

The effects of climate change in the coastal areas of Latin America and the Caribbean

Evaluation of systems for protecting corals and mangroves in Cuba



ECLAC



GOBIERNO DE ESPAÑA

MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA



IHcantabria
INSTITUTO DE HIDRÁULICA AMBIENTAL
UNIVERSIDAD DE CANTABRIA

Thank you for your interest in this ECLAC publication



Please register if you would like to receive information on our editorial products and activities. When you register, you may specify your particular areas of interest and you will gain access to our products in other formats.



www.cepal.org/en/suscripciones

The effects of climate change in the coastal areas of Latin America and the Caribbean

Evaluation of systems for protecting corals and mangroves in Cuba



GOBIERNO DE ESPAÑA

MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA



IHcantabria
INSTITUTO DE HIDRÁULICA AMBIENTAL
UNIVERSIDAD DE CANTABRIA

This document was prepared by the Environmental Hydraulics Institute of the University of Cantabria (IHCantabria), under the supervision of Íñigo J. Losada Rodríguez. The work for the project was carried out by the researchers Adrián Acevedo, Paula Camus, Pedro Díaz-Simal, Antonio Espejo, Melisa Menéndez, Pelayo Menéndez, Marta Ramírez, Alexandra Toimil, Saúl Torres, María Emilia Maza and María Fuentes, all of the Environmental Hydraulics Institute of the University of Cantabria.

The study was conducted as part of the cooperation activities between the Economic Commission for Latin America and the Caribbean (ECLAC) and the Government of Cuba “Evaluation of hurricane and climate change impacts and vulnerability on the northwestern coast of Cuba”, in the framework of the ECLAC project with the Government of Spain “Effects of climate change on the coasts of Latin America and the Caribbean”. Within ECLAC, the team coordinating and supervising the study comprised Carlos de Miguel, Chief of the Public Policies for Sustainable Development Unit; José Javier Gómez, Environmental Affairs Officer; and Karina Martínez and Mauricio Pereira, Researchers, all with the Sustainable Development and Human Settlements Division.

The authors wish to extend particular thanks to the staff of the Spanish Office of Climate Change of the Ministry of the Ecological Transition of Spain, in particular to Ana Pintó and Eduardo González, as well as Victoria Osuna Recio, Rural Development Project Officer of the Spanish International Cooperation Agency for Development (AECID) in Cuba.

Assistance was also provided for this project by a team of staff from the Environment Agency of the Ministry of Science, Technology and Environment of Cuba, comprising Maritza García, Chair; Jesús Guerra Bell, Senior Specialist in International Relations Management; Rudy Montero Mata, Chief of the Risk Assessment Group; Sergio Lorenzo Sánchez, Macroproject Scientific Coordinator; Isabel Torna Falco, Risk Assessment Group Specialist; and Jorge Olivera Acosta and Ramón Pérez Díaz, Macroproject Specialists.

The views expressed in this document, which is a translation of an original that did not undergo formal editorial review, are those of the authors and do not necessarily reflect the views of the Organization.

The boundaries and names shown on the maps included in this publication do not imply official acceptance or endorsement by the United Nations.

United Nations publication
LC/TS.2018/71
Distribution: L
Copyright © United Nations, 2018
All rights reserved
Printed at United Nations, Santiago
S.18-00913

Applications for authorization to reproduce this work in whole or in part should be sent to the Economic Commission for Latin America and the Caribbean (ECLAC), Publications and Web Services Division, publicaciones.cepal@un.org. Member States and their governmental institutions may reproduce this work without prior authorization, but are requested to mention the source and to inform ECLAC of such reproduction.

Contents

Foreword	5
Introduction.....	7
A. Background	7
B. Ecosystem services	9
C. Role of ecosystems in risk reduction.....	10
D. Cuba's coastal ecosystems in a global context.....	11
E. Prior valuation studies.....	12
I. Methodology for valuing the protection service provided by ecosystems	13
II. Results	15
A. Valuing Cuba's coral reefs	15
1. Benefits of flood protection at national level	15
2. Benefits of flood protection at local level.....	16
B. Valuing Cuba's mangroves.....	18
1. Benefits of flood protection at national level	18
2. Benefits of flood protection at local level.....	18
C. Comparison of the valuation of Cuba's corals and mangroves	20
1. Benefits of flood protection at national level	20
2. Benefits of flood protection at local level.....	23
III. Conclusions.....	25
A. Conclusions drawn from the results	25
B. Where Cuba stands in relation to other countries	25
C. Implications and recommendations.....	26
Bibliography.....	29
Tables	
Table 1	Cuba: damage caused in coral areas under scenarios with and without coral, and ecosystem benefits in the case of different coastal flooding events..... 15
Table 2	Cuba: damage caused in mangrove areas under scenarios with and without mangroves, and ecosystem benefits in the case of different coastal flooding events..... 18

Table 3	Cuba: relative damages per hectare produced in coral and mangrove ecosystems under scenarios with and without presence of the ecosystem, and relative benefits in the case of different coastal flooding events.....	21
Table 4	Countries that receive the most flood protection benefits from coral reefs	26
Figure		
Figure 1	Cuba: relative annual benefits provided by coral reefs and mangroves in the case of coastal flooding.....	22
Diagram		
Diagram 1	Possible approaches for modelling friction between flow and the marine ecosystem.....	11
Maps		
Map 1	Cuba: distribution of coral reefs and mangroves	12
Map 2	Comparison of a 10-year return-period flooding event with and without coral reefs	16
Map 3	Cuba: annual expected benefits from the presence of coral reefs.....	17
Map 4	Cuba: annual expected benefits from the presence of coral reefs.....	17
Map 5	Cuba: comparison of a 10-year return-period flooding event with and without mangroves	19
Map 6	Cuba: annual expected benefits from the presence of mangroves.....	19
Map 7	Cuba: annual expected benefits from the presence of mangroves.....	20
Illustrations		
Illustration 1	A low-lying area with an urban settlement (Miami) that benefits directly from the wave-energy dissipation action of coral reefs	8
Illustration 2	Mangrove replanting	8
Illustration 3	Grenada: construction of an artificial coral reef	9
Illustration 4	Key steps for estimating the flood protection benefits provided by marine habitats.....	14

Foreword

Since 2008, the Economic Commission for Latin America and the Caribbean (ECLAC), the Government of Spain and the University of Cantabria (Spain) have been collaborating on a line of research entitled “Subregional study on the effects of climate change on the coasts of Latin America and the Caribbean” the main objectives of which have been to establish a framework for cooperation, provide the best scientific and technical information available in the region to tackle climate change in coastal areas of Latin America and the Caribbean and support the Ibero-American Network of Climate Change Offices (RIOCC).

During the first phase of this collaboration, a specific methodology was developed to assess the impacts of climate change in coastal areas. The results of this phase were published in six documents assessing coastal dynamics and trends, the vulnerability of coastal areas, climate change impacts, climate change risks and the theoretically derived effects of climate change in coastal areas, together with a methodological handbook for risk assessment. In addition, a web viewer was developed for georeferencing the dynamics and impacts with a spatial resolution of 5 kilometres (km) throughout the region’s coastal strip. The methodologies and results stemming from this line of research serve as the basis for conducting new sectoral and subnational studies that allow a high-resolution analysis of impacts and adaptation in coastal areas of Latin America and the Caribbean.

The Caribbean is an area highly vulnerable to climate change impacts, prompting the Governments of Cuba and Spain, ECLAC and the University of Cantabria to undertake collaborative work to explore in more depth the results obtained during phase one, this time as part of a project to assess the hurricane and climate-change impact and vulnerability of Cuba’s north-western coastal area.

Cuba’s coast is extremely important for the country because, as stated in Cuba’s Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC), the presence of high-density, fast-growing centres of population and intensive tourism, industrial and maritime-port activity creates strong rivalry between economic management and ecosystem functioning. This poses an imminent risk of damage to the coast of the Cuban archipelago from mean sea-level rise and flooding caused by extreme hydrometeorological events.

The impact assessment project included a technology-transfer and training programme for technical personnel in the Cuban Environmental Agency (AMA) in the fields of economic appraisal of environmental projects and environmental economic analysis, as well as data generation for wave characterization on the coast of Cuba. The training took the form of a set of courses taught by staff of the Environmental Hydraulics Institute of the University of Cantabria (IHCantabria) and ECLAC in Havana and in Cantabria. These activities were conducted in 2017 and the first half of 2018. The main outputs of this project include documents on a number of subjects: historical reconstruction and projections of climate change impact on waves on the coast of Cuba; evaluation of systems for protecting corals and mangroves in Cuba; and methodologies and tools for assessing the impact of climate change-induced flooding and erosion.

Introduction

A. Background

Flood risk in coastal areas has increased by 23% in recent years (Small and Nicholls, 2003), owing to human settlement, growing economic activities and the resurgence of climatic hazards. Examples of this are the recent tropical cyclones Franklin, Harvey, Irma, Katia, Jose and Maria, which devastated large swathes of the Caribbean islands and coasts of Mexico and Florida between August and September 2017, underscoring the vulnerability of coastal areas. This, coupled with the mean sea-level rise projected by the Intergovernmental Panel on Climate Change (IPCC), will contribute to a growing risk of flooding in the future (see illustration 1). Historically, conventional solutions have been used to overcome flood risk, such as building artificial dykes or enlarging or raising the crest elevation of infrastructure (Morris and others, 2018), all of which are rigid solutions that are not readily adapted to changing climatic conditions and are environmentally unsustainable.

Growing public concern for sustainable development, together with evidence of the multiple services ecosystems can provide, have led to the proposal of alternative coastal defence measures based on natural solutions, such as conserving existing ecosystems or planting mangrove forests (see illustration 2), building artificial coral reefs (Clark and Edwards, 1999 and 1995) (see illustration 2 and illustration 3) or restoring destroyed reefs. The role of these ecosystems in protecting the coast from flooding and erosion has been amply demonstrated (Ferrario and others, 2014). They also have the advantage of being flexible solutions that are easily adapted to long-term changes, such as sea-level rise, with conservation costs much lower than the cost of building artificial defence structures.

Illustration 1

A low-lying area with an urban settlement (Miami) that benefits directly from the wave-energy dissipation action of coral reefs



Source: *Nature Conservancy*, The Nature Conservancy (TNC), Arlington, May-June 2013.

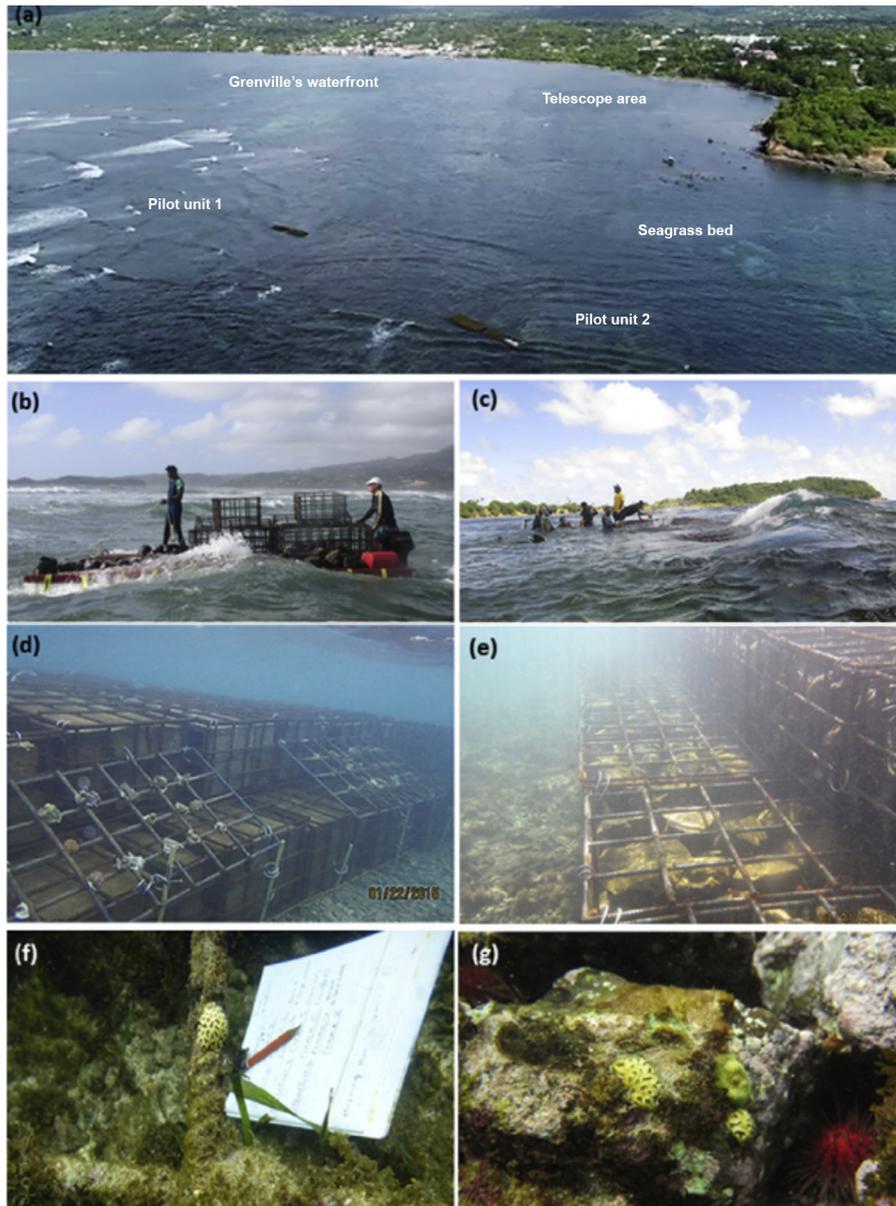
Illustration 2

Example of mangrove replanting



Source: The Nature Conservancy (TNC).

Illustration 3
Grenada: construction of an artificial coral reef



Source: B. G. Reguero and others, “Coral reefs for coastal protection: a new methodological approach and engineering case study in Grenada”, *Journal of Environmental Management*, vol. 210, Elsevier, 2018.

B. Ecosystem services

Marine ecosystems not only provide coastal protection: their total value is the sum of this and other services, such as fisheries, aquaculture, habitat for marine species and tourism. Since the founding of the two reference projects in this field —Millennium Ecosystem Assessment (MA)¹ in 2005 and The Economics of Ecosystems and Biodiversity (TEEB)² in 2010— these services have been classified into

¹ See [online] www.millenniumassessment.org.

² See [online] <http://www.teebweb.org>.

four major groups: provisioning services, regulating services, cultural services and habitat services. Provisioning services include the supply of: wood for fuel or construction, food for humans, medicinal resources, fisheries, raw materials for different purposes, fresh water and crops. Regulating services include flood and erosion protection, soil stabilization, carbon sequestration, oxygen production, water filtration and the supply of food for other species. The main habitat services are the provision of a physical environment for the lifecycle of animal species and wide biodiversity. Cultural services include tourism, recreation (aquatic activities, recreational fishing and other activities), aesthetic appreciation, inspiration for education, art and design, and the spiritual component.

To focus on a few of these services, 30% of the world's coral reefs have a tourism value of US\$ 36 trillion, and 9% of the total value of the tourism industry is located in countries with coral reefs (Spalding and others, 2017). From a fish resources standpoint, the estimated annual benefits worldwide are worth US\$ 5.7 trillion (Cesar, Burke and Pet-Soede, 2003). As regards the coastal protection service, a recent study published by the World Bank shows that mangroves in the Philippines provide the country with protection worth more than US\$ 1 trillion per year (Losada Rodríguez and others, 2017). This analysis has also been extended to a global scale, with the protection provided by mangrove ecosystems worldwide valued at more than US\$ 71 trillion per year (Beck and others, 2018a; Losada Rodríguez and others, 2018). Other studies have valued the global annual contribution of coral reefs at US\$ 4 trillion (Beck and others, 2018b). Even so, few papers have been published on this subject to date.

C. Role of ecosystems in risk reduction

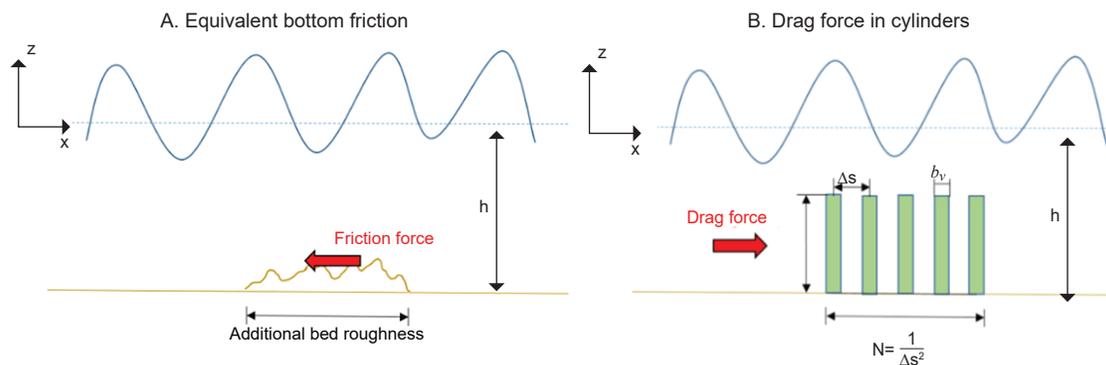
Coastal ecosystems, such as coral reefs, mangroves, seagrasses, marsh vegetation or dunes, act as additional obstacles to waves reaching the coast. As mentioned earlier, one of the main benefits that these natural systems provide directly to humans is their protection service. Wave dissipation depends on the physical characteristics of these barriers (such as shape, density, rigidity and buoyancy) and on the properties of the maritime climate (such as wave height, period, wave direction, tides and storm surges, and wind). Years of study have led the following main conclusions to be drawn regarding the role of ecosystems in protecting coasts from flooding (Tschirky, Hall and Turcke, 2001).

- Larger structures dissipate more energy.
- The denser the vegetation field, the more protection it offers.
- It is the biggest waves that feel the presence of natural barriers the most.
- The lower the water level (depth), the greater the dissipation power.

The main mechanisms of dissipation created by ecosystems like corals or mangroves are wave-breaking and bottom friction. Dissipation by wave-breaking increases in the presence of a coral reef, which not only reduces the relative depth of water, inducing wave steepness, but also modifies the breaker parameter, with this process occurring earlier on sandy ground. Dissipation by friction also increases, owing to the additional roughness provided by ecosystems, producing a loss of energy when the water brushes along the bottom or against the stems of plants. The second process is complex to model numerically, requiring the use of parametrizations to simplify and represent this increase in friction. There are two approaches to resolving or modelling friction: (1) considering an equivalent bottom roughness increased by the presence of vegetation: (2) resolving plant-flow interaction individually. The first approach is less rigorous and is used when the exact geometry of the plant is unknown or when this geometry is so complex that it cannot be represented (for example, coral reefs). The second approach is used when the geometry and flow are known, allowing drag forces to be calculated from the interaction between the two and providing a more accurate indication of energy loss by friction (this approach can be used in the case of mangroves, which have geometrically well-defined trunks). Diagram 1 depicts the two methods.

Diagram 1 Possible approaches for modelling friction between flow and the marine ecosystem

Real case (black mangroves with submerged roots)



Source: Prepared by the authors; photograph: World Wildlife Fund (WWF).

D. Cuba's coastal ecosystems in a global context

Cuba is one of the countries with the largest number of marine ecosystems (see map 1). Coral reefs and mangroves are two important natural resources for the country. Based on data obtained by Spalding, Kainuma and Collins (2010), of a total of more than 150,000 square kilometres (km²) of mangroves in existence in the world today, 3% (nearly 5,000 km²) are found in Cuba and cover 4,450 km of its coastline (75% of Cuba's total 5,800 km of coastline). According to the *World Atlas of Coral Reefs* (Spalding, Ravilious and Green, 2001), there are more than 150,000 km² of coral reefs worldwide, 3,000 km² of which are found in Cuba (2% of total cover), spread along 3,960 km of coastline (68% of Cuba's total 5,800 km of coastline). These values highlight the relative importance of the country's coastal ecosystems and the potential role they can play in terms of providing services to Cuban society.

However, the spatial extent of Cuba's ecosystems —and those of the Caribbean as a whole— is under threat from human action. The anthropogenic effect of overfishing, soil pollution, which reduces water quality, and tourism, are the main agents affecting the status of coral reefs and mangroves. Added to these anthropogenic factors is the impact of hurricanes striking Caribbean islands, which can destroy already bleached or even live corals. Recent studies have analysed the state of Cuba's coral reefs (González Díaz and others, 2018), mangroves and other ecosystems (Galford and others, 2018).

Map 1
Cuba: distribution of coral reefs and mangroves



Source: Prepared by the authors on the basis of M. Spalding, C. Ravilious and E. Green, *World Atlas of Coral Reefs*, Berkeley, University of California Press, 2001; M. Spalding, M. Kainuma and L. Collins, *World Atlas of Mangroves*, London/Washington, D.C., Earthscan, 2010.

Note: Coral reefs are represented by green polygons and mangroves, by red polygons.

E. Prior valuation studies

Following on from the work of Costanza and others (1997), a number of initiatives, collaborations and projects have been launched with the aim of estimating the value of ecosystem services worldwide. Several have included valuations of concrete services and ecosystems, nearly all at the local level and highly specific to the study area. A recently published historical review of these studies (Mehvar and others, 2018) grouped ecosystem values in relation to the surface area they occupy (hectares). To provide an order of magnitude and focusing on the two main marine ecosystems present in Cuba—coral reefs and mangroves—the average ecosystem values are around US\$ 350 per hectare per year and US\$ 200 per hectare per year, respectively (De Groot and others, 2012). However, these average values should not be considered as indisputable because an analysis of several local studies reveals a variation ranging from just under US\$ 1 per hectare per year to more than US\$ 1 million per hectare per year (for highly valuable tourist areas protected by coral reefs). Such a wide range of uncertainty calls for an ecosystem-service valuation methodology that unifies methods and determines valuation standards. To assess the true benefit of Cuba's ecosystems, this methodology will be applied at national and local levels, in order to obtain more precise values than would be possible using regression models based on prior studies.

I. Methodology for valuing the protection service provided by ecosystems

The flood protection service provided by coral reefs and mangroves is studied using a multistep methodology recommended in the World Bank's guidelines for the valuation of natural coastal protection (Losada Rodríguez and others, 2017). This methodology is divided into the following five steps (see illustration 4).

Step 1: Characterization of the offshore maritime climate for both regular climate conditions and sporadic extreme conditions (tropical cyclones).

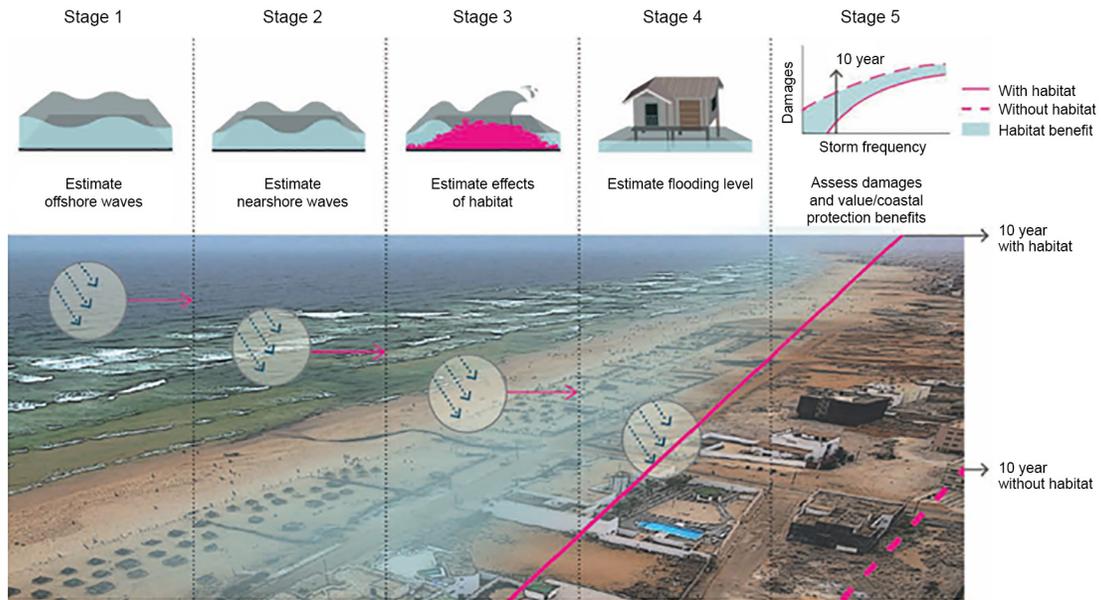
Step 2: Downscaling of the offshore dynamics to the nearshore location of the ecosystem (without traversing it), considering the relevant wave transformation processes.

Step 3: Modelling the effect of ecosystems on marine dynamics.

Step 4: Calculation of flood height and resulting impact on the coast, that is to say, the land area covered by this water level. This is calculated for each ecosystem, in line with different coverage and status scenarios, depending on the intended response. For example, to obtain the present value of a reef, two scenarios should be tested: one representing the current situation and a second hypothetical scenario of reef loss. The difference between the two will be the benefit or value of that ecosystem.

Step 5: Calculation of flooding consequences in social and economic terms using an expected damage function approach for events with different return periods, and annualization of these consequences.

Illustration 4 Key steps for estimating the flood protection benefits provided by marine habitats



Source: M. W. Beck and G. M. Lange (eds.), “Managing coasts with natural solutions: guidelines for measuring and valuing the coastal protection services of mangroves and coral reefs”, *Waves Technical Report*, No. 103340, Washington, D.C., Wealth Accounting and the Valuation of Ecosystem Services (WAVES)/ World Bank, 2016

II. Results

A. Valuing Cuba's coral reefs

1. Benefits of flood protection at national level

Cuba's coral reefs protect an average of 8,042 people every year, avoiding more than US\$ 401 million in economic losses and reducing the flooded area by 76 km², or the equivalent of around 15,000 football pitches (see table 1).

Looking at the response of coral reefs to sporadic extreme weather events, such as a tropical cyclone with a 10-year return period, the benefits of Cuba's coral reefs are considerable: up to 1,398 km², 121,893 people and US\$ 5.031 billion (see table 1).

These values increase significantly for less frequent, but more intense, events with a 100-year return period, rising to an expected protection of 2,849 km², 302,660 people and US\$ 14.155 billion (see table 1).

Table 1
Cuba: damage caused in coral areas under scenarios with and without coral, and ecosystem benefits in the case of different coastal flooding events

		Coral reefs (absolute value)				
		Annual expected damages/benefit	10-year return period	25-year return period	50-year return period	100-year return period
Flooded area (square kilometres)	With coral	40	1 579	1 842	2 110	2 536
	Without coral	117	2 977	4 161	4 801	5 385
	Benefit	76	1 398	2 320	2 691	2 849
People affected by flooding (number of people)	With coral	1 128	3 011	9 079	20 718	30 467
	Without coral	9 170	124 904	209 571	282 089	333 127
	Benefit	8 042	121 893	200 492	261 371	302 660

Table 1 (concluded)

		Coral reefs (absolute value)				
		Annual expected damages/benefit	10-year return period	25-year return period	50-year return period	100-year return period
Built capital lost from flooding (millions of dollars)	With coral	41	69	287	675	1 301
	Without coral	442	5 101	9 050	12 586	15 457
	Benefit	401	5 031	8 762	11 911	14 155

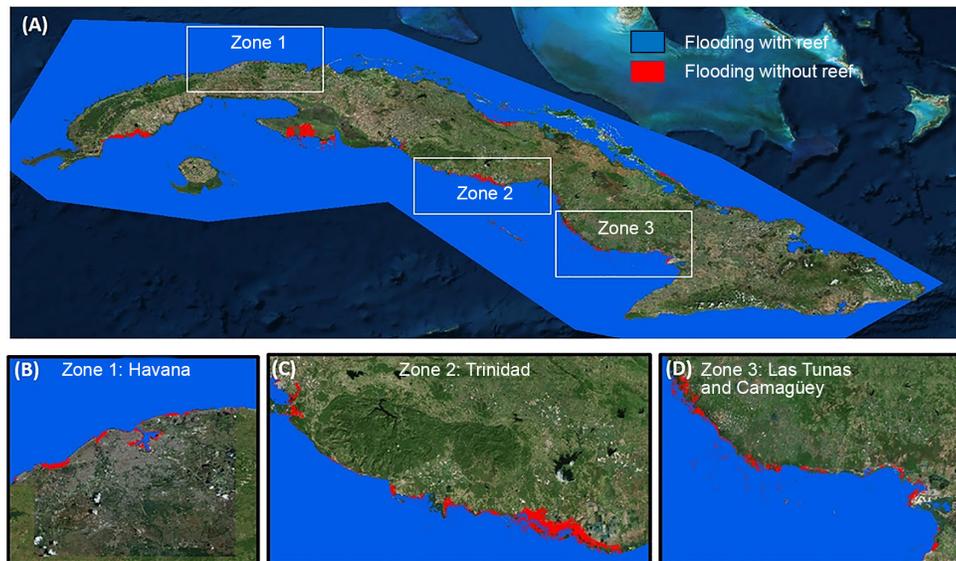
Source: Prepared by the authors.

Note: Figures are national aggregates.

2. Benefits of flood protection at local level

While the valuation of ecosystem benefits in terms of national aggregates provides a rough indicator of the level of protection they offer, the spatial distribution of those benefits needs to be determined in order to discern and apply concrete conservation or restoration policies and to identify the areas where ecosystems play the greatest role. Map 2 (part A) shows a flood map of the whole of Cuba under two scenarios—with and without reef—for a 10-year return-period flooding event. Areas marked in red denote the additional flooding that would occur in the event of a complete loss of the coral ecosystem. One of the areas affected would be the city of Havana (zone 1) where, even though there would not be much flooding, a high percentage of the country's capital is located, making the impact much greater than in areas where flooding extends significantly further inland (zone 2 and zone 3).

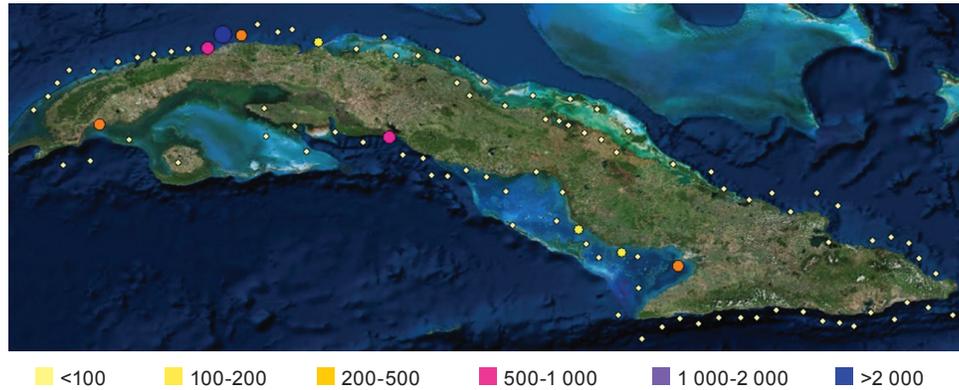
Map 2
Comparison of a 10-year return-period flooding event with and without coral reefs



Source: Prepared by the authors.

The annual number of people protected from coastal flooding by coral reefs coincides with the most highly populated coastal areas. Most of the population deriving direct benefit from this ecosystem (over 3,000 people per year) is found in Havana. The next most important areas shown in map 3 are: Varadero (between 100 people and 200 people protected per year); Bahía de Cortés and Manzanillo (between 200 people and 500 people protected per year); and Cienfuegos (between 500 people and 1,000 people protected per year).

Map 3
Cuba: annual expected benefits from the presence of coral reefs
(Number of people)

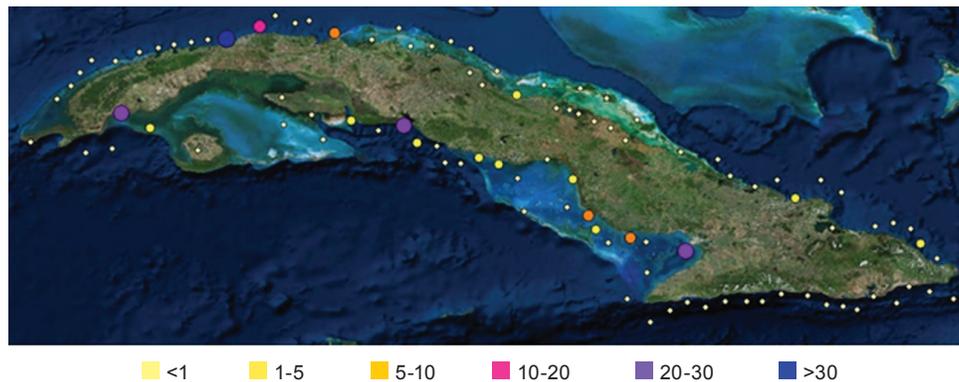


Source: Prepared by the authors.

Note: Aggregation at a scale of 20-kilometre coastal units.

An analysis of the distribution of aggregate annual economic benefits in study units of 20-km stretches of coastline (local scale) confirms the trend shown in map 2. The Havana area enjoys most of the economic benefit from Cuba's corals (more than US\$ 30 million per year). Other areas sensitive to the loss of this ecosystem are Varadero (between US\$ 5 million and US\$ 10 million per year); and the front of Cayos de San Felipe, Cienfuegos and Manzanillo (between US\$ 20 million and US\$ 30 million).

Map 4
Cuba: annual expected benefits from the presence of coral reefs
(Millions of dollars)



Source: Prepared by the authors.

Note: Aggregation at a scale of 20-kilometre coastal units.

B. Valuing Cuba's mangroves

1. Benefits of flood protection at national level

Cuba's mangroves protect an average of 22,476 people each year, avoiding more than US\$ 150 million in economic losses and reducing the flooded area by 222 km², or the equivalent of around 40,000 football pitches (see table 2).

Looking at the response of mangroves to sporadic extreme weather events, such as a 10-year return period tropical cyclone, the benefits of Cuba's mangroves are considerable: up to 324 km², 29,982 people and US\$ 226 million (see table 2).

These values are much higher for less frequent, but more intense, events with a 100-year return period, rising to an expected protection of 4,551 km², 322,006 people and US\$ 2.559 billion (see table 2).

Table 2
Cuba: damage caused in mangrove areas under scenarios with and without mangroves, and ecosystem benefits in the case of different coastal flooding events

		Mangroves (absolute value)				
		Annual expected damages/benefit	10-year return period	25-year return period	50-year return period	100-year return period
Flooded area (square kilometres)	With mangroves	523	796	1 173	1 898	3 313
	Without mangroves	745	1 121	2 120	3 878	7 865
	Benefit	222	324	946	1 980	4 551
People affected by flooding (number of people)	With mangroves	41 270	63 021	88 468	139 212	247 443
	Without mangroves	63 745	93 003	169 950	294 685	569 449
	Benefit	22 476	29 982	81 481	155 473	322 006
Built capital lost from flooding (millions of dollars)	With mangroves	301	453	639	1 019	1 890
	Without mangroves	455	679	1 222	2 154	4 449
	Benefit	154	226	583	1 136	2 559

Source: Prepared by the authors.

Note: Figures are national aggregates.

2. Benefits of flood protection at local level

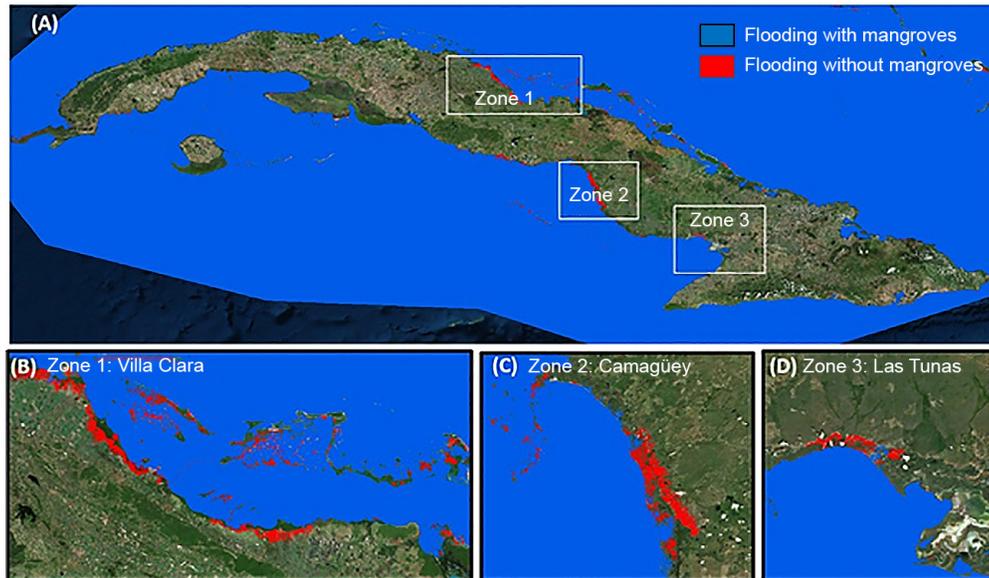
In parallel with the analysis of coral reefs, a study was made of the spatial distribution of the benefits of mangroves on the island of Cuba. As map 1 shows, mangroves are distributed more homogeneously throughout the country, with the result that the benefits are also more evenly distributed across the island. Map 5 shows the areas most affected in terms of additional flooded area as the result of a 10-year return-period event where all mangrove cover would be lost. These areas do not necessarily derive greater socioeconomic benefit, as exemplified by zone 2 (Camagüey), where the maps of annual expected benefits to people and built capital (see map 6 and map 7 respectively) do not show excessively high values compared with other areas, like zone 3 (Las Tunas).

On the southern coast of Artemisa and Mayabeque, specifically in the Playa Majana, Guanímar and Playa Cajío areas, protection levels extend to between 5,000 people and 20,000 people per year and up to US\$ 100 million. The bay in Granma province (zone 3) also provides high levels of protection, with an annual aggregate distribution of ecosystem benefit of around 5,000 people and US\$ 50 million for every

20-km unit of coast. In zone 1, in Villa Clara province, where the flooded area would be a significantly greater in the case of mangrove cover loss, the ecosystem benefit totals 10,000 people and between US\$ 50 million and US\$ 100 million per year. In zone 2, on the southern coast of Camagüey province, where flooding would also cover an extensive area of coastline, the socioeconomic effects are minor.

Map 5

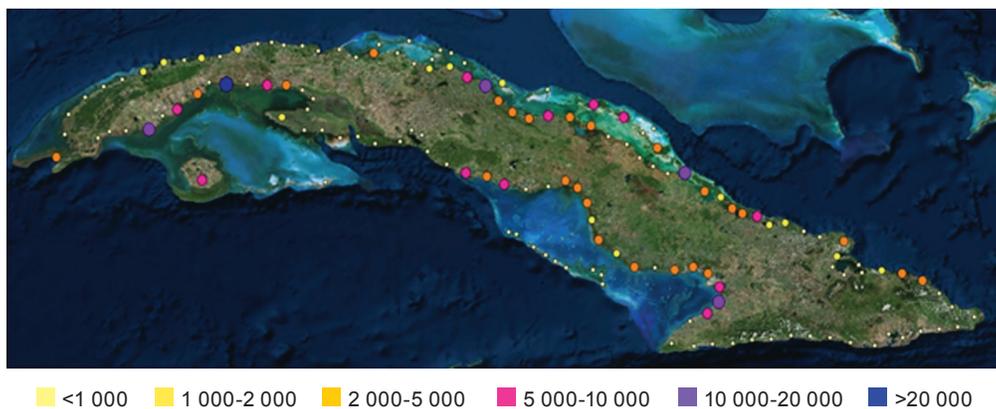
Cuba: comparison of a 10-year return-period flooding event with and without mangroves



Source: Prepared by the authors.

Map 6

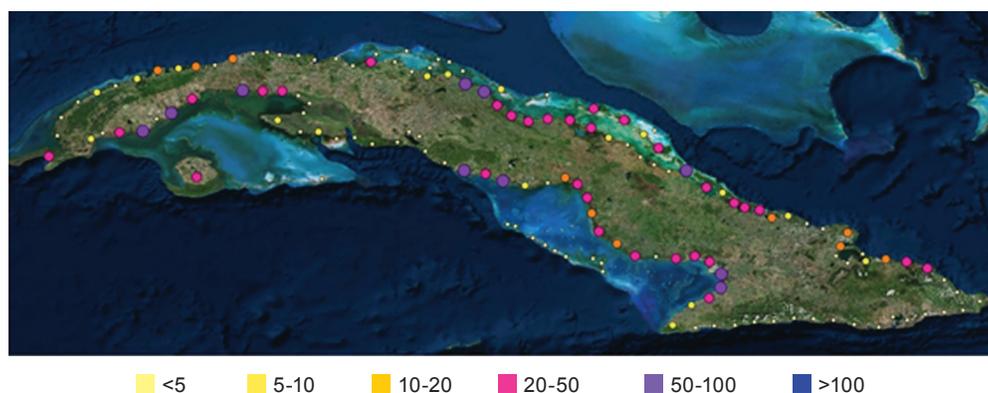
Cuba: annual expected benefits from the existence of mangroves
(Number of people)



Source: Prepared by the authors.

Note: Aggregation at a scale of 20-kilometre coastal units.

Map 7
Cuba: annual expected benefits from the existence of mangroves
(Millions of dollars)



Source: Prepared by the authors.

Note: Aggregation at a scale of 20-kilometre coastal units.

C. Comparison of the valuation of Cuba's corals and mangroves

1. Benefits of flood protection at national level

A comparison of the annual expected benefits of the two ecosystems in absolute terms shows clearly that the flood-protected area and number of people affected are greater in the case of mangroves than in the case of corals: 222 km² compared with 76 km² and 22,476 people compared with 8,043 people, respectively. However, when these figures are translated into economic terms by quantifying the value of built capital (residential and industrial) protected, the trend is reversed, with coral reefs providing the greatest economic value: US\$ 400 million, compared with US\$ 150 million in the case of mangroves (see table 1 and table 2).

This trend reversal can be observed on a global scale in countries where tourism is one of the biggest resources, with coral reefs serving as an attraction to visitors, leading to valuable assets (such as hotels) being sited and built in coastal areas with a reef. However, in countries (mostly with lower purchasing power) where people tend to settle close to mangroves because of their potential resources (fisheries, aquaculture, protection), mangroves have a greater economic value than coral reefs.

It is also important to ascertain the value per unit area to ensure a consistent comparison between the benefits of each ecosystem and to determine the economic efficiency or maximum investment needed to conserve existing ecosystems. In the case of coral reefs, the annual expected benefit is valued at 0.15 hectares, 0.16 people and US\$ 7,739 per hectare of reef. In the case of mangroves, the relative benefit is 0.05 hectares, 0.05 people and US\$ 377 per hectare of mangrove (see figure 1 and table 3).

A nationwide analysis of the flood protection service provided by Cuba's coral reefs and mangroves can be summarized as follows.

- In terms of absolute annual protection, while mangroves protect a wider area and a larger number of people than corals, the value of protected assets is highest in the case of reefs.

- In relative annual terms, the contribution of coral is always greater, emphasizing the need to invest in conserving existing reefs, with a maximum annual investment of up to US\$ 7,739 per hectare of reef for such an investment to be cost-efficient from a flood protection standpoint.
- While the response of coral reefs to extreme events is significantly greater than that of mangroves in economic terms (as with annual values), the analysis differs slightly in terms of people protected and land area not flooded: corals provide greater protection against 10-year to 50-year return-period events, whereas mangroves provide greater protection against 100-year return-period events (see table 3).

Table 3
Cuba: relative damages per hectare produced in coral and mangrove ecosystems under scenarios with and without presence of the ecosystem, and relative benefits in the case of different coastal flooding events

A. Coral areas
(Total area: 51,782 hectares)

		CORAL REEFS (relative value per hectare of reef)				
		Annual expected damages/benefit	10-year return period	25-year return period	50-year return period	100-year return period
Flooded area (hectares)	With coral	0.08	3.05	3.56	4.08	4.90
	Without coral	0.23	5.75	8.04	9.27	10.40
	Benefit	0.15	2.70	4.48	5.20	5.50
People affected by flooding (number of people)	With coral	0.02	0.06	0.18	0.40	0.59
	Without coral	0.18	2.41	4.05	5.45	6.43
	Benefit	0.16	2.35	3.87	5.05	5.84
Built capital lost from flooding (dollars)	With coral	798	1 340	5 552	13 028	25 133
	Without coral	8 537	98 500	174 760	243 055	298 495
	Benefit	7 739	97 160	169 208	230 027	273 362

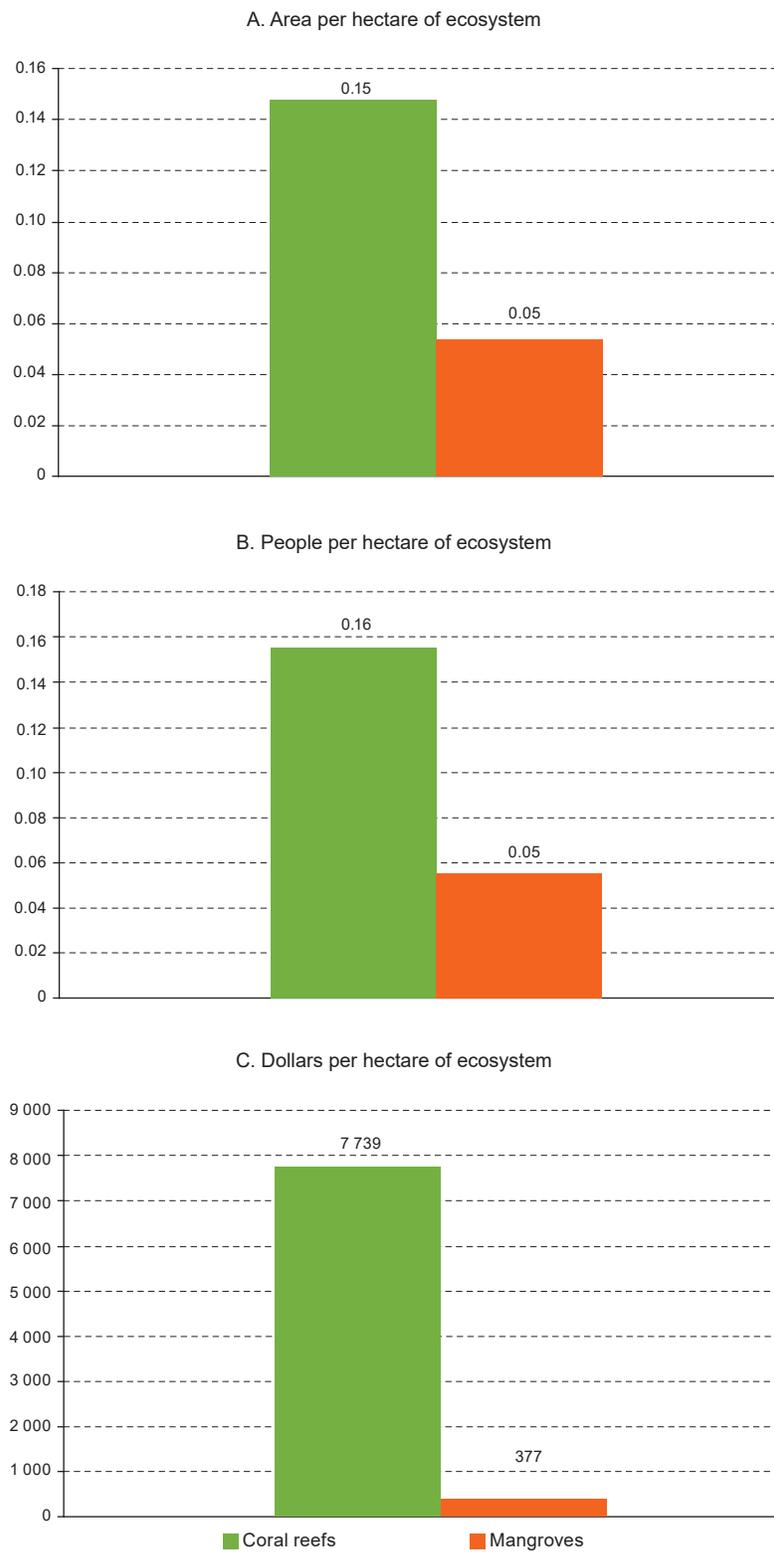
B. Mangrove areas
(Total area: 409,090 hectares)

		MANGROVES (relative value per hectare of mangrove)				
		Annual expected damages/benefit	10-year return period	25-year return period	50-year return period	100-year return period
Flooded area (hectares)	With mangroves	0.13	0.19	0.29	0.46	0.81
	Without mangroves	0.18	0.27	0.52	0.95	1.92
	Benefit	0.05	0.08	0.23	0.48	1.11
People affected by flooding (number of people)	With mangroves	0.10	0.15	0.22	0.34	0.60
	Without mangroves	0.16	0.23	0.42	0.72	1.39
	Benefit	0.05	0.07	0.20	0.38	0.79
Built capital lost from flooding (dollars)	With mangroves	735	1 107	1 561	2 491	4 620
	Without mangroves	1 111	1 660	2 987	5 266	10 876
	Benefit	377	554	1 426	2 776	6 256

Source: Prepared by the authors.

Note: Figures are national aggregates.

Figure 1
Cuba: relative annual benefits provided by coral reefs and mangroves
in the case of coastal flooding



Source: Prepared by the authors.

2. Benefits of flood protection at local level

A comparison of the spatial distribution of the benefit derived from the presence of coral and mangrove ecosystems on the island of Cuba reveals a number of differences. First, the distribution of mangroves throughout the country is more uniform than that of coral reefs, providing more evenly distributed protection for the entire coast than in the case of coral systems whose protection capacity is concentrated in specific areas. This more uniform distribution of mangroves can be seen in map 1 and is confirmed in map 3 and map 4 (people and built capital protected by corals) and in map 6 and map 7 (people and built capital protected by mangroves).

One of the differences observed when comparing the two ecosystems in maps of spatial aggregation of 20-km coastal units is the amount of benefit provided by each ecosystem. The population protected by coral reefs ranges from 0 people to 2,000 people, while that protected by mangroves ranges from 0 people to 20,000 people (up to 10 times more). The same applies when comparing the range of variation of built capital protected: up to US\$ 30 million in the case of corals and over US\$ 100 million in the case of mangroves.

The areas where corals provide the greatest protection to both people and built capital are Havana, Cienfuegos, Bahía de Cortés, Manzanillo, Varadero and Cayos de San Felipe. The areas that receive the greatest benefit from mangroves are the southern coast of Artemisa and Mayabeque, Granma bay, Villa Clara province and Camagüey.

III. Conclusions

A. Conclusions drawn from the results

Cuba's barrier reefs, along with its mangroves, play a key role in reducing coastal flood risk. After having analysed the two ecosystems independently, a calculation was made of benefit they provide in terms of land area, people and built capital. The presence of existing coral reefs provides an annual benefit of 65% less flooded area, 87% fewer people affected and 90% less built capital lost. The contribution of mangroves is 30% less flooded area, 35% fewer people affected and 34% less built capital lost.

The greatest socioeconomic benefits are found in densely populated areas, especially the Havana area, Varadero and Manzanillo. While many hectares all along the Cuban coast receive protection from ecosystems, not all these areas contain exposed assets that increase the value of the country's corals and mangroves. This highlights the need for a multilevel study. While aggregate results at country level can be used to make an initial valuation and provide a rough indication of the value of nature's services, a more detailed level is required to discern and pinpoint hotspots where the greatest ecosystem benefits are concentrated. In order to determine spatial distribution, damages were aggregated at a scale of 20-km coastal units, as this an appropriate unit size for the proposal of concrete adaptation measures and actions for conserving natural capital and maintaining protection levels.

B. Where Cuba stands in relation to other countries

A comparison of the value of Cuba's ecosystems with the value for all countries in the world with corals or mangroves around their coastlines, puts in context the importance of coastal natural resources for flood protection.

Coral reefs provide protection to 260,000 people worldwide (8,000 in Cuba, or 3% of the total) and avoid the loss of US\$ 3.370 billion globally (US\$ 401 million in Cuba, or 12% of the total).

The contribution of mangroves to global risk reduction is to protect 16.5 million people (over 22,400 in Cuba, or 0.14%) and avoid the loss of US\$ 71 billion (US\$ 154 million in Cuba, or 0.2% of the world total).

Table 4
Countries that receive the most flood protection benefits from coral reefs

Annual averted damages (millions of dollars)		Annual averted damages (percentage of gross domestic product)		
1	Indonesia	639	Cayman Islands	0.98
2	Philippines	590	Belize	0.37
3	Malaysia	452	Grenada	0.30
4	Mexico	452	Cuba	0.25
5	Cuba	401	Bahamas	0.16
6	Saudi Arabia	138	Jamaica	0.14
7	Dominican Republic	96	Philippines	0.13
8	United States of America	94	Antigua and Barbuda	0.13
9	Taiwan Province of China	61	Dominican Republic	0.11
10	Jamaica	46	Malaysia	0.09
11	Viet Nam	42	Seychelles	0.06
12	Myanmar	33	Turks and Caicos Islands	0.06
13	Thailand	32	Guadeloupe	0.05
14	Bahamas	14	Indonesia	0.04
15	Belize	9	Solomon Islands	0.04

Source: M. W. Beck and others, “The global flood protection savings provided by coral reefs”, *Nature Communications*, vol. 9, No. 2186, Springer Nature, 2018.

The figures show clearly that Cuba’s coral reefs are more important on a global scale than its mangroves. Cuba ranks fifth in the world in terms of the annual economic benefit provided by coral reefs, surpassed only by Indonesia, the Philippines, Malaysia and Mexico, and ranks fourth in terms of the proportion of gross domestic product (GDP) protected by reefs, with 0.25% of the island’s GDP protected (see table 4).

Cuba ranks 33rd in the world in terms of the economic benefits provided by mangroves, the top five being China (US\$ 19 billion), the United States (US\$ 13 billion), India (US\$ 9 billion), Mexico (US\$ 9 billion) and Vietnam (US\$ 7 billion). Neither does Cuba rank among the leaders when it comes to the proportion of GDP protected by mangroves.

C. Implications and recommendations

These social and economic valuations of mangroves and corals could serve as input for policies and practices in the areas of sustainable development, risk reduction and natural resource conservation. Showing the spatial distribution of the benefit of Cuba’s corals and mangroves makes it possible to pinpoint the places where ecosystem management would provide the greatest benefits. Valuing these benefits in terms familiar to financial institutions and governments (annual expected value) allows them to be included directly in national accounts and enables risk-reduction decisions to be taken based on environmental conservation policies. In turn, these results could minimize ecosystem-related socioeconomic losses and involve society in the important task of conserving the existing natural capital.

In practical terms, a wide range of measures could be implemented to encourage the conservation of mangroves and corals, some of which are summarized below.

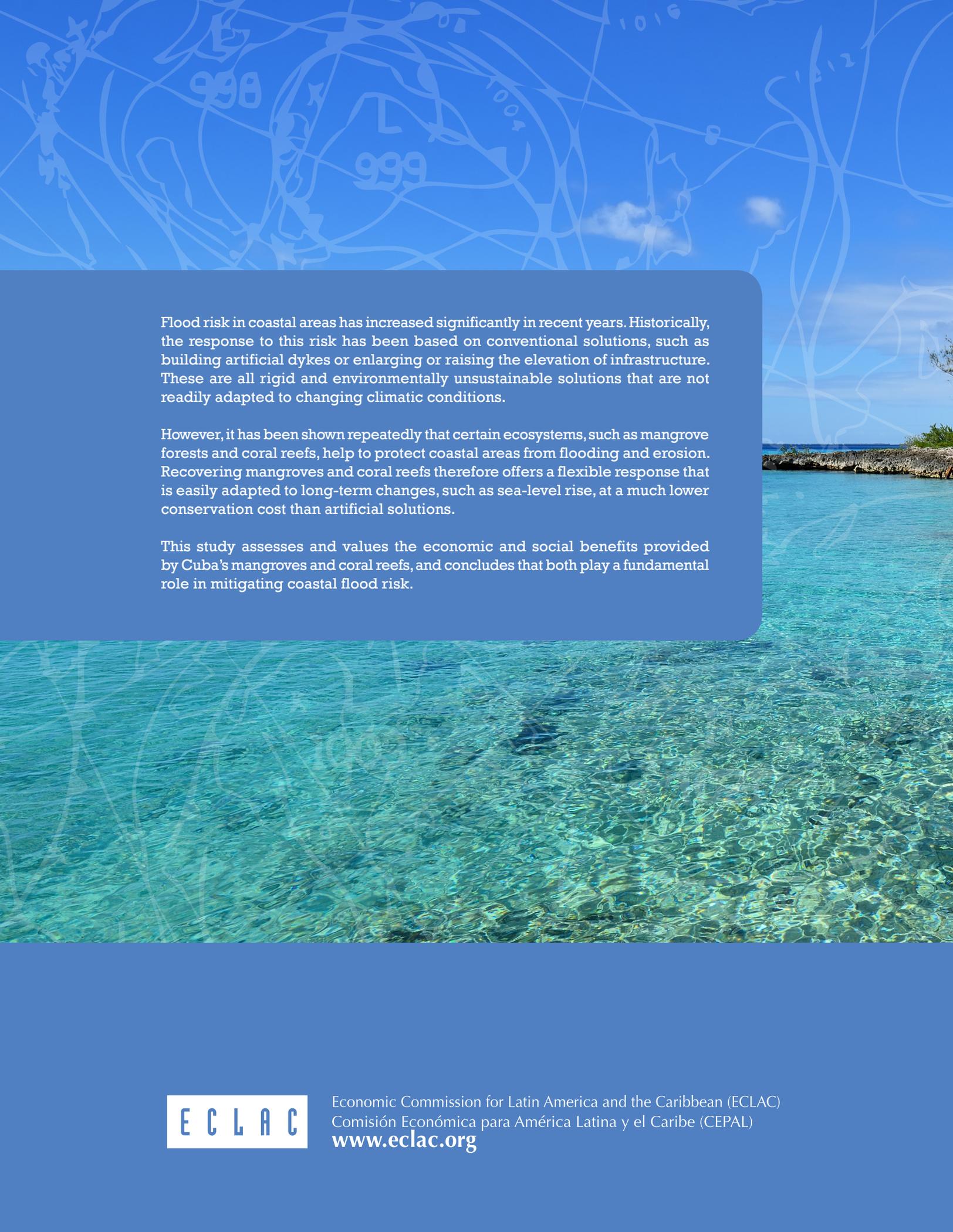
- Governments and non-governmental organizations should raise the scale of restoration measures to the country level rather than focusing solely on local and short-term issues.
- Coastal defences based on reef structures or mangrove forests should be included in national adaptation, land-use and risk-management policies and in development plans.

- Engineers and insurers should include coastal ecosystems in their cost-benefit analyses, while governments and clients should demand this.
- Economists should call for ecosystems to be included in national and regional accounts.
- Domestic and international investors should provide financial support for coral reef and mangrove restoration to reduce flood risk.
- Natural disaster managers, insurers and risk modellers should take into account the benefits of natural barriers in their analyses.
- Financial institutions, insurers, non-governmental organizations and governments should use these flood risk-reduction benefits to create new financial products that support ecosystem conservation and restoration.

Bibliography

- Beck, M. W. and others (2018a), *The Global Value of Mangroves for Risk Reduction. Summary Report*, Berlin, The Nature Conservancy (TNC) [online] <https://conservationgateway.org/ConservationPractices/Marine/crr/library/Documents/GlobalMangrovesRiskReductionSummaryReport10.7291/V9930RBC.pdf>.
- (2018b), “The global flood protection savings provided by coral reefs”, *Nature Communications*, vol. 9, No. 2186.
- Cesar, H., L. Burke and L. Pet-Soede (2003), *The economics of worldwide coral reef degradation*, Zeist, Cesar Environmental Economics Consulting (CEEC).
- Clark, S. and A. J. Edwards (1999), “An evaluation of artificial reef structures as tools for marine habitat rehabilitation in the Maldives”, *Aquatic Conservation: Marine and Freshwater Ecosystems*, vol. 9, No. 1.
- (1995), “Coral transplantation as an aid to reef rehabilitation: evaluation of a case study in the Maldivian Islands”, *Coral Reefs*, vol. 14, No. 4.
- Costanza, R. and others (1997), “The value of the world’s ecosystem services and natural capital”, *Nature*, No. 387.
- De Groot, R. and others (2012), “Global estimates of the value of ecosystems and their services in monetary units”, *Ecosystem Services*, vol. 1, No. 1.
- Ferrario, F. and others (2014), “The effectiveness of coral reefs for coastal hazard risk reduction and adaptation”, *Nature Communications*, vol. 5, No. 3794.
- Galford, G. L. and others (2018), “Cuban land use and conservation, from rainforests to coral reefs”, *Bulletin of Marine Science*, vol. 94, No. 2.
- González Díaz, P. and others (2018), “Status of Cuban coral reefs”, *Bulletin of Marine Science*, vol. 94, No. 2.
- Losada Rodríguez, Í. and others (2018), *The Global Value of Mangroves for Risk Reduction. Technical Report*, Berlin, The Nature Conservancy (TNC)/Environmental Hydraulics Institute (IH Cantabria)/University of California Santa Cruz/Bündnis Entwicklung Hilft [online] <https://conservationgateway.org/ConservationPractices/Marine/crr/library/Documents/GlobalMangrovesRiskReductionTechnicalReport10.7291/V9DV1H2S.pdf>.
- (2017), “Valuing protective services of mangroves in the Philippines: technical report”, *Working Paper*, No. 117830, Washington, D.C., World Bank.
- Mehvar, S. and others (2018), “Quantifying economic value of coastal ecosystem services: a review”, *Journal of Marine Science and Engineering*, vol. 6, No. 5.
- Morris, R. L. and others (2018), “From grey to green: efficacy of eco-engineering solutions for nature-based coastal defence”, *Global Change Biology*, vol. 24, No. 5.
- Reguero, B. G. and others (2018), “Coral reefs for coastal protection: a new methodological approach and engineering case study in Grenada”, *Journal of Environmental Management*, vol. 210.
- Small, C. and R. J. Nicholls (2003), “A global analysis of human settlement in coastal zones”, *Journal of Coastal Research*, vol. 19, No. 3, Coastal Education and Research Foundation.
- Spalding, M., M. Kainuma and L. Collins (2010), *World Atlas of Mangroves*, London/Washington, D.C., Earthscan.

- Spalding, M., C. Ravilious and E. Green (2001), *World Atlas of Coral Reefs*, Berkeley, University of California Press.
- Spalding, M. and others (2017), "Mapping the global value and distribution of coral reef tourism", *Marine Policy*, vol. 82.
- Tschirky, P., K. Hall and D. Turcke (2001), "Wave attenuation by emergent wetland vegetation", *Coastal Engineering 2000*, vol. I, B. Edge (ed.), Reston, American Society of Civil Engineers (ASCE).



Flood risk in coastal areas has increased significantly in recent years. Historically, the response to this risk has been based on conventional solutions, such as building artificial dykes or enlarging or raising the elevation of infrastructure. These are all rigid and environmentally unsustainable solutions that are not readily adapted to changing climatic conditions.

However, it has been shown repeatedly that certain ecosystems, such as mangrove forests and coral reefs, help to protect coastal areas from flooding and erosion. Recovering mangroves and coral reefs therefore offers a flexible response that is easily adapted to long-term changes, such as sea-level rise, at a much lower conservation cost than artificial solutions.

This study assesses and values the economic and social benefits provided by Cuba's mangroves and coral reefs, and concludes that both play a fundamental role in mitigating coastal flood risk.

