Ecosystem Services 56 (2022) 101440

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Short Communication

Return on investment for mangrove and reef flood protection

Michael W. Beck [a], Nadine Heck [a,b], Siddharth Narayan [a,b], Pelayo Menéndez [a,c], Borja G. Reguero [a], Stephan Bitterwolf [a], Saul Torres-Ortega [c], Glenn-Marie Lange [d], Kerstin Pfliegner [e], Valerie Pietsch McNulty [f], Iñigo J. Losada [c]

[a] Institute of Marine Sciences, University of California, 115 McAllister Way, Santa Cruz, CA 95060, USA
[b] Department of Coastal Studies, East Carolina University, Wanchese, NC 27891, USA
[c] Instituto de Hidráulica Ambiental-IHCantabria, Universidad de Cantabria, Santander, Cantabria 39011, Spain
[d] The World Bank, 1818 H St. NW, Washington, DC 20433, USA
[e] ERM, Siemensstrasse 9, Neu-Isenburg 63263, Germany
[f] The Nature Conservancy, Caribbean Program, Coral Gables, Miami, FL 33114, USA

ARTICLE INFO

Keywords:
Coastal protection
Flood risk
Risk reduction
Nature-based solutions

ABSTRACT

There is a growing need for coastal and marine restoration, but it is not clear how to pay for it given that environmental funding is low, and national budgets are stretched in response to natural hazards. We use risk-industry methods and find that coral reef and mangrove restoration could yield strong Return on Investment (ROI) for flood risk reduction on shorelines across more than 20 Caribbean countries. These results are robust to changes in discount rates and the timing of restoration benefits. Data on restoration costs are sparse, but the Present Value (PV) of restored natural infrastructure shows that ROI would be positive in many locations even if restoration costs are in the hundreds of thousand per hectare for mangroves and millions per km for reefs. Based on these benefits, we identify significant sources of funding for restoring these natural defenses.

1. Introduction

Too many marine ecosystems have been deeply degraded for protection alone to succeed (Duarte et al., 2020). Coastal reefs and wetlands are some of the most impacted marine ecosystems. The resolution establishing the United Nations Decade on Ecosystem Restoration (2021–2030) explicitly identifies the critical declines and restoration needs of coral reefs and coastal wetlands (United Nations 2019). Little work however addresses how to pay for and where to focus those restoration efforts cost effectively.

Ecosystems provide benefits that society should pay for, but these services are rarely valued rigorously, spatially, and most importantly in the economic terms needed by investors and government agencies (CCRIF, 2010; Reguero et al., 2018). The limited data on benefits to costs has been identified as a major impediment in the advancement of ecosystem-based adaptation (IPCC, 2019).

Funding for the environment is often low, and ecosystem restoration is perceived to be costly (McCreless and Beck 2016). The biodiversity spending needed could be $100 billion annually, but the international community only spends $4 to 10 billion each year on conservation and management (Barbier et al., 2018). National and multi-national budgets are increasingly stretched in recovery from natural hazards and will be strained further by climate change.

Coastal ecosystems such as reefs and mangroves act as natural barriers to waves and storm surges and reduce flood damages to people and property. These benefits are critical across the Caribbean, where there have been substantial increases in storm risk and extensive habitat loss. To identify where reef and mangrove restoration could yield significant returns on investment (ROI), we build on recent work that rigorously values the annual flood risk reduction benefits of coastal habitats (Beck et al., 2018, Menéndez et al., 2020).

2. Methods

To assess return on investment, we start by estimating flood protection benefits. The methods for assessing the flood protection benefits of reefs and mangroves have been fully described in earlier publications (Beck et al., 2018, Menéndez et al., 2020) and are summarized here. We follow the expected damages approach (Barbier 2015, World Bank 2016), which is also commonly used by the risk industry (e.g., in the insurance and engineering sectors). We use a set of probabilistic hydrodynamic and economic models to map flooding on reef and mangrove coastlines, with and without habitats, for four storm return periods (1-in-10, −25, −50, −100-yr events). We assess flooding in cross-shore transects every 2 km or less globally, and we produce flooding maps (flood depth and extent) at 30-m resolution. We use socio-economic exposure data from the World Bank (UNISDR 2015) and apply flood depth-damage curves. Results are summarized in 20-km coastal

https://doi.org/10.1016/j.ecoser.2022.101440
Received 17 September 2021; Received in revised form 19 April 2022; Accepted 17 May 2022
Available online 28 May 2022

Table 1
Costs of Mangrove Restoration in the Caribbean and other regions. For mangroves, costs are per hectare. For coastal structures costs are per linear km. Number of studies, N indicated in brackets. All numbers are median costs. All costs are in 2019 US$ and rounded off to the nearest 1,000.

Type	Sub-type	Florida	All Other Caribbean	All Other Regions
Mangroves	Planting Seedlings and Saplings	45,000 (47)	23,000 (6)	2,000 (57)
	Hydrological Restoration	141,000 (22)	–	4,000 (8)
Structures	Seawalls	19,935,000 (1)	19,818,000 (3)	5,712,000 (1)
	Levees		24,757,000 (2)	3,136,000 (1)
	Breakwaters		–	20,658,000 (17)

study units. These methods have been applied in previous projects to assess the value of coral reefs for coastal protection globally (Beck et al., 2018) and to assess the value of mangroves for coastal protection in the Philippines, Jamaica and globally (Menéndez et al., 2018, Beck et al., 2019, Menéndez et al., 2020, World Bank 2021). These models have been extensively validated (Beck et al., 2018, Menéndez et al., 2018, Menéndez et al., 2019, Menéndez et al., 2020).

For mangroves, we assume that the flood protection benefit of restoring 1 ha of mangrove forest in a 20-km study unit is equivalent to the average decline in benefit from the loss of 1 ha of mangroves in that unit. For coral reefs, we assume the benefit in restoring 1 m in reef height is equivalent to the average decline in benefit from the loss of 1 m in reef height in that study unit. These assumptions rely on the full restoration of the habitat characteristics that provide flood protection benefits such as reef height and mangrove density. This full restoration may not be immediate, which can reduce the overall benefits (i.e., present value); an issue we address in sensitivity analyses. On the other hand, restoration projects for flood protection would likely be sited to maximize (or at least do better) than the average flood protection in a given study unit, which means our assumptions could underestimate potential restoration benefits.

We multiply annual expected flood reduction benefits in each study unit out over a 30-year project lifespan at a 4 % discount rate. A 30-year lifespan is conservative for infrastructure projects. For example, the US Federal Emergency Management Agency (FEMA) standard values for the useful life of flood infrastructure projects are 50 years (FEMA 2009).

The data on flood reduction benefits are combined with costs of restoration to develop spatially explicit benefit to cost (B:C) ratios. To identify mangrove restoration costs, we used cost data from recent reviews (Bayraktarov et al., 2016, Narayan et al., 2016). We also conducted a literature review for data published between 2016–2019 on Google and Google Scholar search engines. For the 2016–19 literature review we used the keywords “Mangrove” and “Restoration” and “Costs.” Like the reviews conducted by Bayraktarov et al., 2016 and Narayan et al., 2016 we only included studies that published quantitative information on restoration costs. We also further supplemented these data with direct surveys of restoration practitioners and projects in the Caribbean (Narayan et al., 2019). A significant shortcoming is that there is little data on opportunity or maintenance costs for habitat restoration projects. Almost all of the cost data on mangrove and reef projects was the initial (direct investment) costs associated with habitat restoration.

The median costs of mangrove restoration were much higher in Florida ($45,000 ha-1) than in the rest of the Caribbean ($23,000 ha-1) so we used these two region-specific costs in our analyses (Table 1). For reef restoration projects, we used the median structural (i.e., hybrid) reef restoration cost of $1,290 per linear meter identified in a prior review, which identified costs from 10 projects (Ferrario et al., 2014). We identify projects as “cost effective” if B:C > 1.

A Benefit to Cost Ratio provides the simplest indication of return on investment, but we also map Present Value (PV), i.e., benefits from a 30-year restoration project, because cost data on mangrove and reef restoration projects are limited and spatially variable. The PV/ha for mangroves and PV/km for reefs indicates the break-even cost for restoration (i.e., B:C = 1) over the life of a project.

We did sensitivity analyses to assess how discount rates and time to full project benefits could affect Return on Investment (ROI). The appropriate discount rate is a matter of policy and debate and varies within and between institutions. For example, The World Bank uses multiple discount rates including 4 % (World Bank 2021), 6 % (Hallegatte et al., 2021) and 10 % in some project comparisons. FEMA (2009) uses a 7 % discount rate. We considered how these four discount rates affect the number of study units with B:C > 1 for both reefs and mangroves.

We also considered the sensitivity of the B:C results to variation in the timing of flood reduction benefits. In our main calculation, we assume that restoration projects are designed to deliver immediate project benefits as suggested by some flood mitigation funders (e.g., FEMA). These immediate outcomes can be achieved by using hybrid reefs with artificial structures and coral plantings or by using nursery grown mangrove saplings and trees. However, some restoration projects could focus more on the growth of mangrove seedlings and coral fragments over time. We have assessed how return on investment changes if benefits are immediate or begin to accrue only in year 5 or increase linearly from year 1 to full benefits by year 5 with the growth of trees and corals. Maza et al. (2021) show that almost all flood protection benefits can be achieved by year 5 in mangrove restoration projects.

3. Results

Across the Caribbean, there are many coastlines where the benefits of coral reef and mangrove restoration for coastal adaptation outweigh project costs. For mangroves, we find 181 coastal units (i.e., > 3,000 km of coastline) across 20 territories and countries with cost effective opportunities (i.e., B:C > 1) for mangrove restoration (Fig. 1a). Cuba (36), Bahamas (23) and the USA (23) have the most study units with cost effective opportunities for mangrove restoration.

For coral reefs, we identified cost effective opportunities for restoration in 55 coastal study units representing > 1,000 km of shoreline across 13 countries and territories (Fig. 1b). Cuba and Jamaica have the most opportunities for cost effective reef restoration (>10 study units each).

The Present Value (PV) of reefs and mangroves shows that many locations have long term flood protection benefits from mangroves that are in the hundreds of thousands of dollars per hectare (Fig. 2a) and from reefs that are in the tens to hundreds of millions per kilometer (Fig. 2b). These values indicate the potential break-even costs for restoration; ROI will be positive in many locations even if restoration costs are high. For example, mangrove restoration projects near Port au Prince, Haiti that cost less than $168,000 per hectare (considering all potential lifetime costs) would still have a positive return on investment (Fig. 2a).

Overall the results were robust to changes in discount rates and the timing of restoration benefits for mangroves and coral reefs (Figs. A1, A2). Even the most conservative scenario (10 % discount rate and benefits beginning in year 5) only reduced the number of study units with B:C > 1 by approximately 33 % for both reefs and mangroves; there were still many study units with positive returns on investment. Spatially, those study units with B:C > 10 (Fig. 1) remained cost effective whereas many in the two lower categories increasingly did not yield positive ROI under more conservative considerations.

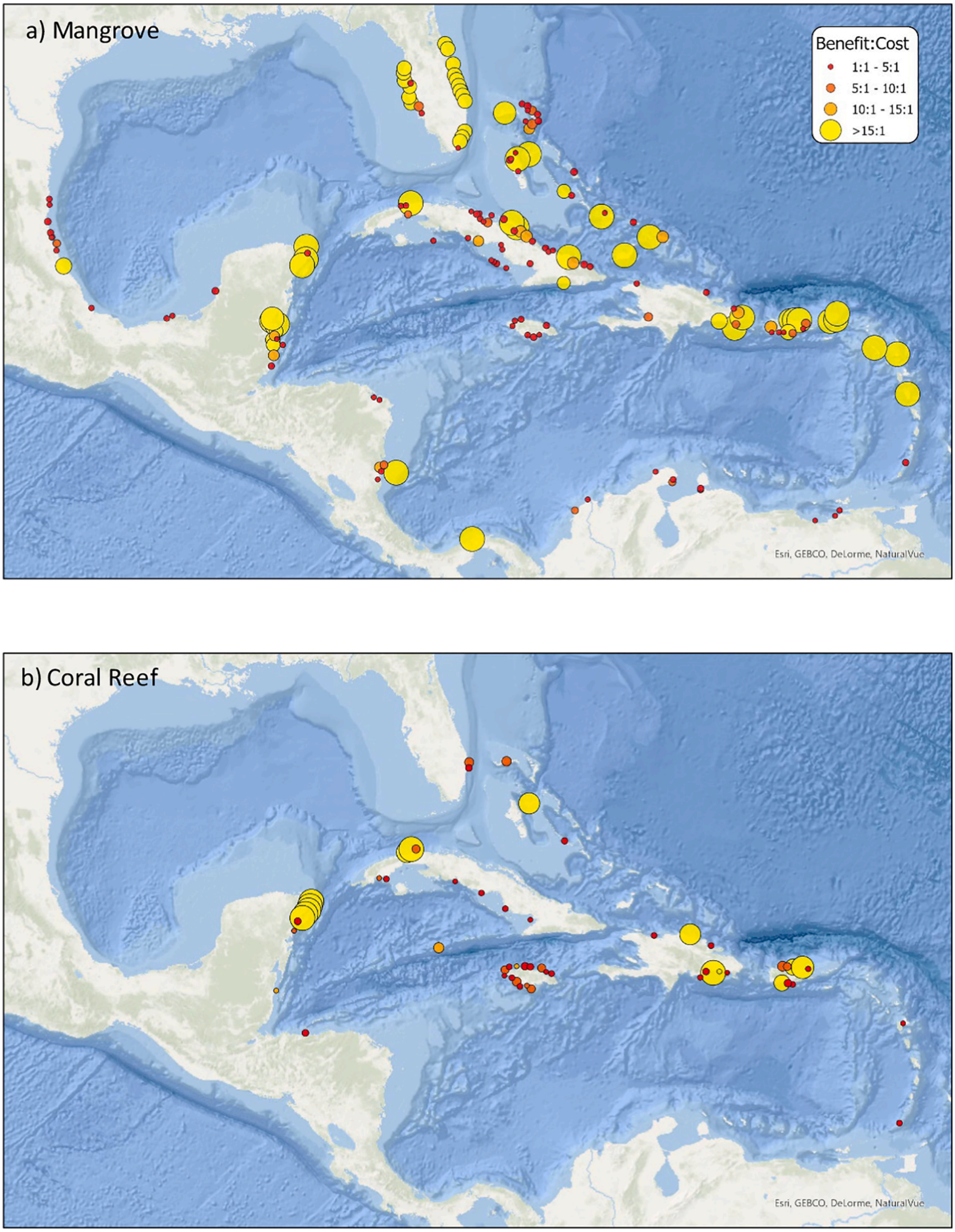

Fig. 1. Benefit to Cost Ratios (B:C) for a) Mangrove and b) Coral Reef restoration across the Caribbean estimated using a 30-year project life with a 4% discount rate. Results are summarized in 20-km coastal study units. Circle sizes and colors indicate B:C ratios.

4. Discussion

The knowledge increasingly exists on how to rebuild marine ecosystems (Duarte et al., 2020), but how to pay for it has been missing. The global budgets for conservation are in the billions of dollars (Barbier et al., 2018) and often decreasing (McCreless and Beck 2016). The budgets and spending for disaster recovery are in the hundreds of billions of dollars, annually and increasing (Reguero et al., 2020).

We have identified where there could be significant returns on investment for coral reef and mangrove restoration across the Caribbean. There are many opportunities for investments in mangroves given their wide distribution and relatively cheap costs of restoration as compared to grey infrastructure (Table 1). Reefs can be very effective at reducing flooding but the structural restoration of reefs in shallow, high energy environments is still a relatively new practice and comparatively expensive. Strategies for effective risk reduction will often combine efforts where reef restoration provides wave energy reduction that allows mangrove restoration to get established on eroding shorelines and offer

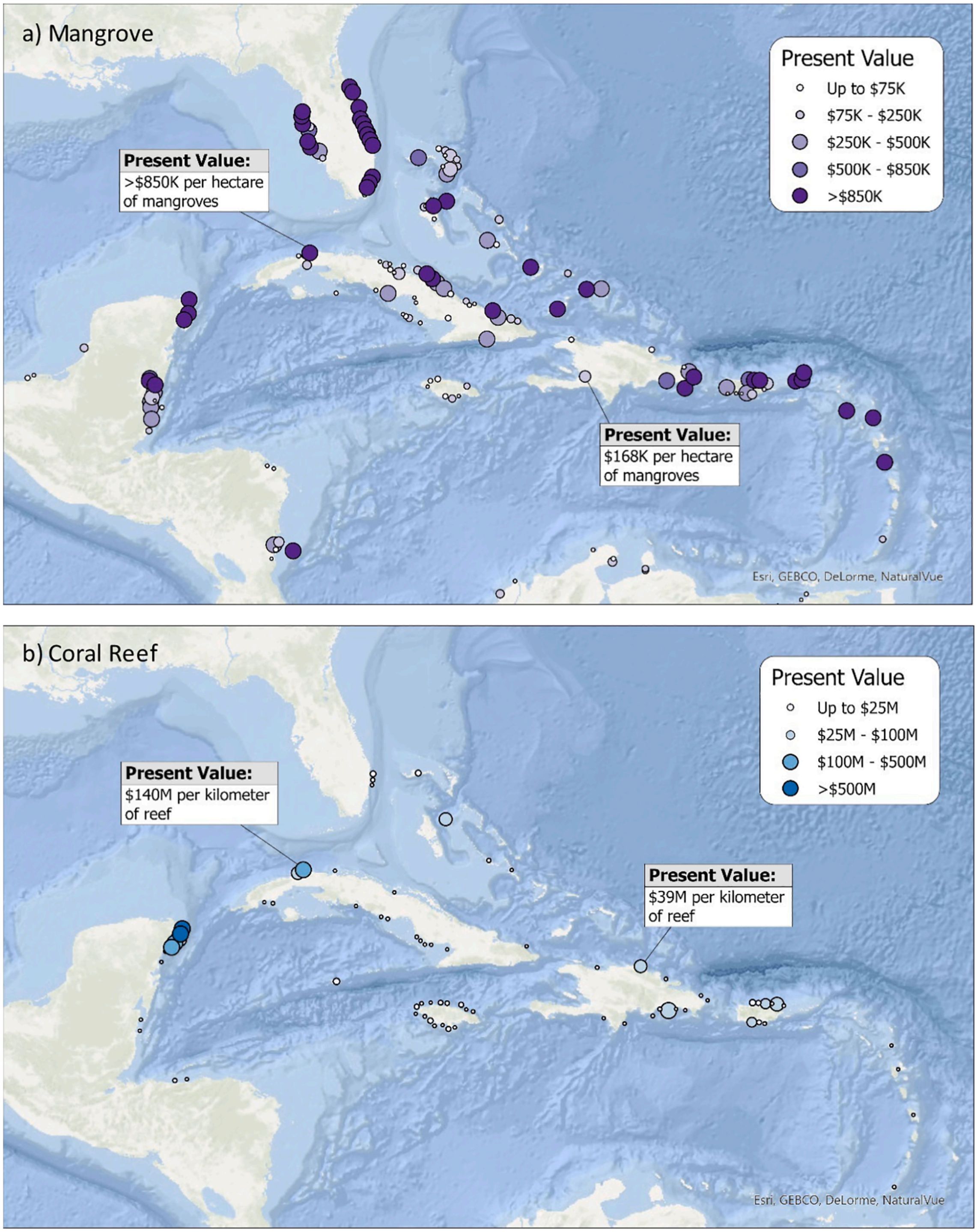

Fig. 2. Present value of flood reduction benefits from restoration for a) Mangroves (US$ per ha) and b) Coral Reefs (US$ per km) estimated using a 30-year project life with a 4% discount rate. These values represent the break-even point for restoration.

storm surge reduction.

There are important limitations to these ROI estimates, but overall they should be conservative for the following reasons. First, we do not consider indirect benefits from averted flooding such as avoided business interruption, which is estimated from claims to be 139 % larger than direct damages to property (Allianz 2019). We also do not add values from additional ecosystem services, such as carbon sequestration, tourism, and fish production. We do not factor in sea level rise or increasing storminess, which would increase the flood reduction benefits. We assume that restoration costs are fixed, but they will likely decrease with economies of scale (e.g., mangrove restoration is much cheaper in SE Asia in part for these reasons, Table 1). The Present Value analyses allow project proponents to consider all the potential break-even restoration costs, which could include values that are rarely reported such as costs of overcoming restoration failures or opportunity costs (e.g., land acquisition for mangroves). We also assume that risk reduction benefits will remain static over time in the future, but we have shown that these benefits increase greatly over time for mangroves (World Bank 2021).

These results open new opportunities to support restoration with

Table 2
Funding Options for Natural Infrastructure. This table identifies some sources of funding for flood risk reduction and adaptation that could be applied to habitat restoration. The annual funding is based on the most recent budget year. Values are in billions/year.

Fund	Annual Funding	Citation
Public Pays: Public Benefits		
EU Climate Change Adaptation & Risk Prevention	$7.05 billion	(European Commission 2020)
US Army Corps of Engineers Flood Risk Management Program	$1.01 billion	(US Army Corps of Engineers 2019)
FEMA Pre-Disaster Mitigation Grants	$0.6 billion	(FEMA 2020b)
FEMA Post-Disaster Recovery	$25 billion	(FEMA 2020b)
US State Infrastructure Banks	$9 billion in loans	(Congressional Budget Office 2018)
US State Tax Exempt Infrastructure Bonds	$43 billion	(Congressional Budget Office 2018)
Green Climate Fund	$1 billion	(Yeo 2019)
EU Natural Capital Financing Facility	$ 0.025 billion	(European Commission 2019)
Mexico Fund for Disaster Prevention (FOPREDEN)	$0.020 billion	(Prevention Web 2019)
Mexico's Natural Disaster Recovery Fund (FONDEN)	$1.1 billion	(Buhler 2019)
World Bank Disaster Risk Management Budget	$4.6 billion	(World Bank 2020)
Private Pays: Public Benefits		
Green Bonds	$167 billion	(Climate Bonds Initiative 2019)
Private Pays: Private Benefits		
FEMA National Flood Insurance Program (NFIP)- Community Rating System (CRS)[2]	FL Only – 240 + communities participate in CRS	(FEMA 2020a)
Special Purpose Tax Districts (Florida only, >1,500)	$17.5 billion	(DeVoe L. Moore Center 2020)
Special Purpose Tax Districts: Flood Control (Florida only)	$0.72 billion	(DeVoe L. Moore Center 2020)
Total	>$259 billion	

[2] FEMA CRS offers insurance premium reductions for open space preservation.

funds from hazard mitigation, climate adaptation, and disaster recovery. We have identified some of the risk reduction funding sources that have traditionally supported grey infrastructure and that could be applied to nature-based solutions (Table 2). Many of these individual annual funding lines are very large relative to the total global funding for biodiversity conservation (Barbier et al., 2018). For example, US FEMA pre-disaster mitigation grant funding was $660 million in 2020 (Table 1) and post-disaster funding by FEMA and others is in the range of tens to hundreds of billions of dollars annually (Reguero et al., 2020, Airoldi et al., 2021). Very little of these funds have been used in the past to support the restoration of habitats for risk reduction and adaptation largely because data on benefits and costs were missing (Airoldi et al., 2021).

A source of revenue rarely used by conservation is Special Purpose Tax Districts. Florida alone has more than 1,500 special purpose districts. In 2018, more than $720 million was spent by Florida Districts on flood and storm water management (Table 1). In 2016, residents in nine San Francisco Bay area counties overwhelmingly approved a parcel tax to finance wetland restoration in part for coastal protection benefits.[1]

Some of the biggest funders of risk reduction including emergency management agencies, development banks, and re-insurers are considering how to invest in coastal habitat restoration to reduce future risk and build resilience (National Academies of Sciences, 2019, Reguero et al., 2020, Airoldi et al., 2021). In the US, FEMA has recently reduced benefit to cost ratio requirements to make it easier to support nature-based projects with flood mitigation and disaster recovery funds. In 2021, they identified $1.16 billion in new funding opportunities including for Building Resilient Infrastructure and Communities, which have stated priorities for nature-based solutions (FEMA, 2021). The US Department of Defense (DoD) also recently announced a new program, Reefense, that "seeks to develop self-healing, hybrid biological and engineered reef-mimicking structures to mitigate the coastal flooding, erosion and storm damage that increasingly threaten civilian and DoD infrastructure and personnel" (DARPA, 2021). Re-insurers have sold policies to protect reefs and are developing approaches that could be used to invest in restoration up front to build resilience and reduce future payouts (Kousky and Light 2019, Reguero et al., 2020).

There are opportunities to align conservation, flood risk reduction and climate adaptation to reduce storm risks. There are many places across the Caribbean where habitat restoration for risk reduction could be cost-effective, and these values open significant opportunities to pay for their needed restoration.

[1] [1] https://www.myparceltax.com/sfbay/.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported in part by the Kingfisher Foundation, the World Bank, AXA XL, AXA Research Fund, The Nature Conservancy, and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) on the basis of a decision adopted by the German Bundestag. We thank Chris Lowrie for help with the figures.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2022.101440.

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