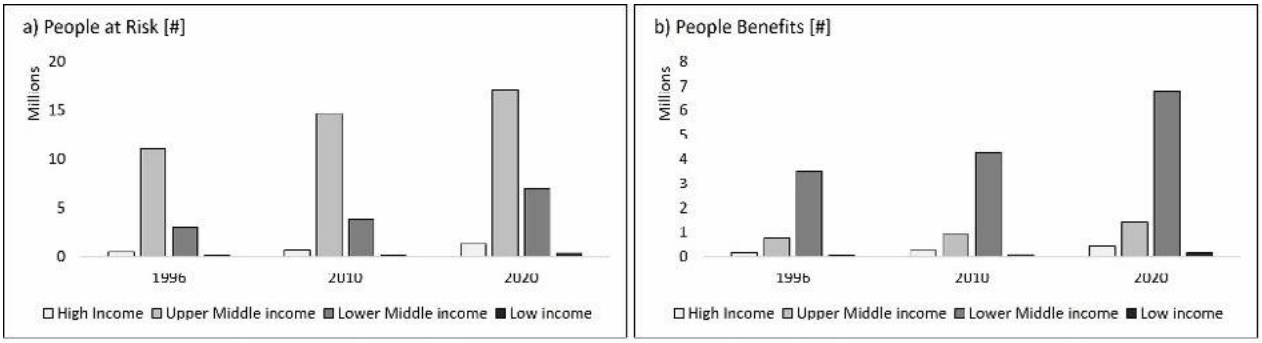
FIGURE 4.3: CHANGES IN TOTAL POPULATION, TOTAL CAPITAL STOCK, AND TOTAL AREA OF MANGROVES ACROSS 97 COUNTRIES (1996–2020)



4.2.2 Flood Risk and Mangrove Benefits by Income Level

FIGURE 4.4: FLOOD RISK AND MANGROVE BENEFITS TO PEOPLE AND CAPITAL STOCK BY INCOME LEVEL





If we analyze the effect of mangrove loss and socioeconomic growth by countries split by income level, we observe the following:

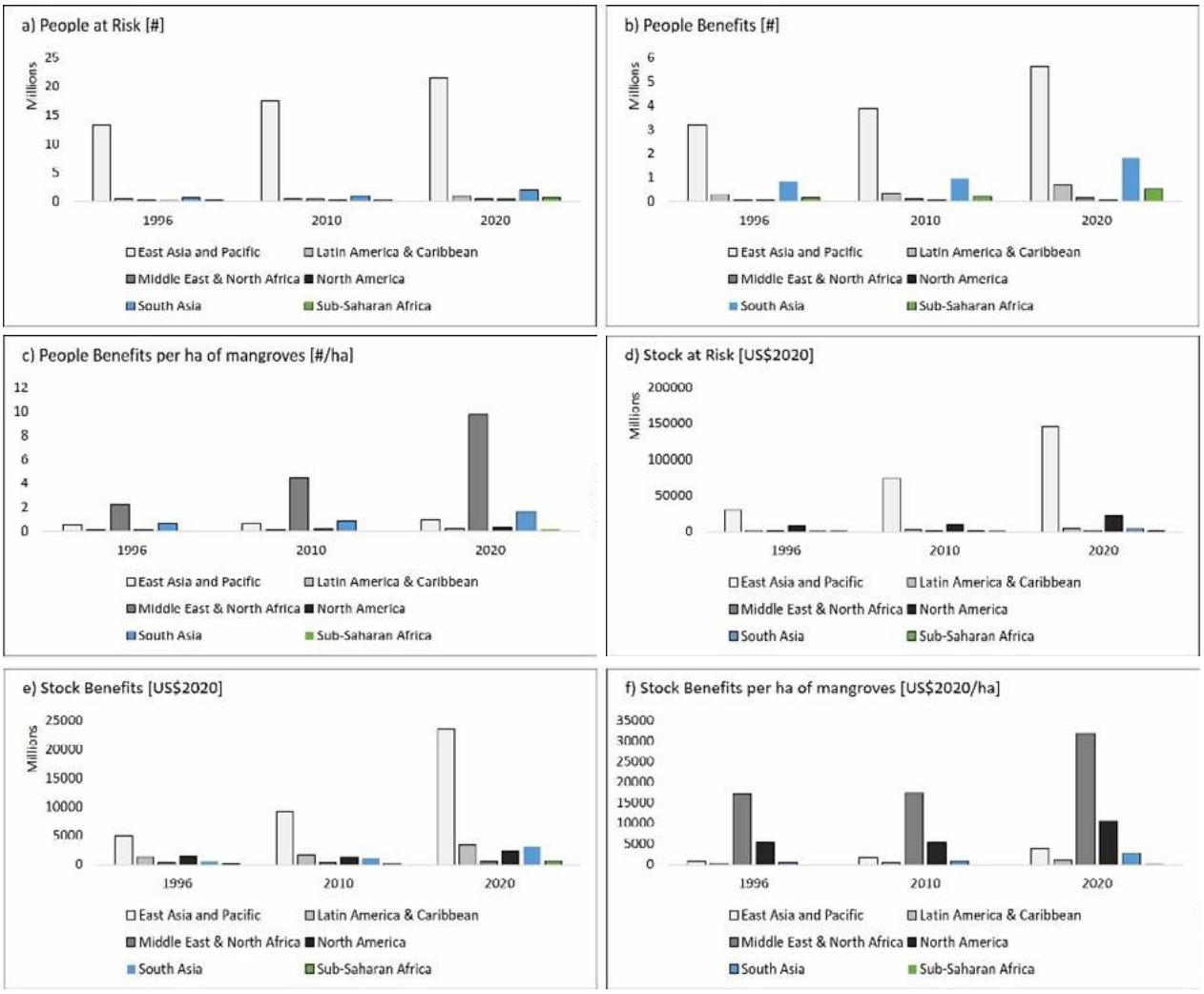
- While upper-middle income countries present the highest risk values (panels (a) and (d) in Figure 4.4), lower-middle income countries show the highest values in terms of benefits provided by mangroves (panels (b) and (e)). This means that mangroves provide more benefits to lower-income communities because in those countries more people live in the mangrove-protected belt.
- In low-income countries, each hectare of mangrove protects more people from flooding (panel (c)) than capital stock (panel (f)). Accounting for the social impact of flooding allows us to highlight the importance of mangrove habitat defending low-income communities.
- The opposite happens in high-income countries, where the economic protection of mangroves (panel (f)) is higher than the social protection (panel (c)).

If we focus on the two different periods (1996 to 2010 and 2010 to 2020) in Figure 4.4, we find differences in patterns than those observed at global scale (Figure 4.2):

- Upper-middle and low-income countries present the same pattern observed at global scale, where flood risk increases more than mangrove benefits in 1996 to 2010, and where flood risk increases less than benefits in 2010 to 2020 (panel (a) versus (b) and panel (d) versus (e) in Figure 4.4).
- High-income countries present a reverse pattern in terms of people, where the number of people at flood risk increased less than the number of people receiving benefits from mangroves in 1996 to 2010 and flood risk increased more than benefits in 2010 to 2020 (panel (a) versus (b) and panel (d) versus (e) in Figure 4.4). This is because coastal population growth in the last decade in high-income countries tends to settle in areas that are potentially flooding under extreme events.

4.2.3 Flood Risk and Mangrove Benefits by World Bank Region

FIGURE 4.5: FLOOD RISK AND MANGROVE BENEFITS TO PEOPLE AND CAPITAL STOCK BY WORLD BANK REGION



By analyzing the time evolution of flood risk and mangrove benefits by World Bank region, we found that the East Asia and Pacific region concentrates 90 percent of the global flood risk and benefits to people and capital stock (Figure 4.5). However, when these risks and benefits are weighed by the area of mangrove, the Middle East and North Africa region stands out due to the lower number of mangrove forests providing valuable protection. The per hectare value of this region exceeds $30,000/hectare in 2020, while the North America mangroves provide the second highest value of flood protection of $10.500/hectare (panel (f) in Figure 4.5). On the opposite side, the lowest unitary value of flood protection benefits from mangroves occurs in Sub-Saharan Africa, where each hectare of mangrove protected $195 in capital stock in 2020; and Latin America and the Caribbean, with a value of $880/hectare (panel (f) in Figure 4.5).

The Middle East and North Africa is the region with the most people protected by hectare of mangrove (panel (c) in Figure 4.5). In 2020, each hectare of mangrove protected an average of 10 people in the Middle East and North Africa. In contrast, in Sub-Saharan Africa and Latin America and the Caribbean, only 0.17 people received direct protection from mangroves in 2020.

4.2.4 Flood Risk and Mangrove Benefits by Country

1996–2010

Flood risk increased substantially from 1996 to 2010. The increase in risk was driven by population and economic growth in coastal areas and countries, as well as from an increase in flooding due to mangrove decline on many coastlines. The countries with the most people annually affected by coastal flooding in 2010 were China, Vietnam, India, the Philippines, and Indonesia. Each of these five countries had more than 400,000 people at risk of flooding annually (Appendix 2, Table A2). The countries with the greatest percentage increase in annual flood risk to people from 1996 to 2010 were Eritrea, Angola, Tonga, Qatar, and Thailand (Appendix 2, Table A6). All these countries had a more than two-fold risk to people in a 15-year period (1996–2010).

The countries leading the economic risk ranking in 2010 were China, the US, Taiwan, Vietnam, and Australia. Each of these five countries was predicted to have more than $1.6 billion in flood losses annually in 2010 (Appendix 2, Table A2). In relative terms, economic flood risk increased the greatest in African countries (Sudan, Angola, Tanzania, Mozambique), where they had at least 1.5 times more economic losses in the 15-year period 1996 to 2010 (Appendix 2, Table A6).

From 1996 to 2010, 0.98 million more people (22 percent) received flood reduction benefits from mangroves annually (Figure 4.2). The countries receiving the most flood risk reduction benefits to their coastal communities from mangroves in 2010 were Vietnam, India, China, Indonesia, and the Philippines (Appendix 2, Table A2). In each of these countries, mangroves are predicted to reduce flood risk to more than 250,000 people annually. The countries where mangrove benefits increased the most from 1996–2010 were Vietnam, India, Brazil, China, and Indonesia. In each of these countries, the increase in people protected by mangroves exceeded 57,000 annually (Appendix 2, Table A4). However, 20 countries experienced a reduction in flood benefits, such as Thailand, Guyana, Puerto Rico, Haiti, and Jamaica, with more than 1,300 people at greater risk in 2010 than in 1996 (Appendix 2, Table A4).

From 1996 to 2010, we estimated that annual flood reduction benefits from mangroves to capital stock increased by $5.3 billion (59 percent) (Figure 4.2). The highest mangrove benefits in 2010 were measured in Vietnam, China, Australia, the US, and Indonesia, with all five countries receiving more than $80 million in annual capital stock protection from mangroves (Appendix 2, Table A2). The increase from 1996 to 2010 was particularly high in Vietnam, China, Puerto Rico, India, and Indonesia, with annual flood reduction benefits from mangroves to capital stock increasing by at least $246 per country (Appendix 2, Table A4). Twenty-two countries, such as Thailand, the US, the United Arab Emirates, the Philippines, and Jamaica present the reverse pattern, where mangrove benefits declined between $5.5 million and $100 million (Appendix 2, Table A4).

2010–2020

Between 2010 and 2020, the changes in flood risk were driven almost exclusively by socioeconomic growth rather than mangrove degradation. The total population in countries with mangroves increased by 12 percent while total capital stock grew by 40 percent in this period. In contrast, mangrove degradation slowed down to 0.66 percent globally (Figure 4.3). This overall pattern does not apply everywhere, as we will describe below.

From 2010 to 2020, the countries with the most people annually affected by coastal flooding in 2020 are the same as those in 2010. China, Vietnam, India, the Philippines, and Indonesia are the top five; all of them exceeding 700,000 people at risk of flooding annually (Appendix 2, Table A3). However, the highest percent increases in flood risk to people were observed in Grenada, the Gambia, Mayotte, and the US Virgin Islands (Appendix 2, Table A7). All these countries multiplied by 15 the risk in the 10-year period (2010–2020). In two nations, Eritrea and Kiribati, flood risk to people decreased between 2010 and 2020, where we observed a 50 percent and 39 percent risk reduction respectively (Appendix 2, Table A7). This decline is mostly explained by a reduction in the coastal population, but it can also be partially explained by the improvement in mangrove conservation and restoration. For example, Kiribati experienced no mangrove loss between 2010 and 2020, according to the GMW dataset.

From 2010 to 2020, the economic risk in mangrove areas increased more significantly than the social risk. We predicted that annual economic flood risk increased by 103 percent ($91 billion) from 2010 to 2020 across all mangrove coastlines (Figure 4.2), particularly in China, the US, Australia, Taiwan, and Vietnam, where annual flood risk was predicted to exceed $4.5 billion per country in all these countries in 2020 (Appendix 2, Table A3). The countries with the highest relative increase in the economic risk of flooding between 2010 and 2020 were Grenada, the Gambia, Guyana, and Equatorial Guinea (Appendix 2, Table A7); in each of these countries annual economic flood risk multiplied by more than 15 from 2010 to 2020. In the same period, there are seven countries where flood risk to capital stock decreased. The top five countries are Sudan, Somalia, Kiribati, Seychelles, and Timor Leste, all of them with more than 47 percent in flood risk reduction (Appendix 2, Table A7). Three of these five countries did not experience significant mangrove loss greater than 0.22 percent from 2010 to 2020.

From 2010 to 2020, 3.4 million (61 percent) more people received annual flood reduction benefits from mangroves (Figure 4.2). The countries receiving the most benefits to coastal populations in 2020 were Vietnam, India, China, Bangladesh, and Indonesia;, with all five countries exceeding 450,000 people protected annually by mangroves (Appendix 2, Table A3). The countries where mangrove benefits increased the most from 2010 to 2020 were Vietnam, Bangladesh, India, China, and Cameroon. In each of these countries, the increase in people protected by mangroves exceeded 145,000 more people protected in 2020 than in 2010 (Appendix 2, Table A5). However, there were seven countries where mangrove benefits declined in this five-year period, such as in Malaysia, Myanmar, Taiwan, Pakistan, Colombia, Jamaica, and French Polynesia (Appendix 2, Table A5).

From 2010 to 2020, we estimated that annual flood reduction benefits from mangroves to capital stock increased by $20.5 billion (142 percent) globally

(Figure 4.2). The countries receiving the highest economic benefits from mangroves in 2020 were China, Vietnam, Australia, the US, and India, with the five countries exceeding $1,620 million in flood protection benefits every year (Appendix 2, Table A3). The highest increase in benefits between 2010 and 2020 was observed in China, Vietnam, Australia, the US, and Bangladesh, each with more than $1,170 million more benefits in 2020 than in 2010 (Appendix 2, Table A5). On the other hand, the four countries with the highest reduction in economic benefits of mangroves were Jamaica, Timor Leste, Belize, and Pakistan, all of them with a benefit reduction up to $7.5 million (Appendix 2, Table A5).

4.3 MANGROVE ASSET VALUE AND CHANGING WEALTH

Following the same approach as the previous CWON report, we are interested in the annual benefits from mangroves and the asset value of mangroves. Some assets, like manufactured capital, are traded in markets with market prices established that represent the value of the asset. But mangroves and the services they provide, like much of natural capital, are not (yet) traded in markets.

For assets like mangroves that do not have market prices, we rely on the economic definition of asset value: the discounted sum of the services mangroves can be expected to generate over their lifetime. This approach has two major components, i) estimation of the value of services using non-market valuation techniques like the expected damage function that was applied to estimate annual flood protection benefits, and ii) projections of the generation of these services in the future.

The previous sections described how coastal protection services are measured and valued over past periods. We now turn to the second component of asset valuation, projections about the generation of protection services by mangroves in the future. This requires the following information:

- A discount rate: 4 percent is used to discount all other assets in CWON so we will apply the same discount to mangrove assets.
- Lifetime over which coastal protection services will be valued: Following international accepted approaches and best practice for valuing natural capital and ecosystem assets (United Nations et al. 2014 and 2021; United Nations Department of Economics, 2021; Ramachandra, 2021), we have assumed a 100-year project lifespan for these coastal habitat assets, which is consistent with other infrastructure assets. Given that these habitats have survived for millennia in these environments (and past sea levels), this is a reasonable assumption. Of course, it will be a management choice to help keep these natural defenses in place over this time period.

The present value (2020) of the global flood reduction benefits from mangroves (100-year asset at 4 percent discount rate) is $855 billion. The countries with the greatest present value of mangroves for flood reduction are China, Vietnam, Australia, the US, and India (Table 4.1).

The increase in the wealth of mangroves for flood risk reduction from 1996 to 2010 was estimated to be over $130 billion (Table 4.1). The countries receiving the greatest increases in wealth in absolute values (US dollars) are Vietnam, China, Puerto Rico, India, and Indonesia (Appendix 2, Table A4), and in relative

values (percent) were Somalia, Djibouti, the Solomon Islands, Vietnam, and Equatorial Guinea (Appendix 2, Table A6). Despite mangrove losses, most countries still saw increases in the asset value or wealth of mangroves for flood risk reduction, largely because of overall increases in flood risk (growth of people and assets on coastlines). However, some nations (22) saw overall losses in mangrove wealth for flood risk reduction, including, most notably, Thailand, the US, Timor Leste, the United Arab Emirates, and Ecuador (Appendix 2, Table A4).

The increase in the wealth of mangroves for flood risk reduction from 2010 to 2020 was estimated to be over $502 billion (Table 4.1). The countries receiving the greatest increases in wealth in absolute values (US dollars) are China, Vietnam, Australia, the US, and Bangladesh (Appendix 2, Table A5), and in relative values (percent) were South Africa, Guyana, Vanuatu, Grenada, and St Lucie (Appendix 2, Table A7). The countries that presented overall losses (four) in mangrove wealth for flood risk reduction were Jamaica, Timor Leste, Belize, and Pakistan (Appendix 2, Table A5).

TABLE 4.1: TOP 20 COUNTRIES IN MANGROVE ASSET VALUE (100YRS AT 4% DISCOUNT) AND ANNUAL EXPECTED BENEFIT FOR FLOOD PROTECTION

COUNTRY	ANNUAL EXPECTED BENEFIT 2020 (# PEOPLE)	ANNUAL EXPECTED BENEFIT 2020 (CAPITAL STOCK)	PRESENT VALUE 1996	PRESENT VALUE 2010	PRESENT VALUE 2020	CHANGE IN PRESENT VALUE 1996–2010	CHANGE IN PRESENT VALUE 2010–2020
China	764,842	7,463,666,893	22,325,626,254	57,590,390,949	182,897,149,728	157.96%	217.58%
Vietnam	3,673,309	7,418,425,588	21,322,836,434	80,523,754,704	181,788,511,594	277.64%	125.76%
Australia	111,606	5,072,180,073	39,671,971,954	41,626,768,977	124,293,767,602	4.93%	198.59%
The US	64,247	2,436,538,383	31,208,751,490	29,457,160,897	59,707,370,632	-5.61%	102.69%
India	1,144,050	1,620,261,180	10,407,317,477	18,292,841,975	39,704,498,591	75.77%	117.05%
Indonesia	489,596	1,532,916,500	13,879,234,598	19,908,597,438	37,564,117,295	43.44%	88.68%
Bangladesh	621,358	1,354,057,650	2,260,971,180	4,473,494,384	33,181,181,355	97.86%	641.73%
Mexico	161,141	1,311,000,444	11,581,011,139	13,741,068,381	32,126,064,565	18.65%	133.80%
Puerto Rico	17,258	996,394,598	9,324,186,523	19,060,043,528	24,416,648,625	104.42%	28.10%
Brazil	265,511	773,487,112	7,430,052,752	9,297,772,021	18,954,300,904	25.14%	103.86%
Philippines	327,137	591,802,185	12,182,335,903	12,045,729,307	14,502,111,950	-1.12%	20.39%
Suriname	69,710	505,220,635	4,950,349,657	7,299,683,830	12,380,431,154	47.46%	69.60%
Japan	2,485	411,913,542	1,202,150,313	913,169,304	10,093,940,934	-24.04%	1005.37%
U. A. Emirates	111,891	308,394,623	7,988,337,549	7,316,262,099	7,557,209,927	-8.41%	3.29%
Taiwan	70,762	271,882,632	3,288,095,836	6,250,250,190	6,662,483,625	90.09%	6.60%
New Caledonia	1,384	251,396,603	865,343,094	2,833,844,905	6,160,473,504	227.48%	117.39%
New Zealand	1,186	223,056,032	1,023,807,610	1,104,894,922	5,465,987,840	7.92%	394.71%
Thailand	23,646	211,367,279	4,626,181,186	2,160,197,680	5,179,554,960	-53.30%	139.77%
Cuba	9,227	157,240,605	1,175,008,404	1,114,094,784	3,853,180,868	-5.18%	245.86%
Ecuador	16,398	144,993,398	1,417,540,996	1,006,511,124	3,553,063,073	-29.00%	253.01%
World total	**8,884,573**	**34.88**	**222,281**	**352,638**	**854,824**	**58.64%**	**142.41%**

5 Discussion

Traditional methods for measuring economic progress, such as GDP, mainly account for market goods and services and overlook the non-market contributions of nature. As a consequence, the benefits provided by habitats are undervalued, as only those services that can be directly taken from the ecosystem are assessed, such as the fish and timber harvests. Essential non-market services such as flood protection and blue carbon sequestration, which depend on habitat preservation, are seldom evaluated. To prevent the depletion of natural capital and ensure the provision of crucial ecosystem services, policy makers and land managers should incorporate these values into their decision-making processes. By conducting better valuations, decision-makers can better meet their management objectives for environmental conservation and hazard mitigation.

In recent years, there have been updates to the data on mangroves, populations, and the PWT. These updates have changed specific quantitative estimates of risk and mangrove benefits, but the overall patterns and country rankings have remained unchanged (i.e., no qualitative changes in results). Unfortunately, flood risks continue to rise in most countries owing to continued growth of coastal populations and built-up infrastructure.

However, mangrove losses did slow after 2010 and, in some countries, mangroves are increasing. As a result, the value of mangroves for flood risk reduction continues to increase. For the first time, in the period 2010 to 2020, flood protection benefits from mangroves increased faster than flood risk. The phenomenon of flood protection benefits increasing at a higher rate than flood risk can be attributed to the significant population migration towards mangrove-protected areas. This coastal population migration puts substantially more people at risk of flooding if mangrove habitat is not maintained by nations. As more people settle in mangrove-protected areas, the contrast between the escalating flood risk in the absence of mangroves and the moderated flood risk with mangroves becomes more evident, resulting in the observed trend of flood protection benefits outpacing flood risk for the first time.

Interestingly, the highest per hectare economic value of mangroves occurs in high-income countries, while the highest per hectare number of people protected takes place in lower-middle income countries. This trend can be attributed to variations in both mangrove ecosystems and socioeconomic conditions. High-income countries often have more developed infrastructure and industries that benefit from mangroves' ecological services, whereas lower-middle income countries may rely heavily on these ecosystems for direct livelihoods and protection, even though the economic value per unit area may be lower.

Currently, the global flood reduction benefits from mangroves have a present value of $855 billion. The countries with the greatest present value of mangroves for flood reduction are China, Vietnam, Australia, the US, and India. The overall change in the wealth of mangroves for flood risk reduction from 1996 to 2010 was estimated at over $130 billion, and from 2010 to 2020 over $502 billion. The rapid increase in asset value observed globally is attributed to the dual impact of the protective function of mangroves and the high population density in mangrove-protected areas. Even narrow stretches of mangroves (some as small as 500m) play a significant role in diffusing a considerable amount of wave

and storm energy—up to 99 percent. Even a minor reduction in the extent of mangrove coverage can have dire consequences, rendering coastal regions susceptible to substantial destruction during storm occurrences. Notably, flood protection does not follow a straightforward linear pattern.

Countries that have seen a swift escalation in both risks and benefits since 2010 or 2015 also house a substantial number of people within regions protected by mangroves. These valuable ecosystems tend to be situated in environmentally delicate zones, which, coincidentally, attract human settlements due to their proximity to water resources and economic opportunities.

The interplay between socioeconomic growth and changes in mangrove cover yields a non-linear effect on flood risk. This complexity hinders a straightforward estimation of the individual contributions of each factor to the overall change in flood risk. For instance, from 1996 to 2010 there is a 4 percent decline in mangrove cover, a 21 percent surge in population, and a substantial 72 percent increase in capital stock. These alterations resulted in a notable 32 percent escalation in risk to the population and an even more pronounced 122 percent amplification in capital stock losses attributed to flooding. In the period from 2010 to 2020, there is a relatively modest 0.66 percent reduction in mangrove cover, a 12 percent growth in population, and a 40 percent expansion in capital stock. Despite these seemingly lesser changes, the impact on flood risk remains significant. During this period, there was an additional 33 percent rise in the risk posed to the population, accompanied by a substantial 103 percent increase in capital stock losses. The observed non-linear effect is intricately linked to the influx of population and capital stock into areas previously safeguarded by mangroves, rendering these regions more susceptible to flooding due to an expanded flooded area. These findings underscore the complex dynamics at play, highlighting the close interaction between economic growth, changes in mangrove forests, and the risk of flooding. It is evident that a deeper understanding of this non-linear interaction is paramount for informed decision-making and effective risk management strategies.

A limiting aspect of these global economic analyses of changing wealth is the use of the PWT for the economic risk calculation, instead of other spatially explicit asset databases (such as GAR 15 used in Menendez et al. 2020). The PWT dataset provides aggregated capital stock data at the country level, which may not capture the spatial heterogeneity of capital distribution within specific coastal areas. This lack of spatial resolution can limit the accuracy of flood risk assessments that require fine-grained information on asset distribution and can restrict the precision of flood risk estimates and hinder the identification of vulnerable areas. The dataset assumes homogeneity in capital stock across sectors within a country. However, coastal areas often exhibit variations in infrastructure and capital assets based on their specific characteristics, such as population density, urbanization, and vulnerability. Failure to account for such variations may lead to inaccurate flood risk estimates. However, the PWT dataset provides capital stock data over a longer time horizon, allowing for analyses and comparisons across different decades or even centuries. This extended temporal coverage is valuable when examining long-term trends, assessing the evolution of capital accumulation, and understanding the dynamics of economic development over time.

The values that we provide are based on process-based evaluations of flood risk and mangrove benefits, and the quality of the final estimates depends on the available input data. Through our prior research and sensitivity analyses, we have determined that

topography estimates (Menéndez et al. 2019) present the largest source of uncertainty in coastal flood risk assessments. In addition, nearshore bathymetry remains a significant gap, despite advances in remote sensing that could enhance flood risk assessments. While our results are based on global mangrove distribution data that are being improved, we still lack information on other critical factors, such as mangrove density, species, and degree of degradation, which can affect mangroves' ability to reduce flooding. In addition, limitations for global coastal flooding models still exist, including the inability to consider flooding as a multidimensional process and the difficulty in accurately representing flooding in small islands.

Mangroves provide a wide range of additional benefits, from fisheries to carbon mitigation, which can be valued and combined with flood reduction values to bolster the case for cost-effective investments in mangrove conservation and restoration.

Considering these limitations, a pragmatic approach to using the data is advisable. Since economic data is available at the national scale—the highest resolution available—the focus should be on assessing relative changes between different years and scenarios, rather than focusing only on absolute values. This approach helps mitigate the influence of underlying socioeconomic data variations, which can substantially impact absolute figures. Interpreting subnational spatial data requires careful consideration of both its advantages and limitations. Subnational data provides a finer level of detail and granularity compared to national-level data, which can offer valuable insights into regional variations and disparities. when working with subnational spatial data derived from global models downscaled to finer resolutions and then aggregated at the national scale, it introduces several nuanced considerations for interpretation:

- Resolution effects: The downscaling process can lead to variations in data quality and detail across regions. Some areas may benefit from higher resolution data, while others may experience a loss of information.
- Spatial bias: The global models used for downscaling may have inherent spatial biases or limitations that persist even at finer resolutions. Interpreters should be cautious of these biases and their potential impact on the accuracy of subnational data.
- Comparative analysis: When interpreting subnational data aggregated from global sources, it is essential to maintain a comparative perspective. This allows for the identification of regional outliers, trends, and anomalies that may not be apparent when solely focusing on national or global levels.

In Appendix 1, we have provided a comprehensive document detailing the intricacies of the data, along with a thorough explanation of the meticulous cleaning and processing procedures that were undertaken. This supplementary resource aims to transparently present the caveats associated with the data, shedding light on the measures employed to ensure its accuracy and reliability.

While this report primarily focuses on mangroves, it is important to acknowledge that the assessment of coastal protection provided by natural assets is incomplete without considering the role of coral reefs in (sub)tropical nations and marshes and oyster reefs in other nations. Coral reefs serve as natural submerged breakwaters, effectively breaking waves and attenuating wave energy (Lowe et al. 2005; Monismith 2007). Research by Ferrario et al. (2014) highlights that coral reefs can reduce incoming wave energy by up to 97 percent. Coral reefs and other coastal habitats should be included in future assessments.

6 Recommendations

These findings demonstrate the important role that mangroves play in protecting against flood risks and the significant economic value they hold. The results can inform decision-making on adaptation, development, and environmental conservation. The effectiveness of mangroves in reducing flood risks presents opportunities to support their conservation and restoration. Using these values, mangrove management can be supported by public funding for hazard mitigation, disaster recovery, and climate adaptation. Public and private funding opportunities for mangrove management include blue bonds, infrastructure bonds, and insurance, among other options (e.g., Airoldi et al. 2021). By assessing spatial variation in mangrove flood protection benefits, we can identify areas where managing mangroves could yield the greatest returns.

Overall, we have identified key considerations and recommendations for mangrove management for risk reduction based in part on our results and our work with field practitioners and decision-makers.

- Conserving existing mangroves is crucial as they make a significant contribution to national wealth and their value is expected to grow over time.
- Mangrove restoration is a well-established practice that can be effectively implemented on a large scale, with public and private funding. Large-scale mangrove restoration for risk reduction has already been successfully carried out in many countries, and while best practices are still evolving, current approaches are well developed.
- Efforts to restore mangroves should be expanded, and the results of this study can be used alongside project costs to identify areas where mangrove restoration could yield significant returns on investment (e.g., Beck et al. 2022).
- Accounting for the flood reduction benefits of mangroves as natural asset values can inform hazard mitigation and disaster recovery spending.
- These valuations enable funding to be prioritized for adaptation and help identify priority sites for mangrove coastal protection, either as standalone solutions or as part of hybrid approaches that combine mangrove natural defenses with built infrastructure.
- Rigorous valuations support innovative finance opportunities for mangrove conservation and restoration. For example, these results can inform risk models used by the insurance industry, which underpin the development of habitat insurance, blue bonds, and insurance incentives such as community and household premium reductions.
- These values can also support the development of catastrophic hazard bonds, resilience bonds, and blue bonds that could use the risk reduction benefits of mangroves to support habitat conservation and restoration.

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Appendix 1: Data Review Process

OVERALL REMARKS

- IMPORTANT: Any difference between CWON 2021 and CWON 2023 observed after 2015 must be ignored. The new CWON 2023 data between 2015-2020 is based on the 2020 data point, while the old CWON 2021 data between 2015-2020 is an extrapolation based on the period 2010-2015.

- Total # of countries in CWON 2023 before cleaning: 121 (111 in CWON 2021)

- Total # of countries in CWON 2023 AFTER cleaning: 97 (92 in CWON 2021)

- Total # of data points that need to be revised (see analysis of outliers below): 6
  ✓ YEM (1996), PHL (2015), DOM (2015), PAN (2010), SLV (2015), LKA (2015)

- The missing countries in 2021 (10):
  ✓ BMU, COG, COK, GUM, KIR, MDV, MHL, PYF, TUV, WLF
  blue=to remove because less 100 ha mangroves

- Countries removed from 2023 analysis (24):
  ✓ ABW, AIA, ASM, BHR, BMU, BRB, COD, COK, COM, DMA, EGY, GNB
  GUM, HKG, IRN, KNA, MAF, MDV, MHL, STP, TUV, VCT, VGB, WLF

- Countries that will have different results in 2023 vs 2021 because there was no mangrove data in CWON 2021 (3):
  ✓ BEN, MAC, TGO (updated mangrove data in CWON 2023)

- Countries that will have different results (>10% difference) in 2023 vs 2021 because of significant changes in mangroves or population data in 2023 vs CWON 2021 (6):
  ✓ MOZ, THA, SYC, VEN, SLB, JAM

- Countries that will have different results (>10% difference) in 2023 vs 2021 because of significant changes in mangroves or stock data in 2023 vs CWON 2021 (8):

  ✓ SYC, SGP, ATG, BRN, SYC, HND, JAM, SDN

- Countries with no population or economic data in PWT 10.0 (21):
  ✓ ANT, CUB, ERI, FSM, GLP, GUF, KIR, MTQ, MYT, NCL, PLW, PNG
  PRI, PYF, SLB, SOM, TLS, TON, VIR, VUT, WSM

DATA CLEANING

1. **REMOVE: Countries with Ha_mang<100**
   - The global model isn't sensitive to countries with few mangroves.
   - Countries (18): ABW, AIA, ASM, BHR, BMU, BRB, COK, COM, DMA, GUM KNA, MAF, MDV, MHL, STP, TUV, VGB, WLF
   - WHAT WE DO: We will check if these countries have risk values and neglect those.
   - Why? We don't have accurate precision, and our global model is not sensitive to areas with very few mangroves.

2. **REMOVE: Countries with Ha_mang<100 and no risk value**
   - All the countries with less than 100 ha mangroves don't have risk value
   - Countries (18): ABW, AIA, ASM, BHR, BMU, BRB, COK, COM, DMA, GUM KNA, MAF, MDV, MHL, STP, TUV, VGB, WLF
   - WHAT WE DO: Neglect these countries and remove them from the analysis.
   - Why? We don't have accurate precision, and our global model is not sensitive to areas with very few mangroves.

3. **REMOVE: Countries with risk to stock but no risk to people**
   - This is a bug in the geospatial analysis.
   - Countries: GNB
   - WHAT WE DO: Remove this country from the analysis.
   - Why? Wrongly taking stock risk values from the contiguous country (Guinea).

4. **REMOVE: Countries with benefits to stock but no benefits to people**
   - This is a bug in the geospatial analysis.
   - Countries: COD, EGY, HKG, IRN, VCT
   - WHAT WE DO: Remove these countries from the analysis.
   - Why? Same as the previous point, wrongly taking stock risk values from the contiguous countries.

DIFFERENCE 2023 VS 2021 AFTER CLEANING

Only differences > 10%

1. Risk to people

These countries were not captured in the 2021 report.

Country	'BEN'	'BEN'	'BEN'	'TGO'	'TGO'	'TGO'
Year	1996	2010	2015	1996	2010	2015
% diff	Inf	Inf	Inf	Inf	Inf	Inf
Abs diff	23699	33041	38421	1425	1452	1132

Differences are explained because:

- Countries with no accurate mangrove data in the CWON 2021 but accurate now (BEN, TGO)

2. Benefits to people

Country	'BEN'	'BEN'	'BEN'	'TGO'	'LKA'	'SLB'	'PHL'	'JAM'	'MYT'	'FSM'	'JPN'	'MOZ'	'NZL'	'DOM'	'THA'	'SYC'	'VEN'	'FJI'
Year	1996	2010	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015
% diff	Inf	Inf	Inf	Inf	362	72	71	37	33	29	28	15	15	14	13	12	11	10
Abs diff	164	166	3350	422	1686	1583	132912	970	59	59	213	3545	46	385	1472	72	1793	191
% diff Mang	2445	3328	1631	5608	6	1	4	4	16	9	4	3	3	0	15	112	1	4
% diff Pop	0	0	0	1	1	100	0	1	NaN	NaN	0	3	0	2	0	1	3	3

Differences are explained because:

- Countries with no accurate mangrove data in the CWON 2021 but accurate now (BEN, TGO)
- Update in mangrove data and pop data since CWON 2021 release, most likely impacting coastal communities (MOZ, THA, SYC, VEN, SLB, JAM)
- Very small absolute value difference (MYT, FSM, JPN, NZL, DOM, FIJ)

What needs to be revisited:

- Outliers: LKA (2015) and PHL (2015)

3. Risk to stock

Country	'BEN'	'BEN'	'BEN'	'TGO'	'TGO'	'TGO'	'SGP'	'SGP'
Year	1996	2010	2015	1996	2010	2015	2010	1996
% diff	Inf	Inf	Inf	Inf	Inf	Inf	35	10
Abs diff	34374174	43522276	55097573	1990829	1694357	1374299	187249	368951
% diff Mang	2445	3328	1631	6416	6605	5608	14	18
% diff Stock	33	14	22	30	27	0	44	50

Differences are explained because:

- Countries with no accurate mangrove data in the CWON 2021 but accurate now (BEN, TGO)
- Update in mangrove data and pop data in this report vs CWON 2021, most likely impacting coastal communities (SGP)

4. Benefits to stock

Country	'BEN'	'BEN'	'BEN'	'TGO'	'YEM'	'SYC'	'PHL'	'DOM'	'SGP'	'ATG'	'BRN'
Year	1996	2010	2015	2015	1996	2010	2015	2015	1996	2010	1996
% diff	Inf	Inf	Inf	Inf	245	181	133	114	84	46	45
Abs diff	518272	426760	3052774	639490	487666	1471938	241443518	3125583	737901	1360157	683702
% diff Mang	2445	3328	1631	5608	17	112	4	0	18	5	1
% diff Stock	33	14	22	0	64	63	34	6	50	80	29

Country	'PAN'	'ATG'	'SLV'	'SGP'	'SYC'	'BRN'	'LKA'	'HND'	'JAM'	'SDN'
Year	2010	1996	2015	2010	1996	2010	2015	2015	2015	1996
% diff	43	36	36	22	14	13	13	12	12	10
Abs diff	1979824	1146874	483601	432780	635805	176484	940306	640763	5575617	3705
% diff Mang	2	5	1	14	110	0	6	3	4	250
% diff Stock	4	71	11	44	63	34	37	14	66	637

Differences are explained because:

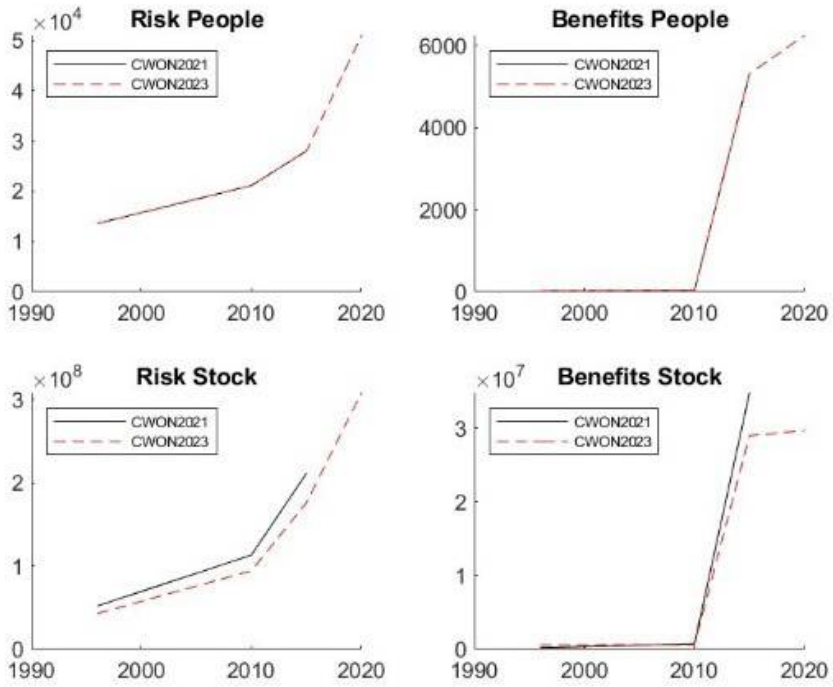
- Countries with no accurate mangrove data in the CWON 2021 but accurate now (BEN, TGO)
- Update in mangrove data and pop data since CWON 2021 release, most likely impacting coastal communities (SYC, SGP, ATG, BRN, SYC, HND, JAM, SDN)

What needs to be revisited:

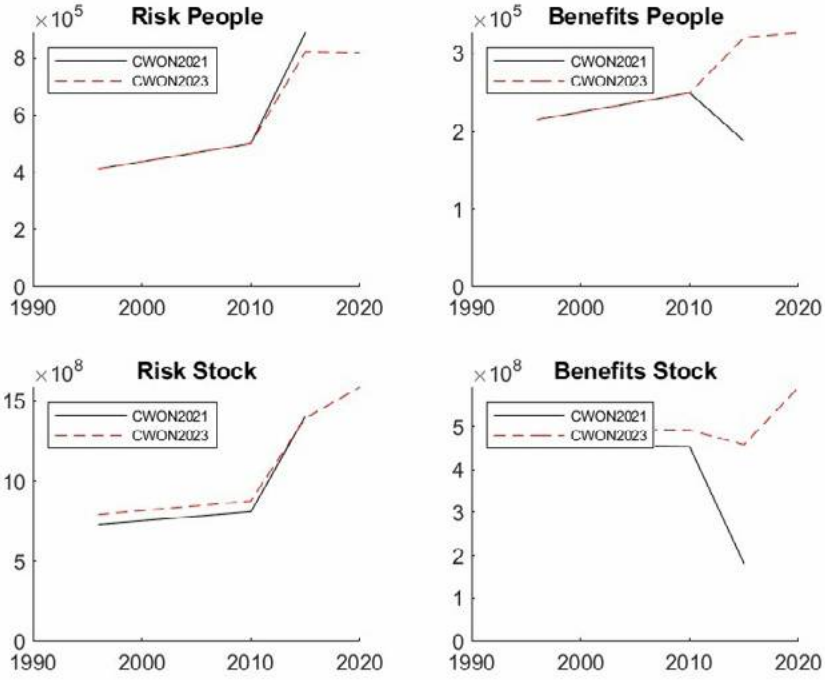
- Outliers: YEM (1996), PHL (2015), DOM (2015), PAN (2010), SLV (2015), LKA (2015)

OUTLIERS

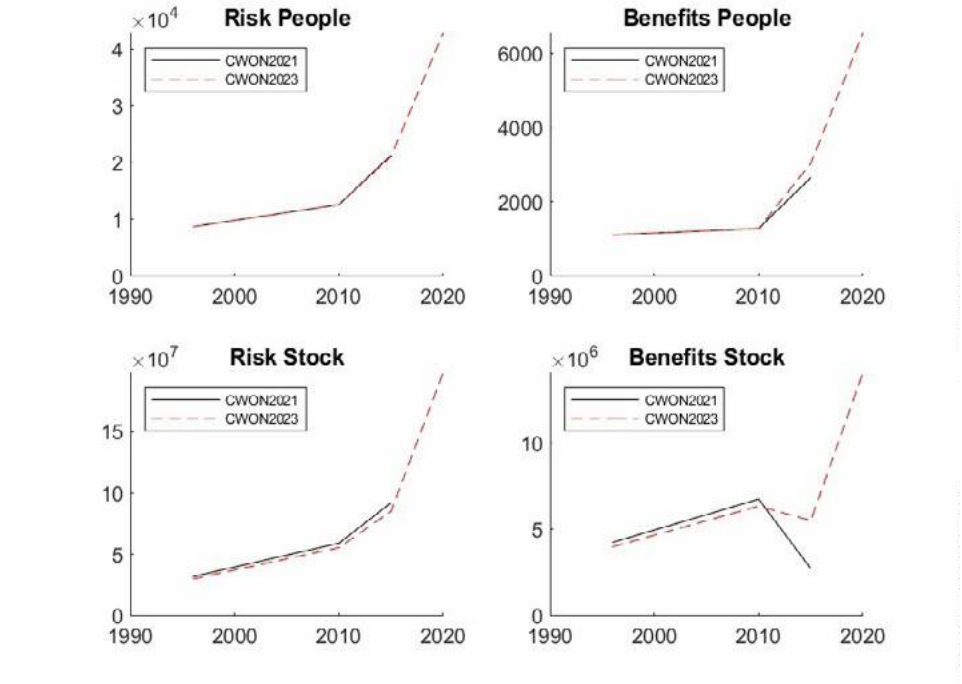
YEM (1996): The most % difference observed in benefits to stock in 1996 is not significant in magnitude compared to the benefit to stock value observed in the following years.



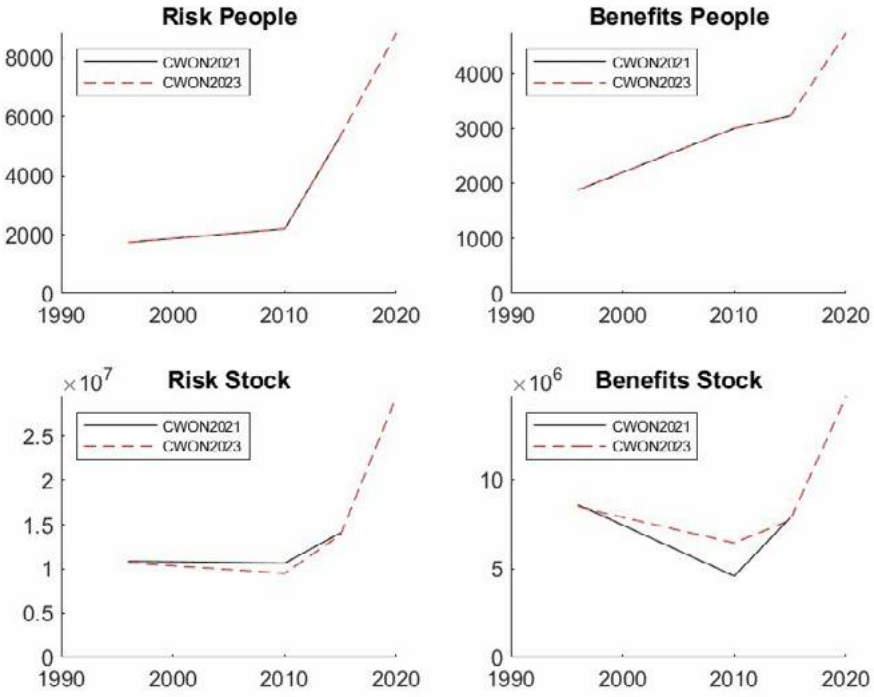
PHL (2015): The 2015 time point calculated in CWON 2021 is incorrect.
The "without mangrove" scenario has been revisited, and the new 2015 value is correct.



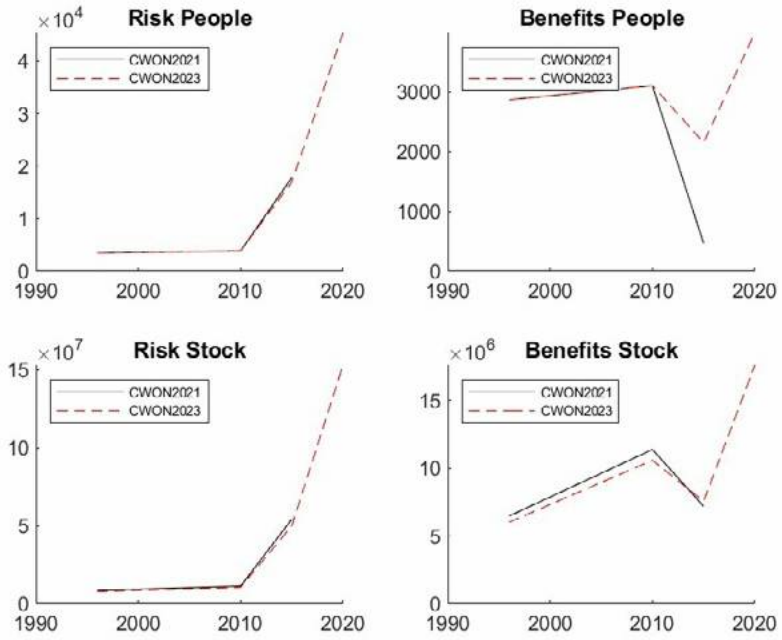
DOM (2015): Same issue as in the Philippines. The 2015 value of the "without mangrove" scenario in CWON 2021 is incorrect and the new value obtained in CWON 2023 must be used.



PAN (2010): Same issue as in the Philippines. The 2010 value of the "without mangrove" scenario in CWON 2021 is incorrect and the new value obtained in CWON 2023 must be used.



LKA (2015): The 2015 value of people benefits "without the mangrove" scenario in CWON 2021 is underestimated, resulting in an incorrect low benefit value. The new value obtained in CWON 2023 must be used.



OTHER CAVEATS EXPLAINED

1. Countries with risk value>0 but benefits=0

- This is because mangroves are not located in populated areas.
- Countries: COG, TGO
- WHAT WE DO: Nothing; this is something that can happen. After reviewing these countries, we observed that no mangrove-protected areas are populated.

2. Countries with no pop and economic data but risk value

- This is because we still don't have socioeconomic data from the PWT, but we have risk to people because the GHS pop dataset used in the analysis has people distributed in these countries:
- Countries (21): ANT, CUB, ERI, FSM, GLP, GUF, KIR, MTQ, MYT, NCL, PLW, PNG. PRI, PYF, SLB, SOM, TLS, TON, VIR, VUT, WSM
- WHAT WE DO: We filled the gaps with updated PWT in the countries in green. The countries in black don't have population or capital stock data yet.

3. Countries that increase rapidly after 2010

- ANT, ATG, BEN, BRN, CIV, COG, DJI, ERI, GAB, GRD, JPN, KIR, LBR, NZL, PLW, PYF

4. Countries that increase rapidly after 2015

- ANT, AUS, BGD, CIV, CMR, COG, DOM, ECU, GMB, GNQ, GRD, LCA, NIC, PER, QAT

The rapid increase in stock risk observed in these countries is attributed to the dual impact of the protective function of mangroves and the high population density in mangrove-protected areas:

- Protective Role of Mangroves: Like a seawall that is overtopped when a flood height level is exceeded, even narrow strips of mangroves (as small as 500m) can dissipate a significant portion of wave and storm energy, up to 99 percent. Even a small reduction in mangrove coverage can lead to catastrophic consequences, leaving the coastal areas vulnerable to severe damage during storm events. In the countries listed that experience a rapid increase in risk and benefits, we identified key coastal areas with narrow strips of mangroves where flooding was triggered after 2010 and 2015. Flood protection is not linear.

- High Population Density in Mangrove Protected Areas: The countries experiencing a rapid increase in stock risk after 2010 or 2015 also exhibit a high number of people living in mangrove-protected areas. Mangroves are often located in ecologically sensitive regions, which also happen to be attractive areas for human settlements due to their proximity to water resources and livelihood opportunities.

Appendix 2: Data Tables

TABLE A1: FLOOD RISK AND FLOOD REDUCTION BENEFITS OF MANGROVES ACROSS 97 COUNTRIES IN 1996

1996															
ID	COUNTRY	ISO3	YEAR	MANG HA	POP	POP EXP	POP RISK	POP BEN	POP BEN HA	STOCK	STOCK EXP	STOCK RISK	STOCK BEN	PV 100yr 4%	STOCK BEN HA
34	China	CHN	1996	29066	1251636186	10952010	10604835	428470	14,74	5169485084548	39516162493	23042962985	911064157	22 325 626 254	31344,67
179	Vietnam	VNM	1996	198962	76068743	1530797	1359172	2000395	10,05	214129906818	1235672038	571426313	870142310	21 322 836 434	4373,41
79	India	IND	1996	510157	982365243	585153	463970	625398	1,23	2409260145291	941166913	341884558	424701812	10 407 317 477	832,49
135	Philippines	PHL	1996	285316	71401749	481894	411847	214885	0,75	356043205229	2315826893	792246178	497136764	12 182 335 903	1742,41
78	Indonesia	IDN	1996	3138690	200756590	520634	344350	306753	0,1	1326463183831	3052363830	635608884	566383806	13 879 234 598	180,45
169	Taiwan	TWN	1996	197	21441432	223872	201491	51363	260,73	478732074637	7524647650	1869931506	134180615	3 288 095 836	681119,87
114	Myanmar	MMR	1996	596955	44452206	250183	198328	76106	0,13	49952821264	33433992	12591490	4363933	106 938 174	7,31
25	Brazil	BRA	1996	1148395	164614688	181016	167462	71223	0,06	1512112407908	2620583832	730392604	303205593	7 430 052 752	264,03
16	Bangladesh	BGD	1996	527667	117649932	162224	136294	161867	0,31	223833397553	183252954	87590645	92265712	2 260 971 180	174,86
174	United States	USA	1996	241100	268335003	132078	120101	32580	0,14	12778466659459	22857664786	7277327214	1273566732	31 208 751 490	5282,32
5	United Arab Emirates	ARE	1996	7591	2539126	85847	78235	38101	5,02	241257321709	12767127465	510208951	325988079	7 988 337 549	42944,02
177	Venezuela	VEN	1996	302537	22385650	80524	74482	11953	0,04					-	
92	Cambodia	KHM	1996	73406	10982917	70244	64045	35576	0,48	16862151815	54226683	22499299	20602220	504 857 380	280,66
122	Malaysia	MYS	1996	590057	21017613	62369	48310	27050	0,05	292432185232	883764750	136971054	88054789	2 157 782 516	149,23
72	Guyana	GUY	1996	39190	760795	43361	36794	36035	0,92	2751373772	302688563	90807	94813	2 323 392	2,42
125	Nigeria	NGA	1996	920270	110668794	55582	35130	31528	0,03	384814447644	272351479	71737782	46054017	1 128 553 640	50,04
108	Madagascar	MDG	1996	282644	13902688	37422	34522	9718	0,03	23797772325	40952686	17130979	6745564	165 300 039	23,87
110	Mexico	MEX	1996	1063983	93147044	41261	29193	64623	0,06	1402920029426	976238225	329784139	472597903	11 581 011 139	444,18
64	Ghana	GHA	1996	18645	17462496	33950	26640	12224	0,66	50578879417	201858068	90582434	46736826	1 145 285 874	2506,67
9	Australia	AUS	1996	1051177	18189277	28685	23843	32329	0,03	643221785094	4227517611	1338157923	1618933833	39 671 971 954	1540,12
14	Benin	BEN	1996	3054	6094259	30496	23699	164	0,05	10641466497	79518215	33990452	512486	12 558 469	167,81
144	Saudi Arabia	SAU	1996	9027	19033845	27348	23306	3971	0,44	852733583618	811353376	131214725	18957358	464 550 039	2100,07
131	Oman	OMN	1996	481	2236654	22888	18853	3450	7,17	65669326462	494625624	78944233	5247658	128 593 854	10909,89
117	Mozambique	MOZ	1996	325865	15960442	19821	18830	24389	0,07	8529292846	3593197	1606752	2866283	70 238 262	8,8
184	Somalia	SOM	1996	6083	7472450	20634	18683	149	0,02	3487368934	9629823	8719297	69538	1 704 029	11,43
163	Thailand	THA	1996	274943	60130186	54408	18306	30207	0,11	656305777631	811189417	131884749	188785202	4 626 181 186	686,63
39	Colombia	COL	1996	299604	37076387	21151	18073	14378	0,05	298293921856	227682040	61802282	35358071	866 449 494	118,02
35	Côte d'Ivoire	CIV	1996	6901	14665127	19241	14890	2532	0,37	42943611117	53036015	13902328	3671123	89 960 865	531,97
132	Pakistan	PAK	1996	107096	127349290	18381	13954	26719	0,25	431043097352	32898784	13185260	14919116	365 592 923	139,31
180	Yemen	YEM	1996	2007	15469274	15034	13551	22	0,01	47190213839	122660860	42807284	571877	14 013 845	284,94

88	Japan	JPN	1996	1025	126644094	15436	13447	1491	1,45	4561300434281	2419961123	542998754	49057350	1 202 150 313	47860,83
146	Senegal	SEN	1996	233472	8912861	17369	11037	7127	0,03	20977338722	42343466	14571306	9983782	244 652 568	42,76
51	Dominican Republic	DOM	1996	19881	7952763	10030	8778	1123	0,06	60753381133	71422063	30261167	4010098	98 267 447	201,71
187	Kiribati	KIR	1996	146	82832	7917	7402	346	2,37	283413912	27088419	25326320	1183857	29 010 415	8108,61
185	PuertoRico	PRI	1996	8550	3724655	9149	7011	18565	2,17	76339157370	187514535	143694874	380501404	9 324 186 523	44503,09
86	Jamaica	JAM	1996	10551	2558637	8733	6890	4626	0,44	25502273532	221413680	84185356	53758474	1 317 351 351	5095,11
186	Cuba	CUB	1996	378885	10963031	8097	6632	5114	0,01	102791263482	75918864	62182772	47949743	1 175 008 404	126,55
118	Mauritania	MRT	1996	1461	2372901	8915	6157	4801	3,29	12618968152	18244867	6207254	5193456	127 265 634	3554,73
76	Haiti	HTI	1996	20990	7887304	6538	5430	11886	0,57	14635512145	15287876	5744449	13244329	324 552 269	630,98
188	SolomonIslands	SLB	1996	52098	386069	4790	4159	800	0,02	319912860	3969194	3446321	662913	16 244 682	12,72
53	Ecuador	ECU	1996	170891	11703174	6718	3973	7881	0,05	105853434221	130946024	28158393	57847013	1 417 540 996	338,5
158	Seychelles	SYC	1996	227	77594	3883	3702	140	0,62	1051999110	140270506	33943560	3941509	96 586 674	17363,48
170	U.R. of Tanzania: Mainland	TZA	1996	124413	29630526	5381	3680	7128	0,06	39216143965	5045154	1813584	3902200	95 623 407	31,36
90	Kenya	KEN	1996	57085	28589451	4480	3612	11736	0,21	113272373079	9925279	3953566	13044870	319 664 526	228,52
100	Sri Lanka	LKA	1996	25861	18367288	5683	3477	2867	0,11	102812165880	24633586	7837000	6014139	147 376 470	232,56
19	Bahamas	BHS	1996	164813	283978	3102	2894	693	0	8046482546	216342054	83454246	24120873	591 081 969	146,35
189	PapuaNew-Guinea	PNG	1996	467722	4785895	4330	2612	3490	0,01	11164843503	10101302	6093442	8141696	199 512 252	17,41
42	Costa Rica	CRI	1996	38153	3632362	2640	2548	1090	0,03	42633054668	33143048	14991188	6259859	153 397 839	164,07
65	Guinea	GIN	1996	262094	7463782	3551	2193	7351	0,03	17397195316	2575623	1003020	2922949	71 626 862	11,15
134	Peru	PER	1996	13386	24753824	2403	2112	71	0,01	154839364798	20286338	9995109	227682	5 579 347	17,01
145	Sudan	SDN	1996	1488	24782383	6704	2111	10	0,01	46872516272	1721176	342386	29458	721 868	19,8
130	New Zealand	NZL	1996	29027	3717349	2360	1975	779	0,03	101942638469	219787874	103597061	41779541	1 023 807 610	1439,33
133	Panama	PAN	1996	155860	2796291	1957	1743	1886	0,01	37312068291	28325504	10704552	8485873	207 946 309	54,45
27	Brunei Darus-salam	BRN	1996	18434	304622	2380	1658	780	0,04	20100671610	220416669	20805850	1860202	45 584 248	100,91
59	Fiji	FJI	1996	48541	784386	1842	1615	1428	0,03	7594613415	10168468	4032108	4691945	114 976 108	96,66
48	Djibouti	DJI	1996	1000	643654	2637	1586	85	0,09	1253541723	2441388	181171	27509	674 108	27,51
162	Togo	TGO	1996	1238	4348805	2386	1425	0	0	6646678002	5133260	1975868	0	-	0
190	NewCaledonia	NCL	1996	33008	197564	1583	1367	966	0,03	7222113698	57867860	49971804	35312921	865 343 094	1069,83
74	Honduras	HND	1996	90153	5874809	1355	1087	1788	0,02	27342997566	7280634	2801232	5156541	126 361 032	57,2
191	Guadeloupe	GLP	1996	3413	0	1367	1082	789	0,23	0	0	0	0	-	0
181	South Africa	ZAF	1996	2566	42241011	1140	1014	33	0,01	401155337743	13133499	7488676	75713	1 855 347	29,51
192	FrenchGuiana	GUF	1996	76023	0	1000	975	658	0,01	0	0	0	0	-	0
148	Sierra Leone	SLE	1996	182270	4312666	3431	950	3301	0,02	5455463412	3091113	543196	1669979	40 922 834	9,16
152	Suriname	SUR	1996	81563	448213	1803	940	26334	0,32	4182226847	30826452	7345366	202013869	4 950 349 657	2476,78
195	Vanuatu	VUT	1996	1585	174714	946	930	21	0,01	596502907	3229803	3175176	71698	1 756 959	45,24

194	MicronesiaFed-eratedStatesof	FSM	1996	9084	110785	987	878	212	0,02	0	0	0	0	-	0
193	TimorLeste	TLS	1996	1373	831269	999	870	1524	1,11	27214769735	32706085	28482777	49893968	1 222 651 636	36339,38
8	Antigua and Barbuda	ATG	1996	860	70173	883	827	367	0,43	887477907	36315031	8301412	4405696	107 961 576	5122,9
149	El Salvador	SLV	1996	52696	5689938	884	780	381	0,01	34428063067	4820840	2417587	1411454	34 587 679	26,78
22	Belize	BLZ	1996	71678	213664	804	738	3725	0,05	1039463186	6374885	3147061	18016148	441 485 689	251,35
197	Eritrea	ERI	1996	9303	2264073	681	681	1141	0,12	0	0	0	0	-	0
98	Liberia	LBR	1996	20647	2160478	2437	648	1560	0,08	769809086	4059217	558342	1378195	33 772 667	66,75
36	Cameroon	CMR	1996	210832	13970813	990	637	6034	0,03	36806291639	2789470	651513	9714234	238 047 294	46,08
126	Nicaragua	NIC	1996	89009	4741578	669	538	771	0,01	19394689687	4074568	1508706	2221245	54 431 606	24,96
38	Congo	COG	1996	2481	2785810	458	458	0	0	10156227143	3505331	2213260	0	-	0
200	Martinique	MTQ	1996	1921	0	459	446	42	0,02	0	0	0	0	-	0
68	Equatorial Guinea	GNQ	1996	33836	515853	484	397	35	0	2583910335	1358673	513859	217805	5 337 311	6,44
166	Trinidad and Tobago	TTO	1996	11867	1257549	414	386	792	0,07	17749195244	2451489	1677183	2525316	61 882 866	212,8
2	Angola	AGO	1996	53180	14400719	470	366	411	0,01	47896152703	4471571	2371291	1700985	41 682 636	31,99
147	Singapore	SGP	1996	16954	3638187	512	360	183	0,01	161990287534	46725153	3282808	1521302	37 279 504	89,73
199	Samoa	WSM	1996	234	176713	464	297	87	0,37	0	0	0	0	-	0
99	Saint Lucia	LCA	1996	163	148834	289	283	15	0,09	1523584982	5393593	3290866	181294	4 442 609	1112,23
61	Gabon	GAB	1996	195378	1112955	360	237	347	0	20138303520	5477582	1047139	1303022	31 930 553	6,67
201	FrenchPolynesia	PYF	1996	122	235189	321	209	144	1,18					-	
71	Guatemala	GTM	1996	29678	10646674	214	207	331	0,01	69970120891	1420540	1042316	1188422	29 122 280	40,04
160	Turks and Caicos Islands	TCA	1996	20631	16926	201	176	142	0,01	204648198	5763406	2908073	2455669	60 176 166	119,03
140	Qatar	QAT	1996	433	522531	109	101	144	0,33	36783433466	7741979	2411838	3054404	74 848 167	7054,05
203	UnitedStatesVir-ginIslands	VIR	1996	281	108095	135	82	77	0,27	0	0	0	0	-	0
206	Palau	PLW	1996	5656	17732	87	78	12	0	0	0	0	0	-	0
202	Tonga	TON	1996	1055	100195	142	53	456	0,43	504796739	715416	267022	2297393	56 297 613	2177,62
207	Mayotte	MYT	1996	677	0	54	43	117	0,17	0	0	0	0	-	0
209	NetherlandsAn-tilles	ANT	1996	292	0	16	16	98	0,34	0	0	0	0	-	0
66	Gambia	GMB	1996	74099	1164091	555	14	638	0,01	2915091706	551269	9018	338159	8 286 586	4,56
70	Grenada	GRD	1996	210	101001	4	4	9	0,04	880388905	90171	37565	125007	3 063 296	595,27
44	Cayman Islands	CYM	1996	4684	34065	0	0	0	0	2453120847	0	0	0	-	0
105	China, Macao SAR	MAC	1996	134	393373	0	0	0	0	18337045569	0	0	0	-	0
120	Mauritius	MUS	1996	553	1141948	0	0	0	0	11349000312	0	0	0	-	0

TABLE A2: FLOOD RISK AND FLOOD REDUCTION BENEFITS OF MANGROVES ACROSS 97 COUNTRIES IN 2010

2010															
ID	COUNTRY	ISO3	YEAR	MANG HA	POP	POP EXP	POP RISK	POP BEN	POP BEN HA	STOCK	STOCK EXP	STOCK RISK	STOCK BEN	PV 100yr 4%	STOCK BEN HA
34	China	CHN	2010	24383	1368810615	14584698	14171614	486224	19,94	14446856973732	202060401635	64918046096	2350148676	57 590 390 949	96384,72
79	India	IND	2010	495010	1234281170	806733	644363	774727	1,57	5772294531564	2600992178	733721444	746494296	18 292 841 975	1508,04
174	United States	USA	2010	233110	309011475	154658	141312	36899	0,16	18069244155380	32524514401	8965434799	1202087823	29 457 160 897	5156,74
78	Indonesia	IDN	2010	2941621	241834215	626755	435851	364345	0,12	2124785018064	5836084091	1106307898	812430045	19 908 597 438	276,18
25	Brazil	BRA	2010	1127630	195713635	181407	167734	136150	0,12	2333846837042	3101619339	823564625	379423481	9 297 772 021	336,48
132	Pakistan	PAK	2010	92278	179424641	30753	22992	30716	0,33	728280171563	60689017	13479473	16161086	396 027 396	175,13
125	Nigeria	NGA	2010	895792	158503197	87349	56413	39402	0,04	921748695649	367104777	90202309	34497476	845 360 615	38,51
16	Bangladesh	BGD	2010	530019	147575430	257493	205842	160900	0,3	482195626425	639539152	277450025	182554359	4 473 494 384	344,43
88	Japan	JPN	2010	1002	128542353	16489	14455	1003	1	4980063550992	3046502318	668524486	37264613	913 169 304	37190,23
110	Mexico	MEX	2010	1002966	114092963	54790	41671	75238	0,08	1964671677829	1607402218	497507398	560745519	13 741 068 381	559,09
135	Philippines	PHL	2010	270166	93966780	567216	500565	249445	0,92	638113930890	3117779988	877535502	491562122	12 045 729 307	1819,48
179	Vietnam	VNM	2010	187530	87967651	1766447	1553534	2459564	13,12	528931202305	4966744132	2064699763	3286013385	80 523 754 704	17522,6
163	Thailand	THA	2010	258898	67195028	74533	55307	8521	0,03	1008888839845	1224148952	296940857	88153347	2 160 197 680	340,49
181	South Africa	ZAF	2010	2616	51216964	1306	1158	39	0,01	620348171335	17102393	9675366	100823	2 470 668	38,54
114	Myanmar	MMR	2010	552084	50600818	343004	276050	86041	0,16	217607973209	254676149	47728715	14605052	357 896 785	26,45
39	Colombia	COL	2010	289011	45222700	32704	28750	18489	0,06	454385085611	390738781	90454480	44572515	1 092 249 435	154,22
170	U.R. of Tanzania: Mainland	TZA	2010	121556	43094401	8677	6338	7939	0,07	87287318838	14150753	5399291	6912988	169 402 764	56,87
90	Kenya	KEN	2010	56274	42030676	7681	6727	11930	0,21	184872696083	18171321	7978539	11298533	276 870 540	200,78
145	Sudan	SDN	2010	832	34545013	9454	4263	21	0,03	108619347133	15808043	2375067	42952	1 052 539	51,63
134	Peru	PER	2010	11168	29027674	3191	2765	91	0,01	294321054297	39880186	17093842	434410	10 645 217	38,9
177	Venezuela (Bolivarian Republic of)	VEN	2010	299267	28439940	110079	100512	16086	0,05					-	
122	Malaysia	MYS	2010	584776	28208035	70672	48361	52769	0,09	527114109460	1261493186	158256759	100018357	2 450 949 738	171,04
144	Saudi Arabia	SAU	2010	8112	27421461	41229	34961	5625	0,69	1255991382365	1616170391	196394747	21347293	523 115 394	2631,57
64	Ghana	GHA	2010	17961	24779619	41756	32905	14766	0,82	104314081136	278614909	125717540	63635518	1 559 388 305	3542,98
117	Mozambique	MOZ	2010	314551	23531574	25416	23238	27501	0,09	25520952048	9131978	3915405	6102208	149 534 601	19,4
2	Angola	AGO	2010	52341	23356246	2459	2041	1476	0,03	131616570361	21449056	7290192	5621128	137 745 736	107,39
180	Yemen	YEM	2010	1675	23154855	23313	21104	33	0,02	91774642577	326965294	94138600	620486	15 205 009	370,44
169	Taiwan	TWN	2010	212	23140948	210227	186109	83358	393,2	906267082174	12125102815	2341735210	255060210	6 250 250 190	1203114,2
9	Australia	AUS	2010	1000126	22154679	34063	28652	39175	0,04	1015941161100	6807717905	1605608107	1698705190	41 626 768 977	1698,49
108	Madagascar	MDG	2010	275202	21151640	61812	56818	17118	0,06	36200947474	74240070	27919724	9856259	241 527 617	35,81
35	Côte d'Ivoire	CIV	2010	6873	20532950	25464	20592	2663	0,39	56103173740	60885325	16670224	3283295	80 457 141	477,71

36	Cameroon	CMR	2010	211898	20341241	1502	898	11990	0,06	64309759552	4544770	968674	10168552	249 180 357	47,99
100	Sri Lanka	LKA	2010	17938	20261737	6404	3860	3102	0,17	210171711947	47200552	10479399	10579614	259 253 430	589,79
53	Ecuador	ECU	2010	159993	15011117	8692	7683	7680	0,05	164418793296	168935748	36653011	41073706	1 006 511 124	256,72
71	Guatemala	GTM	2010	29304	14630417	248	225	380	0,01	114578203710	1954303	1431278	1585539	38 853 632	54,11
92	Cambodia	KHM	2010	68007	14312212	77276	73030	39337	0,58	49146059442	126045593	56069026	45355713	1 111 441 702	666,93
146	Senegal	SEN	2010	234932	12678148	27342	17289	11430	0,05	37557726405	79478324	15997476	19351007	474 196 407	82,37
184	Somalia	SOM	2010	5965	12026649	23743	21408	904	0,15	4160448440	8213554	7405794	312726	7 663 350	52,43
186	Cuba	CUB	2010	350286	11290417	9018	7076	5431	0,02	94514323693	75491470	59234602	45463980	1 114 094 784	129,79
65	Guinea	GIN	2010	260150	10192176	3784	2160	9089	0,03	27507941015	4727164	1707976	6249574	153 145 805	24,02
76	Haiti	HTI	2010	19114	9949322	13597	12302	9722	0,51	16072658887	48966039	20698229	19385464	475 040 776	1014,2
51	Dominican Republic	DOM	2010	19390	9695121	14292	12631	1294	0,07	127578324321	197898473	55712393	6360643	155 867 550	328,04
14	Benin	BEN	2010	2742	9199259	41889	33041	166	0,06	19074085139	100595504	43036432	421996	10 341 012	153,9
5	United Arab Emirates	ARE	2010	7717	8549988	232333	213573	72943	9,45	456217128221	17951901093	450554648	298562024	7 316 262 099	38688,87
74	Honduras	HND	2010	92650	8317470	2328	2051	2025	0,02	45929748146	15462756	6534975	7237867	177 363 924	78,12
189	PapuaNew-Guinea	PNG	2010	467085	7583269	4771	2957	3908	0,01	28486216511	17922052	11107840	14680230	359 739 021	31,43
162	Togo	TGO	2010	1274	6421679	2365	1452	0	0	8541388683	4237072	1681624	0	-	0
148	Sierra Leone	SLE	2010	180334	6415634	4003	1352	3343	0,02	9980542633	2680981	549464	1298506	31 819 888	7,2
149	El Salvador	SLV	2010	53459	6183875	788	659	420	0,01	47421516609	6644294	3262820	2119818	51 946 138	39,65
126	Nicaragua	NIC	2010	91642	5824065	873	717	949	0,01	31108024102	5884245	2139419	2821134	69 131 886	30,78
147	Singapore	SGP	2010	16363	5131172	1209	1006	317	0,02	347963239672	149117480	327786	2243956	54 988 140	137,14
42	Costa Rica	CRI	2010	38496	4577378	2792	2695	1496	0,04	79169997461	54694026	17673123	5731427	140 448 613	148,88
130	New Zealand	NZL	2010	30193	4370062	2749	2324	809	0,03	149768077644	336043977	144691584	45088552	1 104 894 922	1493,34
38	Congo	COG	2010	2449	4273731	744	744	0	0	18075276601	6161965	2192821	0	-	0
98	Liberia	LBR	2010	20701	3891356	3972	1087	2652	0,13	5091835958	4477524	636782	1575033	38 596 182	76,08
185	PuertoRico	PRI	2010	8625	3721525	11230	9566	14972	1,74	193334928149	583403643	496958081	777802257	19 060 043 528	90179,97
133	Panama	PAN	2010	156292	3642687	2591	2193	3010	0,02	80489135288	59395261	9508379	6462343	158 359 709	41,35
118	Mauritania	MRT	2010	1359	3494195	10399	7180	5855	4,31	18002350551	30747988	10718815	9012928	220 861 792	6632,03
197	Eritrea	ERI	2010	7243	3147727	9180	9180	0	0	0	0	0	0	-	0
131	Oman	OMN	2010	311	3041434	40607	33764	5185	16,67	100989599199	1284848368	107246179	3344165	81 948 760	10752,94
86	Jamaica	JAM	2010	10621	2810460	8767	7605	3282	0,31	26747398296	244536034	108789282	46400510	1 137 044 451	4368,75
140	Qatar	QAT	2010	434	1856327	443	397	580	1,34	203025574388	53303315	4903216	4547543	111 437 537	10478,21
66	Gambia	GMB	2010	75168	1793196	405	7	560	0,01	4906805141	585784	6724	414732	10 163 007	5,52
61	Gabon	GAB	2010	195438	1624140	384	274	422	0	21594976839	4982945	972298	1455760	35 673 397	7,45
166	Trinidad and Tobago	TTO	2010	11395	1328147	712	686	415	0,04	42641951800	5277469	1955300	632082	15 489 169	55,47
120	Mauritius	MUS	2010	391	1247955	0	0	0	0	21047836494	0	0	0	-	0

193	TimorLeste	TLS	2010	1347	1088486	1385	1174	1522	1,13	14129126078	17978035	15239143	19756368	484 129 778	14666,94
68	Equatorial Guinea	GNQ	2010	34004	943639	649	527	59	0	33789655963	20353066	442089	755486	18 513 184	22,22
59	Fiji	FJI	2010	48767	859818	1356	1128	1813	0,04	9392392987	9415484	3950336	6732854	164 988 581	138,06
48	Djibouti	DJI	2010	693	840198	4293	2554	110	0,16	2533400848	10732907	769688	115938	2 841 061	167,3
72	Guyana	GUY	2010	40390	749436	53542	43699	29326	0,73	6101135187	421116891	126335	82746	2 027 691	2,05
188	SolomonIslands	SLB	2010	52275	540394	6963	5658	1444	0,03	951595572	12261350	9963337	2542782	62 310 870	48,64
105	China, Macao SAR	MAC	2010	124	538219	0	0	0	0	52564328374	0	0	0	-	0
152	Suriname	SUR	2010	84943	529131	3888	2513	32112	0,38	7295609793	94614808	28486494	297885498	7 299 683 830	3506,89
27	Brunei Darus-salam	BRN	2010	18582	388646	2938	2138	986	0,05	23901175438	274706284	23770897	1305590	31 993 482	70,26
19	Bahamas	BHS	2010	142069	354942	4342	4106	821	0,01	10700438474	471402538	168473459	39444371	966 584 272	277,64
22	Belize	BLZ	2010	67513	322464	1438	1299	5490	0,08	1978480722	12936012	5276016	21180817	519 035 899	313,73
201	FrenchPolynesia	PYF	2010	119	283788	383	256	162	1,36					-	
190	NewCaledonia	NCL	2010	32148	249750	1759	1503	1061	0,03	27221465561	191721954	163819270	115643543	2 833 844 905	3597,22
195	Vanuatu	VUT	2010	1601	245453	857	838	19	0,01	1849825928	6458674	6315483	143191	3 508 895	89,44
199	Samoa	WSM	2010	240	194672	380	270	61	0,25	0	0	0	0	-	0
99	Saint Lucia	LCA	2010	162	174085	284	278	16	0,1	2022826606	8961406	3342898	405282	9 931 435	2501,74
203	UnitedStates-VirginIslands	VIR	2010	273	108357	132	76	78	0,29	0	0	0	0	-	0
187	Kiribati	KIR	2010	146	107995	7067	6418	424	2,9	431646817	28246197	25652199	1694692	41 528 426	
194	MicronesiaFed-eratedStatesof	FSM	2010	8997	107588	752	666	137	0,02	0	0	0	0	-	0
202	Tonga	TON	2010	1071	107383	261	221	341	0,32	964490813	2344245	1984974	3062788	75 053 617	2859,75
70	Grenada	GRD	2010	209	106233	3	3	10	0,05	1382088016	127813	54350	208927	5 119 756	999,65
158	Seychelles	SYC	2010	227	91264	4182	4017	149	0,66	1681786978	209231209	36193510	1734235	42 497 427	7639,8
8	Antigua and Barbuda	ATG	2010	841	88028	765	713	340	0,4	1243184861	50485210	22896669	4396622	107 739 218	5227,85
44	Cayman Islands	CYM	2010	4459	56672	0	0	0	0	3830571472	0	0	0	-	0
160	Turks and Caicos Islands	TCA	2010	12429	32660	433	408	89	0,01	459623272	38132727	19684138	5887262	144 267 349	473,67
206	Palau	PLW	2010	5702	18540	104	104	2	0	0	0	0	0	-	0
192	FrenchGuiana	GUF	2010	77846	0	1377	1327	1216	0,02	0	0	0	0	-	0
207	Mayotte	MYT	2010	692	0	93	73	164	0,24	0	0	0	0	-	0
209	NetherlandsAn-tilles	ANT	2010	237	0	27	27	144	0,61	0	0	0	0	-	0
200	Martinique	MTQ	2010	1927	0	456	445	53	0,03	0	0	0	0	-	0
191	Guadeloupe	GLP	2010	3431	0	1472	1334	484	0,14	0	0	0	0	-	0
														352 638 497 469	

TABLE A3: FLOOD RISK AND FLOOD REDUCTION BENEFITS OF MANGROVES ACROSS 97 COUNTRIES IN 2020

2020															
ID	COUNTRY	ISO3	YEAR	MANG HA	POP	POP EXP	POP RISK	POP BEN	POP BEN HA	STOCK	STOCK EXP	STOCK RISK	STOCK BEN	PV 100yr 4%	STOCK BEN HA
34	China	CHN	2020	24926	1439919586	17237935	16077932	764 842	30,68	22066954093611	503328178904	121390511628	7 463 666 893	182 897 149 728	299433
79	India	IND	2020	492571	1380193228	1559486	1210902	1 144 050	2,32	10544231204789	7721477376	1733514554	1 620 261 180	39 704 498 591	3289,4
174	United States	USA	2020	231525	331033569	378332	329242	64 247	0,28	22583187924602	82306728605	21906039066	2 436 538 383	59 707 370 632	10523,87
78	Indonesia	IDN	2020	2913232	273580593	1145396	783119	489 596	0,17	3551482344809	15221306577	2578974892	1 532 916 500	37 564 117 295	526,19
132	Pakistan	PAK	2020	82083	220902350	54119	42299	21 578	0,26	1114688608941	103165962	19940747	15 305 644	375 064 791	186,47
25	Brazil	BRA	2020	1138408	212629731	387813	348868	265 511	0,23	2507912321150	7441494892	1789208830	773 487 112	18 954 300 904	679,45
125	Nigeria	NGA	2020	887472	206052515	201334	133742	94 983	0,11	1242930041098	964197244	208762747	93 448 379	2 289 952 434	105,3
16	Bangladesh	BGD	2020	531711	164715614	785889	657059	621 358	1,17	944499321470	3493814052	1423614981	1 354 057 650	33 181 181 355	2546,6
110	Mexico	MEX	2020	1004711	128960270	139412	104691	161 141	0,16	2423514373478	4625531937	1191043651	1 311 000 444	32 126 064 565	1304,85
88	Japan	JPN	2020	1016	126518410	37717	33178	2 485	2,45	5463369531448	7340739543	1337335759	411 913 542	10 093 940 934	405426,71
135	Philippines	PHL	2020	274939	109581836	921223	817650	327 137	1,19	1152134708370	6636454709	1587984994	591 802 185	14 502 111 950	2152,49
179	Vietnam	VNM	2020	186363	97378250	3054035	2467538	3 673 309	19,71	976490541756	13368713959	4763444998	7 418 425 588	181 788 511 594	39806,32
163	Thailand	THA	2020	264930	69822711	196404	124711	23 646	0,09	1368329275145	3799821323	840303431	211 367 279	5 179 554 960	797,82
181	South Africa	ZAF	2020	2654	59324022	10060	8866	1 603	0,6	712029114557	140434889	76226762	19 888 539	487 368 628	7493,8
170	U.R. of Tanzania: Mainland	TZA	2020	120155	58026159	24907	19894	10 681	0,09	166628255923	65544673	27787778	15 381 416	376 921 584	128,01
114	Myanmar	MMR	2020	546707	54382520	557333	469825	63 024	0,12	393081087972	1323031211	186443130	71 031 161	1 740 618 529	129,93
90	Kenya	KEN	2020	56260	53755381	19316	15358	34 183	0,61	316018342362	55593858	16973713	30 239 949	741 029 920	537,5
39	Colombia	COL	2020	289936	51017838	85513	71822	15 055	0,05	646151159225	1305068446	203611042	71 735 854	1 757 887 030	247,42
145	Sudan	SDN	2020	684	43824943	8327	6649	3 564	5,21	154300616960	17291685	2239910	999 635	24 496 055	1461,45
144	Saudi Arabia	SAU	2020	6127	34834300	105468	82993	17 490	2,85	1679407656786	5240755693	494669022	103 970 766	2 547 803 517	16969,28
134	Peru	PER	2020	11845	33031646	8609	8188	659	0,06	429569152836	153187717	66167515	5 575 666	136 631 690	470,72
2	Angola	AGO	2020	51756	32840803	12342	11775	6 739	0,13	151786681522	107089034	25544965	25 724 543	630 379 900	497,03
122	Malaysia	MYS	2020	579537	32371521	134338	106284	22 448	0,04	858632009547	3247177863	326202137	101 506 964	2 487 428 051	175,15
117	Mozambique	MOZ	2020	304897	31236068	50833	41997	28 845	0,09	41999747798	48988659	21831867	20 673 476	506 603 509	67,8
64	Ghana	GHA	2020	18391	31068610	92572	59157	18 397	1	196992841710	598480629	238007943	104 120 600	2 551 475 199	5661,5
180	Yemen	YEM	2020	1566	29825161	59110	50926	6 239	3,98	40531798299	764720226	307617994	29 685 563	727 444 692	18956,3
177	Venezuela (Bolivarian Republic of)	VEN	2020	300542	28144540	144021	128871	19 847	0,07					-	
108	Madagascar	MDG	2020	275833	27676301	113228	103671	20 020	0,07	50127560367	123876405	31042035	13 542 987	331 870 883	49,1
36	Cameroon	CMR	2020	211303	26536493	11569	9922	159 861	0,76	100262884445	38220698	13402059	86 809 675	2 127 270 999	410,83
35	Côte d'Ivoire	CIV	2020	6453	26363858	87478	82261	32 548	5,04	138705040325	266796665	96549850	12 464 196	305 435 110	1931,54
9	Australia	AUS	2020	988392	25508244	119134	98148	111 606	0,11	1247675517506	26021029061	5373035758	5 072 180 073	124 293 767 602	5131,75

169	Taiwan	TWN	2020	167	23611974	469337	389704	70 762	423,72	1195742591991	31096278116	5051365408	271 882 632	6 662 483 625	
100	Sri Lanka	LKA	2020	18119	21418703	51794	45376	3 985	0,22	331303280206	604177527	153022483	17 583 436	430 882 082	970,44
71	Guatemala	GTM	2020	29554	17915095	1757	1684	996	0,03	162903260127	13715393	8035086	4 633 208	113 536 757	156,77
53	Ecuador	ECU	2020	162785	17662966	35865	30509	16 398	0,1	209442935936	798905577	142529876	144 993 398	3 553 063 073	890,7
146	Senegal	SEN	2020	232995	16738405	50280	30551	32 980	0,14	61323779034	175016917	35195408	43 351 208	1 062 321 309	186,06
92	Cambodia	KHM	2020	69351	16723292	101530	92456	71 430	1,03	97311570007	269136301	116612032	110 580 366	2 709 771 758	1594,5
184	Somalia	SOM	2020	5886	16537016	26538	21804	2 039	0,35	4641219516	7448060	6119432	572 258	14 023 182	97,22
65	Guinea	GIN	2020	253417	13128199	14768	7795	21 210	0,08	49747828142	33535451	10941961	35 497 912	869 876 298	140,08
14	Benin	BEN	2020	2970	12117258	91341	70975	7 469	2,51	44453903282	244459495	101259778	6 809 478	166 866 252	2292,75
76	Haiti	HTI	2020	18837	11402976	32329	29641	32 354	1,72	19346133743	140521875	70343431	82 257 844	2 015 728 385	4366,82
186	Cuba	CUB	2020	342417	11300698	33617	29447	9 227	0,03	192579234168	572879314	501816853	157 240 605	3 853 180 868	459,21
51	Dominican Republic	DOM	2020	19270	10850775	45178	42807	6 554	0,34	213350265311	861913506	198454163	14 110 676	345 782 101	732,26
5	United Arab Emirates	ARE	2020	7393	9910099	323118	249755	111 891	15,13	647638636076	27732260735	499717857	308 394 623	7 557 209 927	41714,41
74	Honduras	HND	2020	85226	9904712	7825	6683	2 721	0,03	64976689587	55174221	23723407	8 703 728	213 284 846	102,13
189	PapuaNew-Guinea	PNG	2020	461059	9749640	26358	22150	8 133	0,02	46690143258	126226076	106074345	38 948 201	954 425 626	84,48
162	Togo	TGO	2020	1455	8275639	8215	4973	4 786	3,29	19770572881	17086086	5917452	2 349 117	57 565 110	1614,51
148	Sierra Leone	SLE	2020	172741	7976280	16630	10778	6 660	0,04	15545890652	13878968	6386342	3 624 628	88 821 506	20,98
126	Nicaragua	NIC	2020	86057	6625503	6220	5268	8 175	0,09	39336029220	47887833	19871485	16 609 848	407 024 309	193,01
149	El Salvador	SLV	2020	51920	6486360	2655	2324	1 222	0,02	58771070279	26116400	15432669	2 211 573	54 194 594	42,6
147	Singapore	SGP	2020	15222	5851175	6372	5046	1 192	0,08	490410857871	960621673	8122326	4 813 679	117 959 199	316,23
38	Congo	COG	2020	2500	5516657	1001	1001	1 510	0,6	16310826822	11226038	7336084	1 686 750	41 333 807	674,7
131	Oman	OMN	2020	387	5120499	51012	38018	14 581	37,68	132034377473	1579581787	129390724	30 014 604	735 507 841	77557,12
42	Costa Rica	CRI	2020	37034	5095681	4923	4394	2 729	0,07	109928199585	119030888	36367818	16 181 122	396 518 378	436,93
98	Liberia	LBR	2020	19726	5055775	18142	11220	5 823	0,3	7266664186	25975300	7704047	5 179 471	126 922 932	262,57
130	New Zealand	NZL	2020	29676	4822995	24559	23126	1 186	0,04	201472933694	3402247113	1315012005	223 056 032	5 465 987 840	7516,38
118	Mauritania	MRT	2020	1563	4648079	21934	16060	6 652	4,26	26841093079	105178233	31499215	22 558 559	552 797 466	14432,86
133	Panama	PAN	2020	152860	4316009	9396	8837	4 742	0,03	142258286551	432989773	29488915	14 716 690	360 632 474	96,28
197	Eritrea	ERI	2020	7175	3555868	4628	4570	6 838	0,95	0	0	0	-	-	0
185	PuertoRico	PRI	2020	8200	3281538	17793	14668	17 258	2,1	189460350901	1027282946	846860352	996 394 598	24 416 648 625	121511,54
86	Jamaica	JAM	2020	9767	2961711	12126	9981	2 804	0,29	29330849256	342650890	157691761	38 824 287	951 389 114	3975,05
140	Qatar	QAT	2020	460	2882452	3810	3051	6 533	14,2	283597278193	655662501	43318936	57 131 953	1 400 018 451	124199,9
66	Gambia	GMB	2020	74425	2415318	3197	2784	1 687	0,02	6459215166	4096410	1778693	1 397 478	34 245 197	18,78
61	Gabon	GAB	2020	194197	2225883	2293	2162	1 557	0,01	31052975545	35277709	4512528	2 956 009	72 436 998	15,22
68	Equatorial Guinea	GNQ	2020	33795	1402997	4245	3803	1 290	0,04	24417268575	113355638	7067366	11 432 764	280 159 870	338,3

166	Trinidad and Tobago	TTO	2020	11169	1400103	2831	3000	567	0,05	39559069658	51048847	16350499	6 937 261	169 997 574	621,12
193	TimorLeste	TLS	2020	1344	1299995	2700	2188	3 698	2,75	4782237753	9932378	8048905	13 603 679	333 358 140	10121,78
120	Mauritius	MUS	2020	396	1272151	0	0	-	0	30158458634	0	0	-	-	0
48	Djibouti	DJI	2020	779	988197	5709	4169	6 547	8,4	5945590252	27144682	944435	1 075 824	26 363 066	1381,03
59	Fiji	FJI	2020	48811	896423	6302	5564	3 911	0,08	12606096425	55773758	26223658	18 000 774	441 108 949	368,79
72	Guyana	GUY	2020	38703	786526	73204	56761	33 613	0,87	8928041978	596287984	26437556	10 643 910	260 829 004	275,02
188	SolomonIslands	SLB	2020	51928	691191	14244	12568	4 837	0,09	2268082456	46740433	41240786	15 872 190	388 948 000	305,66
105	China, Macao SAR	MAC	2020	122	649254	0	0	-	0	62706830508	0	0	-	-	0
152	Suriname	SUR	2020	85438	586754	6293	4230	69 710	0,82	7834100992	169048742	42509610	505 220 635	12 380 431 154	5913,3
27	Brunei Darus-salam	BRN	2020	18707	437607	5115	4636	1 602	0,09	25333602841	608827310	47223278	7 818 968	191 603 803	417,97
22	Belize	BLZ	2020	68012	397635	3628	3252	5 925	0,09	2333555212	35366730	13669276	19 687 220	482 435 306	289,47
19	Bahamas	BHS	2020	145902	393327	7569	6953	2 378	0,02	12077227252	901310859	321316069	133 727 487	3 276 991 935	916,56
195	Vanuatu	VUT	2020	1532	311685	6177	5656	1 607	1,05	2899356943	57459704	52613257	14 948 639	366 316 384	9757,6
201	French Polynesia	PYF	2020	126	301920	2115	1753	122	0,97					-	
190	NewCaledonia	NCL	2020	33481	271130	6612	5427	1 384	0,04	49249393849	1201036374	985787115	251 396 603	6 160 473 504	7508,63
199	Samoa	WSM	2020	231	214929	579	543	2 568	11,12	0	0	0	-	-	0
99	Saint Lucia	LCA	2020	162	183691	1178	1108	1 933	11,93	2381591197	40887955	24267845	30 791 157	754 537 271	190068,87
187	Kiribati	KIR	2020	146	126463	4934	3919	890	6,1	581128449	22672938	18008765	4 089 768	100 219 761	28012,11
70	Grenada	GRD	2020	209	112552	1616	1594	623	2,98	1889054893	60951484	37890019	18 732 052	459 028 915	89627,04
194	MicronesiaFeder-atedStatesof	FSM	2020	8711	112106	3307	2962	420	0,05	0	0	0	-	-	0
203	UnitedStatesVir-ginIslands	VIR	2020	274	106290	1552	1395	257	0,94	0	0	0	-	-	0
202	Tonga	TON	2020	1039	105254	1245	896	1 404	1,35	1380935130	16334431	11755543	18 420 515	451 394 702	17729,08
158	Seychelles	SYC	2020	227	98382	5641	5287	652	2,87	2646840504	326410103	25239839	10 276 077	251 815 257	45269,06
8	Antigua and Barbuda	ATG	2020	869	97950	1231	1050	452	0,52	1675958120	93134444	38271361	14 072 879	344 855 886	16194,34
44	Cayman Islands	CYM	2020	4432	65722	0	0	-	0	4949331518	0	0	-	-	0
160	Turks and Caicos Islands	TCA	2020	15037	38717	899	827	1 641	0,11	699238769	74687008	47566667	71 921 778	1 762 443 098	4782,99
206	Palau	PLW	2020	5687	17972	561	584	253	0,04	0	0	0	-	-	0
192	FrenchGuiana	GUF	2020	83100	0	3646	3484	6 074	0,07	0	0	0	-	-	0
207	Mayotte	MYT	2020	675	0	2270	2167	1 335	1,98	0	0	0	-	-	0
209	NetherlandsAn-tilles	ANT	2020	228	0	526	458	6 468	28,37	0	0	0	-	-	0
200	Martinique	MTQ	2020	1944	0	2419	2384	620	0,32	0	0	0	-	-	0
191	Guadeloupe	GLP	2020	3415	0	2766	2631	1 016	0,3	0	0	0	-	-	0

TABLE A4: ABSOLUTE CHANGES IN FLOOD RISK AND FLOOD REDUCTION BENEFITS OF MANGROVES ACROSS 97 COUNTRIES BETWEEN 1996-2010

1996 vs 2010 (ABSOLUTE VALUE)															
ID	COUNTRY	ISO3	YEAR	MANG HA	POP	POP EXP	POP RISK	POP BEN	POP BEN HA	STOCK	STOCK EXP	STOCK RISK	STOCK BEN	PV 100yr 4%	STOCK BEN HA
79	India	IND	1996	-15147	251915927	221580	180393	149329	0,34	3363034386273	1659825265	391836886	321792484	7885524497,711	675,55
34	China	CHN	1996	-4683	117174429	3632688	3566779	57754	5,2	9277371889184	162544239142	41875083111	1439084519	35264764694,912	65040,05
132	Pakistan	PAK	1996	-14818	52075351	12372	9038	3997	0,08	297237074211	27790233	294213	1241970	30434473,604	35,82
125	Nigeria	NGA	1996	-24478	47834403	31767	21283	7874	0,01	536934248005	94753298	18464527	-11556541	-283193025,616	-11,53
78	Indonesia	IDN	1996	-197069	41077625	106121	91501	57592	0,02	798321834233	2783720261	470699014	246046239	6029362839,948	95,73
174	United States	USA	1996	-7990	40676472	22580	21211	4319	0,02	5290777495921	9666849615	1688107585	-71478909	-1751590593,363	-125,58
25	Brazil	BRA	1996	-20765	31098947	391	272	64927	0,06	821734429134	481035507	93172021	76217888	1867719269,005	72,45
16	Bangladesh	BGD	1996	2352	29925498	95269	69548	-967	-0,01	258362228872	456286198	189859380	90288647	2212523204,189	169,57
135	Philippines	PHL	1996	-15150	22565031	85322	88718	34560	0,17	282070725661	801953095	85289324	-5574642	-136606596,619	77,07
110	Mexico	MEX	1996	-61017	20945919	13529	12478	10615	0,02	561751648403	631163993	167723259	88147616	2160057241,681	114,91
170	U.R. of Tanzania: Mainland	TZA	1996	-2857	13463875	3296	2658	811	0,01	48071174873	9105599	3585707	3010788	73779356,921	25,51
90	Kenya	KEN	1996	-811	13441225	3201	3115	194	0	71600323004	8246042	4024973	-1746337	-42793986,434	-27,74
179	Vietnam	VNM	1996	-11432	11898908	235650	194362	459169	3,07	314801295487	3731072094	1493273450	2415871075	59200918270,124	13149,19
145	Sudan	SDN	1996	-656	9762630	2750	2152	11	0,02	61746830861	14086867	2032681	13494	330670,456	31,83
181	South Africa	ZAF	1996	50	8975953	166	144	6	0	219192833592	3968894	2186690	25110	615320,525	9,03
2	Angola	AGO	1996	-839	8955527	1989	1675	1065	0,02	83720417658	16977485	4918901	3920143	96063100,284	75,4
144	Saudi Arabia	SAU	1996	-915	8387616	13881	11655	1654	0,25	403257798747	804817015	65180022	2389935	58565354,778	531,5
39	Colombia	COL	1996	-10593	8146313	11553	10677	4111	0,01	156091163755	163056741	28652198	9214444	225799940,979	36,2
180	Yemen	YEM	1996	-332	7685581	8279	7553	11	0,01	44584428738	204304434	51331316	48609	1191163,496	85,5
117	Mozambique	MOZ	1996	-11314	7571132	5595	4408	3112	0,02	16991659202	5538781	2308653	3235925	79296338,880	10,6
64	Ghana	GHA	1996	-684	7317123	7806	6265	2542	0,16	53735201719	76756841	35135106	16898692	414102430,513	1036,31
108	Madagascar	MDG	1996	-7442	7248952	24390	22296	7400	0,03	12403175149	33287384	10788745	3110695	76227577,855	11,94
122	Malaysia	MYS	1996	-5281	7190422	8303	51	25719	0,04	234681924228	377728436	21285705	11963568	293167221,842	21,81
163	Thailand	THA	1996	-16045	7064842	20125	37001	-21686	-0,08	352583062214	412959535	165056108	-100631855	-2465983505,857	-346,14
36	Cameroon	CMR	1996	1066	6370428	512	261	5956	0,03	27503467913	1755300	317161	454318	11133062,134	1,91
114	Myanmar	MMR	1996	-44871	6148612	92821	77722	9935	0,03	167655151945	221242157	35137225	10241119	250958610,825	19,14
177	Venezuela (Bolivarian Republic of)	VEN	1996	-3270	6054290	29555	26030	4133	0,01	0	0	0	0	0	0
5	United Arab Emirates	ARE	1996	126	6010862	146486	135338	34842	4,43	214959806512	5184773628	-59654303	-27426055	-672075450,271	-4255,15
35	Côte d'Ivoire	CIV	1996	-28	5867823	6223	5702	131	0,02	13159562623	7849310	2767896	-387828	-9503724,751	-54,26
184	Somalia	SOM	1996	-118	4554199	3109	2725	755	0,13	673079506	-1416269	-1313503	243188	5959321,696	41

134	Peru	PER	1996	-2218	4273850	788	653	20	0	139481689499	19593848	7098733	206728	5065869,433	21,89
71	Guatemala	GTM	1996	-374	3983743	34	18	49	0	44608082819	533763	388962	397117	9731351,687	14,07
9	Australia	AUS	1996	-51051	3965402	5378	4809	6846	0,01	372719376006	2580200294	267450184	79771357	1954797023,286	158,37
146	Senegal	SEN	1996	1460	3765287	9973	6252	4303	0,02	16580387683	37134858	1426170	9367225	229543839,231	39,61
92	Cambodia	KHM	1996	-5399	3329295	7032	8985	3761	0,1	32283907627	71818910	33569727	24753493	606584321,141	386,27
53	Ecuador	ECU	1996	-10898	3307943	1974	3710	-201	0	58565359075	37989724	8494618	-16773307	-411029871,214	-81,78
14	Benin	BEN	1996	-312	3105000	11393	9342	2	0,01	8432618642	21077289	9045980	-90490	-2217457,359	-13,91
189	PapuaNew-Guinea	PNG	1996	-637	2797374	441	345	418	0	17321373008	7820750	5014398	6538534	160226769,113	14,02
65	Guinea	GIN	1996	-1944	2728394	233	-33	1738	0	10110745699	2151541	704956	3326625	81518942,289	12,87
74	Honduras	HND	1996	2497	2442661	973	964	237	0	18586750580	8182122	3733743	2081326	51002891,543	20,92
148	Sierra Leone	SLE	1996	-1936	2102968	572	402	42	0	4525079221	-410132	6268	-371473	-9102945,492	-1,96
162	Togo	TGO	1996	36	2072874	-21	27	0	0	1894710681	-896188	-294244	0	0	0
76	Haiti	HTI	1996	-1876	2062018	7059	6872	-2164	-0,06	1437146742	33678163	14953780	6141135	150488507,016	383,22
88	Japan	JPN	1996	-23	1898259	1053	1008	-488	-0,45	418763116711	626541195	125525732	-11792737	-288981008,359	-10670,6
100	Sri Lanka	LKA	1996	-7923	1894449	721	383	235	0,06	107359546067	22566966	2642399	4565475	111876960,297	357,23
51	Dominican Republic	DOM	1996	-491	1742358	4262	3853	171	0,01	66824943188	126476410	25451226	2350545	57600102,868	126,33
98	Liberia	LBR	1996	54	1730878	1535	439	1092	0,05	4322026872	418307	78440	196838	4823514,993	9,33
169	Taiwan	TWN	1996	15	1699516	-13645	-15382	31995	132,47	427535007537	4600455165	471803704	120879595	2962154354,251	521994,33
147	Singapore	SGP	1996	-591	1492985	697	646	134	0,01	185972952138	102392327	-2955022	722654	17708635,545	47,41
38	Congo	COG	1996	-32	1487921	286	286	0	0	7919049458	2656634	-20439	0	0	0
140	Qatar	QAT	1996	1	1333796	334	296	436	1,01	166242140922	45561336	2491378	1493139	36589369,698	3424,16
118	Mauritania	MRT	1996	-102	1121294	1484	1023	1054	1,02	5383382399	12503121	4511561	3819472	93596157,530	3077,3
126	Nicaragua	NIC	1996	2633	1082487	204	179	178	0	11713334415	1809677	630713	599889	14700279,343	5,82
42	Costa Rica	CRI	1996	343	945016	152	147	406	0,01	36536942793	21550978	2681935	-528432	-12949225,630	-15,19
197	Eritrea	ERI	1996	-2060	883654	8499	8499	-1141	-0,12	0	0	0	0	0	0
133	Panama	PAN	1996	432	846396	634	450	1124	0,01	43177066997	31069757	-1196173	-2023530	-49586600,621	-13,1
131	Oman	OMN	1996	-170	804780	17719	14911	1735	9,5	35320272737	790222744	28301946	-1903493	-46645094,056	-156,95
130	New Zealand	NZL	1996	1166	652713	389	349	30	0	47825439175	116256103	41094523	3309011	81087311,237	54,01
66	Gambia	GMB	1996	1069	629105	-150	-7	-78	0	1991713435	34515	-2294	76573	1876421,288	0,96
61	Gabon	GAB	1996	60	511185	24	37	75	0	1456673319	-494637	-74841	152738	3742844,537	0,78
149	El Salvador	SLV	1996	763	493937	-96	-121	39	0	12993453542	1823454	845233	708364	17358459,110	12,87
68	Equatorial Guinea	GNQ	1996	168	427786	165	130	24	0	31205745628	18994393	-71770	537681	13175872,366	15,78
186	Cuba	CUB	1996	-28599	327386	921	444	317	0,01	-8276939789	-427394	-2948170	-2485763	-60913619,822	3,24
193	TimorLeste	TLS	1996	-26	257217	386	304	-2	0,02	-13085643657	-14728050	-13243634	-30137600	-738521857,777	-21672,44
86	Jamaica	JAM	1996	70	251823	34	715	-1344	-0,13	1245124764	23122354	24603926	-7357964	-180306900,441	-726,36
48	Djibouti	DJI	1996	-307	196544	1656	968	25	0,07	1279859125	8291519	588517	88429	2166952,556	139,79
188	SolomonIs-lands	SLB	1996	177	154325	2173	1499	644	0,01	631682712	8292156	6517016	1879869	46066187,960	35,92

105	China, Macao SAR	MAC	1996	-10	144846	0	0	0	0	34227282805	0	0	0	0	0
22	Belize	BLZ	1996	-4165	108800	634	561	1765	0,03	939017536	6561127	2128955	3164669	77550210,671	62,38
120	Mauritius	MUS	1996	-162	106007	0	0	0	0	9698836182	0	0	0	0	0
27	Brunei Darus-salam	BRN	1996	148	84024	558	480	206	0,01	3800503828	54289615	2965047	-554612	-13590766,504	-30,65
152	Suriname	SUR	1996	3380	80918	2085	1573	5778	0,06	3113382946	63788356	21141128	95871629	2349334172,500	1030,11
59	Fiji	FJI	1996	226	75432	-486	-487	385	0,01	1797779572	-752984	-81772	2040909	50012472,998	41,4
19	Bahamas	BHS	1996	-22744	70964	1240	1212	128	0,01	2653955928	255060484	85019213	15323498	375502303,123	131,29
195	Vanuatu	VUT	1996	16	70739	-89	-92	-2	0	1253323021	3228871	3140307	71493	1751935,893	44,2
166	Trinidad and Tobago	TTO	1996	-472	70598	298	300	-377	-0,03	24892756556	2825980	278117	-1893234	-46393697,271	-157,33
190	NewCaledonia	NCL	1996	-860	52186	176	136	95	0	19999351863	133854094	113847466	80330622	1968501811,551	2527,39
201	FrenchPoly-nesia	PYF	1996	-3	48599	62	47	18	0,18	0	0	0	0	0	0
99	Saint Lucia	LCA	1996	-1	25251	-5	-5	1	0,01	499241624	3567813	52032	223988	5488825,715	1389,51
187	Kiribati	KIR	1996	0	25163	-850	-984	78	0,53	148232905	1157778	325879	510835	12518011,163	3498,87
44	Cayman Islands	CYM	1996	-225	22607	0	0	0	0	1377450625	0	0	0	0	0
199	Samoa	WSM	1996	6	17959	-84	-27	-26	-0,12	0	0	0	0	0	0
8	Antigua and Barbuda	ATG	1996	-19	17855	-118	-114	-27	-0,03	355706954	14170179	14595257	-9074	-222358,361	104,95
160	Turks and Cai-cos Islands	TCA	1996	-8202	15734	232	232	-53	0	254975074	32369321	16776065	3431593	84091183,024	354,64
158	Seychelles	SYC	1996	0	13670	299	315	9	0,04	629787868	68960703	2249950	-2207274	-54089247,156	-9723,68
202	Tonga	TON	1996	16	7188	119	168	-115	-0,11	459694074	1628829	1717952	765395	18756003,707	682,13
70	Grenada	GRD	1996	-1	5232	-1	-1	1	0,01	501699111	37642	16785	83920	2056459,516	404,38
206	Palau	PLW	1996	46	808	17	26	-10	0	0	0	0	0	0	0
203	UnitedStates-VirginIslands	VIR	1996	-8	262	-3	-6	1	0,02	0	0	0	0	0	0
192	FrenchGuiana	GUF	1996	1823	0	377	352	558	0,01	0	0	0	0	0	0
207	Mayotte	MYT	1996	15	0	39	30	47	0,07	0	0	0	0	0	0
209	Netherland-sAntilles	ANT	1996	-55	0	11	11	46	0,27	0	0	0	0	0	0
200	Martinique	MTQ	1996	6	0	-3	-1	11	0,01	0	0	0	0	0	0
191	Guadeloupe	GLP	1996	18	0	105	252	-305	-0,09	0	0	0	0	0	0
185	PuertoRico	PRI	1996	75	-3130	2081	2555	-3593	-0,43	116995770779	395889108	353263207	397300853	9735857004,333	45676,88
194	Micronesi-aFederated-Statesof	FSM	1996	-87	-3197	-235	-212	-75	0	0	0	0	0	0	0
72	Guyana	GUY	1996	1200	-11359	10181	6905	-6709	-0,19	3349761415	118428328	35528	-12067	-295701,823	-0,37

TABLE A5: ABSOLUTE CHANGES IN FLOOD RISK AND FLOOD REDUCTION BENEFITS OF MANGROVES ACROSS 97 COUNTRIES BETWEEN 2010-2020

2010 VS 2020 (ABSOLUTE VALUE)															
ID	COUNTRY	ISO3	YEAR	MANG HA	POP	POP EXP	POP RISK	POP BEN	POP BEN HA	STOCK	STOCK EXP	STOCK RISK	STOCK BEN	PV 100yr 4%	STOCK BEN HA
179	Vietnam	VNM	1996	-1167	9410599	1287588	914004	1213745	6,59	447559339451	8401969827	2698745235	4132412203	101264756890,334	22283,72
34	China	CHN	1996	543	71108971	2653237	1906318	278618	10,74	7620097119879	301267777269	56472465532	5113518217	125306758779,503	203048,28
185	PuertoRico	PRI	1996	-425	-439987	6563	5102	2286	0,36	-3874577248	443879303	349902271	218592341	5356605096,990	31331,57
79	India	IND	1996	-2439	145912058	752753	566539	369323	0,75	4771936673225	5120485198	999793110	873766884	21411656616,165	1781,36
78	Indonesia	IDN	1996	-28389	31746378	518641	347268	125251	0,05	1426697326745	9385222486	1472666994	720486455	17655519857,237	250,01
169	Taiwan	TWN	1996	-45	471026	259110	203595	-12596	30,52	289475509817	18971175301	2709630198	16822422	412233434,240	424925,51
152	Suriname	SUR	1996	495	57623	2405	1717	37598	0,44	538491199	74433934	14023116	207335137	5080747324,259	2406,41
16	Bangladesh	BGD	1996	1692	17140184	528396	451217	460458	0,87	462303695045	2854274900	1146164956	1171503291	28707686971,115	2202,17
110	Mexico	MEX	1996	1745	14867307	84622	63020	85903	0,08	458842695649	3018129719	693536253	750254925	18384996184,733	745,76
190	NewCaledonia	NCL	1996	1333	21380	4853	3924	323	0,01	22027928288	1009314420	821967845	135753060	3326628599,160	3911,41
9	Australia	AUS	1996	-11734	3353565	85071	69496	72431	0,07	231734356406	19213311156	3767427651	3373474883	82666998624,832	3433,26
25	Brazil	BRA	1996	10778	16916096	206406	181134	129361	0,11	174065484108	4339875553	965644205	394063631	9656528882,469	342,97
92	Cambodia	KHM	1996	1344	2411080	24254	19426	32093	0,45	48165510565	143090708	60543006	65224653	1598330056,355	927,57
64	Ghana	GHA	1996	430	6288991	50816	26252	3631	0,18	92678760574	319865720	112290403	40485082	992086893,810	2118,52
19	Bahamas	BHS	1996	3833	38385	3227	2847	1557	0,01	1376788778	429908321	152842610	94283116	2310407663,028	638,92
122	Malaysia	MYS	1996	-5239	4163486	63666	57923	-30321	-0,05	331517900087	1985684677	167945378	1488607	36478313,042	4,11
114	Myanmar	MMR	1996	-5377	3781702	214329	193775	-23017	-0,04	175473114763	1068355062	138714415	56426109	1382721744,458	103,48
146	Senegal	SEN	1996	-1937	4060257	22938	13262	21550	0,09	23766052629	95538593	19197932	24000201	588124901,436	103,69
39	Colombia	COL	1996	925	5795138	52809	43072	-3434	-0,01	191766073614	914329665	113156562	27163339	665637594,954	93,2
189	PapuaNew-Guinea	PNG	1996	-6026	2166371	21587	19193	4225	0,01	18203926747	108304024	94966505	24267971	594686605,018	53,05
76	Haiti	HTI	1996	-277	1453654	18732	17339	22632	1,21	3273474856	91555836	49645202	62872380	1540687608,849	3352,62
100	Sri Lanka	LKA	1996	181	1156966	45390	41516	883	0,05	121131568259	556976975	142543084	7003822	171628651,086	380,65
2	Angola	AGO	1996	-585	9484557	9883	9734	5263	0,1	20170111161	85639978	18254773	20103415	492634164,414	389,64
118	Mauritania	MRT	1996	204	1153884	11535	8880	797	-0,05	8838742528	74430245	20780400	13545631	331935674,071	7800,83
160	Turks and Caicos Islands	TCA	1996	2608	6057	466	419	1552	0,1	239615497	36554281	27882529	66034516	1618175748,357	4309,32
65	Guinea	GIN	1996	-6733	2936023	10984	5635	12121	0,05	22239887127	28808287	9233985	29248338	716730493,358	116,06
130	New Zealand	NZL	1996	-517	452933	21810	20802	377	0,01	51704856050	3066203136	1170320421	177967480	4361092918,926	6023,04
117	Mozambique	MOZ	1996	-9654	7704494	25417	18759	1344	0	16478795750	39856681	17916462	14571268	357068907,727	48,4
22	Belize	BLZ	1996	499	75171	2190	1953	435	0,01	355074490	22430718	8393260	-1493597	-36600592,987	-24,26
108	Madagascar	MDG	1996	631	6524661	51416	46853	2902	0,01	13926612893	49636335	3122311	3686728	90343265,943	13,29
170	U.R. of Tanzania: Mainland	TZA	1996	-1401	14931758	16230	13556	2742	0,02	79340937085	51393920	22388487	8468428	207518819,647	71,14

144	Saudi Arabia	SAU	1996	-1985	7412839	64239	48032	11865	2,16	423416274421	3624585302	298274275	82623473	2024688123,006	14337,71
51	Dominican Republic	DOM	1996	-120	1155654	30886	30176	5260	0,27	85771940990	664015033	142741770	7750033	189914550,893	404,22
74	Honduras	HND	1996	-7424	1587242	5497	4632	696	0,01	19046941441	39711465	17188432	1465861	35920922,335	24,01
59	Fiji	FJI	1996	44	36605	4946	4436	2098	0,04	3213703438	46358274	22273322	11267920	276120368,300	230,73
188	SolomonIslands	SLB	1996	-347	150797	7281	6910	3393	0,06	1316486884	34479083	31277449	13329408	326637129,673	257,02
140	Qatar	QAT	1996	26	1026125	3367	2654	5953	12,86	80571703805	602359186	38415720	52584410	1288580914,316	113721,69
132	Pakistan	PAK	1996	-10195	41477709	23366	19307	-9138	-0,07	386408437378	42476945	6461274	-855442	-20962605,352	11,34
202	Tonga	TON	1996	-32	-2129	984	675	1063	1,03	416444317	13990186	9770569	15357727	376341084,734	14869,33
147	Singapore	SGP	1996	-1141	720003	5163	4040	875	0,06	142447618199	811504193	7794540	2569723	62971059,538	179,09
149	El Salvador	SLV	1996	-1539	302485	1867	1665	802	0,01	11349553670	19472106	12169849	91755	2248456,183	2,95
126	Nicaragua	NIC	1996	-5585	801438	5347	4551	7226	0,08	8228005118	42003588	17732066	13788714	337892422,742	162,23
68	Equatorial Guinea	GNQ	1996	-209	459358	3596	3276	1231	0,04	-9372387388	93002572	6625277	10677278	261646686,682	316,08
187	Kiribati	KIR	1996	0	18468	-2133	-2499	466	3,2	149481632	-5573259	-7643434	2395076	58691334,978	16404,63
36	Cameroon	CMR	1996	-595	6195252	10067	9024	147871	0,7	35953124893	33675928	12433385	76641123	1878090642,256	362,84
71	Guatemala	GTM	1996	250	3284678	1509	1459	616	0,02	48325056417	11761090	6603808	3047669	74683125,789	102,66
184	Somalia	SOM	1996	-79	4510367	2795	396	1135	0,2	480771076	-765494	-1286362	259532	6359831,400	44,79
99	Saint Lucia	LCA	1996	0	9606	894	830	1917	11,83	358764591	31926549	20924947	30385875	744605836,403	187567,13
134	Peru	PER	1996	677	4003972	5418	5423	568	0,05	135248098539	113307531	49073673	5141256	125986473,124	431,82
98	Liberia	LBR	1996	-975	1164419	14170	10133	3171	0,17	2174828228	21497776	7067265	3604438	88326749,575	186,49
61	Gabon	GAB	1996	-1241	601743	1909	1888	1135	0,01	9457998706	30294764	3540230	1500249	36763600,240	7,77
48	Djibouti	DJI	1996	86	147999	1416	1615	6437	8,24	3412189404	16411775	174747	959886	23522005,467	1213,73
70	Grenada	GRD	1996	0	6319	1613	1591	613	2,93	506966877	60823671	37835669	18523125	453909159,549	88627,39
66	Gambia	GMB	1996	-743	622122	2792	2777	1127	0,01	1552410025	3510626	1771969	982746	24082189,744	13,26
195	Vanuatu	VUT	1996	-69	66232	5320	4818	1588	1,04	1049531015	51001030	46297774	14805448	362807488,392	9668,16
180	Yemen	YEM	1996	-109	6670306	35797	29822	6206	3,96	-51242844278	437754932	213479394	29065077	712239682,737	18585,86
181	South Africa	ZAF	1996	38	8107058	8754	7708	1564	0,59	91680943222	123332496	66551396	19787716	484897960,736	7455,26
145	Sudan	SDN	1996	-148	9279930	-1127	2386	3543	5,18	45681269827	1483642	-135157	956683	23443515,956	1409,82
177	Venezuela (Bolivarian Republic of)	VEN	1996	1275	-295400	33942	28359	3761	0,02	0	0	0	0	0	0
192	FrenchGuiana	GUF	1996	5254	0	2269	2157	4858	0,05	0	0	0	0	0	0
207	Mayotte	MYT	1996	-17	0	2177	2094	1171	1,74	0	0	0	0	0	0
209	NetherlandsAntilles	ANT	1996	-9	0	499	431	6324	27,76	0	0	0	0	0	0
201	FrenchPolynesia	PYF	1996	7	18132	1732	1497	-40	-0,39	0	0	0	0	0	0
200	Martinique	MTQ	1996	17	0	1963	1939	567	0,29	0	0	0	0	0	0
203	UnitedStatesVirginIslands	VIR	1996	1	-2067	1420	1319	179	0,65	0	0	0	0	0	0

162	Togo	TGO	1996	181	1853960	5850	3521	4786	3,29	11229184198	12849014	4235828	2349117	57565109,729	1614,51
38	Congo	COG	1996	51	1242926	257	257	1510	0,6	-1764449779	5064073	5143263	1686750	41333807,058	674,7
44	Cayman Islands	CYM	1996	-27	9050	0	0	0	0	1118760046	0	0	0	0	0
105	China, Macao SAR	MAC	1996	-2	111035	0	0	0	0	10142502134	0	0	0	0	0
120	Mauritius	MUS	1996	5	24196	0	0	0	0	9110622140	0	0	0	0	0
206	Palau	PLW	1996	-15	-568	457	480	251	0,04	0	0	0	0	0	0
199	Samoa	WSM	1996	-9	20257	199	273	2507	10,87	0	0	0	0	0	0
194	MicronesiaFed-eratedStatesof	FSM	1996	-286	4518	2555	2296	283	0,03	0	0	0	0	0	0
191	Guadeloupe	GLP	1996	-16	0	1294	1297	532	0,16	0	0	0	0	0	0
197	Eritrea	ERI	1996	-68	408141	-4552	-4610	6838	0,95	0	0	0	0	0	0
8	Antigua and Barbuda	ATG	1996	28	9922	466	337	112	0,12	432773259	42649234	15374692	9676257	237116668,081	10966,49
72	Guyana	GUY	1996	-1687	37090	19662	13062	4287	0,14	2826906791	175171093	26311221	10561164	258801313,229	272,97
14	Benin	BEN	1996	228	2917999	49452	37934	7303	2,45	25379818143	143863991	58223346	6387482	156525240,004	2138,85
148	Sierra Leone	SLE	1996	-7593	1560646	12627	9426	3317	0,02	5565348019	11197987	5836878	2326122	57001617,277	13,78
35	Côte d'Ivoire	CIV	1996	-420	5830908	62014	61669	29885	4,65	82601866585	205911340	79879626	9180901	224977969,798	1453,83
42	Costa Rica	CRI	1996	-1462	518303	2131	1699	1233	0,03	30758202124	64336862	18694695	10449695	256069765,496	288,05
27	Brunei Darus-salam	BRN	1996	125	48961	2177	2498	616	0,04	1432427403	334121026	23452381	6513378	159610321,358	347,71
90	Kenya	KEN	1996	-14	11724705	11635	8631	22253	0,4	131145646279	37422537	8995174	18941416	464159380,085	336,72
166	Trinidad and Tobago	TTO	1996	-226	71956	2119	2314	152	0,01	-3082882142	45771378	14395199	6305179	154508405,072	565,65
131	Oman	OMN	1996	76	2079065	10405	4254	9396	21,01	31044778274	294733419	22144545	26670439	653559080,949	66804,18
133	Panama	PAN	1996	-3432	673322	6805	6644	1732	0,01	61769151263	373594512	19980536	8254347	202272764,957	54,93
158	Seychelles	SYC	1996	0	7118	1459	1270	503	2,21	965053526	117178894	-10953671	8541842	209317829,644	37629,26
186	Cuba	CUB	1996	-7869	10281	24599	22371	3796	0,01	98064910475	497387844	442582251	111776625	2739086083,530	329,42
135	Philippines	PHL	1996	4773	15615056	354007	317085	77692	0,27	514020777480	3518674721	710449492	100240063	2456382643,289	333,01
86	Jamaica	JAM	1996	-854	151251	3359	2376	-478	-0,02	2583450960	98114856	48902479	-7576223	-185655337,017	-393,7
125	Nigeria	NGA	1996	-8320	47549318	113985	77329	55581	0,07	321181345449	597092467	118560438	58950903	1444591818,896	66,79
88	Japan	JPN	1996	14	-2023943	21228	18723	1482	1,45	483305980456	4294237225	668811273	374648929	9180771629,429	368236,48
53	Ecuador	ECU	1996	2792	2651849	27173	22826	8718	0,05	45024142640	629969829	105876865	103919692	2546551948,244	633,98
5	United Arab Emirates	ARE	1996	-324	1360111	90785	36182	38948	5,68	191421507855	9780359642	49163209	9832599	240947828,634	3025,54
193	TimorLeste	TLS	1996	-3	211509	1315	1014	2176	1,62	-9346888325	-8045657	-7190238	-6152689	-150771637,775	-4545,16
174	United States	USA	1996	-1585	22022094	223674	187930	27348	0,12	4513943769222	49782214204	12940604267	1234450560	30250209734,834	5367,13
163	Thailand	THA	1996	6032	2627683	121871	69404	15125	0,06	359440435300	2575672371	543362574	123213932	3019357280,095	457,33

TABLE A6: PERCENTAGE CHANGES IN FLOOD RISK AND FLOOD REDUCTION BENEFITS OF MANGROVES ACROSS 97 COUNTRIES BETWEEN 1996-2010

1996 vs 2010 (PERCENTAGE)															
ID	COUNTRY	ISO3	YEAR	MANG HA	POP	POP EXP	POP RISK	POP BEN	POP BEN HA	STOCK	STOCK EXP	STOCK RISK	STOCK BEN	PV 100yr 4%	STOCK BEN HA
140	Qatar	QAT	1996	0,002	2,553	3,064	2,931	3,028	3,061	4,519	5,885	1,033	0,489	0,489	0,485
5	United Arab Emirates	ARE	1996	0,017	2,367	1,706	1,730	0,914	0,882	0,891	0,406	-0,117	-0,084	-0,084	-0,099
160	Turks and Caicos Islands	TCA	1996	-0,398	0,930	1,154	1,318	-0,373	0	1,246	5,616	5,769	1,397	1,397	2,979
68	Equatorial Guinea	GNQ	1996	0,005	0,829	0,341	0,327	0,686	0	12,077	13,980	-0,140	2,469	2,469	2,450
98	Liberia	LBR	1996	0,003	0,801	0,630	0,677	0,7	0,625	5,614	0,103	0,140	0,143	0,143	0,140
44	Cayman Islands	CYM	1996	-0,048	0,664	0	0	0	0	0,562	0	0	0	0	0
2	Angola	AGO	1996	-0,016	0,622	4,232	4,577	2,591	2	1,748	3,797	2,074	2,305	2,305	2,357
184	Somalia	SOM	1996	-0,019	0,609	0,151	0,146	5,067	6,5	0,193	-0,147	-0,151	3,497	3,497	3,587
189	PapuaNewGuinea	PNG	1996	-0,001	0,585	0,102	0,132	0,120	0	1,551	0,774	0,823	0,803	0,803	0,805
66	Gambia	GMB	1996	0,014	0,540	-0,270	-0,5	-0,122	0	0,683	0,063	-0,254	0,226	0,226	0,211
38	Congo	COG	1996	-0,013	0,534	0,624	0,624	0	0	0,780	0,758	-0,009	0	0	0
108	Madagascar	MDG	1996	-0,026	0,521	0,652	0,646	0,761	1	0,521	0,813	0,630	0,461	0,461	0,500
14	Benin	BEN	1996	-0,102	0,509	0,374	0,394	0,012	0,2	0,792	0,265	0,266	-0,177	-0,177	-0,083
22	Belize	BLZ	1996	-0,058	0,509	0,789	0,760	0,474	0,6	0,903	1,029	0,676	0,176	0,176	0,248
180	Yemen	YEM	1996	-0,165	0,497	0,551	0,557	0,5	1	0,945	1,666	1,199	0,085	0,085	0,300
148	Sierra Leone	SLE	1996	-0,011	0,488	0,167	0,423	0,013	0	0,829	-0,133	0,012	-0,222	-0,222	-0,214
162	Togo	TGO	1996	0,029	0,477	-0,009	0,019	0	0	0,285	-0,175	-0,149	0	0	0
117	Mozambique	MOZ	1996	-0,035	0,474	0,282	0,234	0,128	0,286	1,992	1,541	1,437	1,129	1,129	1,205
118	Mauritania	MRT	1996	-0,070	0,473	0,166	0,166	0,220	0,310	0,427	0,685	0,727	0,735	0,735	0,866
90	Kenya	KEN	1996	-0,014	0,470	0,715	0,862	0,017	0	0,632	0,831	1,018	-0,134	-0,134	-0,121
61	Gabon	GAB	1996	0,000	0,459	0,067	0,156	0,216	0	0,072	-0,090	-0,071	0,117	0,117	0,117
36	Cameroon	CMR	1996	0,005	0,456	0,517	0,410	0,987	1	0,747	0,629	0,487	0,047	0,047	0,041
170	U.R. of Tanzania: Mainland	TZA	1996	-0,023	0,454	0,613	0,722	0,114	0,167	1,226	1,805	1,977	0,772	0,772	0,813
144	Saudi Arabia	SAU	1996	-0,101	0,441	0,508	0,500	0,417	0,568	0,473	0,992	0,497	0,126	0,126	0,253
125	Nigeria	NGA	1996	-0,027	0,432	0,572	0,606	0,250	0,333	1,395	0,348	0,257	-0,251	-0,251	-0,230
146	Senegal	SEN	1996	0,006	0,422	0,574	0,566	0,604	0,667	0,790	0,877	0,098	0,938	0,938	0,926
64	Ghana	GHA	1996	-0,037	0,419	0,230	0,235	0,208	0,242	1,062	0,380	0,388	0,362	0,362	0,413
74	Honduras	HND	1996	0,028	0,416	0,718	0,887	0,133	0	0,680	1,124	1,333	0,404	0,404	0,366
147	Singapore	SGP	1996	-0,035	0,410	1,361	1,794	0,732	1	1,148	2,191	-0,900	0,475	0,475	0,528
132	Pakistan	PAK	1996	-0,138	0,409	0,673	0,648	0,150	0,32	0,690	0,845	0,022	0,083	0,083	0,257
195	Vanuatu	VUT	1996	0,010	0,405	-0,094	-0,099	-0,095	0	2,101	0,100	0,989	0,997	0,997	0,977

35	Côte d'Ivoire	CIV	1996	-0,004	0,400	0,323	0,383	0,052	0,054	0,306	0,148	0,199	-0,106	-0,106	-0,102
188	SolomonIslands	SLB	1996	0,003	0,400	0,454	0,360	0,805	0,5	1,975	2,089	1,891	2,836	2,836	2,824
145	Sudan	SDN	1996	-0,441	0,394	0,410	1,019	1,1	2	1,317	8,184	5,937	0,458	0,458	1,608
197	Eritrea	ERI	1996	-0,221	0,390	12,480	12,480	-1	-1	0	0	0	0	0	0
71	Guatemala	GTM	1996	-0,013	0,374	0,159	0,087	0,148	0	0,638	0,376	0,373	0,334	0,334	0,351
105	China, Macao SAR	MAC	1996	-0,075	0,368	0	0	0	0	1,867	0	0	0	0	0
65	Guinea	GIN	1996	-0,007	0,366	0,066	-0,015	0,236	0	0,581	0,835	0,703	1,138	1,138	1,154
131	Oman	OMN	1996	-0,353	0,360	0,774	0,791	0,503	1,325	0,538	1,598	0,359	-0,363	-0,363	-0,014
122	Malaysia	MYS	1996	-0,009	0,342	0,133	0,001	0,951	0,8	0,803	0,427	0,155	0,136	0,136	0,146
135	Philippines	PHL	1996	-0,053	0,316	0,177	0,215	0,161	0,227	0,792	0,346	0,108	-0,011	-0,011	0,044
193	TimorLeste	TLS	1996	-0,019	0,309	0,386	0,349	-0,001	0,018	-0,481	-0,450	-0,465	-0,604	-0,604	-0,596
48	Djibouti	DJI	1996	-0,307	0,305	0,628	0,610	0,294	0,778	1,021	3,396	3,248	3,215	3,215	5,081
187	Kiribati	KIR	1996	0	0,304	-0,107	-0,133	0,225	0,224	0,523	0,043	0,013	0,432	0,432	0,432
92	Cambodia	KHM	1996	-0,074	0,303	0,100	0,140	0,106	0,208	1,915	1,324	1,492	1,201	1,201	1,376
133	Panama	PAN	1996	0,003	0,303	0,324	0,258	0,596	1	1,157	1,097	-0,112	-0,238	-0,238	-0,241
53	Ecuador	ECU	1996	-0,064	0,283	0,294	0,934	-0,026	0	0,553	0,290	0,302	-0,290	-0,290	-0,242
27	Brunei Darussalam	BRN	1996	0,008	0,276	0,234	0,290	0,264	0,25	0,189	0,246	0,143	-0,298	-0,298	-0,304
177	Venezuela (Bolivarian Republic of)	VEN	1996	-0,011	0,270	0,367	0,349	0,346	0,25	0	0	0	0	0	0
190	NewCaledonia	NCL	1996	-0,026	0,264	0,111	0,099	0,098	0	2,769	2,313	2,278	2,275	2,275	2,362
76	Haiti	HTI	1996	-0,089	0,261	1,080	1,266	-0,182	-0,105	0,098	2,203	2,603	0,464	0,464	0,607
42	Costa Rica	CRI	1996	0,009	0,260	0,058	0,058	0,372	0,333	0,857	0,650	0,179	-0,084	-0,084	-0,093
79	India	IND	1996	-0,030	0,256	0,379	0,389	0,239	0,276	1,396	1,764	1,146	0,758	0,758	0,811
8	Antigua and Barbuda	ATG	1996	-0,022	0,254	-0,134	-0,138	-0,074	-0,070	0,401	0,390	1,758	-0,002	-0,002	0,020
16	Bangladesh	BGD	1996	0,004	0,254	0,587	0,510	-0,006	-0,032	1,154	2,490	2,168	0,979	0,979	0,970
19	Bahamas	BHS	1996	-0,138	0,250	0,400	0,419	0,185	0	0,330	1,179	1,019	0,635	0,635	0,897
126	Nicaragua	NIC	1996	0,030	0,228	0,305	0,333	0,231	0	0,604	0,444	0,418	0,270	0,270	0,233
110	Mexico	MEX	1996	-0,057	0,225	0,328	0,427	0,164	0,333	0,400	0,647	0,509	0,187	0,187	0,259
39	Colombia	COL	1996	-0,035	0,220	0,546	0,591	0,286	0,2	0,523	0,716	0,464	0,261	0,261	0,307
51	Dominican Republic	DOM	1996	-0,025	0,219	0,425	0,439	0,152	0,167	1,100	1,771	0,841	0,586	0,586	0,626
9	Australia	AUS	1996	-0,049	0,218	0,187	0,202	0,212	0,333	0,579	0,610	0,200	0,049	0,049	0,103
181	South Africa	ZAF	1996	0,019	0,212	0,146	0,142	0,182	0	0,546	0,302	0,292	0,332	0,332	0,306
201	FrenchPolynesia	PYF	1996	-0,025	0,207	0,193	0,225	0,125	0,153	0	0	0	0	0	0
78	Indonesia	IDN	1996	-0,063	0,205	0,204	0,266	0,188	0,2	0,602	0,912	0,741	0,434	0,434	0,531

25	Brazil	BRA	1996	-0,018	0,189	0,002	0,002	0,912	1	0,543	0,184	0,128	0,251	0,251	0,274
152	Suriname	SUR	1996	0,041	0,181	1,156	1,673	0,219	0,188	0,744	2,069	2,878	0,475	0,475	0,416
158	Seychelles	SYC	1996	0	0,176	0,077	0,085	0,064	0,065	0,599	0,492	0,066	-0,560	-0,560	-0,560
130	New Zealand	NZL	1996	0,040	0,176	0,165	0,177	0,039	0	0,469	0,529	0,397	0,079	0,079	0,038
134	Peru	PER	1996	-0,166	0,173	0,328	0,309	0,282	0	0,901	0,966	0,710	0,908	0,908	1,287
99	Saint Lucia	LCA	1996	-0,006	0,170	-0,017	-0,018	0,067	0,111	0,328	0,661	0,016	1,235	1,235	1,249
179	Vietnam	VNM	1996	-0,057	0,156	0,154	0,143	0,230	0,305	1,470	3,019	2,613	2,776	2,776	3,007
174	United States	USA	1996	-0,033	0,152	0,171	0,177	0,133	0,143	0,414	0,423	0,232	-0,056	-0,056	-0,024
114	Myanmar	MMR	1996	-0,075	0,138	0,371	0,392	0,131	0,231	3,356	6,617	2,791	2,347	2,347	2,618
163	Thailand	THA	1996	-0,058	0,117	0,370	2,021	-0,718	-0,727	0,537	0,509	1,252	-0,533	-0,533	-0,504
100	Sri Lanka	LKA	1996	-0,306	0,103	0,127	0,110	0,082	0,545	1,044	0,916	0,337	0,759	0,759	1,536
199	Samoa	WSM	1996	0,026	0,102	-0,181	-0,091	-0,299	-0,324	0	0	0	0	0	0
86	Jamaica	JAM	1996	0,007	0,098	0,004	0,104	-0,291	-0,295	0,049	0,104	0,292	-0,137	-0,137	-0,143
59	Fiji	FJI	1996	0,005	0,096	-0,264	-0,302	0,270	0,333	0,237	-0,074	-0,020	0,435	0,435	0,428
34	China	CHN	1996	-0,161	0,094	0,332	0,336	0,135	0,353	1,795	4,113	1,817	1,580	1,580	2,075
120	Mauritius	MUS	1996	-0,293	0,093	0	0	0	0	0,855	0	0	0	0	0
149	El Salvador	SLV	1996	0,014	0,087	-0,109	-0,155	0,102	0	0,377	0,378	0,350	0,502	0,502	0,481
169	Taiwan	TWN	1996	0,076	0,079	-0,061	-0,076	0,623	0,508	0,893	0,611	0,252	0,901	0,901	0,766
202	Tonga	TON	1996	0,015	0,072	0,838	3,170	-0,252	-0,256	0,911	2,277	6,434	0,333	0,333	0,313
166	Trinidad and Tobago	TTO	1996	-0,040	0,056	0,720	0,777	-0,476	-0,429	1,402	1,153	0,166	-0,750	-0,750	-0,739
70	Grenada	GRD	1996	-0,005	0,052	-0,25	-0,25	0,111	0,25	0,570	0,417	0,447	0,671	0,671	0,679
206	Palau	PLW	1996	0,008	0,046	0,195	0,333	-0,833	0	0	0	0	0	0	0
186	Cuba	CUB	1996	-0,075	0,030	0,114	0,067	0,062	1	-0,081	-0,006	-0,047	-0,052	-0,052	0,026
88	Japan	JPN	1996	-0,022	0,015	0,068	0,075	-0,327	-0,310	0,092	0,259	0,231	-0,240	-0,240	-0,223
203	UnitedStatesVirgin-Islands	VIR	1996	-0,028	0,002	-0,022	-0,073	0,013	0,074	0	0	0	0	0	0
185	PuertoRico	PRI	1996	0,009	-0,001	0,227	0,364	-0,194	-0,198	1,533	2,111	2,458	1,044	1,044	1,026
72	Guyana	GUY	1996	0,031	-0,015	0,235	0,188	-0,186	-0,207	1,217	0,391	0,391	-0,127	-0,127	-0,153
194	MicronesiaFeder-atedStatesof	FSM	1996	-0,010	-0,029	-0,238	-0,241	-0,354	0	0	0	0	0	0	0
192	FrenchGuiana	GUF	1996	0,024	0	0,377	0,361	0,848	1	0	0	0	0	0	0
207	Mayotte	MYT	1996	0,022	0	0,722	0,698	0,402	0,412	0	0	0	0	0	0
209	NetherlandsAntilles	ANT	1996	-0,188	0	0,688	0,688	0,469	0,794	0	0	0	0	0	0
200	Martinique	MTQ	1996	0,003	0	-0,007	-0,002	0,262	0,5	0	0	0	0	0	0
191	Guadeloupe	GLP	1996	0,005	0	0,077	0,233	-0,387	-0,391	0	0	0	0	0	0

TABLE A7: PERCENTAGE CHANGES IN FLOOD RISK AND FLOOD REDUCTION BENEFITS OF MANGROVES ACROSS 97 COUNTRIES BETWEEN 2010-2020

2010 vs 2020 (PERCENTAGE)															
ID	COUNTRY	ISO3	YEAR	MANG HA	POP	POP EXP	POP RISK	POP BEN	POP BEN HA	STOCK	STOCK EXP	STOCK RISK	STOCK BEN	PV 100yr 4%	STOCK BEN HA
179	Vietnam	VNM	1996	-0,006	0,107	0,729	0,588	0,493	0,502	0,846	1,692	1,307	1,258	1,258	1,272
34	China	CHN	1996	0,022	0,052	0,182	0,135	0,573	0,539	0,527	1,491	0,870	2,176	2,176	2,107
185	PuertoRico	PRI	1996	-0,049	-0,118	0,584	0,533	0,153	0,207	-0,020	0,761	0,704	0,281	0,281	0,347
79	India	IND	1996	-0,005	0,118	0,933	0,879	0,477	0,478	0,827	1,969	1,363	1,170	1,170	1,181
78	Indonesia	IDN	1996	-0,010	0,131	0,828	0,797	0,344	0,417	0,671	1,608	1,331	0,887	0,887	0,905
169	Taiwan	TWN	1996	-0,212	0,020	1,233	1,094	-0,151	0,078	0,319	1,565	1,157	0,066	0,066	0,353
152	Suriname	SUR	1996	0,006	0,109	0,619	0,683	1,171	1,158	0,074	0,787	0,492	0,696	0,696	0,686
16	Bangladesh	BGD	1996	0,003	0,116	2,052	2,192	2,862	2,9	0,959	4,463	4,131	6,417	6,417	6,394
110	Mexico	MEX	1996	0,002	0,130	1,544	1,512	1,142	1	0,234	1,878	1,394	1,338	1,338	1,334
190	NewCaledonia	NCL	1996	0,041	0,086	2,759	2,611	0,304	0,333	0,809	5,264	5,018	1,174	1,174	1,087
9	Australia	AUS	1996	-0,012	0,151	2,497	2,426	1,849	1,75	0,228	2,822	2,346	1,986	1,986	2,021
25	Brazil	BRA	1996	0,010	0,086	1,138	1,080	0,950	0,917	0,075	1,399	1,173	1,039	1,039	1,019
92	Cambodia	KHM	1996	0,020	0,168	0,314	0,266	0,816	0,776	0,980	1,135	1,080	1,438	1,438	1,391
64	Ghana	GHA	1996	0,024	0,254	1,217	0,798	0,246	0,220	0,888	1,148	0,893	0,636	0,636	0,598
19	Bahamas	BHS	1996	0,027	0,108	0,743	0,693	1,896	1	0,129	0,912	0,907	2,390	2,390	2,301
122	Malaysia	MYS	1996	-0,009	0,148	0,901	1,198	-0,575	-0,556	0,629	1,574	1,061	0,015	0,015	0,024
114	Myanmar	MMR	1996	-0,010	0,075	0,625	0,702	-0,268	-0,25	0,806	4,195	2,906	3,863	3,863	3,912
146	Senegal	SEN	1996	-0,008	0,320	0,839	0,767	1,885	1,8	0,633	1,202	1,200	1,240	1,240	1,259
39	Colombia	COL	1996	0,003	0,128	1,615	1,498	-0,186	-0,167	0,422	2,340	1,251	0,609	0,609	0,604
189	PapuaNewGuinea	PNG	1996	-0,013	0,286	4,525	6,491	1,081	1	0,639	6,043	8,550	1,653	1,653	1,688
76	Haiti	HTI	1996	-0,014	0,146	1,378	1,409	2,328	2,373	0,204	1,870	2,399	3,243	3,243	3,306
100	Sri Lanka	LKA	1996	0,010	0,057	7,088	10,755	0,285	0,294	0,576	11,800	13,602	0,662	0,662	0,645
2	Angola	AGO	1996	-0,011	0,406	4,019	4,769	3,566	3,333	0,153	3,993	2,504	3,576	3,576	3,628
118	Mauritania	MRT	1996	0,150	0,330	1,109	1,237	0,136	-0,012	0,491	2,421	1,939	1,503	1,503	1,176
160	Turks and Caicos Islands	TCA	1996	0,210	0,185	1,076	1,027	17,438	10	0,521	0,959	1,416	11,217	11,217	9,098
65	Guinea	GIN	1996	-0,026	0,288	2,903	2,609	1,334	1,667	0,808	6,094	5,406	4,680	4,680	4,832
130	New Zealand	NZL	1996	-0,017	0,104	7,934	8,951	0,466	0,333	0,345	9,124	8,088	3,947	3,947	4,033
117	Mozambique	MOZ	1996	-0,031	0,327	1,000	0,807	0,049	0	0,646	4,365	4,576	2,388	2,388	2,495
22	Belize	BLZ	1996	0,007	0,233	1,523	1,503	0,079	0,125	0,179	1,734	1,591	-0,071	-0,071	-0,077
108	Madagascar	MDG	1996	0,002	0,308	0,832	0,825	0,170	0,167	0,385	0,669	0,112	0,374	0,374	0,371
170	U.R. of Tanzania: Mainland	TZA	1996	-0,012	0,346	1,870	2,139	0,345	0,286	0,909	3,632	4,147	1,225	1,225	1,251
144	Saudi Arabia	SAU	1996	-0,245	0,270	1,558	1,374	2,109	3,130	0,337	2,243	1,519	3,870	3,870	5,448

51	Dominican Republic	DOM	1996	-0,006	0,119	2,161	2,389	4,065	3,857	0,672	3,355	2,562	1,218	1,218	1,232
74	Honduras	HND	1996	-0,080	0,191	2,361	2,258	0,344	0,5	0,415	2,568	2,630	0,203	0,203	0,307
59	Fiji	FJI	1996	0,001	0,043	3,647	3,933	1,157	1	0,342	4,924	5,638	1,674	1,674	1,671
188	SolomonIslands	SLB	1996	-0,007	0,279	1,046	1,221	2,350	2	1,383	2,812	3,139	5,242	5,242	5,284
140	Qatar	QAT	1996	0,060	0,553	7,600	6,685	10,264	9,597	0,397	11,301	7,835	11,563	11,563	10,853
132	Pakistan	PAK	1996	-0,110	0,231	0,760	0,840	-0,297	-0,212	0,531	0,700	0,479	-0,053	-0,053	0,065
202	Tonga	TON	1996	-0,030	-0,020	3,770	3,054	3,117	3,219	0,432	5,968	4,922	5,014	5,014	5,200
147	Singapore	SGP	1996	-0,070	0,140	4,270	4,016	2,760	3	0,409	5,442	23,779	1,145	1,145	1,306
149	El Salvador	SLV	1996	-0,029	0,049	2,369	2,527	1,910	1	0,239	2,931	3,730	0,043	0,043	0,074
126	Nicaragua	NIC	1996	-0,061	0,138	6,125	6,347	7,614	8	0,264	7,138	8,288	4,888	4,888	5,271
68	Equatorial Guinea	GNQ	1996	-0,006	0,487	5,541	6,216	20,864	0	-0,277	4,569	14,986	14,133	14,133	14,225
187	Kiribati	KIR	1996	0	0,171	-0,302	-0,389	1,099	1,103	0,346	-0,197	-0,298	1,413	1,413	1,413
36	Cameroon	CMR	1996	-0,003	0,305	6,702	10,049	12,333	11,667	0,559	7,410	12,835	7,537	7,537	7,561
71	Guatemala	GTM	1996	0,009	0,225	6,085	6,484	1,621	2	0,422	6,018	4,614	1,922	1,922	1,897
184	Somalia	SOM	1996	-0,013	0,375	0,118	0,018	1,256	1,333	0,116	-0,093	-0,174	0,830	0,830	0,854
99	Saint Lucia	LCA	1996	0	0,055	3,148	2,986	119,813	118,3	0,177	3,563	6,260	74,975	74,975	74,975
134	Peru	PER	1996	0,061	0,138	1,698	1,961	6,242	5	0,460	2,841	2,871	11,835	11,835	11,101
98	Liberia	LBR	1996	-0,047	0,299	3,567	9,322	1,196	1,308	0,427	4,801	11,098	2,288	2,288	2,451
61	Gabon	GAB	1996	-0,006	0,370	4,971	6,891	2,690	0	0,438	6,080	3,641	1,031	1,031	1,043
48	Djibouti	DJI	1996	0,124	0,176	0,330	0,632	58,518	51,5	1,347	1,529	0,227	8,279	8,279	7,255
70	Grenada	GRD	1996	0	0,059	537,667	530,333	61,3	58,6	0,367	475,880	696,148	88,658	88,658	88,658
66	Gambia	GMB	1996	-0,010	0,347	6,894	396,714	2,013	1	0,316	5,993	263,529	2,370	2,370	2,402
195	Vanuatu	VUT	1996	-0,043	0,270	6,208	5,749	83,579	104	0,567	7,897	7,331	103,396	103,396	108,097
180	Yemen	YEM	1996	-0,065	0,288	1,535	1,413	188,061	198	-0,558	1,339	2,268	46,842	46,842	50,172
181	South Africa	ZAF	1996	0,015	0,158	6,703	6,656	40,103	59	0,148	7,211	6,878	196,262	196,262	193,442
145	Sudan	SDN	1996	-0,178	0,269	-0,119	0,560	168,714	172,667	0,421	0,094	-0,057	22,273	22,273	27,306
177	Venezuela (Bolivarian Republic of)	VEN	1996	0,004	-0,010	0,308	0,282	0,234	0,4	0	0	0	0	0	0
192	FrenchGuiana	GUF	1996	0,067	0	1,648	1,625	3,995	2,5	0	0	0	0	0	0
207	Mayotte	MYT	1996	-0,025	0	23,409	28,685	7,140	7,25	0	0	0	0	0	0
209	NetherlandsAntilles	ANT	1996	-0,038	0	18,481	15,963	43,917	45,508	0	0	0	0	0	0
201	FrenchPolynesia	PYF	1996	0,059	0,064	4,522	5,848	-0,247	-0,287	0	0	0	0	0	0
200	Martinique	MTQ	1996	0,009	0	4,305	4,357	10,698	9,667	0	0	0	0	0	0
203	UnitedStatesVirginIslands	VIR	1996	0,004	-0,019	10,758	17,355	2,295	2,241	0	0	0	0	0	0
162	Togo	TGO	1996	0,142	0,289	2,474	2,425	0	0	1,315	3,033	2,519	0	0	0
38	Congo	COG	1996	0,021	0,291	0,345	0,345	0	0	-0,098	0,822	2,346	0	0	0

44	Cayman Islands	CYM	1996	-0,006	0,160	0	0	0	0	0,292	0	0	0	0	0
105	China, Macao SAR	MAC	1996	-0,016	0,206	0	0	0	0	0,193	0	0	0	0	0
120	Mauritius	MUS	1996	0,013	0,019	0	0	0	0	0,433	0	0	0	0	0
206	Palau	PLW	1996	-0,003	-0,031	4,394	4,615	125,5	0	0	0	0	0	0	0
199	Samoa	WSM	1996	-0,038	0,104	0,524	1,011	41,098	43,48	0	0	0	0	0	0
194	MicronesiaFeder-atedStatesof	FSM	1996	-0,032	0,042	3,398	3,447	2,066	1,5	0	0	0	0	0	0
191	Guadeloupe	GLP	1996	-0,005	0	0,879	0,972	1,099	1,143	0	0	0	0	0	0
197	Eritrea	ERI	1996	-0,009	0,130	-0,496	-0,502	0	0	0	0	0	0	0	0
8	Antigua and Bar-buda	ATG	1996	0,033	0,113	0,609	0,473	0,329	0,3	0,348	0,845	0,671	2,201	2,201	2,098
72	Guyana	GUY	1996	-0,042	0,049	0,367	0,299	0,146	0,192	0,463	0,416	208,265	127,634	127,634	133,156
14	Benin	BEN	1996	0,083	0,317	1,181	1,148	43,994	40,833	1,331	1,430	1,353	15,136	15,136	13,898
148	Sierra Leone	SLE	1996	-0,042	0,243	3,154	6,972	0,992	1	0,558	4,177	10,623	1,791	1,791	1,914
35	Côte d'Ivoire	CIV	1996	-0,061	0,284	2,435	2,995	11,222	11,923	1,472	3,382	4,792	2,796	2,796	3,043
42	Costa Rica	CRI	1996	-0,038	0,113	0,763	0,630	0,824	0,75	0,389	1,176	1,058	1,823	1,823	1,935
27	Brunei Darussalam	BRN	1996	0,007	0,126	0,741	1,168	0,625	0,8	0,060	1,216	0,987	4,989	4,989	4,949
90	Kenya	KEN	1996	-0,000	0,279	1,515	1,283	1,865	1,905	0,709	2,059	1,127	1,676	1,676	1,677
166	Trinidad and Tobago	TTO	1996	-0,020	0,054	2,976	3,373	0,366	0,25	-0,072	8,673	7,362	9,975	9,975	10,197
131	Oman	OMN	1996	0,244	0,684	0,256	0,126	1,812	1,260	0,307	0,229	0,206	7,975	7,975	6,213
133	Panama	PAN	1996	-0,022	0,185	2,626	3,030	0,575	0,5	0,767	6,290	2,101	1,277	1,277	1,328
158	Seychelles	SYC	1996	0	0,078	0,349	0,316	3,376	3,348	0,574	0,560	-0,303	4,925	4,925	4,925
186	Cuba	CUB	1996	-0,022	0,001	2,728	3,162	0,699	0,5	1,038	6,589	7,472	2,459	2,459	2,538
135	Philippines	PHL	1996	0,018	0,166	0,624	0,633	0,311	0,293	0,806	1,129	0,810	0,204	0,204	0,183
86	Jamaica	JAM	1996	-0,080	0,054	0,383	0,312	-0,146	-0,065	0,097	0,401	0,450	-0,163	-0,163	-0,090
125	Nigeria	NGA	1996	-0,009	0,300	1,305	1,371	1,411	1,75	0,348	1,626	1,314	1,709	1,709	1,734
88	Japan	JPN	1996	0,014	-0,016	1,287	1,295	1,478	1,45	0,097	1,410	1,000	10,054	10,054	9,901
53	Ecuador	ECU	1996	0,017	0,177	3,126	2,971	1,135	1	0,274	3,729	2,889	2,530	2,530	2,470
5	United Arab Emirates	ARE	1996	-0,042	0,159	0,391	0,169	0,534	0,601	0,420	0,545	0,109	0,033	0,033	0,078
193	TimorLeste	TLS	1996	-0,002	0,194	0,949	0,864	1,430	1,434	-0,662	-0,448	-0,472	-0,311	-0,311	-0,310
174	United States	USA	1996	-0,007	0,071	1,446	1,330	0,741	0,75	0,250	1,531	1,443	1,027	1,027	1,041
163	Thailand	THA	1996	0,023	0,039	1,635	1,255	1,775	2	0,356	2,104	1,830	1,398	1,398	1,343

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