Resilient Islands

Two men stand atop an artificial reef in Grenada. The structures protect coastlines from strong wave action and reduce the impacts from climate change, such as severe erosion. © Tim Calver

Coastal Protection

A Cost Comparison Between Natural and Artificial Structures

There is increasing interest in the Caribbean in protecting and restoring coral reef and mangrove ecosystems as alternatives to building artificial structures to provide adaptation and risk reduction benefits to people. To decide on where and how to invest in cost-effective restoration projects, it is critical to understand the costs of ecosystem restoration, the costs of potential alternatives such as gray infrastructure for coastal protection, and the factors that may determine spatial variation in these costs. While there is a significant body of knowledge on the techniques for mangrove restoration and growing knowledge on reef restoration, data and knowledge on the costs of restoration projects and the factors that influence these costs are limited. This policy brief reviews and synthesizes data on the costs of coral reef and mangrove restoration in the Caribbean region with emphasis on Jamaica, Grenada and the Dominican Republic. It focuses on the costs of ecosystem restoration with respect to coastal protection benefits and provides comparisons to the costs of building artificial coastal defenses. This policy brief aims to review costs and the factors that create variation in costs to inform policies, practices and incentives for scaling up restoration actions.

Overview

TOP TO BOTTOM Staghorn coral restoration in the Dominican Republic. © Paul A Selvaggio; Mangrove seedlings growing in mudflat at Woburn Bay Marine Protected Area, Grenada. © Marjo Aho

BACKGROUND

This brief is part of a collaboration between The Nature Conservancy and the University of California Santa Cruz (Siddharth Narayan, Stephan Bitterwolf, Michael W. Beck). This project is part of the International Climate Initiative (IKI) and is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

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KEY POINTS

- The Caribbean islands are high-risk regions when it comes to coastal flooding from storms and hurricanes. In this region, **coral reefs and mangroves** together protect millions of people and over a billion dollars of property every year from coastal flood damages[1,2].
- **Coral reef and mangrove restoration projects in the Caribbean** are ten to one hundred times cheaper than artificial coastal defenses.
- On average **mangrove restoration** in the Caribbean (excluding Florida) costs US$23,000 per hectare.
- **Coral reef restoration** costs around US$1 Million per linear kilometer across the Caribbean
- Artificial structures for coastal protection such as seawalls and levees cost nearly US$19 Million per linear kilometer
- Mangrove restoration projects show strong economies of scale: restoration becomes three times cheaper per hectare for projects larger than 10 hectares.
- Regarding coral reefs, projects that involve structural reef restoration have considerably higher unit costs than projects that only involve biological restoration (e.g., planting of nursery raised corals).
- Structural reef restoration projects for coastal protection are relatively new and experimental. As these projects become more common and larger in scale, costs should decline.
- There is a general understanding of the various factors that can influence mangrove and reef restoration costs but limited information on the cost components of individual projects
- **The comparative cost-effectiveness of nature-based solutions for risk reduction and adaptation** make these projects attractive investments for pre-hazard mitigation; disaster recovery and adaptation funding.

Resilient Islands

Supported by:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

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IFRC

The Nature Conservancy

COST-EFFECTIVE RESTORATION OF MANGROVES AND CORAL REEFS

Restoration efforts in ecosystems such as coral reefs and mangroves are increasingly focusing on the returns on investment in terms of the critical benefits and values these ecosystems provide to people[3–6]. Coral reef and mangrove ecosystems provide significant economic value to nations and coastal communities in the Caribbean and globally, in terms of coastal protection, carbon sequestration, tourism and fisheries benefits[1,7–9]. Today, regional institutions, national government agencies such as the Caribbean Biodiversity Fund (CBF) and the Federal Emergency Management Agency (FEMA) in the U.S.A., and also international institutions like the World Bank, the United Nations and the International Federation of the Red Cross and Red Crescent Societies explicitly recognize the economic payoffs of funding restoration for disaster recovery, climate adaptation and conservation[10]. When the economic benefits from coastal protection, or other benefits like tourism enhancement or fish production outweigh the costs of restoring a coral reef or mangrove, the restoration project is said to have a benefit-to-cost ratio greater than one. Understanding where habitat restoration can have a benefit-to-cost ratio of 1 or greater, from coastal protection and other co-benefits, can be critical for the availability of funding from disaster recovery programs[11].

Despite their significant economic benefits, coral reef and mangrove ecosystems continue to disappear. Around 75% of the Caribbean's coral reefs are at risk due to a combination of human and natural disturbances. More than 80% of the region's coral reefs and nearly one quarter of mangrove forests in the region were lost between 1980 and 2005[12]. Even so, these coral reefs and mangrove forests provide over a billion dollars of flood damage reduction benefits and protect millions of people every year[1,2]. The loss and degradation of these ecosystems has a direct impact on coastal populations in the Caribbean due to a loss in coastal protection and other vital ecosystem service benefits[13].

In the Caribbean, targeted and effective restoration practices can help reverse the adverse impacts of habitat loss and provide substantial economic benefits. To assess cost-effectiveness, we

Mangrove in the shallow coastal salt flats of Warderick Wells Cay in The Bahamas Exuma Cays Land & Sea Park. Mangroves stabilize the shoreline, provide buffers from storm surges and provide feeding, breeding, and nursery grounds for a variety of fish. © Mark Godfrey

Figure 1 Structural reef restoration in Grenada to help reduce coastal erosion.

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need an understanding of the costs of restoration efforts in comparison to their economic benefits[4,14]. While there is considerable information on the economic benefits of habitat restoration including coastal protection, there is limited information on restoration costs or the components that influence project costs, which hinders decision-making on where to prioritize restoration efforts.

Globally, hundreds of thousands of hectares of mangroves have been restored over the last few decades, sometimes at large scales, such as in Vietnam, The Philippines and Guyana[15]. Many of these projects are focused on restoration for the delivery of specific ecosystem service benefits such as carbon sequestration or coastal protection[16,17]. Typically, mangrove restoration projects involve planting mangrove saplings in areas with degraded or lost mangroves and hydrological restoration to establish the right conditions for mangrove establishment, either naturally or through planting[18,19]. In both cases, successful mangrove restoration – i.e. the successful establishment and growth of mangrove forests – can provide significant coastal protection benefits to nearby populations[7].

In coral reefs, restoration efforts are increasing world-wide, though very few of these projects are directed at achieving coastal protection benefits. Most reef restoration projects in the past have been directed at nursery work to revive coral populations though recent years have seen an increase in structural reef restoration projects including those for mitigation after ship groundings, Reef Balls, and MARRS (Mars Assisted Reef Restoration System)[20,21] (Figure 1). Restoring damaged reefs through planting of fragments in nurseries can deliver significant ecosystem service benefits for coastal resilience by reviving healthy coral habitats, enhancing fisheries and improving tourism opportunities (see companion policy brief). Studies have also shown that restoring – or conserving – the top meter in height of living reef is critical for delivering coastal protection and flood risk reduction benefits[1,22]. To achieve these benefits, reef restoration projects on degraded reefs will most likely include some structural restoration, which is already common in very large oyster reef restoration projects[23].

The costs of restoration depend on numerous factors, including the habitat being restored, the location and scale of the restoration project and the techniques used[14,17,24].

In general, the costs of a restoration project will include:

i) costs of land or ocean space, including the costs of permitting

ii) costs of obtaining and transporting the necessary material

iii) costs of designing and constructing the restoration project and associated labor costs

iv) maintenance, monitoring and management costs[19,21,25]

In this context, restoration refers to an anthropogenic intervention to re-establish an ecosystem to an improved condition, following its degradation due to natural or human stressors[26–28]. Depending on the specific goals and conditions, restoration efforts can range from passive restoration, such as the cessation of harmful practices like stopping direct flows of pollution to mangroves, to active restoration, such as modifying landscapes and hydrological processes to restore fully degraded mangrove or reef habitats[29-30]. These variations in project methods and techniques also influence the costs of restoration and ultimately the economic payoffs from the restoration effort. While coastal restoration projects are on-going, their costs and the factors influencing these costs are not well understood or documented for the Caribbean.

This policy brief reviews the costs of restoration efforts in coral reef and mangrove ecosystems and the factors that influence these costs. Additionally, we compare costs of habitat restoration to those for building coastal protection structures such as seawalls. The information provided in this policy brief will inform and support decisions on when and where to fund and implement cost-effective mangrove and reef restoration projects in the Caribbean.

Remnants of old pier and mangroves at are seen in the erosion, Grenville Bay, Grenada. © Marjo Aho

Methods

Estimating Coral Reef and Mangrove Restoration Costs in the Caribbean

This review was done through a combination of literature reviews and a series of practitioner interviews. For coral reefs, the review and interviews were specific to the Caribbean with a focus on the islands of Jamaica, the Dominican Republic, and Grenada. For mangroves, due to the relative lack of information on restoration projects in the Caribbean, the review and synthesis were extended to include data from projects world-wide. For artificial coastal structures, cost data were collected for traditional coastal protection structures such as seawalls and levees. Cost data for coral reef restoration projects and coastal structures are reported on a per linear kilometer basis and mangrove restoration costs are reported on a per hectare basis.

Figure 2 Coral outplant monitoring in St. Croix, Virgin Islands

© John Melendez

In addition to the literature review we also collected data on costs from restoration practitioners. Coral reef and mangrove restoration practitioners in the Caribbean, including Florida, were emailed and interviewed about restoration costs, to supplement the data collected from the literature review. For coral reefs, restoration practitioners were identified via a Google search using the terms (coral restoration OR coral rehabilitation) AND (Caribbean OR Jamaica OR Dominican Republic OR Grenada). From these, a database of coral restoration practitioners was developed. Each organization was then contacted and asked to create an estimated cost associated with maintaining coral nursery structures, paying personnel, transplanting coral fragments, and monitoring transplanted coral sites. This information was used to determine a total cost per transplanted fragment.

To estimate the costs of a coral restoration project we converted the cost per fragment to a cost per linear kilometre of coral reef assuming a 10 m wide reef restoration project and a transplantation density of 5.4 fragments per square meter[14] (Figure 2). In addition, we were able to examine and break down the cost categories for a couple of different kinds of structural reef restoration projects.

For mangroves, restoration practitioners were identified across Florida's Gulf and Atlantic coastlines, and Jamaica with particular focus on practitioners from The Nature Conservancy and the World Bank. Each practitioner was contacted for information on the typical costs of a mangrove restoration project and any site-specific factors that would influence these costs. All cost data were combined with information on project area to obtain a cost per hectare. For 3 of the 10 data points, cost information was provided directly in terms of a cost per hectare with no information on project area. For gray protections structures, all cost data from the literature review were combined with information on the linear length of the structures to obtain a cost per meter.

Figure 3 Case studies of coral reef and mangrove restoration and gray infrastructure for coastal protection in the Caribbean

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CORAL CASE STUDY JAMAICA

Since 2008 Seascape Caribbean has been using drop-line nurseries to grow coral colonies for private coral restoration projects in Jamaica. Corals reared in nurseries begin at 1-2 cm in length and grow to 18 cm in 10 months. Survival of corals raised using this method are over 95%. Each drop-line nursery is capable of raising 200 coral at low cost (~$142 material, ~34 hours labor, and $350 permitting). These expenses equate to a cost of USD 5.96 per fragment and USD 321,840 per hectare restored.

© Marcos Lopez/TNC

MANGROVE CASE STUDY GUYANA

Between 2011 and 2013 Guyana's Mangrove Restoration Project planted ~420,000 mangrove seedlings along its coastlines to reduce erosion and buffer coasts from storm damage. Over two years, 58.7% of transplanted mangroves survived. At some sites, survival was 100% while at others, King tide events resulted in 0% survival. In total, 35 hectares were part of the restoration project at the cost of USD 20,000 per hectare.

© Tim Calver

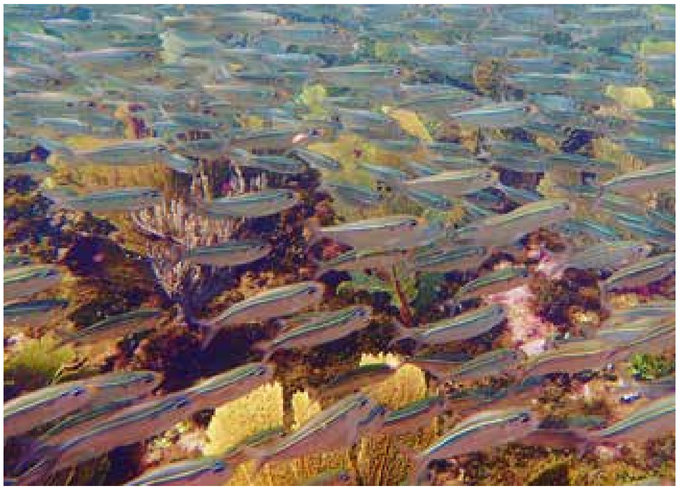
GRAY INFRASTRUCTURE JAMAICA

Jamaica's Kingston harbor is at risk to storms and predicted sea level rise of 2m in the Caribbean. As part of this study, Seawalls and Dykes were designed and priced to protect the harbor. The costs of a Seawall and Dyke Hybrid structure was estimated at 60.7 and 294.75 million USD respectively. This cost equates to a per km cost of 5.2 and 91.6 million USD for seawalls and dykes respectively.

Sandy Island Oyster Bay Marine Protected Area coral reef underwater. © Marjo Aho

Results

Coral Reef and Mangrove Restoration Costs in the Caribbean



Cloud of Silversides, Maria Island Nature Reserve St Lucia © Jessica Wiseman/TNC

Across the Caribbean, the median unit costs of coral reef and mangrove restoration are orders of magnitude cheaper than the unit costs of building gray (i.e., artificial) coastal protection structures (Table 1). Coral reef restoration in the Caribbean costs between $640,000 and just over $2 Million per linear kilometer, whereas coastal protection structures cost nearly $20 Million per kilometer. Mangrove restoration is by far the cheapest with costs ranging from $14,000 to $32,000 per hectare.

The median cost of coastal protection structures across all regions in this study was $17 million per linear kilometer. In the Caribbean, Structures such as sea dykes, seawalls, levees and breakwaters cost just over $10 million per kilometer (Figure 3). In general, sea dykes were the costliest structures per kilometer followed by seawalls, levees and breakwaters. In Kingston, Jamaica, 7.5 miles of a vertical seawall cost $15 million per kilometer - less than a third of the cost of an equivalent length of sea dyke farther offshore. In Grenada, an offshore breakwater about 0.5 km in length is being constructed at a total cost of $90,000, or $180,000 per linear kilometer.

Reef restoration in Jamaica is below the Caribbean average, at $640,000 per kilometer whereas current projects in Grenada and Dominican Republic had higher costs. The U.S.A – specifically Florida, is the costliest geography for coral reef restoration, nearly $2.5 million per kilometer. By comparison, the reef restoration projects identified in South-east Asia and the Pacific are cheaper, costing $61,000 per kilometer. Projects focused on biological restoration (sourcing, creating and out-planting coral fragments) are on average several times cheaper than those focused on structural reef restoration projects, such as the repair of reefs damaged by boats. For example, Reef Ball installations can cost between $17 and $23 million per kilometer. These costs vary depending on the site conditions and the design requirements of the offshore structure (see Discussion; Figure 4). In comparison, a rebar structure for reef restoration installed in Grenada had a cost of approximately $3 million per kilometer.

Mangrove restoration costs are an order of magnitude cheaper than reef restoration. In Grenada unit restoration costs are below the Caribbean average with somewhat higher costs in Jamaica. No data on mangrove restoration costs were available for the Dominican Republic. Unit mangrove restoration costs drop sharply with area size. Restoration projects larger than 10 hectares are, on average, more than 10 times cheaper per hectare than projects smaller than that area size. Mangrove restoration techniques also influence unit costs. For example, in Florida, the unit costs of projects mainly involving mangrove planting were about one-third the costs of projects that required hydrological modification (i.e. engineering to restore hydrological connectivity and flows).

The median cost of coastal protection structures across all regions in this study was $17 million per linear kilometer. In the Caribbean, Structures such as sea dykes, seawalls, levees and breakwaters cost just over $10 million per kilometer (Figure 3). In general, sea dykes were the costliest structures per kilometer followed by seawalls, levees and breakwaters. In Kingston, Jamaica, 7.5 miles of a vertical seawall cost $15 million per kilometer - less than a third of the cost of an equivalent length of sea dyke farther offshore. In Grenada, an offshore breakwater about 0.5 km in length is being constructed at a total cost of $90,000, or $180,000 per linear kilometer.

Table 1 Costs of Reef Restoration, Mangrove Restoration and Coastal Structures in the Caribbean and other regions. For mangroves costs are per hectare. For structural reef restoration and coastal structures costs are per linear km assuming a 10 m wide structure. Number of studies, N indicated in brackets. All numbers are median costs, unless N=1. All costs are in 2019 US$ and rounded off to the nearest 1,000.

Type	Sub-type	Jamaica ($)	Dominican Republic ($)	Grenada ($)	Florida ($)	All Other Caribbean ($)	All Other Regions ($)
Coral reefs	Planting Fragments	640,000 (4 studies)	2,025,000 (1 study)	No studies	2,469,000 (7 studies)	1,286,000 (3 studies)	61,000 (14 studies)
	Structural Restoration	No studies	No studies	3,136,000 (1 study)	11,300 (9 studies)	2,964,000 (4 studies)	60,000,000 (15 studies)
Mangroves	Planting Saplings	32,000 (2 studies)	No studies	14,000 (1 study)	45,000 (47 studies)	23,000 (3 studies)	2,000 (57 studies)
	Hydrological Restoration	No studies	No studies	No studies	141,000 (22 studies)	No studies	4,000 (8 studies)
Structures	Seawalls	No studies	No studies	3,671,000	19,935,000 (1)	19,818,000 (3)1	5,712,000 (1)
	Levees	No studies	No studies	No studies	No studies	24,757,000 (2)1	3,136,000 (1)
	Breakwaters	No studies	No studies	17,871,000 (1)	No studies	No studies	20,658,000 (17)
	Sea Dykes	11,675,000 (2)	No studies	No studies	No studies	No studies	No studies

[1]These include uniform per kilometer cost data for seawalls and levees across multiple Caribbean cities, including Jamaica, Grenada and the Dominican Republic (CARIBSAVE, 2014).

Discussion

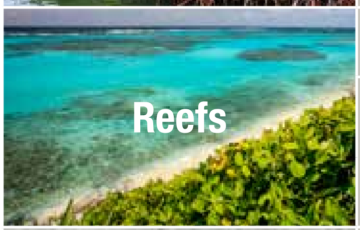
The components of the total life-cycle costs of reefs or mangrove restoration, or of coastal structures are four-fold: i) the costs of land and permitting; ii) the costs of obtaining and transporting the material; iii) the costs of designing and constructing the project, and; iv) the costs of monitoring and maintaining the project post-construction (Figure 4).

A significant amount of costs of coral reef restoration – whether structural or nursery-based, stem from the human component of the project. For the structural reef restoration project in Grenada, most of the project's costs (>70%) were for labor and supervision for the installation of the structure due to the specialist nature of the project. This 1.3 m high, 5 m wide and 300 m long structure was deployed at a depth of about 5 m offshore, and utilized rebar frames filled with rocks quarried locally. The project involved the use of specialist design and construction techniques and equipment for the structural components and specialist techniques for the attachment of coral fragments to the structure.

For Reef Ball projects, construction, offshore deployment and anchoring alone can account for nearly 50% of the total cost of the project. Even with nursery-based restoration, where it is expected that corals will grow in their natural environment once planted, the maintenance of structures, transplanting fragments, and travel to the restoration site significantly contribute to project costs. In some cases, labor costs can contribute to up to 50% of the total costs of a reef restoration project[30]. Project costs can be greatly reduced if a project is able to train volunteers or has access to cheaper labor[32,33]. A recent study which monitored coral for over 10 years in a Marine Protected Area (MPA) indicated that the costs of paid labor, boats and scuba gear, could increase the costs of re-attaching corals from $1 to around $20 per coral[34].

Mangrove restoration costs are influenced by factors unique to coastal and inter-tidal ecosystem restoration projects. Since these typically happen in the inter-tidal zone, the availability and price of land are important factors. Large-scale projects on government owned land typically have much lower unit costs than smaller projects on private lands[19]. Another critical issue is ease of permitting for activity in offshore and inter-tidal locations, especially in countries like the U.S.A where the modification of coastal and marine waters is governed by strict regulations. While in some locations like Florida the clearing of existing mangrove forests cannot happen without a permit, similarly, new

Figure 4 Major Cost Components for a Habitat Restoration or Coastal Structure Project (adapted from the Reef Rehabilitation Manual[30], Lewis et al., 2001[19] and the US Army Corps of Engineers' Coastal Engineering Manual[31])

Cost Component	Land and Permitting	Sourcing and Transporting Material	Design and Creation	Maintenance and Monitoring
 Mangroves	Cost of land	Nursery costs for planting	Design costs	Labor
	Permits for intertidal modification	Sediment delivery costs	Site access	Monitoring equipment
			Labor for planting	Regular maintenance and upkeep
			Engineering costs for protecting saplings	
			Engineering costs for hydrological restoration	
 Reefs	Permits for offshore modification	Costs of sourcing fragments	Design costs	Labor
	Cost of ocean space	Reef nursery cost	Site access	Monitoring equipment
		Delivery of fragments to site	Labor for outplanting	Regular maintenance and upkeep
			Engineering costs for hydrological restoration	
 Structures	Cost of land	Cost of construction material, i.e. sand, rock, armoring, concrete, etc.	Design costs	Labor
	Permits for coastal structures		Site access	Monitoring equipment
			Labor and engineering equipment for construction	Regular maintenance and upkeep

TOP TO BOTTOM © Marjo Aho; © Marjo Aho; © Tim Calver

activity in coastal waters – including ecological restoration – also requires permits from multiple agencies. This process can often be time-consuming and costly[25]. Larger projects on government-owned land typically have easier, expedited permitting processes than projects on private land, substantially reducing these initial costs. For restoration projects that primarily involve mangrove planting, labor costs and the availability of volunteers to offset these costs can make a significant difference to the overall cost of the project. Often, restoration projects involve voluntary mangrove planting activities that are also combined with outreach and education initiatives. Projects involving hydrological restoration and sediment management can be substantially more expensive due to the need for specialized equipment, labor and, in some cases, the purchase and transportation of sediment from external sources. While most projects reviewed here do not report maintenance and monitoring costs and efforts, this is nevertheless an important and significant aspect of successful mangrove restoration. Examples of mangrove maintenance include clearing debris after hurricanes, removing invasive species and maintaining hydrological flows. The costs of these activities will depend on the scale of the project and the availability of volunteers.

The unit costs of reef and mangrove restoration projects can be expected to come down significantly as these projects increase in size. For mangrove habitats, this is evident in the significantly lower unit costs for larger scale restoration projects. The same is expected to be true for coral reefs. The costliest reef restoration per kilometer in the Caribbean in this dataset is in Grenada, where project costs were approximately $3,000 for a 100 m long structural reef restoration. Though this is reported as a per kilometer value, as projects scale up in size it is expected that their unit costs will drop significantly as seen for mangroves.

The factors influencing the costs of coastal protection structures are broadly similar to the factors for restoration projects. Typically, coastal structures like seawalls and levees take up less space than a mangrove restoration project, though the taller a structure, the more space it generally requires, and the costlier it becomes[35,36]. Artificial structures can also be costly to build in terms of material, labor and expertise; and costly to maintain in terms of repairing damage or upgrading in response to changes in sea-level. Offshore structures such as sea dykes or offshore breakwaters are typically costlier due to more difficult working environments. The costs of offshore structures will also be significantly influenced by the depth of water at the installation site[17].

The Way Forward

Implications for Restoration, Nature-based Solutions

These results have important implications for the consideration of nature-based solutions within adaptation, insurance, hazard mitigation and disaster recovery decisions. It is increasingly clear that mangroves and reefs offer significant benefits for flood risk reduction and there have been previous peer reviewed analyses identifying spatial variation in these benefits across the Caribbean. The results presented in this policy brief show that restoring mangroves and reefs can be cost effective for flood risk reduction, particularly when compared to the costs of gray infrastructure. Also, as restoration scales up, the unit costs are likely to come down significantly.

These results can be used by public agencies to inform hazard mitigation and disaster recovery funding decisions. Following hurricanes (for example from the 2017 season), significant aid and support flows into the Caribbean and much of this support goes to building or re-building gray infrastructure including dikes, levees and seawalls. The results presented here show that it can also make economic sense to support restoration of nature-based solutions with these funds. In Puerto Rico and the U.S. Virgin Islands, FEMA is actively working to identify where reef restoration may meet requirements for funding from the 2017 hurricane recovery funding. The key criterion for eligibility for FEMA disaster recovery funding is to show that the reef restoration project achieves, say over a 25-year period, a flood reduction benefit (represented as "B") that exceeds the cost (represented as "C") of habitat restoration (i.e. a B:C ratio > 1). The results presented here on restoration project costs provide the basis for assessing these ratios and this same approach could be applied widely throughout the Caribbean.

Indeed, many funders (from development banks to climate adaptation funds) would be compelled by assessments that show where nature-based solutions have B:C > 1. The results could be used to support national applications to the Green Climate Fund, World Bank, IDB and other supporters of infrastructure, risk reduction and adaptation projects in the region. Even where these costs of restoration may seem high, it is important to note that (i) the benefits of restoration can extend over long time periods, (ii) include indirect flood reduction benefits (i.e. to especially vulnerable populations) (iii) also include many co-benefits such as fisheries and tourism.

This work can also be used to inform the development of insurance approaches like those being tested on the MesoAmerican Reef in Mexico[37]. There, a policy has been taken out on the reef based on the flood protection benefits to coastal hotels and the Mexican economy. The value of the policy was determined in part by the costs of restoring benefits if the reef were damaged in a storm. Similar approaches in other areas can now be tested.

APPENDIX Additional Information on Methodology

The systematic literature review for the costs of coral reef restoration, mangrove restoration and coastal protection structures was done in Google Scholar, Web of Science, Scopus, and Google. Bayraktarov et al. (2016) published an extensive dataset of restoration costs for coral reefs, mangroves, and other coastal marine habitats up to 2014. Here, this dataset (here-after the Bayraktarov dataset) was extended to include studies beyond 2014. For coral reefs and mangroves, we expanded the Bayraktarov dataset to include projects in the Caribbean and specifically in Jamaica, Grenada and Dominican Republic and records of restoration costs beyond the year 2014. These records were then individually searched for the term "cost." Papers and reports containing the term cost were further examined and emailed to get details about the total cost. Cost data prior to 2014 was obtained from datasets compiled in the Bayraktarov dataset. For 'gray' coastal protection structures such as seawalls and levees, the search was conducted using the terms: (Cost) AND (Coastal OR Shoreline) AND (Protection OR Defense OR Seawall OR Levee OR Structure) AND (Caribbean OR Jamaica OR Dominican Republic OR Grenada). These were supplemented with previously published data on breakwater costs[17, 20].

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