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InsuResilience Global Partnership

The Value of Reefs for Protecting the Most Vulnerable Populations in the Dominican Republic, Jamaica and Grenada

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This publication is part of a series of knowledge contributions to the working group on "integrated resilience approaches" under the InsuResilience Global Partnership.

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Executive Summary

The aim of this study was to assess the flood protection benefits of reefs for protecting the most vulnerable people in the Dominican Republic (DR), Jamaica and Grenada. The study aims to support work on nature-based defenses and insurance by testing approaches for assessing connections between the benefits of nature-based defenses and socially vulnerable populations. We used hydrodynamic and socio-economic models to compare flood risk and reef benefits for scenarios with and without reefs for four storm return periods including the 1 in 50-year storm. The without reefs scenarios assume only a decrease of 1 m in the height and roughness of coral reefs.

We assessed reef benefits in terms of averted damage in two ways, property and affected people, by comparing two different methods for assessing vulnerability based on (i) Purchasing Power Parity (PPP) and (ii) nationally-derived vulnerability definitions. Reefs annually avert $96M (DR), $46M (Jamaica) and $4M (Grenada) in flood damages to property. Likewise, reefs avert flooding to 171,254 (DR), 38,868 (Jamaica) and 515 (Grenada) people with PPP < $15 for the 1 in 50-year storm event. In DR, we used nationally-derived census data and vulnerability definitions ("ICV") and estimated that reefs reduce flooding to more than 1.3 million vulnerable people for the 1 in 50-year event.

Our findings reveal large differences in estimates of vulnerable people protected by reefs in the DR as measured by the two different approaches – PPP (171,000 people) vs national vulnerability data (1,300,000 people). The DR national vulnerability data likely give the most accurate picture of reef protection benefits to vulnerable people, because national survey data take the uneven distribution of vulnerable people into account. While this approach is more robust and accurate, it is at the same time more time consuming and requires census data. Since census data and vulnerability definitions will vary by country, it will be difficult to achieve consistency in such assessments across nations. Indeed, many countries do not have robust assessments of vulnerable populations. The PPP analysis is less accurate for the assessment of flood protection benefits, but it allows comparison across nations.

All of these numbers are conservative as they only estimate the direct flood protection benefits from reefs. We did not assess indirect benefits such as avoided interruption of business or jobs for the most vulnerable people or avoided impacts to the most critical infrastructure such as hospitals. We have however provided some additional valuations of the co-benefits of reefs for ecosystem services such as fisheries and tourism benefits.

The quantitative, spatially-explicit analyses applied in this study highlight where reefs provide the greatest flood protection services to vulnerable populations in DR, Jamaica and Grenada. Reefs provide significant annual flood protection savings for property and for vulnerable people. This work identifies where future reef loss may have the greatest impacts on vulnerable populations and where enhanced conservation and restoration will deliver the most benefits.

This work shows that – despite variations in the (sub)national data – we can quantify the social benefits provided by reefs for flood risk reduction. This quantification helps bolster the case for nature-based solutions and their role in climate adaptation and risk management as more than a "no-regret measure". Restoring and managing coral reefs, quantifiably contributes to disaster risk reduction and livelihoods improvement and should thus be included in national adaptation and disaster risk management plans, particularly in the tropical Small Island Developing States where nature-based solutions can be a critical element of coastal protection.

1. Introduction

The impacts of coastal flooding are growing given population growth, coastal development and climate change. There is a pressing need to advance resilience and adaptation strategies to reduce flooding impacts (Hallegatte et al. 2013, Kumar and Taylor 2015, UNISDR 2011, 2015).

Coral reefs serve as natural, low-crested, submerged breakwaters, which provide flood reduction benefits through wave breaking and wave energy attenuation. These processes are functions of reef depth and secondarily rugosity (Sheppard et al. 2005, Quataert et al. 2015, Monismith et al. 2013). The flood reduction benefits of coral reefs and other habitats are predicted to be high in comparison to traditional, grey infrastructure approaches such as engineered break-waters (Costanza et al. 2008, CCRIF 2010, Ferrario et al. 2014, Narayan et al 2016).

Coral reefs can provide significant coastal protection benefits to people and property. Globally TNC, UCSC and IH Cantabria have shown that the annual expected damages from flooding would double, and costs from frequent storms would triple without reefs (Beck et al. 2018).

Natural flood protection benefits can be quantified with robust, process-based flooding models that are widely used in the engineering and insurance sectors to inform risk management and development decisions. These process-based models value benefits by comparing the flood damages avoided in scenarios with and without structures (e.g., seawalls or reefs) (World Bank 2016).

Using hydrodynamic flooding models, we estimate the annual expected benefit of coral reefs for protecting the most vulnerable people in the Dominican Republic (DR), Jamaica and Grenada. Building on earlier methods and recommended approaches, we compare flooding for scenarios with and without reefs for four storm return periods (1 in 10-, 25-, 50- and 100-year events). The without reefs scenarios assume only a decrease of 1m in the height and roughness of coral reefs.

The aim of this study was to assess the flood protection benefits of reefs for protecting the most vulnerable people in DR, Jamaica and Grenada. The study was funded by the InsuResilience Secretariat (https://www.insuresilience.org/), which is hosted by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) with the following aims: a) to support work on connecting nature-based defenses with climate risk insurance; b) to examine the benefits of solutions combining nature-based defenses and insurance for vulnerable people; and c) to provide a sample approach on how to correlate nature-based defenses with social vulnerability that the Secretariat can share more broadly through the Partnership's working group on integrated approaches.

2. Methods

We estimate the vulnerable population protected by reefs in DR, Jamaica and Grenada at 90m resolution. Below we first describe our model for estimating the flood protection benefits from reefs for people and property (see Beck et al 2018). We then describe the specific data and methods used for assessing benefits to the most vulnerable people in these three nations.

Reef Flood Model Overview: To estimate the role of coral reefs in coastal protection, we follow the Expected Damage Function approach, which is commonly used in engineering and insurance and recommended for the assessment of coastal protection services (World Bank 2016, Beck et al. 2018, Barbier 2015). The benefits provided by reefs are assessed by their avoided flood damages. We summarize the main steps of the Expected Damage Function approach in Figure 1 (page 9).

Define coastal profiles and study units: We delineated cross-shore profiles every 2 km for all coral reefs in the DR, Jamaica and Grenada and grouped these into 20-km study units.

Estimate offshore hydrodynamics: We identified sea states offshore for each profile from the combined effects of waves, tides, storm surge and sea level. We used global wave and sea level numerical hindcast datasets from 1979 to 2010, which have been used extensively and validated with instrumental data.

Estimate nearshore hydrodynamics and the effects of reefs: At each profile, we propagated the waves through the reef profiles, using a propagation model that accounts for shoaling, breaking and the friction induced by the coral reefs. From the wave propagation, we calculate the wave run-up on the shore.

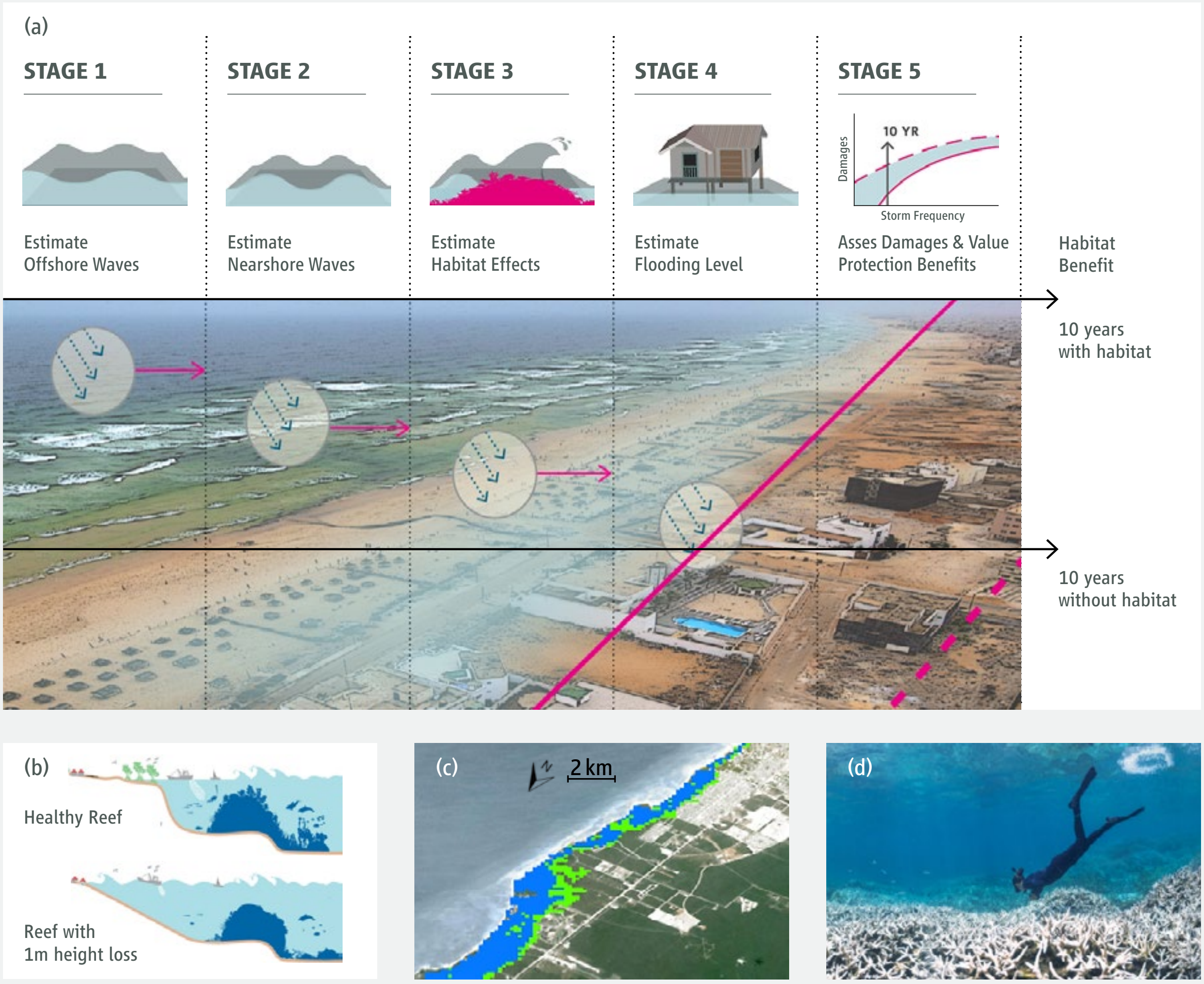
Define extreme water levels along the shore: We combined run-up and sea level to estimate flood heights at the coastline. We then calculated the flood heights for four storm return periods (10, 25, 50, 100 yr).

Identify people and assets flooded: For each profile and storm return period, we identified flooding levels on land by intersecting the flood height with topography. We extended the flood heights inland by ensuring hydraulic connectivity between points at a 90m resolution. We then developed a flood envelope across each 20-km study unit and calculated the land, people and built capital within this envelope.

Develop flooding scenarios with and without reefs: We repeated the steps above for reef bathymetry under current conditions and for a reef bathymetric profile reduced by 1m and with lower friction.

Figure 1

Key steps and data for estimating the flood protection benefits provided by reefs



(a) Stage 1: Oceanographic data are combined to assess offshore sea states. Stage 2: Waves are modified by nearshore hydrodynamics. Stage 3: Effects of habitat on wave run-up are estimated. Stage 4: Flood heights are extended inland along profiles (every 2 km) for 1 in 10, 25, 50, 100-yr events with and without coral reefs. Stage 5: The land, people and built capital damaged under the flooded areas are estimated.

(b) The scenarios for reef loss only assume a loss of the top 1m in height and roughness across the reef profile.

(c) Example results for Mayan Riviera in Mexico; blue polygons are expected flooding in 25-yr event and green polygons are added flooding without the top 1m of reefs.

(d) Inset photo shows coral reef bleaching of top most branching corals in 2015 El Nino event at the island of Guam, organized territory of the United States in Micronesia (adapted from Beck et al. 2018).

3. Assessing flood reduction benefits from reefs

We assessed benefits provided by coral reefs in the DR, Jamaica and Grenada to the most vulnerable people during the 50-year return period event. We first calculated the 50-year flood extent with and without coral reefs. The difference in these two flood layers or "envelopes" represents the protection benefits that reefs currently provide in reducing flooding (flood reduction layer).

We assessed the flood protection benefits using two different approaches and sources of data. The first approach is more general and can be used across these three countries and it can serve at the same time as an approach for other nations and globally. We combined the flood benefit layer with 2018 UN population data layers for all three countries (www.worldpop.org). We then adjusted the total number of people that benefit from coral reef flood protection by the percentage of vulnerable people, defined by living on less than $15 per day (Table 1), to estimate the number of vulnerable people that receive flood protection from reefs in these countries. The threshold of below $15 per day is the indicator level for the definition of vulnerable people by the InsuResilience Global Partnership (Box 1). The percentage of the population living on less than $15 per day was assessed using country-level earnings and consumption statistics (see sources in table 1 below) calculated at current exchange rates. For example, using the Jamaica Survey of Living Conditions which reports on the percentage distribution of households by consumption expenditure for 2015, we identified the percentage of the population that consumes less than $15 a day (in the JMD $700,000 - $800,000 range annually), or 56.2 % of Jamaicans.

The data on the percentage of people living on less than $1.9 to $3.1 USD PPP a day (moderately poor people) was obtained from the World Bank (WB) data portal for the DR and Jamaica (https://data.worldbank.org/). For Grenada, we used the 2008 percentage of people living in indigence as a proxy for the WB extreme poverty category (less than $1.9 PPP a day, which coincides with the InsuResilience indicator for extremely poor people) and the 2008 Grenada national poverty line as a proxy for people living on less than $3.1 a day (which falls within the moderately poor category according to the InsuResilience definition).

The second approach uses country supplied data from the Vice-Presidency of the DR and their Unique Beneficiary System (SIUBEN) on vulnerable populations. We were able to do these analyses only in the DR, where we had access to the survey-derived SIUBEN data (2012) on vulnerable populations by barrio (i.e., neighborhoods). The SIUBENderived data, or Indice de Calidad de Vida – ICV (quality of life index) surveys homes in zones identified as poor in the national poverty map and gathers household-level data on income, education, quality of the home, and access to basic services, to categorize these homes in four groups according to their vulnerability. The most vulnerable groups, 1 and 2, are eligible for access to government-led social programs.

To calculate the number of vulnerable people protected by reefs, we first selected all the vulnerable barrios (ICV 1 - 4) that intersected areas that receive flood protection from reefs. We then calculated the number of people living in these barrios based on the 2010 national census. For barrios with missing census data, we took the number of vulnerable households within barrios, where available, and multiplied this number by 5 (average size of a Dominican household) to get an estimate of vulnerable people in these barrios. All spatial calculations were conducted using ArcGIS 10.5.

Box 1

InsuResilience Global Partnership Vulnerability/ Poverty Definition

Based on a study by the Munich Climate Insurance Initiative (MCII), the target group of the InsuResilience Global Partnership is defined as follows:

Extremely poor: people living on < $1.9 PPP / day
Moderately poor: people living on $1.9 - $3.1 PPP / day
Vulnerable: people living on $3.1 - $15 PPP / day

Table 1

Percentage of national populations that are identified as vulnerable by PPP

Vulnerability is determined by Purchasing Power Parity per day (PPP) with the most vulnerable populations living below $1.9/day.

Country	% of pop (PPP < $15 / day)	% of pop (PPP < $3.1 / day)	% of pop (PPP < $1.9 / day)	Year of data	Data source
Dominican Republic	82.5 %	9 %	1.6 %	2018	Labor Force Survey of the Central Bank of the DR and WB data portal
Jamaica	56.25 %	8.16 %	1.7 %	2015	Jamaica Survey of Living Conditions and WB data portal
Grenada	67.9 %	37.7 %	2.4 %	2017	Labor Force Survey of the Central Statistics Office of the Ministry of Finance of Grenada and the Country Poverty Assessment of Grenada, Carriacou, and Petite Martinique of 2008

4. Results

Global Results

Globally, reefs avert substantial flood damages and thus provide significant annual expected benefits for flood protection. Across reef coastlines (71,000 km), reefs reduce the annual expected damages from storms by more than $4 billion. Without reefs, annual damages would more than double (118 %) and the flooding of land would increase by 69 % affecting 81 % more people annually (Beck et al. 2018). Reefs provide annual expected benefits of hundreds of millions of US-Dollars in avoided flood damages for five countries and millions of dollars in annual benefits for more than 20 additional countries.

Specifically for DR, Jamaica, and Grenada, reefs annually avert $96M, $46M and $4M respectively in flood damages to property (Beck et al. 2018).

Benefits to the Most Vulnerable People in the Dominican Republic, Jamaica and Grenada

Our analysis reveals that the DR has the highest number of vulnerable people that are protected by reefs followed by Jamaica and Grenada (Table 2 & Figs. 2 - 4).

The findings also reveal differences in vulnerable people protected by reefs as measured by two different approaches (PPP vs national vulnerability survey) for the DR. The number of vulnerable people protected by reefs is estimated to be much higher using the national census survey of vulnerable people (1.36M) as compared to the PPP-based estimate (171k) (Table 2). There are also considerable spatial differences in the vulnerable people receiving these benefits as estimated by the two different approaches (Figs. 4 - 7). The national vulnerability data provide a much more detailed analysis of flood reduction benefits from reefs to people (Fig. 7). The analysis based on WorldPop data in combination with PPP only identifies the general distribution of vulnerable people (Figs. 4 - 6). Survey data thus provides a much more precise result of flood reduction benefits provided by reefs to vulnerable people.

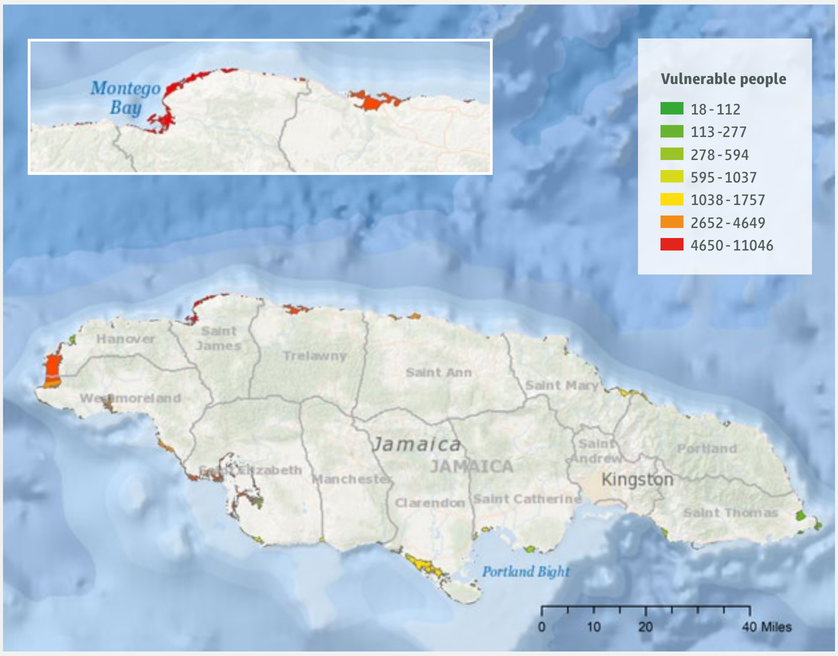
Table 2

Number of people and vulnerable people receiving flood protection benefits from reefs across the DR, Jamaica and Grenada

For the DR, two methods were used to identify vulnerable populations: (A) one based on PPP and (B) the second based on the national census.

Country	# of people	# of vulnerable people (PPP < $15 / day)	# of vulnerable people (PPP < $3.1 / day)	# of vulnerable people (PPP < $1.9 / day)	# of vulnerable people (national census)
A. Reef Benefits-PPP analysis					
Jamaica	69,160	38,868	5,643	1,176	—
Grenada	758	515	286	18	—
Dominican Republic	207,580	171,254	18,682	3,321	—
B. Reef Benefits-Census of vulnerable people					
Dominican Republic	—	—	—	—	**1,363,600**

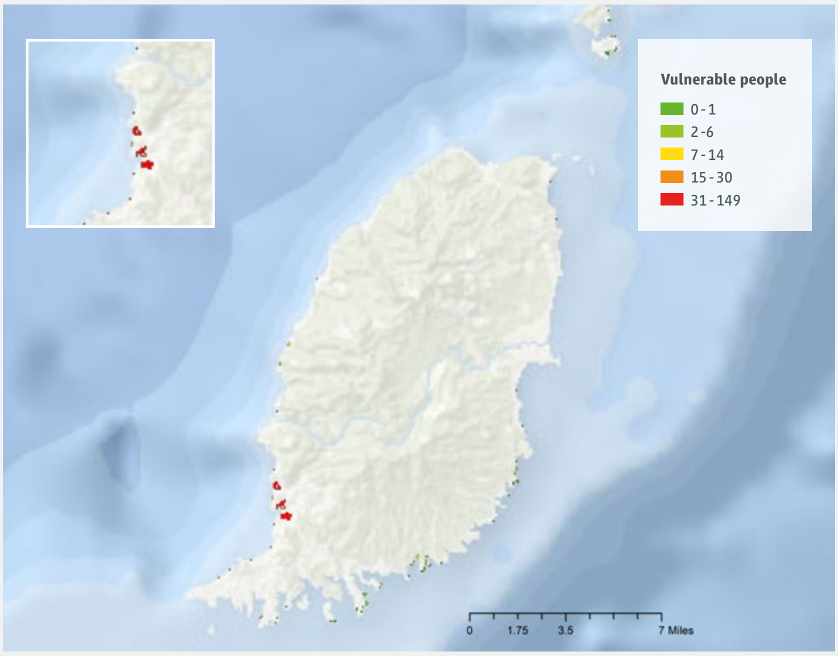
Figure 2



Jamaica

The number and spatial variation of vulnerable people (PPP<$15/day) receiving flood protection benefits from reefs in **Jamaica** for a 1 in 50-year event. The polygons represent the flood zones from the 1 in 50-year event if the topmost meter of reefs were lost. The values are the additional vulnerable people that would be flooded if these reefs were lost,i.e., the difference in vulnerable people flooded with reefs at present versus with 1m reef loss. These are the people receiving benefits (averted damages) by conserving and/or restoring present reefs. The inset map shows Montego Bay in northwest Jamaica.

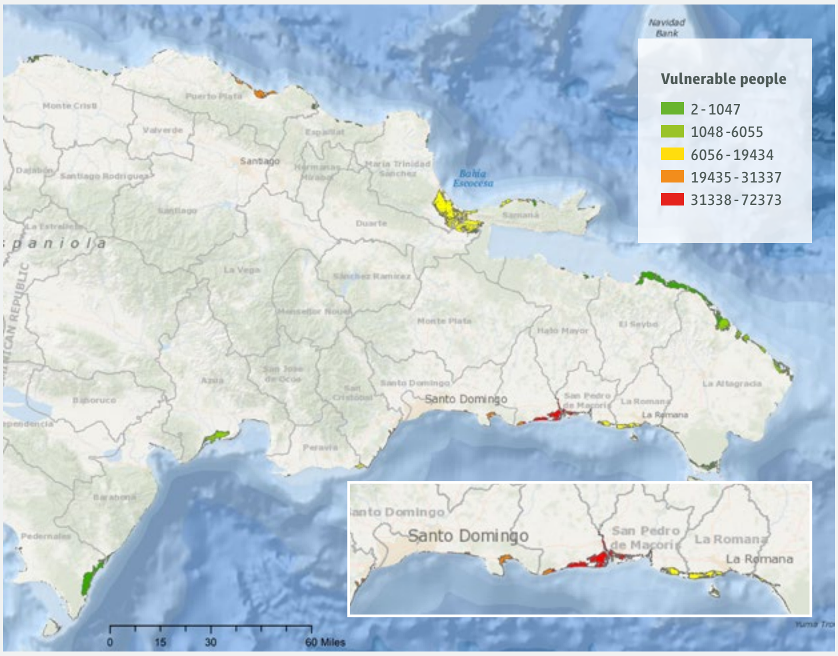
Figure 3



Grenada

The number and spatial variation of vulnerable people (PPP<$15/day) receiving flood protection benefits from reefs in **Grenada** for a 1 in 50-year event. The polygons represent the flood zones from the 1 in 50-year event if the topmost meter of reefs were lost. The values are the additional vulnerable people that would be flooded if these reefs were lost, i.e., the difference in vulnerable people flooded with reefs at present versus with 1m reef loss. These are the people receiving benefits (averted damages) by conserving and/or restoring present reefs. The inset map shows St. Georges in southwest Grenada.

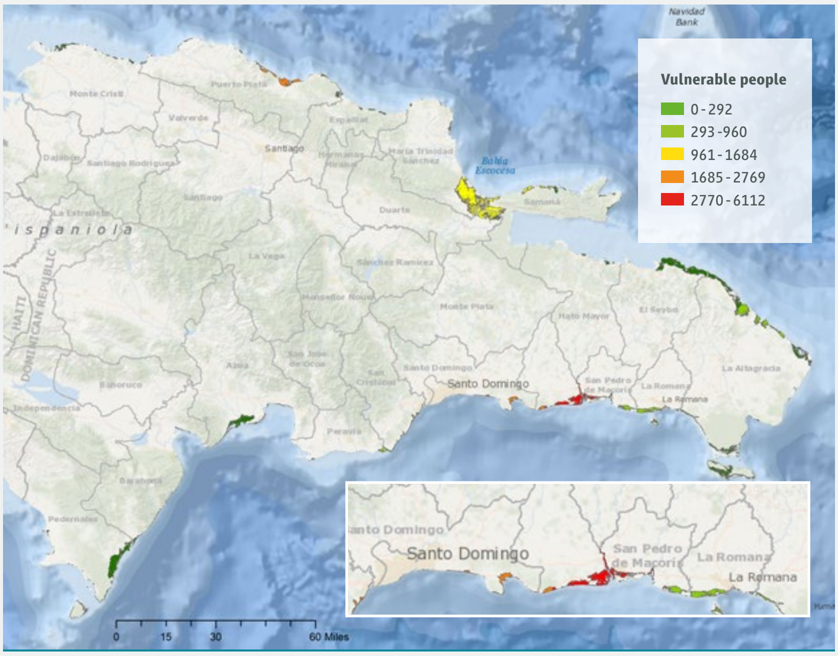
Figure 4



Dominican Republic

The number and spatial variation of vulnerable people (**PPP<$15 / day**) receiving flood protection benefits from reefs in the **DR** for a 1 in 50-year event. The polygons represent the flood zones from the 1 in 50-year event if the topmost meter of reefs were lost. The values are the additional vulnerable people that would be flooded if these reefs were lost, i.e., the difference in vulnerable people flooded with reefs at present versus with 1m reef loss. These are the people receiving benefits (averted damages) by conserving and/ or restoring present reefs. The inset map shows Santa Domingo in southeast DR.

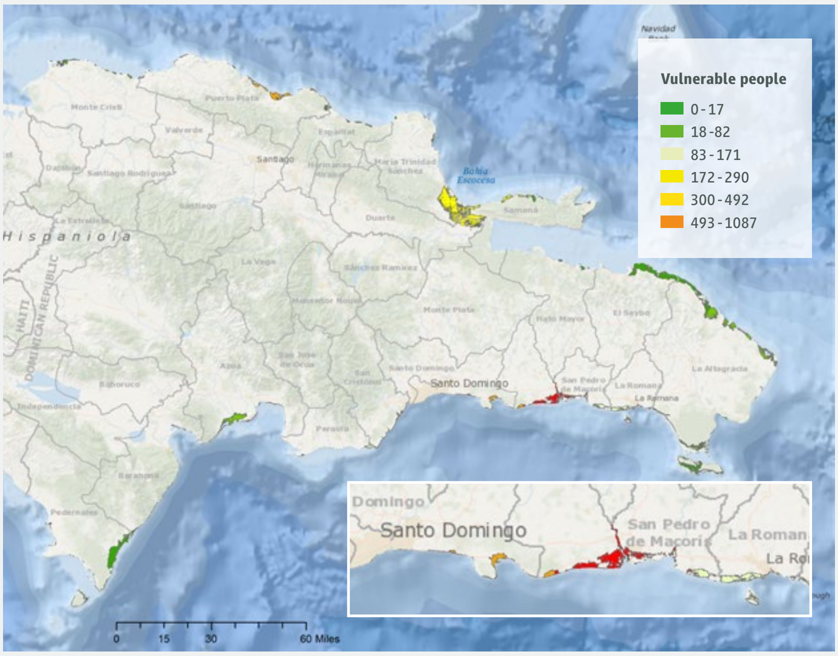
Figure 5



Dominican Republic

The number and spatial variation of vulnerable people (**PPP<$3.1 / day = moderately poor**) receiving flood protection benefits from reefs in the **DR**.

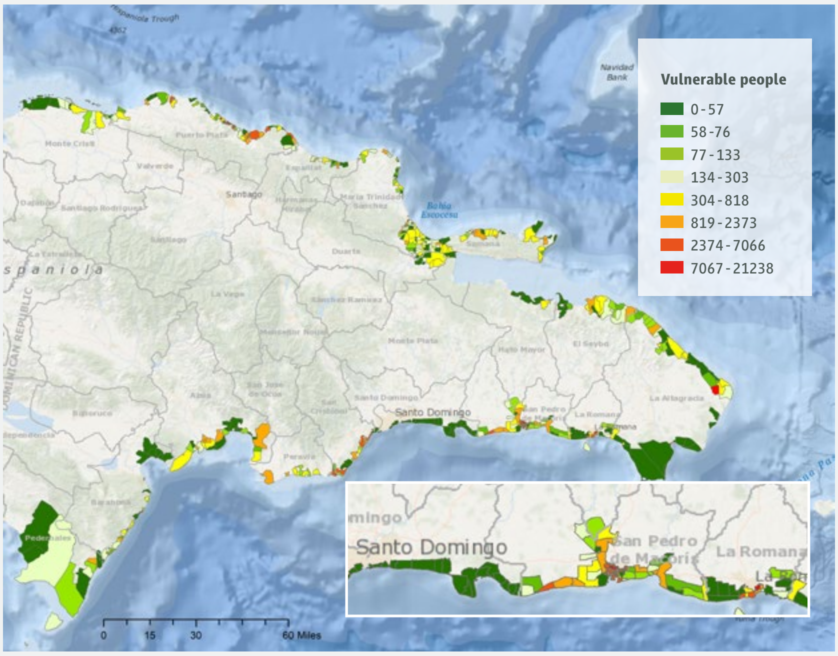
Figure 6



Dominican Republic

The number and spatial variation of vulnerable people (**PPP<$1.9 / day = extremely poor**) receiving flood protection benefits from reefs in the **DR**.

Figure 7



Dominican Republic

The number and spatial variation of vulnerable people protected by reefs in the **DR** based on the national census determination of vulnerable people (class IV). The polygons in this figure are the barrios (census districts) that overlap with the envelopes identifying where reefs are providing flood protection benefits. The number of vulnerable people was identified as part of the national census.

Table 3

Ecosystem service values provided by reefs in Jamaica, Grenada and the Dominican Republic in million US$*

Ecosystem	Ecosystem Service	Jamaica	Grenada	Dominican Republic
Coral reefs	Biodiversity	36.8	—	—
	Fisheries	37.0	—	19.2
	Pharmaceutical	106.0	—	—
	Tourism	342.4	23.8	525.5

*converted to US$ 2019, rounded to nearest 1,000

Additional Ecosystem Service Benefits in Jamaica, Grenada & the Dominican Republic

In this study, we only estimate the direct flood protection benefits from reefs. We did not assess indirect benefits such as avoided interruption of business or jobs for the most vulnerable people or avoided impacts to the most critical infrastructure such as hospitals.

As part of the Resilient Islands project for the International Climate Initiative (funded by the German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety), we estimated an overall value of ecosystem service benefits that these countries receive from their reefs. These are co-benefits in addition to the direct flood protection benefits.

Across the three countries, Jamaica is the most well-studied and Grenada the least, in terms of different ecosystem service benefits. We found additional benefits from reefs of US$ 522 million for Jamaica, US$ 24 million for Grenada, and US$ 545 million for the DR. Jamaica has the highest value for coral reef related tourism (Table 3). The DR also has high value for tourism. Grenada, on the other hand, has the important values for reef related fisheries with the commercial fishing sector generating significant cash flows relative to the recreational fishing sector.

5. Discussion and Policy implications

These quantitative, spatially-explicit analyses highlight where reefs provide the greatest flood protection services to vulnerable populations in the DR, Jamaica and Grenada. Reefs provide significant annual flood protection savings for property (Beck et al. 2018) and for vulnerable people. This work identifies where reef loss may have the greatest impacts on vulnerable populations and where enhanced conservation and restoration will deliver the most benefits.

The analyses first identify vulnerable people protected by reefs based on population data adjusted by PPP. Such an approach is very general as it can be applied in any area around the world where flood protection by reefs is calculated and PPP data is available. Yet, this approach assumes that the distribution of the most vulnerable people is spatially consistent nationwide. We know this is not true.

Our second approach takes the national census-based distribution of vulnerable people into account and provides a much more in depth and more accurate assessment of the distribution of vulnerable people in DR and thus of areas where reef benefits are greatest. This approach is more robust and accurate but is more time consuming as it requires rigorous data from individual countries. These data sets per country will differ and will not be uniform in their methods of collection and analysis. Therefore, the results on social impacts from different countries may not be directly comparable with each other. Another constraint of this approach is the fact that many countries do not have robust assessments of the most vulnerable populations. Thus, data availability is critical when deciding on the approach for assessing flood risk benefits of reefs to vulnerable people.

Importantly, flood protection is just one of the services provided by reefs, and our analyses identify benefits only from the topmost 1m of the reef profile.

Reef flood protection benefits are particularly critical for many Small Island Developing States such as in the DR, Jamaica and Grenada, which have a limited capacity (relative to their GDP) to respond to severe flooding and the losses of natural coastal defenses. The protection of nearshore shallow reefs should be a high priority for these nations as a critical part of their coastal management and adaptation strategies.

Reefs also offer indirect risk reduction benefits by reducing social vulnerability (e.g., by supporting nutrition and livelihoods) and improving coping and adaptive capacity. Furthermore, reefs protect critical public infrastructure, such as roads, ports, and schools, from being damaged or destroyed. The rebuilding of such critical infrastructure, e.g. hospitals and market places, is usually the focus of nations during disaster recovery due to their importance to maintain local livelihoods and economies.

In addition to providing protection from flood risk for vulnerable households and critical infrastructure that upkeep local livelihoods, reefs also protect hotels and other tourism related amenities which support local businesses and employment.

Better valuations of the protection services from coastal habitats inform decisions for meeting multiple objectives in risk reduction and environmental management. These spatially-explicit benefits can be directly considered by governments (e.g., national accounts, recovery plans) and businesses (e.g., insurance).

This study of three Caribbean Small Island Developing States shows that nature-based solutions can help meet goals for reducing social vulnerability and improving biodiversity. We have long known that ecosystem restoration can be a no regret strategy of climate adaptation, but we are now increasingly able to quantify their resilience benefits. This quantification is particulary important in order to integrate these benefits as factors in risk models. Based on this information, innovative risk financing products can be developed, such as joint insurance and nature-based solutions. Moreover, not only does the restoration and management of healthy reef systems reduce the exposure of vulnerable people to weather related climate hazards, they also present a cost-effective hazard mitigation option compared to grey infrastructure. Further they provide additional co-benefits for fisheries and livelihoods. Nature-based climate risk management should therefore be considered as an integrative element of national adaptation planning as well as disaster risk management and finance plans. They also serve as complementary measure to traditional grey measures.

Global initiatives should continue to promote and support the development of nature-based solutions. The InsuResilience Global Partnership, in its specific mandate to close the protection gap, could actively explore integrated solutions that link risk finance and insurance mechanisms to nature-based resilience. Unlocking co-benefits between financial protection and nature-based resilience could support the Partnership's vision to strengthen the resilience of developing countries and protect poor and vulnerable people against the impact of disasters.

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