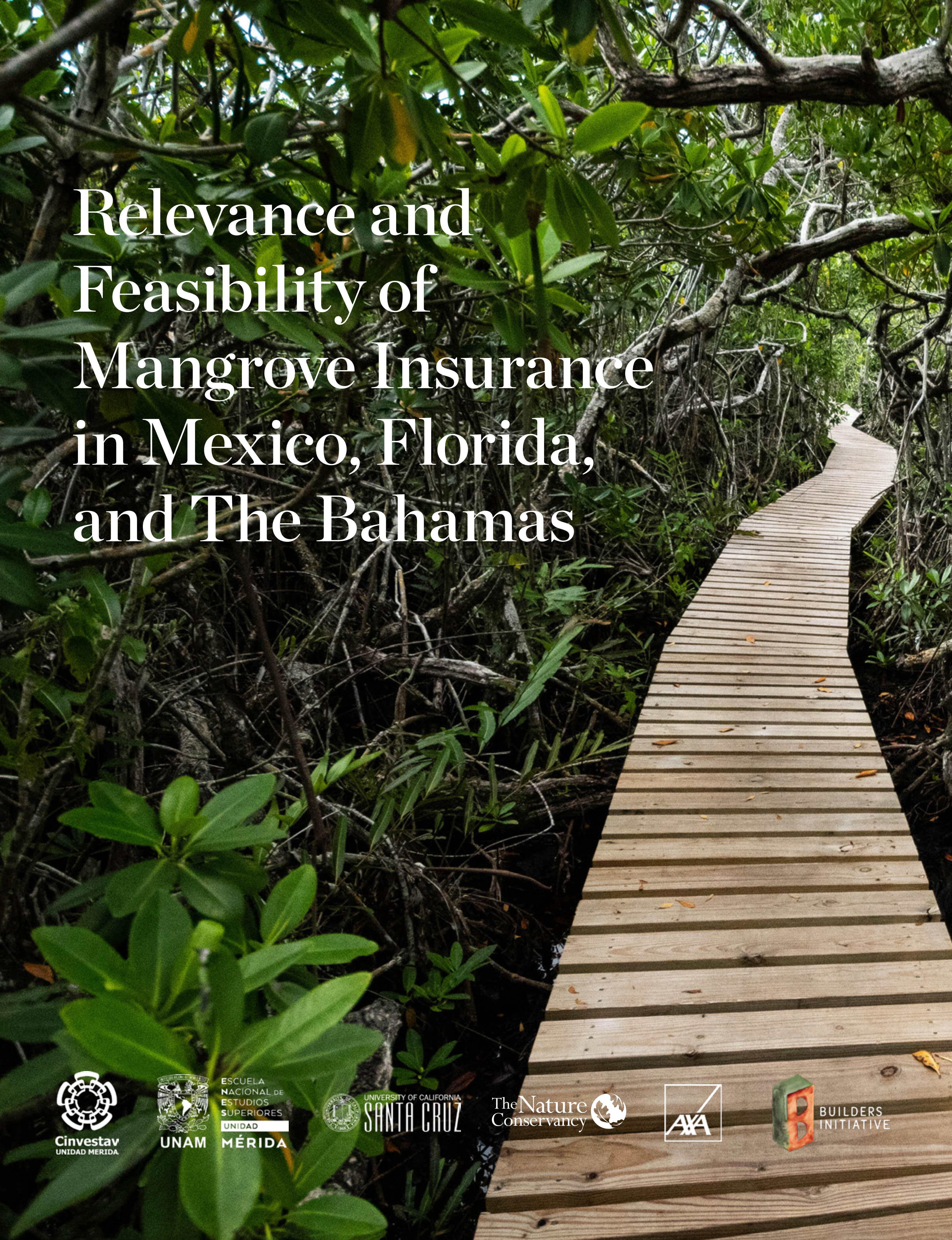
Relevance and Feasibility of Mangrove Insurance in Mexico, Florida, and The Bahamas



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Relevance and Feasibility of Mangrove Insurance in Mexico, Florida, and The Bahamas

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Cover image: A wooden path winds through mangroves in Lucayan National Park on Grand Bahama Island, The Bahamas. © Shane Gross.

Back cover image: Sub-adult lemon sharks move away from the safety of the mangroves to forage in the nearby seagrass beds. The mangroves are teaming with life and provide critical habitat for numerous species, The Bahamas. © Jillian Morris/TNC Photo Contest 2021.

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This report is the final of three reports to be released by The Nature Conservancy (TNC) in collaboration with our partners at AXA XL, CINVESTAV-Merida, and the University of California, Santa Cruz. The reports are part of a year-long project to assess the feasibility of a mangrove insurance policy in the Gulf of Mexico and Caribbean. In the first report, we document the types of mangrove damages that may result from hurricanes, the appropriate restoration techniques to adequately restore damaged mangroves, and the costs of these restoration efforts. In the second report, we document the protective value of mangroves in the study region. In this final report, we aggregate information from the first two reports and identify specific areas where a mangrove insurance policy would be most cost-effective. We also summarize the efforts of our market analysis in Mexico, Florida, and The Bahamas, and identify specific locations where a mangrove insurance policy could be piloted. As described in this report, tropical storms and hurricanes can cause significant damages to mangroves and restoration costs can be high. Financing these restoration activities, through innovative finance mechanisms like an insurance policy, will be critical to ensuring that the protective benefits of mangroves are sustained in the future.

The work for this report was conducted from March 2021 through September 2022. The findings do not take into account any impacts or changes that may have resulted from the landfall of Hurricane Ian in late September 2022.

Executive Summary

Mangroves often serve as a first line of coastal defense during tropical storms and have been shown to reduce wave height up to 66% over the first 100 meters of forest (McIvor et al., 2012a). In general, mangrove root systems help stabilize the soil and reduce erosion while the roots, trunk, and canopy dissipate wave energy and slow storm surge penetration (McIvor et al., 2012a; McIvor et al., 2012b; Thampanya et al., 2006).

In this study, we focus on mangroves in Mexico, Florida, and The Bahamas, where they provide more than $17 billion in flood protection benefits (measured over 30 years using a 4% discount rate, 2020 USD) (Menéndez et al., 2022). Erosion and hurricanes remain two of the primary threats to mangrove loss in much of this area (Goldberg et al., 2020). Identifying adequate and reliable funding sources to finance the restoration and protection of mangroves is essential to ensuring their resilience and the resilience of the communities that they protect.

Mangrove insurance is an important new source for this funding. Mangrove insurance can serve as a risk-transfer tool that provides immediate funding for mangrove restoration and repair following hurricane damage. This quick response hastens mangrove recovery time and enhances the resilience of mangroves to future hurricanes (Herrera-Silveira et al., 2022).

Over the course of 2021, we explored the feasibility for a mangrove insurance policy in Mexico, Florida, and The Bahamas, where coastal communities and infrastructure are especially vulnerable to hurricanes. Our work builds on earlier studies that showed promising enabling conditions in these places and provided detailed analyses of the protective benefits of mangroves and techniques and costs for their restoration (Beck et al., 2021; Herrera-Silveira et al., 2022; Menéndez et al., 2022). Our stakeholder engagements focused on six key questions:

1. How valuable are the flood protection benefits of mangroves?
2. Are there stakeholders who value or benefit from the flood protection of mangroves?
3. Are stakeholders interested in managing risk to mangroves and potentially buying an insurance?
4. Are the stakeholders legally entitled to buy the insurance?
5. Do the stakeholders have the capacity to pay an insurance premium?
6. Is there an existing institution or financial entity that could convene beneficiaries to buy the insurance?

Through our engagements, we found that strong interest exists among stakeholders to continue exploring how a mangrove insurance policy might be designed and managed. We identified nine locations—three in Mexico, four in Florida, and two in The Bahamas—as potential sites for a mangrove insurance pilot policy. These locations were identified based on the presence of large areas of mangroves, the high protective value of mangroves, and strong interest from key stakeholders.

While these stakeholder engagements make us optimistic about opportunities for a mangrove insurance policy in these high-risk locations, more work remains. Future analyses will need to consider how to design the insurance policy and manage the payouts to ensure the appropriate restoration work takes place. As we move forward with this work, TNC's goal is to launch a pilot mangrove insurance policy and demonstrate that, when used appropriately, these types of risk transfer tools can be a cost-effective means of protecting our coastlines and coastal communities.

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Introduction

Mangrove forests cover nearly 14 million hectares of tropical and subtropical coasts across 118 countries (Spalding et al., 2010). These critical ecosystems provide a range of benefits to people and properties. First, mangroves are some of the world's most productive fishing grounds. They serve as important nurseries for many reef fish populations, such as the yellowtail, and can have a large impact on the fish communities of nearby coral reefs (Mumby, 2004; Serafy, 2015). In addition, recreational fishing in mangroves for fish such as tarpon, bonefish, and snapper can be a significant source of economic benefits to the local economy. In The Bahamas, this fishing is estimated to generate $169 million annually in total economic benefits (Fedler, 2018). Second, mangroves store a disproportionate amount of carbon relative to their landcover (Hutchison, 2014). Mangrove soils have been estimated to store more than 6.4 billion tons of carbon globally (Sanderman, 2018). And, finally, mangroves serve as a first line of defense in the event of tropical storms. Mangroves have been shown to dissipate wave energy, slow storm surge penetration, and reduce erosion (McIvor et al., 2012a; McIvor et al., 2012b; Thampanya et al., 2006). Globally, mangroves provide over $65 billion in flood protection benefits annually and protect over 15 million people (Menéndez et al., 2020).

Today, mangroves are at increasing risk from direct and indirect human activities. Between 1980 and 2005 alone, nearly 20% of global mangrove cover was lost (Giri et al., 2010; Spalding et al., 2010). Mangrove clearing for aquaculture or urban settlements is the primary driver of mangrove loss worldwide, with 80% of this loss occurring in just six countries: Indonesia, Myanmar, Malaysia, the Philippines, Thailand, and Vietnam (Goldberg et al., 2020). Outside of these six countries, the primary drivers of mangrove loss are erosion and hurricanes (Goldberg et al., 2020). The frequency and intensity of hurricanes is expected to increase in the coming years.

When a hurricane passes over a mangrove forest, it can cause critical changes to the structure of mangrove trees, topography, hydrology, or sediment characteristics (Herrera-Silveira et al., 2022).[1] Following a hurricane event, mangroves can naturally recover in three to five years but full recovery, especially when following a more severe storm, may take up to 20 years (Danielson et al., 2017; Imbert, 2018). Active restoration and repair of mangroves following hurricane damage can hasten their recovery time and enhance their resilience to future hurricanes (Herrera-Silveira et al., 2022). The ability of mangroves to naturally recover following a hurricane may also become compromised in the future if the frequency of severe hurricanes increases, as is predicted to occur with climate change (Kossin, 2020).

Therefore, funding the post-storm restoration and repair of mangroves is critical to ensuring that the flood protection and other benefits of mangrove ecosystems are maintained in the future. A mangrove insurance policy represents an innovative financial mechanism to fund this repair work. In regions where the flood protection benefits of mangroves are high, protecting and restoring mangroves is a cost-effective means of reducing the risks to people and property from hurricanes. A mangrove insurance policy can be used to guarantee funding to repair mangroves after damage is sustained from a hurricane, much like other insurance policies are used to repair built infrastructure. The Nature Conservancy (TNC) and the Government of Quintana Roo, Mexico, launched an insurance policy for coral reefs and beaches in 2019 that demonstrates this concept (TNC, 2021).

1 In this report, we use the term hurricanes when referring to tropical cyclones as we focus our discussion on mangroves in the Gulf of Mexico and Caribbean, where tropical cyclones are referred to as hurricanes.

Assess if a natural asset needs insurance

Does the natural asset provide a valuable service?

Is the natural asset at risk? Can an event severely damage it and impair their ecosystem services?

Is this risk insurable?

Is it possible to repair the damages to the natural asset, so the services it provides can stay functional or be recovered?

Is the cost of repairing the asset lower than the avoided losses?

Is insurance needed for the natural asset?

Are there stakeholders who could buy the insurance?

Are there stakeholders who value the natural asset?

Are there stakeholders interested in repairing the damages?

Is the cost of restoration above the financial capacity of stakeholders and/or will they prefer to tranfer the risk?

Do the interested stakeholders have the capacity to pay the premium?

Who is the entitled to buy insurance for the natural asset?

Are there potential buyers?

Figure 1: Guiding questions for mangrove insurance feasibility assessment. Adapted from Secaira Fajardo et al., (2019).

In this report, we summarize findings from a feasibility assessment aimed at identifying potential locations to pilot a mangrove insurance policy in Mexico, Florida, and The Bahamas. This work builds upon a pre-feasibility assessment that showed that these three regions have some of the largest areas of mangroves that would be cost-effective to restore for their flood risk reduction benefits and that these regions are also most likely to have suitable insurance market and governance conditions to make a policy feasible and attractive (Beck et al., 2020). During this feasibility assessment, we engaged key stakeholders in Mexico, Florida, and The Bahamas to identify who may be an appropriate mangrove insurance customer, what is their interest in purchasing such a policy, and how might the mangrove insurance policy be structured. The goal of these discussions was to assess if there is a need for mangrove insurance and to identify potential purchasers of the policy. Figure 1 highlights the guiding questions that we used to direct this work.

In each of the following sections, we present key elements that are needed for insurance to be a suitable tool for protecting and restoring mangroves. In the following two sections, we show that mangroves provide valuable flood protection benefits in Mexico, Florida, and The Bahamas and that many mangrove stands in these regions are at risk of damage or loss from hurricanes. We then show that within each of these regions, there are many locations where it would be highly cost-effective to restore mangroves. In these locations, mangroves could be repaired post-hurricane to hasten their recovery and ensure that their protective benefits are maintained in the future. Together, this information provides the rationale for mangrove insurance. Next, we summarize key learnings from our stakeholder engagements in Mexico, Florida, and The Bahamas. We used the stakeholder engagements to identify potential buyers of a mangrove insurance policy, potential locations where a policy could be piloted, and to prioritize key questions to address in subsequent phases of the work.

Flood protection benefits of mangroves

Mangroves often serve as a first line of coastal defense during tropical storms and have been shown to reduce wave height up to 66% over the first 100 meters of forest (McIvor et al., 2012a). In general, mangrove root systems help stabilize the soil and reduce erosion while the roots, trunk, and canopy dissipate wave energy and slow storm surge penetration (McIvor et al., 2012a; McIvor et al., 2012b; Thampanya et al., 2006).

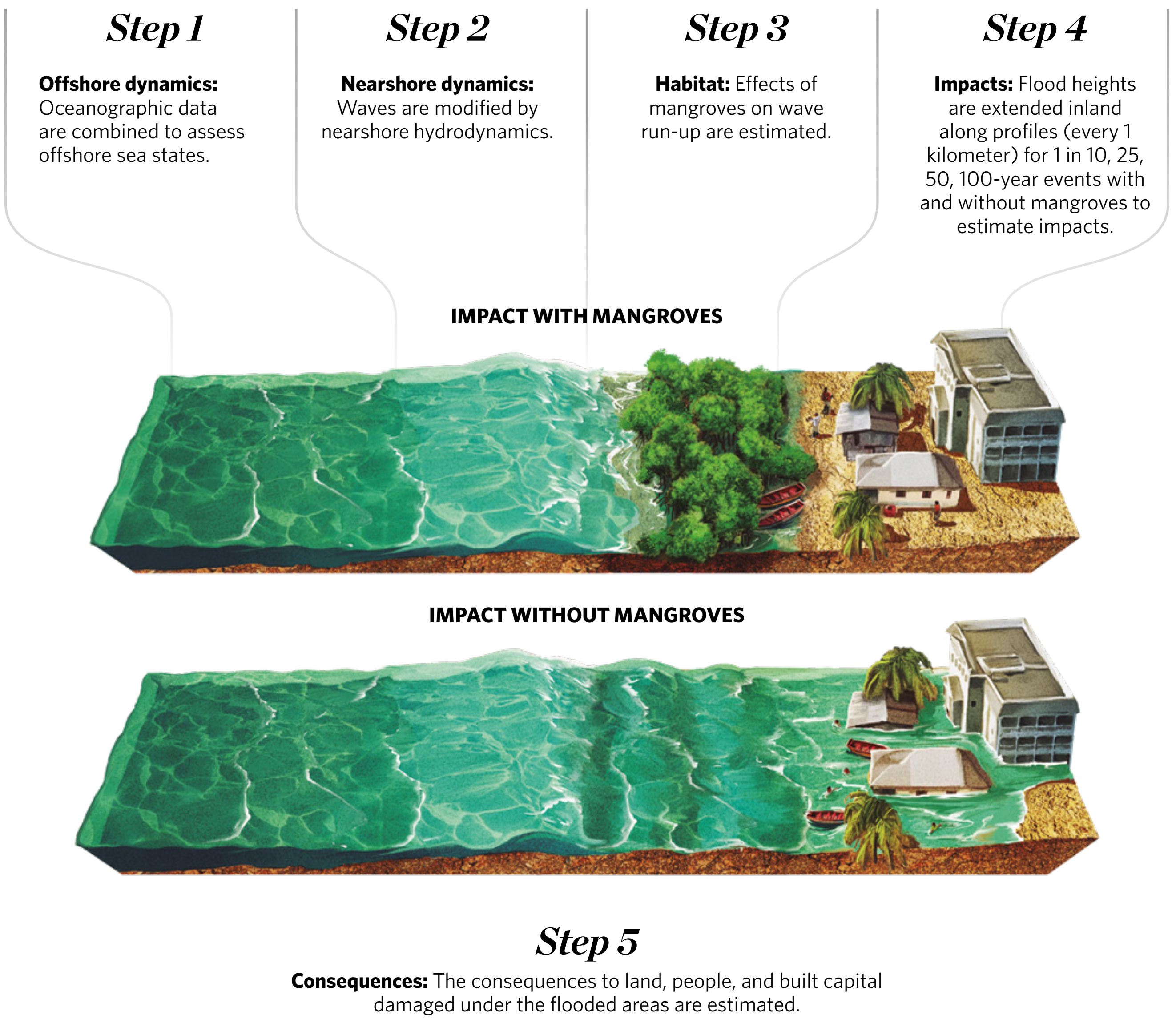

Figure 2: Key steps and data for estimating the flood protection benefits provided by mangroves (adapted from Beck et al. 2019). © Puntoaparte Editores.

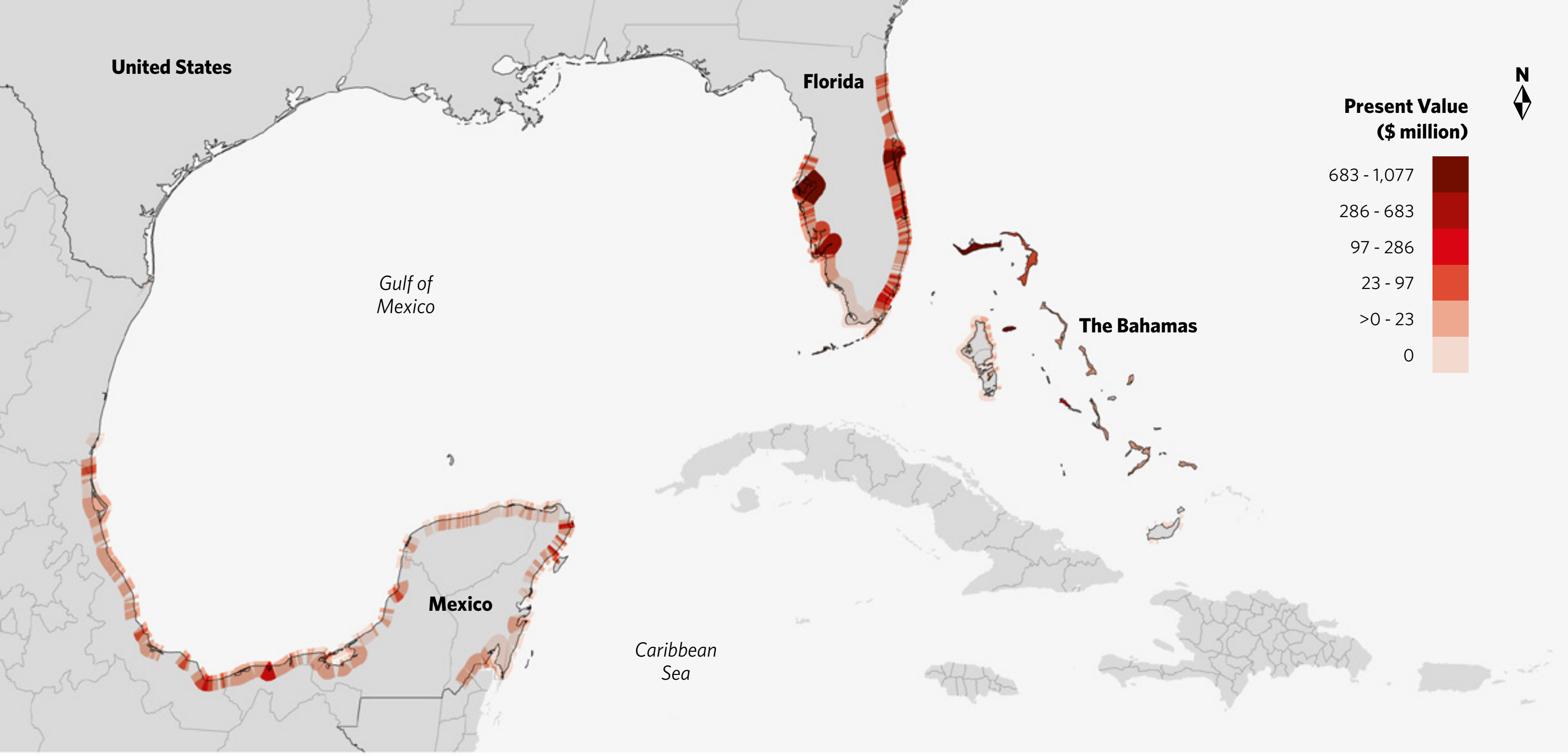

Figure 3: Present value of the flood protection benefits of mangroves in Mexico, Florida, and The Bahamas over 30 years assuming a 4% discount rate. Analysis excludes western Mexico. Source: Menéndez et al. 2022.

Our study region is home to over one million hectares of mangroves—more than 500,000 hectares in Mexico, nearly 400,000 in Florida, and 40,000 in The Bahamas.[2] To better understand the flood protection benefits of these mangroves, TNC worked with science partners at the University of California Santa Cruz to estimate these benefits at the 5-kilometer level (previous global estimates used a 20-kilometer scale) (Beck et al., 2020; Menéndez et al., 2020; Menéndez et al., 2022).[3] Figure 2 outlines the general steps used to model the flood protection benefits of mangroves, which are estimated as the difference in inland flooding damage with and without mangroves. Damage curves were used to relate the level of flooding with an estimated number of impacted people and dollar value of damaged building stock.[4]

Figure 3 shows the present value of flood protection benefits for each 5-kilometer study unit assuming a 30-year life and a discount rate of 4%, which is consistent with discount rates used in World Bank project assessments.[5] The present value of benefits are greatest in areas where there are significant mangrove stands in front of or near high value building stock. Across our entire study region, we estimate the present value of flood protection benefits of mangroves to be $17 billion—$2 billion in Mexico, $13 billion in Florida, and $2 billion in The Bahamas.[6]

2 In Mexico, our study region only includes mangroves on the eastern side of the country and excludes mangroves on the Pacific Coast. Across all of Mexico, there are over 900,000 hectares of mangroves (Menéndez et al., 2022).

3 While each coastal segment is approximately 5 kilometers in width, the length of the segment can vary. The majority of study units are less than 100 kilometers, but some are as large as 1,000 kilometers or more. Moreover, very narrow islands—such as many in The Bahamas—are considered as a single study unit because the splitting of the islands would make the flooding models functionally difficult to run.

4 For people, the models assume that 0% of people are impacted with flooding up to 0.5 meters and that 100% of people are impacted with flooding greater than 0.5 meters (Beck, 2020). For building stock, the model uses the damage functions from Huizinga et al. (2017). Generally, any flooding greater than 6 meters will result in 100% damage of building stock.

5 Estimates rely on global asset data and are presented in 2020 USD. In the full analysis, mangrove benefits were also estimated using a 7% discount rate (Menéndez et al., 2022).

6 Across all of Mexico, mangroves provide $6.2 billion in flood protection benefits (Menéndez et al., 2022); however, our study region only includes mangroves located on the eastern coast.

Mangrove degradation and loss

Human-made and natural causes result in mangrove loss and degradation, threatening these systems at a global scale. Human activity was the primary driver of mangrove loss from 2000 to 2016 at the global scale, though natural causes were one of the largest drivers in many areas of the world, particularly outside of Asia and the Pacific (Goldberg et al., 2020). In a 2010 review of mangrove species globally, eleven of the 70 species assessed were estimated to be at an elevated threat of extinction, with two mangrove species critically endangered (Polidoro et al., 2010).

Figure 4 outlines many of the primary threats to mangrove systems around the world. The human-induced risks from development and pollution pose an undeniable threat to mangrove systems. Often, development and pollution can stress mangrove systems, making mangroves more susceptible to high levels of tree mortality following storm events (Lewis et al., 2016). Many of the risks associated with climate change – changes in temperature, changes in precipitation, and rising sea levels – will lead to mangrove expansion in some regions of the world and mangrove die-off in other regions. For example, in Central America, where many models predict temperature to increase and precipitation to decrease during the wet season, mangrove systems will likely become stressed due to limited sediment supply and increased water stress (Ward et al., 2016). Conversely, on the east coast of Florida, the area of mangroves has doubled at the northern end of their range over the last 28 years as the frequency of extreme cold events has decreased (Cavanaugh et al., 2014).

Hurricanes are expected to pose an increasing threat to mangroves in the future. In 2017 alone, over one million hectares of mangroves were affected by tropical storms or hurricanes in the Atlantic Ocean, the largest mangrove area to be affected by storms in the last four decades (Taillie et al., 2020). As climate change intensifies, conditions in the Atlantic Ocean are predicted to become more favorable to hurricanes (Herrera-Silveira et al., 2022) including an increase in the frequency of severe hurricanes, an increase in rainfall from hurricanes, and an increase in storm surge as a result of sea-level rise (Christensen et al., 2013; Knutson et al., 2010; Knutson et al., 2015; Kossin et al., 2017; Patricola and Wehner, 2018 Sobel et al., 2016; Vitousek et al., 2017).

Hurricanes tend to impact and damage mangroves in four ways (Herrera-Silveira et al., 2022):

1. **Changes in the structure, composition, and biomass of mangrove trees,** such as defoliation, changes in species dominance, or root detachment;
2. **Changes in the topography** of the mangrove forest, such as increases or decreases in the elevation and/or the opening or closing of channels and outlets;
3. **Changes in the hydrology** of the mangrove system, such as changes in freshwater and marine water balance or an increase in flood periods and levels; and
4. **Changes in sediment characteristics,** such as changes in sediment salinization or hypoxia.

However, the extent and severity of mangrove forest damage following a hurricane event is a function of several factors, including (Herrera-Silveira et al., 2022):

1. **Forest structure:** In general, mangrove trees with larger trunk diameters and/or that are taller will be most affected by a hurricane;
2. **Ecological type:** Fringing mangroves, located parallel to the coastline, will suffer more damage than other mangrove types;
3. **Fragmentation/Degradation:** In general, mangroves located near populated areas or that have compromised hydrologic flows will be most affected by a hurricane; and
4. **Hurricane Path:** In the Caribbean, mangroves located in the hurricane eye walls and to the right sides of the path of the eye will be the most affected by a hurricane.

Hurricanes

↓

Strong winds and storm surge can uproot and kill mangrove trees, knock down trunks and branches, and defoliate the canopy which can modify sediment dynamics, succession patterns, and nutrient cycles in the mangrove system (Baldwin et al., 2001; Herbert et al., 1999; Herrera-Silveira et al., 2022).

Changes in Temperature

↑↓

As temperature rises and the frequency of extreme cold events decreases, defined as days cooler than -4°C (25°F), mangroves will expand poleward into salt marsh communities. As temperature exceeds 32°C (100°F), photosynthesis productivity declines and salinity can increase, stressing existing mangrove systems (Ward et al., 2016).

Changes in Precipitation

↑↓

Regions projected to receive an increase in precipitation, such as Southeast Asia, could see mangrove expansion as they migrate further inland (Alongi, 2015; Ward et al., 2016). Regions projected to receive a decrease in precipitation, such as parts of the Caribbean and Central America, could see mangrove dieback as systems become stressed with increased soil salinity and decreased growth and productivity rates (Ward et al., 2016).

Sea-Level Rise & Shoreline Erosion

↑↓

To avoid drowning, mangroves must move to higher elevations. If blocked by development, they can suffer from "coastal squeeze" – instances where there is no suitable space for them to migrate (Alongi, 2015). In addition, recent research suggests that mangroves may not be able to expand fast enough to keep up with the increasing rate of sea level rise within the next 30 years (Saintilan et al., 2020).

Pollution

↓

Stormwater, agriculture, and sewage runoff pollute mangroves and can cause already stressed mangroves to degrade further or, in extreme events, can kill mangrove trees (Garcés-Ordóñez et al., 2019; World Bank 2019).

Development

↓

Direct deforestation of mangroves for shrimp aquaculture, timber, or coastal development results in mangrove loss. Indirect effects of development can be equally lethal by changing hydrology and blocking water flows to mangrove systems that can increase salinity and/or reduce sediment levels (Lewis et al., 2016). Dredge and fill activities can also lead to excessive flooding of mangrove habitat.

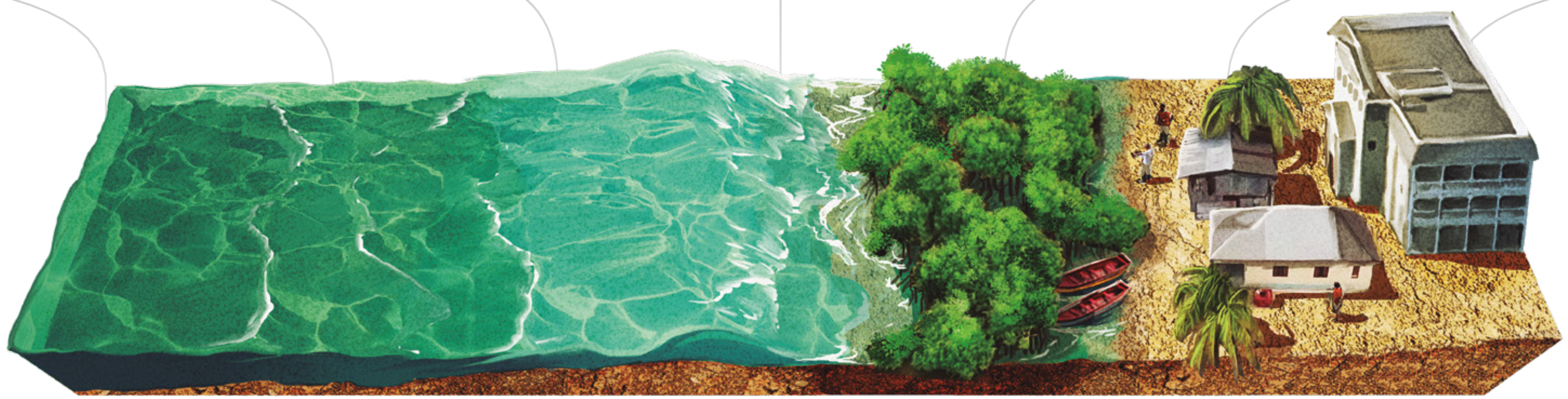

Figure 4: Primary drivers of mangrove loss and degradation

Note: "↓" denotes a projected loss to mangrove area and "↑" a projected increase to mangrove area.
A "↑↓" denotes that there are some regions of the globe where mangrove area may increase and others where mangrove area may decrease.

MINIMUM
74-95 mph (119-153 km/h)

1. Slight defoliation
2. Breakage of small branches
3. Suspended particles in water column

MODERATE
96-110 mph (154-177 km/h)

1. Small and medium branch breakage
2. Moderate flooding (up to 2.5 meters)
3. Moderate channel sedimentation

EXTENSIVE
111-129 mph (178-208 km/h)

1. Breakage of large branches
2. Large volumes of fallen woody material
3. Extensive flooding (2.7 to 3.6 meters)
4. Hydrological flow disruption
5. Sediment salinization

EXTREME
130-156 mph (209-251 km/h)

1. Large trees downed/uprooted
2. Change in structure and composition (height and size)
3. Extreme flooding (3.9 to 5.5 meters)
4. Sea water intrusion
5. Opening of inlets through barrier islands or dune systems

CATASTROPHIC
157 mph or highers (>252 km/h)

1. No presence of seedlings or juveniles
2. Large trees downed/uprooted
3. Decrease in density and complexity
4. Catastrophic and prolonged flooding (higher than 5.5 meters)
5. Sediment salinization
6. Opening of inlets through barrier islands and dune systems

Figure 5: Extent of damage to mangroves based on hurricane intensity, using the Saffir-Simpson scale. Modified from Krauss and Osland, 2020.

Mangrove damage from hurricanes in the Caribbean has been shown to be primarily a function of wind speed (Figure 5); the relationship is nonlinear with little damage at low wind speeds, then increasing damage with higher winds, and near complete damage at the highest wind speeds. Previous research shows some evidence of damages around 100 kilometers per hour (e.g., tropical storm level winds) and much higher rates of loss at wind speeds of 130 kilometers per hour (e.g., Category 1 level winds) and above (Imbert, 2018). In recent work, Menéndez et al. (2022) relied on assessed mangrove loss and recovery from six hurricanes spanning 30 years (Han et al., 2018) to estimate the relationship between wind speed and mangrove loss at wind speeds exceeding 110 kilometers per hour.[7] Using this estimated relationship, they simulated the projected damage from 6,635 hurricanes of varying strengths, representing 1,000 simulated years. From these simulations, they were then able to estimate the expected annual loss of mangroves from hurricanes in 27 sub-regions in Mexico, Florida, and The Bahamas.

7 A Category 1 hurricane has measured wind speeds in excess of 119 kilometers per hour.

The expected annual losses of mangroves from hurricanes varies from 1.4% to nearly 8% (Figure 6) of current mangrove stands across the 27 sub-regions. While all ten sub-regions in The Bahamas had a relatively high—greater than 4%—expected annual loss of mangroves, Mexico and Florida had more variability across the sub-regions. In Mexico, the central region of Quintana Roo had the highest expected annual loss at 6.9%), and in Florida, Martin, St. Lucie, Indian River, and Brevard Counties all had expected annual losses of 7.9%.

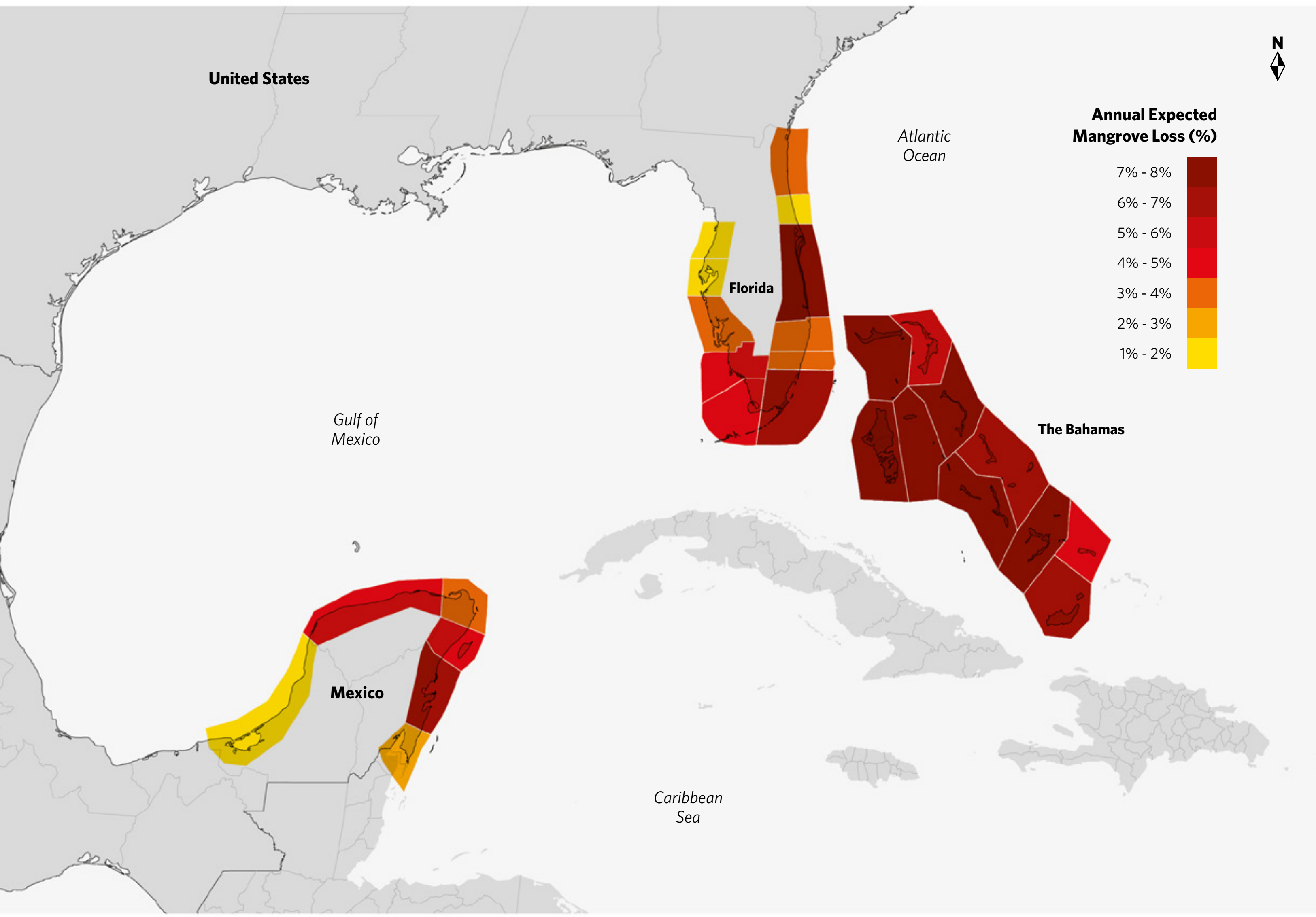

Figure 6: Annual expected loss of mangroves caused by tropical storms and hurricanes in 27 sub-regions across Mexico, Florida, and The Bahamas. Source: Menéndez et al. 2022.

Mangrove damage can be reduced

In the Caribbean and Gulf of Mexico, many mangrove stands are particularly vulnerable to hurricane damage due to low tidal ranges and the frequency of hurricane events (Lugo et al., 1981; Ward et al., 2016). Consequently, mangrove species in these regions evolved the ability to naturally recover from hurricanes (Herrera-Silveira et al., 2022). With Category 1 and Category 2 hurricanes, many mangroves in the Caribbean and Gulf of Mexico will naturally recover in less than five years (Danielson et al., 2017). With hurricanes of Category 3 and above, natural recovery of mangroves may take as long as 20 years (Imbert, 2018). However, the increasing frequency of severe hurricanes predicted with climate change can inhibit the natural recovery of mangroves, resulting in an accumulation of damage that can eventually lead to the death of mangrove trees (Herrera-Silveira et al., 2022; Taillie et al., 2020). Active post-storm restoration and repair of mangroves can hasten mangrove recovery time, making them more resilient to hurricanes in the future (Herrera-Silveira et al., 2022; Imbert, 2018).

While the specific restoration and repair activities that will be needed following a storm event depend on the type and magnitude of damage, as well as the pre-storm state of the forest, the general categories of restoration and repair include (Herrera-Silveira, 2022):[8]

1. **Hydrologic rehabilitation,** including dredging channels and rehabilitating water crossings;
2. **Topographic rehabilitation,** including sediment removal and the preparation of dispersion centers; and
3. **Reforestation,** including the use of propagules and/or nursery-grown seedlings.

The cost of these activities can vary widely depending on factors such as the type of restoration and repair, cost of materials and labor, and the distance and accessibility of the site (Herrera-Silveira et al., 2022). Reforestation should generally be used as a last resort, after both hydrologic and topographic rehabilitation of the site and natural seed and propagule dispersal has taken place (Herrera-Silveira et al., 2022).

We assessed 64 mangrove restoration projects and associated costs across Mexico (16), Florida (16 in eastern Florida and 27 in western Florida), and The Bahamas (5) (Herrera-Silveira et al., 2022).[9] We found that in Mexico the median restoration cost was $4,538 per hectare; in eastern Florida the median restoration cost was $118,524; in western Florida the median restoration cost was $54,653; and in The Bahamas the median restoration cost was $35,955 (Herrera-Silveira et al., 2022; Menéndez et al., 2022).[10]

8 For the purposes of this report, we use the definitions of restoration and repair as outlined in Berg et al. (2020). Restoration refers to ecological restoration and repair refers to actions taken to hasten recovery and minimize further damage after an event to restore its flood protection benefits. Generally speaking, repair is what occurs soon after damage happens, while restoration is a longer-term process.

9 We treated eastern and western Florida separately due to large differences in restoration project costs in the two areas.

10 The mangrove restoration projects that we identified took place over 30 years. All restoration costs were converted to U.S. dollars (USD) and adjusted for inflation to 2021 USD.

Cost-effective locations for mangrove restoration and protection

We compared the median restoration costs with the present value of mangrove flood protection benefits (Figure 3) to obtain a benefit to cost ratio (BCR) for mangrove restoration. Figure 7 identifies the BCR for 5-kilometer study units across our study region in Mexico, Florida, and The Bahamas. The BCR exceeds one in areas where the flood protection benefits of mangroves, measured over 30 years using a 4% discount rate, exceed the costs of mangrove restoration on a per hectare basis (see Menéndez et al., 2022 for a full description of methods).

We identified nearly 250 5-kilometer coastal study units spanning 80,000 hectares of mangroves and 1,200 kilometers of coastline where the BCR was higher than one, indicating that there are many cost-effective opportunities for mangrove restoration in Mexico, Florida, and The Bahamas. This includes more than 100 5-kilometer-wide study units spanning more than 50,000 hectares of mangroves and 500 kilometers of coastline in Mexico; more than 100 5-kilometer-wide study units spanning nearly 20,000 hectares of mangroves and more than 600 kilometers of coastline in Florida; and more than a dozen 5-kilometer-wide study units spanning nearly 3,000 hectares of mangroves and more than 60 kilometers of coastline in The Bahamas.

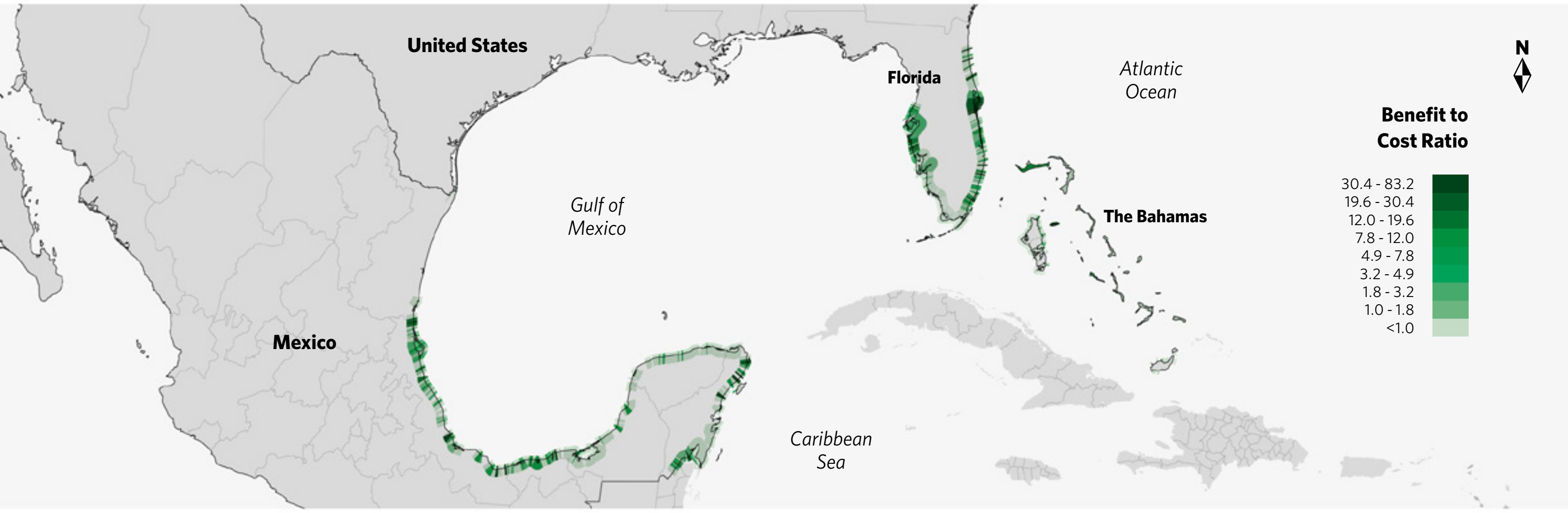

Figure 7: Benefit to cost ratio for 5-kilometer coastal study units, assuming a median restoration cost of $4,538 per hectare for projects in Mexico, $118,524 per hectare in eastern Florida, $54,653 per hectare in western Florida, and $35,955 per hectare across The Bahamas. Analysis excludes western Mexico. Source: Menéndez et al., 2022.

Insuring mangroves

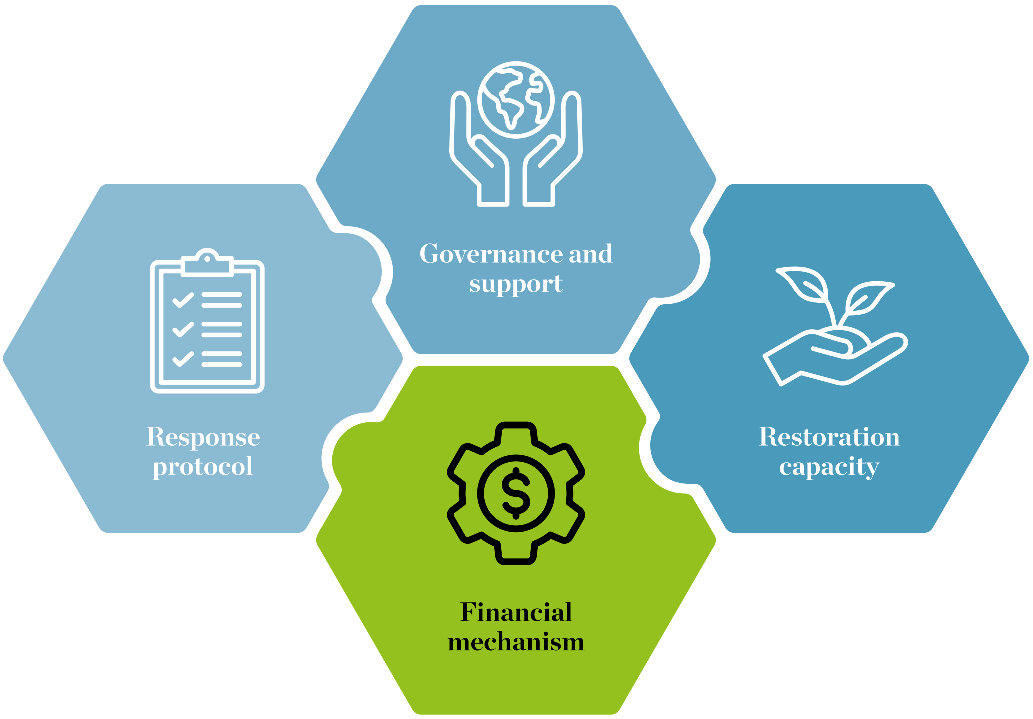

Figure 8: Effectively managing the risk to mangroves requires a comprehensive strategy. Mangrove insurance can be a cost-effective financial mechanism to fund the restoration and repair of damaged mangroves.

In many areas of Mexico, Florida, and The Bahamas, major hurricanes of Category 3 or more, make landfall more often than in other parts of the world (Krauss and Osland, 2020). In the event of these storms, mangroves often serve as the first line of defense in dissipating wave energy, slowing storm surge, and reducing inland flooding. In areas where the protective benefits of mangroves exceed the costs of mangrove restoration (e.g., those areas where the BCR exceeds one), mangrove protection and restoration can serve as a critical component of a broader coastal risk management strategy.

Effectively managing the risk to mangroves requires a comprehensive strategy that includes: (i) support of government or other management entity for mangrove restoration, repair, and protection; (ii) protocol for post-damage restoration and repair; (iii) physical capacity and expertise to conduct restoration and repair; and (iv) funding to cover costs of restoration, repair, and protection (Figure 8). Funding these costs may require more than one financial mechanism, for example, a combination of a self-insuring emergency fund and a risk-transfer mechanism such as an insurance policy. Other potential financial mechanisms include resilience credits and catastrophe bonds. A careful analysis will help determine whether a mangrove insurance policy is feasible, as compared to the other possible funding mechanisms (Kousky and Light, 2019).

Developing a mangrove insurance policy

Insurance serves as a risk transfer tool (Kousky and Light, 2019), where the buyer pays the insurance company a set amount, referred to as the premium, to transfer a specified risk to the insurance company. The buyer then receives a guaranteed payout in the event of specified damage (in the case of indemnity insurance) or in the event of a predetermined level of hazard (in the case of parametric insurance). With a mangrove insurance policy, the policy holder may be able to insure a mangrove forest against losses related to specified damage, a predetermined level of the hazard or both (Beck, 2020). Figure 9 summarizes the primary components of a mangrove insurance policy.

Insurance Purchaser	**Customer**	An entity or individual may purchase an insurance policy if they demonstrate an insurable interest, that is if they own the asset or have an economic interest in it.
	Justifying the policy	The customer must value the benefits provided by mangroves and have an interest in protecting and restoring them post-damage.
Policy Type	**Type of insurance**	Identify the type of insurance policy, e.g., indemnity, parametric or a combined parametric-indemnity policy.
Characteristics of the Policy	**Insured asset**	Delineation of the mangroves to be insured.
	Payout	Maximum amount of restoration costs covered by the insurance policy.
	Policy trigger	Define the trigger of the payout, which is usually a characteristic of the hurricane and a threshold (e.g., wind speed of 100 kilometers or more).
	Loss adjustment	In the case of parametric insurance, losses will be based on an identified trigger event (e.g., wind speed) in a specified area (e.g., polygon). In the case of indemnity insurance, losses will be based on assessed damage at the site. The policy must identify the source of the data and method to estimate the payout or compensation.
Policy Price	**Exposure**	Exposure to hurricanes depends on the probability of hurricanes occurring in the location of the mangroves. A fragility curve is used to estimate the relationship between the trigger event (e.g., wind speed) and mangrove damage.
	Policy characteristics	The main elements of the policy (payout and trigger) along with the exposure of the site determine the cost of the policy.
Insurance Claims	**Policy beneficiary**	Identify individual or entity that will receive insurance payouts and process for effectively utilizing claims for restoration work.

Figure 9: Primary components of a mangrove insurance policy.

Black mangroves, roots, and breathing tubes, Exuma Cays Land and Sea Park, The Bahamas. © Jeff Yonover.

Insurance purchaser

Entities or individuals may purchase a mangrove insurance policy if they can show an insurable interest (Kousky and Light, 2019; Secaira Fajardo et al., 2019). That is, the entity or individual must be able to demonstrate ownership and/or that they would suffer a financial loss if the insured mangrove was damaged. In most cases, the entities or individuals must demonstrate a financial loss related to physical assets that they own, though it may be possible to claim losses even if they do not own the asset that is damaged. For example, a fishing company whose business relies on mangroves for fisheries production may want to insure mangroves to avoid fishing-related business interruption and revenue loss in the event the mangroves are damaged.

The identified entity or individual must not only have an insurable interest in the mangrove forest but must also find it cost-effective to purchase the insurance policy. The entity or individual should value the benefits provided by the mangrove forest and also be interested and able to pay the insurance premium (Secaira Fajardo et al., 2019). Because of additional challenges with creating an insurance policy for a single private property owner, we identified the public sector as the most feasible market in previous work (Beck et al., 2020).

Policy type

There are two main types of insurance policies: (i) indemnity policies which base payouts on assessed losses; and (ii) parametric policies which base payouts on observed events. While payouts related to indemnity policies may take several weeks to be disbursed after losses are assessed, payouts related to parametric policies can be disbursed within a few days of the observed event.

The type of insurance policy used to cover a mangrove forest will depend on the identified restoration needs post-storm. For example, if all of the required mangrove restoration must be performed immediately following the storm event, then a parametric policy will be the best option. But, if some of the required restoration can be performed several months after the storm event then a combined parametric-indemnity policy may be more suitable. Recent research suggests that inland areas prone to hydrologic isolation were most susceptible to mangrove dieback six months following a storm event, suggesting that delayed assessment of hydrologic management needs may be important in developing an effective post-storm response (Lagomasino et al., 2021).

Characteristics of the policy

The first step in creating a mangrove insurance policy is to identify the insured asset. That is, the specific area of mangrove to be covered by the policy. In general, an insurance policy will have a payout up to the replacement cost of the insured asset. For mangrove insurance, the payout can be estimated using restoration costs for the site. In earlier work, we have documented a range of mangrove restoration costs per hectare (Herrera-Silveira et al., 2022). The actual restoration costs on site will depend on local factors such as site accessibility, post-storm damage, and local labor costs. Once the insured mangroves have been identified, site-specific restoration costs can be estimated using past storm damage to the mangrove forest and all restoration activities and costs that were incurred as a result of this damage. In the absence of these data, restoration costs can be estimated based on observed characteristics of the site and input from local restoration experts.

Any mangrove insurance policy will need to carefully state when the policy payouts will be triggered, referred to as a trigger event. The trigger event is typically defined around a specific parameter, such as wind speed, occurring at or beyond a specific threshold in a designated area, referred to as a trigger polygon. The polygon generally encompasses an area several kilometers around the insured asset, as wind speeds above 100 kilometers per hour can occur up to 85 kilometers from the center of the hurricane (Secaira Fajardo et al., 2019b). In the case of a mangrove insurance policy, the events that trigger the policy are likely to be related to the occurrence of a hurricane, as non-hurricane related risks to mangroves (listed in Figure 4) are not random enough in nature to be covered under an insurance policy.

The actual payout is generally a structure of staggered payments, where the payout increases with the intensity of the parameter and, in the case of indemnity, with the level of assessed damages. For example, payouts in the insurance policy for coral reefs and beaches in Quintana Roo, Mexico were 40% of the maximum payout at wind speeds greater than 100 knots, 80% at wind speeds greater than 130 knots, and 100% only in the event of wind speeds exceeding 160 knots (TNC, 2021). With an indemnity policy, payouts will be based on assessed damage at the site and with a combined policy, payouts will be based on both the trigger event and assessed damages.

Policy price

The price of the insurance policy is based on the characteristics of the policy (e.g., payout and trigger event) and the potential hurricane damage, based on characteristics of the site (e.g., mangrove species, elevation, geographic location, i.e., in an area more prone to hurricanes). The potential for hurricane damage at a given mangrove site is referred to as the site's exposure.

Fragility curves help identify the storm conditions under which mangroves are destroyed and/or fail during storm events by estimating the relationship between damage to the mangroves and a characteristic of the hurricane, such as wind speed or storm surge. Fragility curves can also be used to identify the cost of restoration needed for various storm intensities and to estimate the amount of payouts that will be required. Menéndez et al. (2022) presents initial estimates of the correlation between damages to mangroves and wind speed caused by six hurricanes in Florida. This preliminary fragility curve estimated related wind speed (knots) to mangrove damage, measured as a percent, and was used, in combination with assumptions about predicted wind speeds, to build out the annual expected mangrove damage presented in Figure 6 (Menéndez et al., 2022). Ultimately, fragility curves require dozens of data points on mangrove damage resulting from past hurricanes in several locations and can take many years to develop.

Finally, the policy price must be informed by the financial capacity of the buyer. The insurance purchaser will decide at what hurricane intensities and estimated mangrove damage levels they will need to cover with an insurance policy. They may choose to cover less severe storms and damage with their own emergency funds rather than transfer the risk to an insurer.

Insurance claims

The final component needed to complete a mangrove insurance policy is the determination of the loss adjustment procedures and the policy beneficiary. In the case of a parametric policy, the loss adjustment process involves identifying a credible third-party data source (e.g., NOAA National Hurricane Center) that will be used to determine the occurrence of the trigger event in the trigger polygon. In the case of an indemnity policy, the loss adjustment process involves determining which individuals or organizations will be responsible for assessing damage to the mangroves on site, as well as the method and timeline for doing so.

The policy beneficiary, referred to as the Named Insured and usually the first person or entity named on a policy, is responsible for insurance premium payments, submitting claims, and receipt and management of policy benefits. The policy beneficiary can designate third-party loss payees to receive some or all of the insurance policy payouts. In the case of the reef insurance in Quintana Roo, Mexico, the Named Insured was an existing trust fund, which then used revenue contributed by coastal property owners, local governments, and others to purchase and manage the insurance policy and payments (TNC, 2021). As illustrated in Figure 10, the trust fund manages other coral reef restoration activities, as well.

Figure 10: Structure of trust fund that manages reef insurance in Quintana Roo, Mexico.

Opportunities for mangrove insurance in Mexico, Florida, and The Bahamas

To assess the feasibility of a mangrove insurance policy in Mexico, Florida, and The Bahamas, we engaged a diverse set of stakeholders across each of these three regions over the course of the project. Stakeholders in all three regions expressed interest and excitement about the possibility of a mangrove insurance policy. Most stakeholders wanted to learn more about how a mangrove insurance policy may be structured, the types of perils it may cover, the restoration activities that might be implemented with payouts, how much it might cost, and how prices would be determined.

The stakeholder engagement activities focused on identifying potential mangroves to insure, the beneficiaries of the mangroves' ecosystem services, and potential buyers of an insurance policy. The map in Figure 11 shows the locations of nine potential pilot site locations identified in the three study regions. In each region, we used the following questions to guide our discussions and describe the findings for each region below (Berg et al., 2020; Secaira Fajardo et al., 2019):

1. How valuable are the flood protection benefits of mangroves?
2. Are there stakeholders who value or benefit from the flood protection of mangroves?
3. Are these stakeholders interested in managing risk to mangroves and potentially buying an insurance policy?
4. Are these stakeholders legally entitled to purchase insurance?
5. Do these stakeholders have the capacity to pay an insurance premium?
6. Is there an existing institution or financial entity that could convene beneficiaries to buy the insurance?

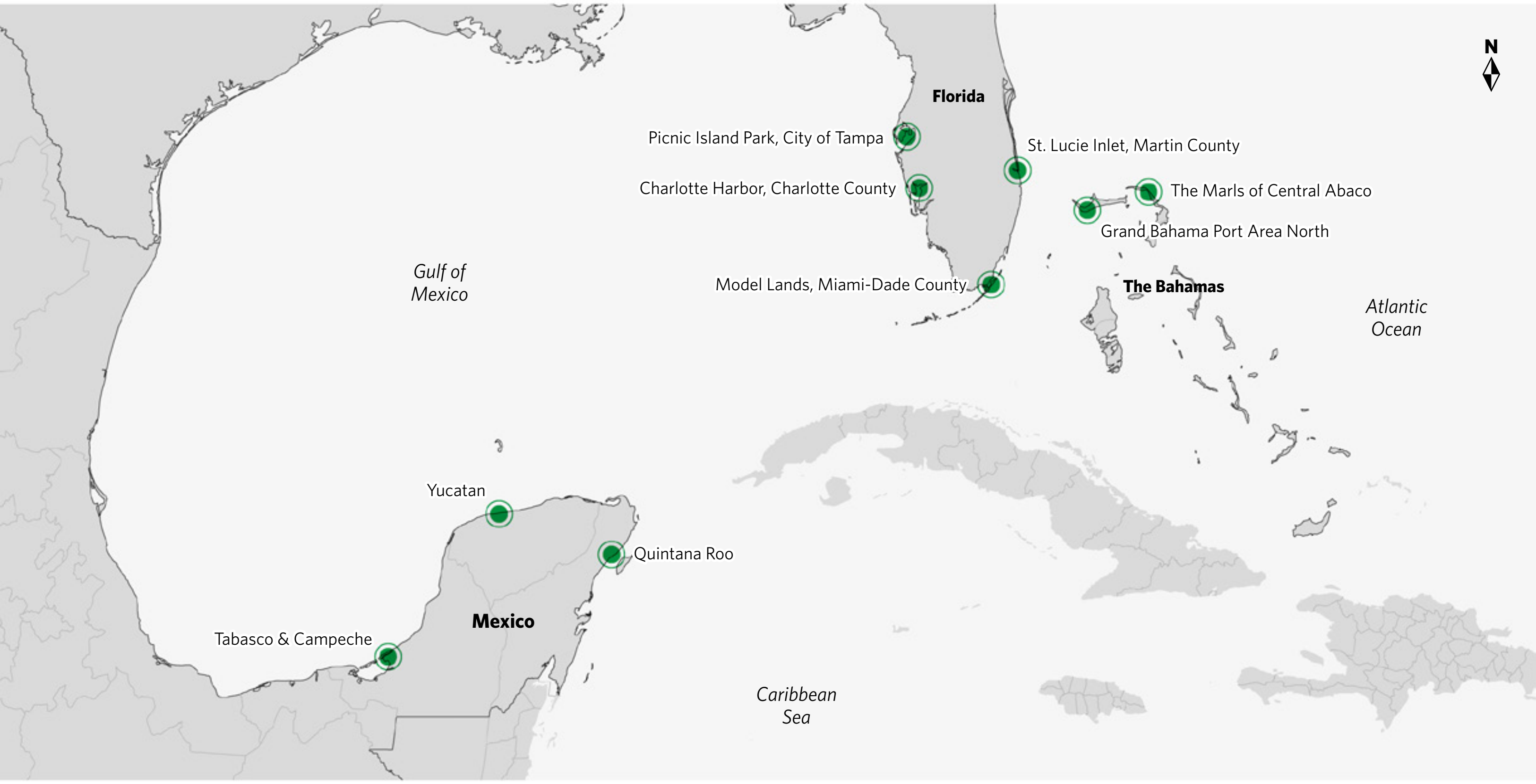

Figure 11: Potential mangrove insurance pilot site locations in Mexico, Florida, and The Bahamas

Mexico

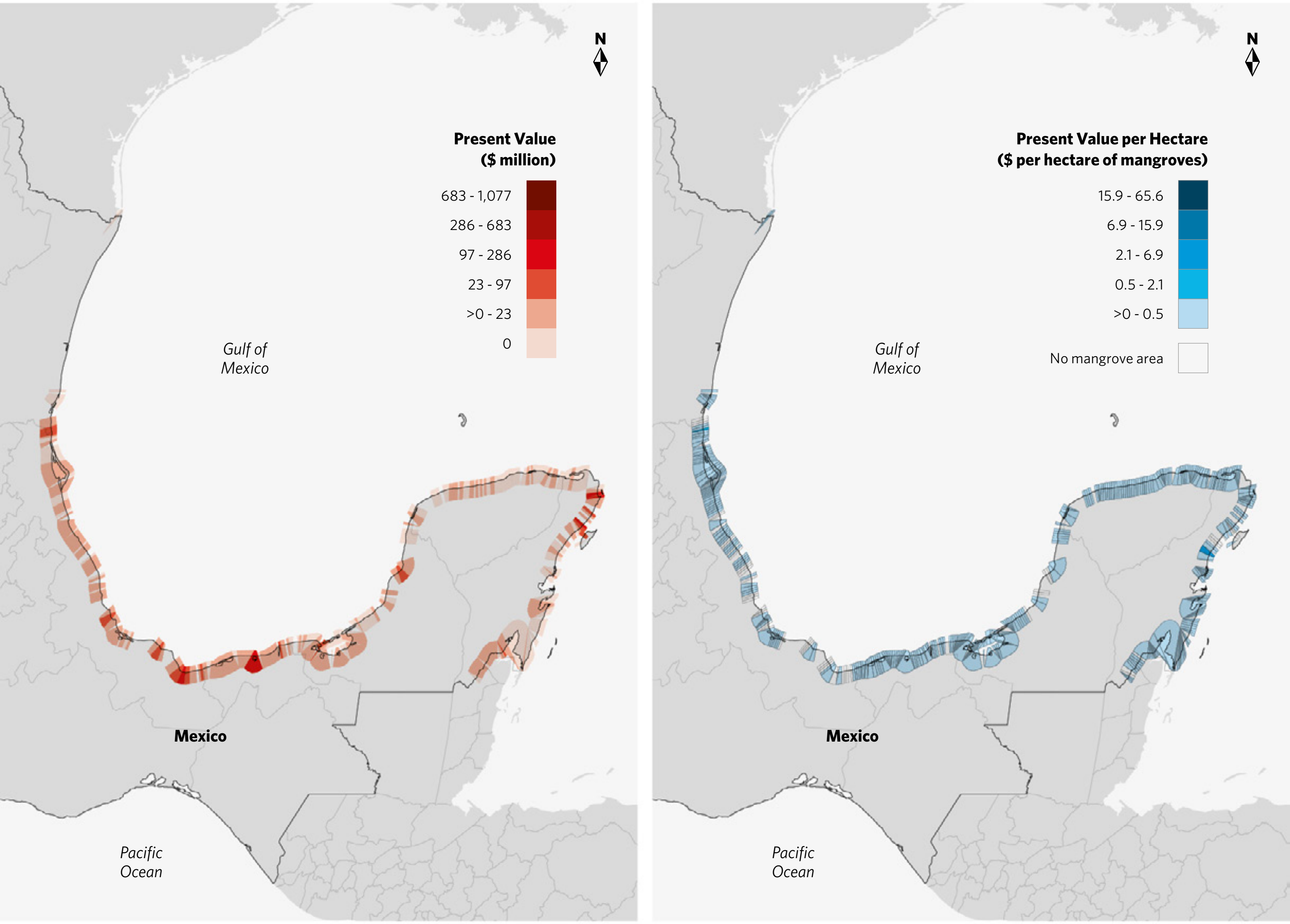

Figure 12: Present value (a) and present value per hectare (b) of mangrove flood protection benefits in the Yucatan Peninsula over 30 years assuming a 4% discount rate. Source: Menéndez et al., 2022.

In Mexico, the national government owns most of the mangroves and the Comisión Nacional de Áreas Naturales Protegidas (CONANP, the National Commission of Natural Protected Areas) manages the country's nationally protected areas. Interest in insurance policies to protect and restore coastal assets is strong in Mexico, given the success of the Quintana Roo coral reef insurance policy (TNC, 2021).

CONANP is currently assessing how its Natural Protected Areas Fund could purchase an insurance policy to fund the restoration of damages to these areas. CONANP is particularly interested in a multi-peril insurance that could simultaneously protect mangroves, dunes, and reefs against hurricanes, droughts, and fires. In addition, Fondo Mexicano para la Conservación de la Naturaleza, A.C. (FMCN, the Mexican Fund for the Conservation of Nature) has the ability to purchase an insurance policy, receive the payouts, and disburse funding for restoration work via its Natural Protected Areas Fund. According to Mexico Article 85 of El Ley Sobre El Contrato de Seguro (Article 85 of Mexico Insurance Law), any individual or entity that has an economic interest in the "non-occurrence of a loss" may purchase an insurance contract.

We identified three primary locations of interest in the broader Yucatan Peninsula: the states of Tabasco and Campeche; Yucatan; and Quintana Roo (Figure 11 and Table 1). Figure 12 shows the distribution of the present value and present value per hectare of flood protection benefits across these three locations, assuming a 30-year life and 4% discount rate. Across the entire Yucatan Peninsula, mangroves provide over $2 billion in flood protection benefits, with benefits exceeding $100 million in four areas: Cancun, Playa del Carmen, Villahermosa and Coatzacoalcos (Figure 12a). Over 500 kilometers of coastline have a BCR exceeding one and over 100 kilometers have a BCR exceeding ten, including Tulum and Campeche (Figure 12b).

These three regions were proposed for the relatively high level of flood protection benefits provided by mangroves, the large number of communities dependent on coastal fishing, recreation, or tourism activities, and the state governments' general interest in identifying innovative ways to protect and restore coastal assets. The Yucatan Peninsula is also highly vulnerable to hurricanes. Between 2000 and 2021, 30 hurricanes made landfall in the area, including 12 that were Category 3 or above (NOAA, 2022).

	Tabasco and Campeche	**Yucatan**	**Quintana Roo**
Hectares of site	188,000	74,000	146,000
Key assets protected	Villahermosa City; medium and small-sized coastal fishing and recreational communities	Medium and small-sized coastal fishing and recreational communities	Cancún; Puerto Morelos; Mahahual; Xcalak; state highways and trains
Key stakeholders	CONANP	CONANP; Yucatan State Government	CONANP; Quintana Roo State Government
Possible financial mechanisms	FMCN via its Natural Protected Areas Fund	FMCN via its Natural Protected Areas Fund	FMCN via its Natural Protected Areas Fund; Quintana Roo State Trust for Coastal Management

Table 1: High-priority locations for a potential mangrove insurance policy in Mexico. CONANP refers to Comisión Nacional de Áreas Naturales Protegidas and FMCN refers to Fondo Mexicano para la Conservación de la Naturaleza, A.C.

Florida

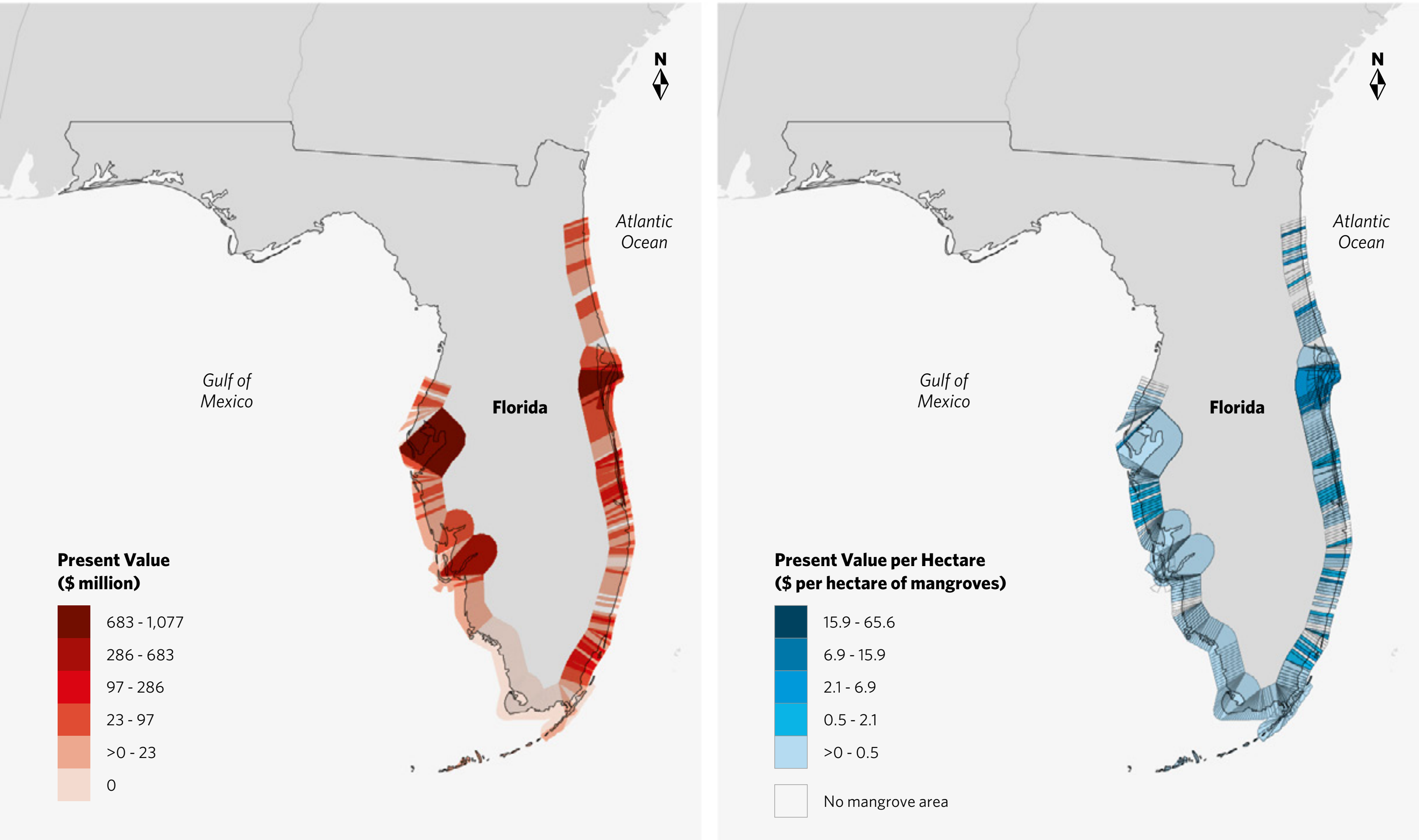

Figure 13: Present value (a) and present value per hectare (b) of mangrove flood protection benefits in Florida over 30 years assuming a 4% discount rate. Source: Menéndez et al., 2022.

In Florida, mangroves are managed by the landowner or through collaborations or partnerships with government agencies charged with management of natural resources. As a result, the bulk of mangroves are either owned or managed by federal, state, or municipal governments.

The state has a policy of self-insuring its assets, so the state has little interest in purchasinga mangrove insurance policy. However, Florida Statute § 627.405(2) allows any entity (e.g., local governments or organizations) or individual that can demonstrate "substantial economic interest" in the asset to legally purchase an insurance policy on state-owned mangroves.

Florida's mangroves are highly vulnerable to hurricanes. Between 2000 and 2021, 15 hurricanes—more than 40% of all hurricanes to hit the US—made landfall in Florida, including 9 that were Category 3 and above (NOAA, 2021; NOAA, 2022).

Stakeholders in Florida understand the benefits and value of ecosystem services that mangroves provide coastal communities. They also understand that these benefits and services may be reduced in the future due to accumulated damages caused by climate change, development, and hurricanes. Though many stakeholders expressed interest in the potential of insurance to manage this future risk within their jurisdictions, their individual willingness or capacity to purchase annual premiums is challenged by various factors, including:

- uncertainty regarding the advantage of purchasing an insurance policy for mangroves;
- lost opportunity cost associated with diverting limited funding for natural resource management and restoration work to insurance premiums; and
- reluctance to purchase an insurance policy for a natural resource that has been historically under-valued and/or required minimal capital investment to maintain its flood risk reduction benefits.

Nevertheless, we identified four sites with potential to pilot a mangrove insurance policy: Picnic Island Park in Tampa Bay, Model Lands in Miami-Dade County, Charlotte Harbor in Charlotte County, and St. Lucie Inlet in Martin County (Figure 11 and Table 2). Across the four sites, the present value of mangrove flood protection benefits ranges from $18 million in St. Lucie Inlet to $1 billion in the Picnic Island Park area (Figure 13a). The BCR was above 2 around Picnic Island Park, Model Lands, and Martin County and above one in areas around the Charlotte Harbor site (Figure13b). At each of these sites, we identified opportunities for topographic and hydrologic restoration of mangroves and for improved management of the land to better enable landward mangrove migration resulting from sea level rise and storm surge. Many local governments in Florida also have strategies linked to increasing resilience and adaptive capacity, making them key partners in building out a pilot insurance policy. For example, the City of Tampa has a Resilient Tampa strategy and the Greater Miami region has a Resilient305 strategy.[11]

11 For more information, see the Resilient Tampa website: https://www.tampa.gov/green-tampa/resilience; and the Resilient305 website: https://resilient305.com/.

	Picnic Island Park	Model Lands	Charlotte Harbor	Martin County
Hectares of site	200	400	200	200
Key considerations	Borders MacDill Air Force Base; Port Tampa City is a frontline community with regards to sea level rise	Key migration space for mangroves	Extensive area of mangroves with multiple jurisdictions charged with conservation and restoration	High protection benefits; strong interest in partnering from local stakeholders
Key stakeholders	City of Tampa; Tampa Bay Estuary Program; MacDill Air Force Base	Miami-Dade County; Florida Power and Light; South Florida Water Management District; US Department of the interior	City of Punta Gorda; Charlotte County; State of Florida; Coastal and Heartland National Estuary Partnership	City of Stuart; Martin County; State of Florida; Florida Inland Navigation District; US Fish and Wildlife

Table 2: High-priority locations for potential mangrove insurance policy in Florida.

The Bahamas

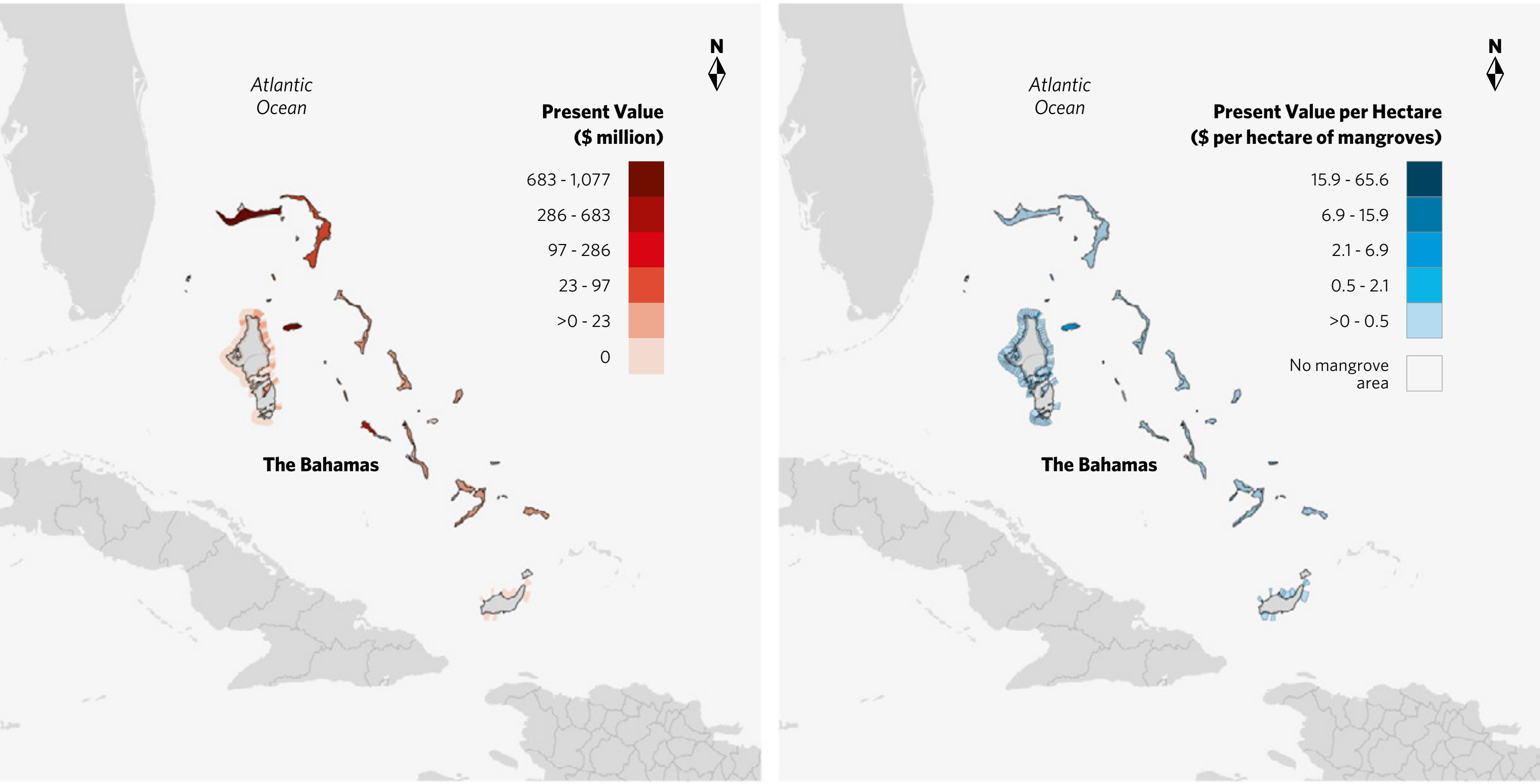

Figure 14: Present value (a) and present value per hectare (b) of mangrove flood protection benefits in The Bahamas over 30 years assuming a 4% discount rate. Source: Menéndez et al., 2022.

The mangroves in The Bahamas are especially vulnerable to damage from hurricanes (Figure 5). Between 2000 and 2021, 20 hurricanes made landfall in The Bahamas, including 12 that were Category 3 and above—and 5 that were Category 5 (NOAA, 2022). In 2019, Category 5 Hurricane Dorian severely damaged mangroves and other coastal ecosystems.

Measuring the protective benefits of mangroves in The Bahamas is challenging due to the large number of small islands and dispersed populations. In our analysis, with the exception of Andros and Inagua, the protective benefits of mangroves in The Bahamas were measured on an island-by-island basis rather than in the five-kilometer study units used in Mexico and Florida (Figure 14). In addition, the majority of the population in The Bahamas is concentrated on two islands—nearly 70% on New Providence and 15% on Grand Bahama. In other areas, such as West Andros, mangroves offer lower total flood protection benefits due to small local populations and limited infrastructure, however, they provide significant tourism and fishery benefits (Figure 14; Fedler, 2018). Despite these limitations, our results show that mangroves provide over $2 billion in flood protection benefits in The Bahamas with a country-level BCR above one (Figure 14a and 14b).

The northern port area of Grand Bahama and The Marls of Central Abaco, which make up nearly 15% of The Bahamas' Gross Domestic Product, emerged as the two primary focal areas for a potential mangrove insurance policy (Zegarra et al., 2020). In Grand Bahama, mangroves provide over $900 million in flood protection benefits. In Abaco, mangroves provide over $26 million in flood protection benefits (Figure 14a). Both islands are home to large areas of mangroves, including mangroves that are adjacent to key public infrastructure, such as airports (Table 3). Both also intersect with potential blue carbon sites, and stakeholders expressed interest in understanding whether and how mangrove insurance and blue carbon payments might be pursued jointly. Grand Bahama and Abaco Islands are two of the islands in The Bahamas that are most frequently impacted by hurricanes (Winkler, 2020). In 2019, Hurricane Dorian caused significant damage to mangroves on both islands, and an estimated $1 million over the next five years is still needed to complete restoration of the damaged areas.[12]

Many local businesses and organizations in The Bahamas lack the capacity to fund a mangrove insurance premium. Moreover, many of the mangroves in The Bahamas are on Crown land, meaning they are owned by the federal government, which tends to self-insure like the State of Florida. However, the Bahamas Protected Areas Fund—a national conservation trust fund established in 2014 with a mandate to provide sustainable financing for protected areas management and biodiversity conservation, among other things—could likely fund an insurance premium. With modest changes to its structure and governance, the trust fund could also serve as the hub for all activities related to mangrove insurance, similar to the trust fund in Quintana Roo, Mexico. While Bahamian insurance law does not explicitly address insurable interest related to property policies, the common principle requiring an economic interest will likely apply since Bahamian law tends to follow English common law.[13]

12 Estimate based on conversations with several local stakeholder groups.

13 See https://www.inhouselawyer.co.uk/feature/commercial-litigation-focus-the-bahamas/.

	Grand Bahama Port Area North	The Marls of Central Abaco
Hectares of site	8,000	30,000
Key assets protected	International airport; industrial zone; residential development	International airport; medium and small-sized coastal fishing and recreational communities
Key stakeholders	Forestry unit of the Ministry of the Environment and Natural Resources; Grand Bahama Port Authority; Grand Bahama Development Company; Businesses in industrial zone; NGOs implementing mangrove restoration (e.g., Bonefish and Tarpon Trust, Water Keepers Bahamas, Blue Action Lab)	Forestry unit of the Ministry of the Environment and Natural Resources; Tourism and other commercial property owners; NGOs implementing mangrove restoration (e.g., Friends of the Environment, Bahamas National Trust)
Possible financial mechanisms	Bahamas Protected Area Fund	Bahamas Protected Area Fund

Table 3: High-priority locations for potential mangrove insurance policy in The Bahamas.

Conclusions: Outlook and opportunities

In much of the Gulf of Mexico and Caribbean region, mangroves provide high-value flood protection benefits. Across our entire study region in Mexico, Florida, and The Bahamas, mangroves provide over $17 billion in flood protection benefits over 30 years (Menéndez et al., 2022). Based on our BCR assessments, a mangrove insurance policy to fund restoration following hurricane damage would be cost-effective in many areas across the region. We identified nearly 250 5-kilometer coastal study units, spanning more than 80,000 hectares of mangroves and 1,200 kilometers of coastline in these areas, where the BCR was higher than one.

In all three areas, our stakeholder engagement revealed strong interest in exploring how a mangrove insurance policy might be designed and managed. Stakeholder consultations identified nine locations across Mexico, Florida, and The Bahamas with significant potential to advance a mangrove insurance pilot policy. Key lessons and learnings from these initial conversations include:

- **The geographic area of interest for insurance coverage will be location specific and determined by stakeholders.** In Mexico, interest is largely around an insurance policy that would cover an entire state of Yucutan, while in Florida and The Bahamas interest is focused on smaller and more discrete areas of mangroves.
- **In each region, a mangrove insurance policy could be purchased by an entity that can demonstrate an insurable interest,** i.e., the entity receives an economic benefit from the insured asset even if it does not own the mangroves. In Mexico and The Bahamas, mangroves are predominately owned by the federal government while in Florida they are owned by the state. However, as long as another local government or organization could demonstrate an insurable interest in the mangroves, they could legally be eligible to purchase a mangrove insurance policy.
- **In nearly all of the conversations with stakeholders, the primary concerns were how much an insurance policy would cost, who or which entity would pay for it, and/or how funds could be secured to pay for it.** Identifying ways to fund the purchase of the insurance premium is critical.

With the work that we have done to date, we are optimistic about the potential for establishing mangrove insurance policies to fund restoration of mangroves damaged by hurricanes. While this phase of work focused on the feasibility of a mangrove insurance policy in specific locations, the next phase of work will focus on how to design the insurance scheme and manage the payouts to ensure the appropriate restoration work takes place (Figure 15). As we move into the design phase of work, key science needs include:

- In order to determine the best type of policy (parametric vs. indemnity vs. combined), **we need to better understand the mangrove restoration needs at a specific site,** including what post-storm restoration work is cost-effective in terms of speeding up the natural recovery process of damaged mangroves.

For example, understanding when mangrove dieback will occur post-storm in the absence of human intervention and which restoration techniques would be needed to avoid the dieback.

- In order to more accurately determine the policy price, **we need to build out data points in the fragility curve that links the intensity of a hurricane to mangrove damage.** Because on-the-ground observational damage data is limited, this work will likely need to rely on regional analyses based on satellite images.

By filling in these science gaps and holding additional stakeholder engagements in each high-priority location, we will aim to answer the following questions during the design phase of work:

- What are the post-storm restoration actions that would need to be insured? How do these actions influence the type of insurance scheme created?
- Which suite of financial tools would be needed to fund a post storm response? How much of the funding needs should be self-insured (e.g., through an emergency fund) and how much should be transferred via an insurance policy?
- What institutional arrangements are needed to ensure that the insurance payouts are used appropriately? Does additional on-the-ground restoration capacity need to be developed (e.g., labor force, skillset, permits) in order to effectively use the insurance payouts?
- How much would a mangrove insurance policy cost?
- What is the best way to fund the mangrove insurance premium?
- What opportunities are there to link a mangrove insurance policy with resilience and/or blue carbon credits?

In much of the Caribbean and Gulf of Mexico, erosion and hurricanes are the primary threats to mangrove loss (Goldberg et al., 2020). Identifying innovative funding to finance the restoration and protection of mangroves going forward will be critical to ensuring their resilience and the resilience of the communities that they protect. Insurance is an important avenue for this funding. As we move forward with this work, TNC's goal is to launch a pilot mangrove insurance policy and demonstrate that, when used appropriately, these types of risk transfer tools can be a cost-effective means of protecting our coastlines and coastal communities.

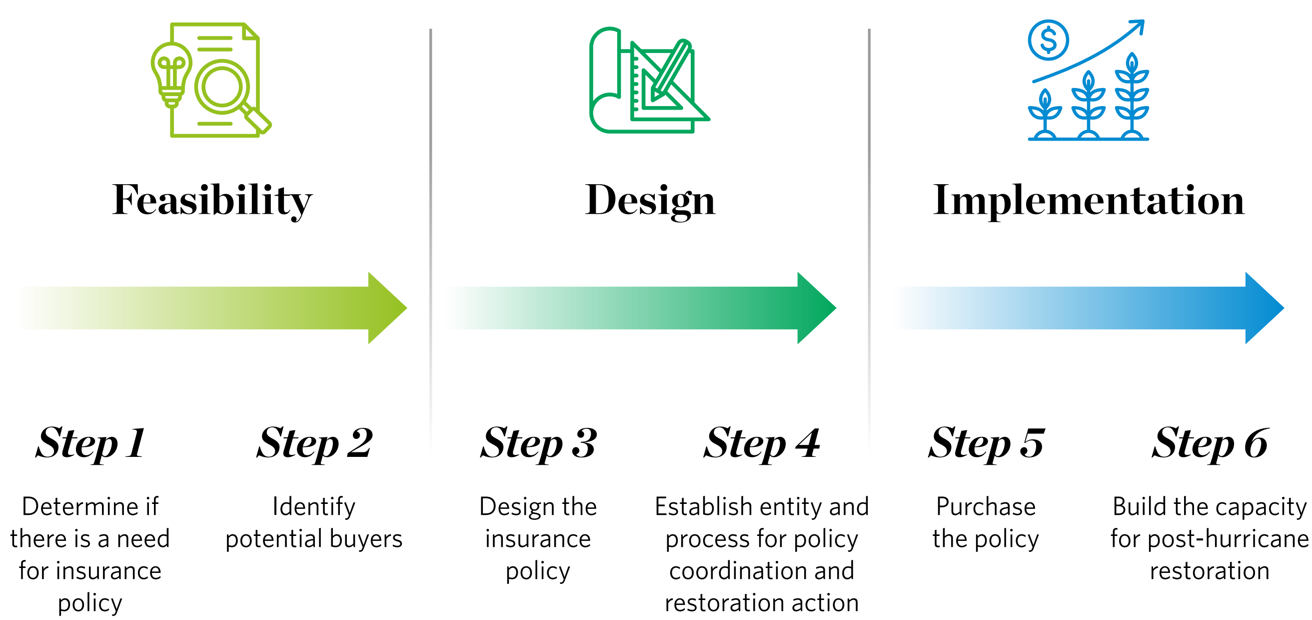

Figure 15: Process to assess, design and buy an insurance policy. Adapted from Secaira Fajardo et al., (2019).

White mangroves at Levera, Grenada. © Marjo Aho.

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