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Sustainable Asset Valuation of Restoring the Mallorquín Swamp, Colombia

NBI REPORT

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Sustainable Asset Valuation of Restoring the Mallorquín Swamp, Colombia

May 2023

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Author contributions

All authors are listed in alphabetical order. Emma Cutler developed the system dynamics model and integrated cost-benefit analysis, coordinated communications with WRI and the City of Barranquilla, and led the writing of the report. Marco Guzzetti conducted the spatial analysis and prepared the corresponding technical appendix. Morten Siersted led the financial analysis. Edoardo Carlucci contributed to the financial analysis and writing of the report.

Executive Summary

Barranquilla is Colombia's fourth largest city and sits along the Caribbean coast. Population expansion in and around Barranquilla has created numerous environmental problems. For example, encroachment in the Mallorquín Swamp on the northern edge of the city has made residents more vulnerable to climate change and harmed livelihoods. Mangroves in the swamp have historically provided significant value by mitigating floods, protecting biodiversity and fisheries, storing carbon, and supporting tourism. However, urban development and waste disposal have damaged the ecosystem and limited the swamp's capacity to provide these important services.

As part of the BiodiverCities initiative, mangrove restoration is underway in the Mallorquín Swamp. This will help stabilize the coastline and protect against floods. It will also increase nursery grounds for fisheries, improve water quality, and sequester carbon. Furthermore, an eco-park is being developed to support ecotourism as a sustainable source of income for the local community.

Community engagement is a critical part of this project. Members of the communities have been involved in the planting and maintenance activities. Residents can also participate in and benefit from ecotourism in the swamp.

By improving environmental quality, the project will directly benefit 17,206 people (8,660 men and 8,546 women) living in the Las Flores and La Playa neighbourhoods next to and within the Mallorquín Swamp. The entire Barranquilla metropolitan area of approximately 2 million people will benefit from protection against extreme weather events and increased accessibility of urban green spaces.

We conducted a sustainable asset valuation (SAVi) assessment of nature-based infrastructure (NBI) in the Mallorquín Swamp. Throughout the analysis, we engaged with World Resources Institute (WRI) Colombia and Barranquilla Verde (the city's environmental authority). The assessment incorporates a spatially explicit analysis with a system dynamics model to quantify the economic, environmental, and social impacts of mangrove restoration in Barranquilla. We used an integrated cost-benefit analysis to assess the monetized social, economic, and environmental outcomes of restoration over 20 years. We evaluate the value for money of the project and calculated the benefit-to-cost ratio (BCR), the net integrated value in present value (PV) terms and the internal rate of return (IRR) of net integrated value (Table ES1).

Finally, we conducted a financing analysis to assess possible financing structures for the mangrove restoration project under different climate scenarios and tourism investments. To do so, we built a financing model that considers a combination of debt and non-repayable grant (50% debt and 50% grant). To assess the capacity of the project to cover implementation costs and debt, we looked at potential alternative revenue streams that could be generated by the project (e.g., tourism benefits, wages, fishing income, and avoided flood and erosion damage). We then determine the level of benefits and avoided costs that need to be converted into a revenue stream to make the project break even financially (Table ES2).

We compared the outcomes of the NBI to those of grey infrastructure that provides similar services. Specifically, we consider a breakwater to reduce flooding and erosion, a wastewater treatment plant to improve water quality, and photovoltaic solar panels to reduce greenhouse gas emissions.

For both the NBI and grey infrastructure options, we assessed the outcomes with and without new tourism investments. We then simulated each intervention scenario twice—once assuming a low climate change scenario and once assuming a high climate change scenario. With two options for infrastructure type (NBI or grey), three tourism scenarios (high tourism, low tourism, or no tourism) and two climate scenarios, we included a total of 12 scenarios.

By examining the total value, including social and environmental benefits, of mangrove restoration, we can start to understand the systemic effects of this NBI relative to grey infrastructure in a changing climate. Furthermore, we can identify the largest sources of value creation. This can provide evidence to support increased funding and financing for NBI.

Results

From the spatial analysis, we find that:

- **Restoration can counteract degradation and address environmental concerns**. In the area surrounding Barranquilla, land-use/land cover change has reduced carbon storage, worsened habitat quality, and increased nutrient export. From 2017–2021, carbon storage decreased by 16%, habitat quality declined 8%, nitrogen export rose 17%, and phosphorus increased 22%.

Key findings from the cost-benefit analysis (Table ES1) include:

- **NBI in the Mallorquín Swamp creates more value for society at a lower cost than the grey infrastructure alternative**. For example, the discounted BCR of NBI is about 1.2–1.4 times larger than that of grey infrastructure.
- **The restored swamp could support the local economy and provide large climate adaptation benefits**. Specifically, the largest benefits of restoration are tourism income and avoided flood and erosion damages. In most scenarios assessed, these two indicators combined more than offset the cumulative construction and maintenance costs. When discounting the results, grey infrastructure is a worthwhile investment[1] only if tourism is also developed. Furthermore, both the NBI and grey infrastructure generate higher values when potential climate damages are larger.
- **Supporting the local economy by providing a sustainable source of income increases the net value of the investment**. Although not necessary to justify restoration, investing in ecotourism makes the NBI project more economically attractive. Despite the higher direct costs, including ecotourism increases the BCR by a factor of up to 2.3.

[1] In this context the investment is considered “worthwhile” from a societal perspective as the analysis integrates monetized benefits and avoided costs.

- **NBI can be an effective long-term climate adaptation strategy**. In the initial years after the project is completed, the amount of tourism has a large impact on net benefits, but after some time, the climate adaptation benefits become more important. Specifically, for approximately 15 years, the net benefits depend most strongly on the number of visitors. However, after 15 years, avoided climate damages play a larger role in determining the total value, and the NBI starts to outperform the grey infrastructure.

Table ES1. Discounted analysis

		High tourism		Low tourism		No tourism	
		NBI	Grey	NBI	Grey	NBI	Grey
Representative Concentration Pathway (RCP) 4.5	IRR of Net Integrated Value	20.2%	19.7%	10.6%	9.5%	6.9%	3.3%
	Net Integrated Value PV at Dec 22	231.32	212.16	67.45	48.30	11.68	-7.48
	BCR on PV at Dec 22	2.69	1.95	1.49	1.22	1.17	0.95
RCP 8.5	IRR of Net Integrated Value	21.2%	20.5%	12.3%	11.3%	10.7%	8.7%
	Net Integrated Value PV at Dec 22	263.81	243.85	99.94	79.99	44.16	24.21
	BCR on PV at Dec 22	2.92	2.09	1.73	1.36	1.64	1.16

The financing analysis (Table ES2) demonstrates that:

- **Investing in ecotourism infrastructure has a strong impact on the financial viability of the intervention**. Under the 50:50 debt-grant financing option, investing in ecotourism is critical, as the NBI actions alone would not generate the revenue streams required to cover project costs and repay the debt. Also, the grey infrastructure is unable to generate enough potential revenue streams from avoided costs and benefits without tourism.
- **NBI is more favourable than the grey infrastructure from a financing perspective**. When limited financial resources require the municipality to seek out blended finance options, the NBI is a better investment choice, as it needs to generate less of a revenue stream to finance the project. Under the only-grant financing option, we observe that a much smaller portion of monetized avoided costs and benefits is needed to make the NBI break even. The grey infrastructure needs a larger revenue stream from tourism and avoided flood/erosion damage to fund the intervention for both financing options.

Table ES2. Debt financing analysis (50% debt–50% grant and 100% grant) based on internalization of benefits and avoided costs

			NBI	Grey infrastructure
High tourism	RCP 4.5	50% debt–50% grant	43.0%	57.1%
		100% grant	5.8%	16.2%
	RCP 8.5	50% debt–50% grant	42.6%	55.3%
		100% grant	5.7%	15.7%
Low tourism	RCP 4.5	50% debt–50% grant	85.5%	96.6%
		100% grant	11.4%	27.4%
	RCP 8.5	50% debt–50% grant	83.7%	91.1%
		100% grant	11.2%	25.8%
No tourism	RCP 4.5	50% debt–50% grant	n.a	n.a
		100% grant	20.0%	46.9%
	RCP 8.5	50% debt–50% grant	n.a	n.a
		100% grant	18.6%	41.5%

The results of this work demonstrate that NBI in the Mallorquín Swamp is investment worthy and will provide benefits in the form of income and climate adaptation for the local community. The restoration will also create positive environmental benefits, including greenhouse gas mitigation and water quality improvements, although the magnitude of these benefits is small relative to the value of ecotourism and avoided flood and erosion damages. Furthermore, the analysis has shown that NBI creates more value and costs less than grey infrastructure that provides similar services.

These results can be used by a variety of stakeholders to increase investments in NBI (Table ES3). For example, the WRI, Barranquilla city government, and university partners can use these results to make the case for further swamp restoration. More generally, the results demonstrate the value of mangrove restoration and ecotourism and can support decisions to fund similar projects in other places.

Table ES3. How stakeholders and decision-makers can use the results of this assessment

Stakeholder	Role in the project	How can the stakeholder use the results of the assessment?
WRI	Supported the Colombian Ministry of Environment and Sustainable Development in the conceptualization of the BiodiverCities Initiative.	WRI can relay the results to city government and use this assessment to make the case that restoring mangroves will have positive net benefits for Barranquilla. WRI can also use its network to share the Barranquilla results and make the case for other coastal cities in Colombia and other countries.
EPA Barranquilla Verde	Implement nature-based solutions in Barranquilla, including ecological restoration of mangroves in the Mallorquín Swamp.	EPA Barranquilla Verde, the city's environment authority, can use the results of this assessment to inform decisions about scaling up mangrove restoration in the Mallorquín Swamp.
Universidad del Atlántico	Universidad del Atlántico has partnered with EPA Barranquilla Verde to implement mangrove restoration in the Mallorquín Swamp.	Universidad del Atlántico can use the results of this assessment to identify benefits of mangrove restoration and motivate participation in other NBI projects or scaling up this project.
Donors and funders	Funding NBI and biodiversity initiatives.	Donors and funders can use the results of this assessment to inform future funding decisions regarding BiodiverCities and other NBI projects.
National government	The Colombian government and the World Economic Forum have partnered to scale the global BiodiverCities by 2030 initiative.	The Colombian national government can use the results of this assessment to help make the case for urban NBI in other locations.
World Economic Forum	Together with the Colombian government, the World Economic Forum is leading the global BiodiverCities by 2030 initiative.	The World Economic Forum can use the results of this assessment to help make the case for urban NBI in other locations.

Glossary

Discounting: A finance process to determine the present value (PV) of a future cash value.

Indicator: Parameters of interest to one or several stakeholders that provide information about the development of key variables in the system over time and trends that unfold under specific conditions (United Nations Environment Programme [UNEP], 2014).

Internal Rate of Return (IRR): An indicator of the profitability prospects of a potential investment. The IRR is the discount rate that makes the net present value of all cash flows from a particular project equal to zero. Cash flows net of financing give us the equity IRR.

Integrated Valuation of Ecosystem Services and Trade-offs: "A suite of models used to map and value the goods and services from nature that sustain and fulfill human life. It helps explore how changes in ecosystems can lead to changes in the flows of many different benefits to people" (Natural Capital Project, 2019).

Methodology: The theoretical approach(es) used for the development of different types of analysis tools and simulation models. This body of knowledge describes both the underlying assumptions used as well as qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014).

Net benefits: The cumulative amount of monetary benefits accrued across all sectors and actors over the lifetime of investments compared to the baseline, reported by the intervention scenario.

Net Present Value (NPV): The difference between the PV of cash inflows net of financing costs and the PV of cash outflows. It is used to analyze the profitability of a projected investment or project.

Scenarios: Expectations about possible future events used to analyze potential responses to these new and upcoming developments. Consequently, scenario analysis is a speculative exercise in which several future development alternatives are identified, explained, and analyzed for discussion on what may cause them and the consequences these future paths may have on our system (e.g., a country or a business).

Simulation model: Models can be regarded as systemic maps in that they are simplifications of reality that help to reduce complexity and describe, at their core, how the system works. Simulation models are quantitative by nature and can be built using one or several methodologies (UNEP, 2014).

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1.0 Introduction

Barranquilla is Colombia's fourth largest city and sits along the Caribbean coast. Population expansion and development in and around the city has created numerous environmental problems. From 2010 through 2020, the urban population grew more than 20%, from 1.9 million to 2.3 million people (United Nations, Department of Economic and Social Affairs, Population Division, 2018). As a result, built-up areas have expanded and encroached on the Mallorquín Swamp on the northern edge of the city. This has made residents more vulnerable to climate change and harms livelihoods.

Mangroves in the Mallorquín Swamp have historically provided significant value by mitigating floods, protecting biodiversity and fisheries, storing carbon, and supporting tourism. However, urban development and waste disposal have damaged the ecosystem and limited the swamp's capacity to provide these important services. Port development has restricted the flow of fresh water from the Magdalena River into the swamp. As a result, the ecosystem, and specifically mangroves in the swamp, have suffered, and the Mallorquín Swamp has decreased in size by approximately 35%, from 1,065 hectares in 1984 to 694 hectares in 2017 (Barranquilla Verde, 2021). If no interventions are made, it is possible that by mid-century the existing mangroves may be reduced by an additional 50% (H. Donado, personal communication, November 17, 2021).

In response to this degradation, EPA Barranquilla Verde (Barranquilla's environmental authority) and Universidad del Atlántico have been leading a restoration project. In 2019, 20,100 mangrove seedlings were planted on 2.89 hectares of the coastal sand barrier that forms the northern border of the Mallorquín Swamp with the sea. An additional 40,000 seedlings were planted at the same site in 2021. This will help stabilize the coastline while protecting against floods, providing nursery grounds for fisheries, improving water quality, and sequestering carbon. Furthermore, an eco-park is being developed to support ecotourism in the swamp (H. Donado, personal communication, November 17, 2021).

By improving environmental quality in and around the swamp, the project will directly benefit 17,206 people (8,660 men and 8,546 women) living in the Las Flores and La Playa neighbourhoods next to and within the Mallorquín Swamp. The entire Barranquilla metropolitan area of approximately 2 million people will benefit from protection against extreme events and increased accessibility of urban green spaces (H. Donado, personal communication, November 17, 2021).

Community engagement has been a critical part of this project, and EPA Barranquilla Verde and Universidad del Atlántico have actively engaged with local communities. In particular, the Las Flores and La Playa communities were consulted through citizen participatory processes (H. Donado, personal communication, November 17, 2021). Members of these communities have been directly involved in restoration and maintenance activities (Barranquilla Verde, 2021). Furthermore, local residents can participate in and benefit from ecotourism in the swamp.

This project is part of the BiodiverCities by 2030 initiative, a collaboration between the World Economic Forum and the Government of Colombia, which aims to centre nature and biodiversity in urban development and infrastructure investments (Calvo & Arispe, 2021; World Economic Forum, 2022). The project also supports the country's second Institutional Strategy Update 2020-2023, the Sustainable Infrastructure Strategy for Competitiveness and Inclusive Growth, the Housing and Urban Development Sector Framework, and the Inter-American Development Bank Group's Country Strategy with Colombia 2019–2022 (Rojas et al., n.d.). At the city level, Barranquilla's Development Plan 2020–2023 has a BiodiverCity component that mentions this project.

This report presents the results of a sustainable asset valuation (SAVi) assessment for restoring the Mallorquín Swamp. Throughout the analysis, we engaged with WRI Colombia and Barranquilla Verde. The assessment incorporates a spatially explicit analysis with a system dynamics model to quantify the economic, environmental, and social outcomes of mangrove restoration in Barranquilla compared to grey infrastructure that provides similar services. These indicators are evaluated in an integrated cost-benefit analysis over 20 years. We also conduct a financing analysis that considers a combination of debt and non-repayable grants financed through alternative revenue streams generated by the internalization of benefits and avoided costs.

By examining the total value, including social and environmental benefits, of mangrove restoration, we can start to understand the systemic outcomes of this NBI relative to grey infrastructure. Furthermore, we can identify the sources of value creation and possible financing strategies. This can provide evidence to support increased funding and financing for NBI, including additional mangrove restoration projects in Colombia and elsewhere.

2.0 Methodology

The assessment combines a spatially explicit analysis with a system dynamics model to quantify direct and indirect costs and benefits of mangrove restoration in the Mallorquín Swamp and grey infrastructure alternatives that provide similar benefits. An Excel spreadsheet is used to assess the value creation over a 20-year period of analysis and financing strategies.

2.1 Causal Loop Diagram

We developed a causal loop diagram collaboratively with WRI staff. The diagram displays feedback loops related to environmental quality, health, income, and climate change (Figure 1). These dynamics help explain the observed degradation of the Mallorquín Swamp, and the diagram exposes possible outcomes from intervening in the system.

Box 1. Reading a causal loop diagram

A causal loop diagram shows relations between components of a system. Arrows indicate causality, and plus and minus signs are used to show the direction of causality. A plus sign means that two variables change in the same direction (a positive correlation), while a negative sign means that they change in opposite directions (a negative correlation). Feedback loops are labelled as either reinforcing (R) or balancing (B). A reinforcing loop indicates that a change in one variable will lead to further change in the same direction, whereas a balancing loop dampens change.

To understand Figure 1, we start on the left-hand side with "population." The arrows pointing from this variable indicate that population growth in and around Barranquilla has led to both formal urbanization and the development of informal settlements. Formal urbanization was driven primarily by the exploitation of natural resources, profiting from the good quality of the environment. Informal urbanization emerged out of necessity, with the area around the Mallorquín Swamp available to newcomers.

The causal loop diagram we have created shows how these two trends are interconnected. It shows how formal and informal development are both affected by environmental quality and the extent to which the wetland can provide income and security to the local population.

The high quality of the wetland has led to urbanization. This has resulted in increasing land encroachment over time. Combined with the creation of port infrastructure, this has reduced the extent of the wetland and negatively impacted mangroves. As a result, the quality of the wetland has declined, and so has the attractiveness of the areas for new developments (B5).

Informal settlements have developed in the wetland, which is peripheral to the main part of Barranquilla. Infrastructure, improved access to the area, and income opportunities have further stimulated informality around the swamp. Several trends have emerged as a result.

First, development of informal settlements has led to more waste and wastewater generation, which lowered water quality (R3). This reduced human health and security, leading to more informal settlements (R1). This further encroached on the swamp, resulting in a smaller extent of mangroves and lower quality of the wetland (R2).

Second, environmental degradation affected income creation. Specifically, the loss of mangroves limited fish supply directly, as habitat size shrank (R6), and indirectly, as habitat quality declined (R4). This lowered income, creating security problems and possibly strengthening the growth of informal settlements in the area.

Climate change has affected both formal and informal settlements, and will continue to do so in the future, especially if the loss of mangroves and wetland degradation continue. With more people exposed to extreme climate events and worse damage from these events, human health declined. This decreased security, so there are more informal settlements, more land encroachment, and a smaller extent of mangroves. With the loss of mangroves, exposure to and damage from extreme events increased (R7), and income and security declined (R8).

Overall, the diagram shows that, under a business-as-usual (BAU) scenario, the size of the Mallorquín Swamp and the extent of mangroves within the wetland will continue to decline. Urbanization and port development will continue to encroach on wetland area, while also disrupting the exchange of fresh and salt water, which is detrimental to habitat quality and biodiversity. With the loss of mangroves, erosion gets worse and climate vulnerability increases. Waste and wastewater generation from urbanization and informal settlements will continue to challenge water quality, which harms human health and well-being. Limited water flow exchange, loss of biodiversity, and reduced nutrient uptake from mangroves exacerbate water pollution.

Reduced wetland area, smaller mangrove extent, and declining habitat quality will lead to a further decline in fish supply, an important source of income for the local population. With less income, human well-being is further threatened. Loss of income and reduced human health may also increase illegal activities, making the area less safe. Similarly, declining wetland quality results in fewer people spending time in the area, and so security further declines. A less-safe area not only reduces human well-being but also makes the area less attractive to development.

Planting mangroves can combat these cycles of degradation and poverty by improving biodiversity, nutrient uptake, fish supply, and the overall quality of the wetland while also reducing exposure to and damage from extreme events. This can improve water quality, human health and well-being, income, and security. This would reduce land encroachment and allow the mangroves to further recover.

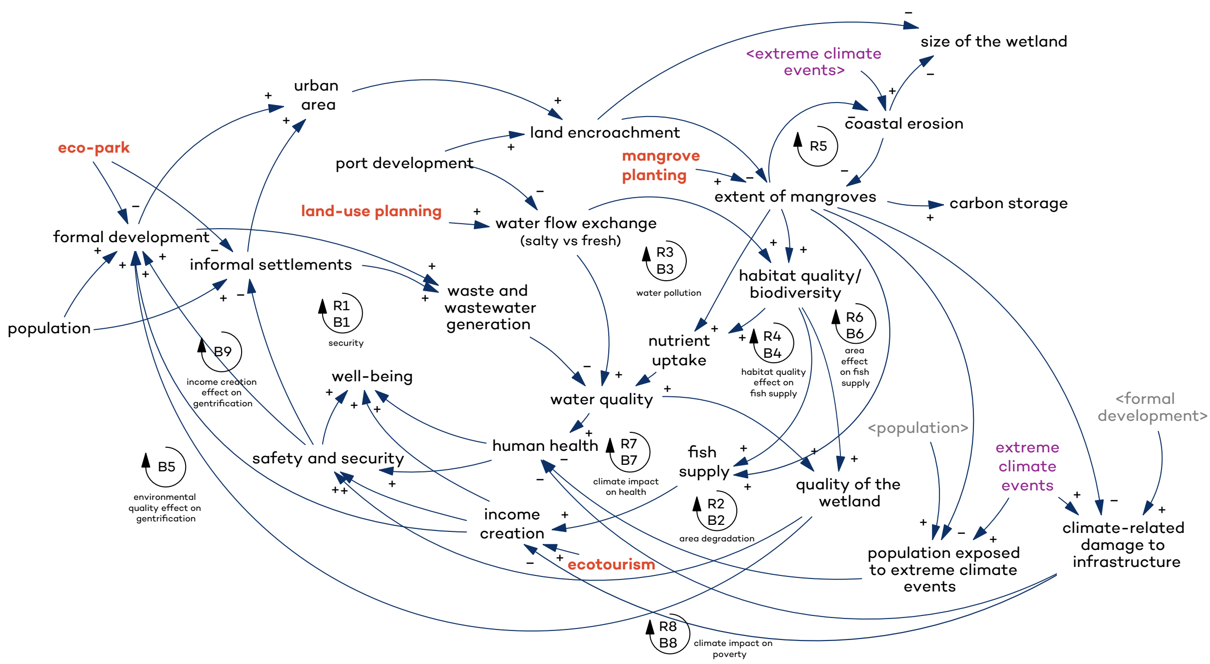
However, as income and the quality of the wetland improve, formal urban development may increase (see B5 related to environmental quality and B9 related to income creation) and informal settlements may be replaced with formal urbanization, limiting the extent to which the swamp can recover.

To avoid encroachment from this urbanization, ecotourism, through the creation of an eco-park, could create an additional source of income. This could help maximize the investment in mangrove restoration while also reducing urbanization and expansion of informal settlements.

Finally, restoring the flow of fresh water into the swamp could improve habitat and water quality, leading to better fish supply, income, health, and security.

These three interventions, when implemented simultaneously, may reduce informal settlements in the swamp. With less land encroachment, the wetland can further recover. Ultimately, this could create a situation in which there is a high-quality wetland (B2) that provides nutrient uptake (B3), income from fishing (B4 and B6), and protection from extreme events (B7 and B8). As safety increases (B1), the Mallorquín Swamp can provide income and climate resilience for a local population that coexists with a healthy wetland.

Figure 1. Causal loop diagram. Feedback loops explain observed wetland degradation and loss of mangroves. Interventions (shown in orange), such as planting mangroves, conserving the area as an eco-park, land-use planning, and development of ecotourism activities, can promote environmental recovery and improve human well-being. Instead of restoring the wetland, grey infrastructure could be used to directly address the circled impacts. Feedback loops are highlighted and explained in detail in the technical appendix (part A).



Source: Authors' diagram.

2.2 Spatially Explicit Analysis

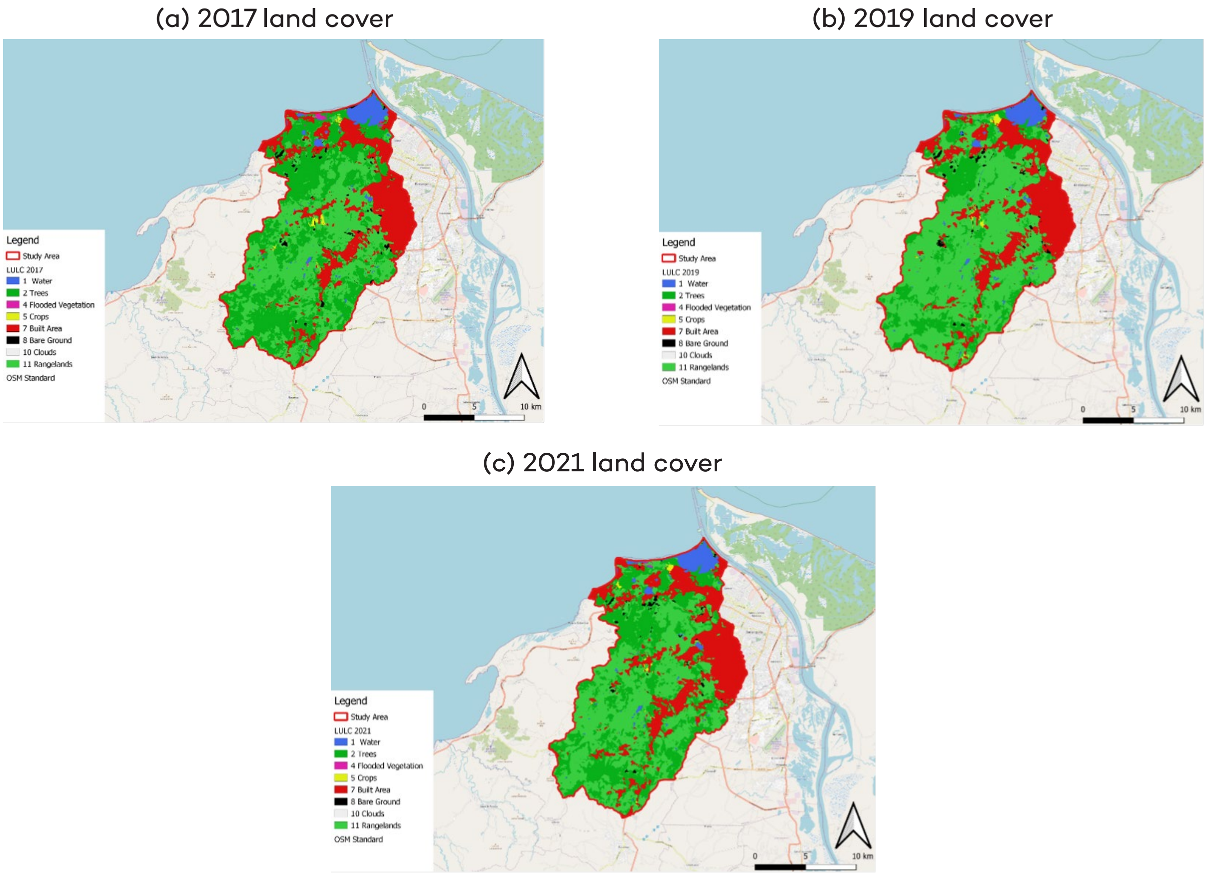
The spatially explicit analysis relies on the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) suite of models. These models, developed by the Natural Capital Project, take land-use/land cover maps as input and quantify a wide range of ecosystem services (Natural Capital Project, 2019).

The causal loop diagram (see Section 2.1) identified carbon storage, habitat quality, and nutrient export as relevant regulating ecosystem services associated with the Mallorquín Swamp.

Using land cover maps from 2017, 2019, and 2021 that included Barranquilla and the surrounding watersheds (Figure 2), we applied InVEST to calculate carbon storage, habitat quality, and nutrient export. This allowed us to track changes in these ecosystem services over time and provided historical context for the Mallorquín Swamp restoration project.

The InVEST carbon storage model calculates the amount of carbon stored in the landscape. Habitat quality is defined using a unitless index that ranges from 0 to 1, where 0 represents no habitat, and 1 is the highest quality habitat. This model relies on land cover and proximity to anthropogenic threats to assess habitat extent and quality. The InVEST nutrient export model calculates the annual mass of nitrogen and phosphorus exported by each pixel. For more information about the spatial analysis methods and assumptions, please see the technical appendix (part B).

Figure 2. Land cover maps used for the spatially explicit analysis. Since 2017, there has been a loss of trees and expansion of rangelands. Built-up area has also increased.



Source: Authors' diagram.

2.3 Integrated Cost-Benefit Analysis

We use a system dynamics model to quantitatively represent the dynamics captured in Figure 1. The model simulates land-use/land cover change, population, water quality, fishery production, coastal flooding and erosion, tourism, and carbon emissions, both with and without interventions. A full description of the model is in the technical appendix (part C).

When possible, we used local data provided by WRI and the City of Barranquilla. Data gaps were filled using international peer-reviewed literature and other assumptions validated by local stakeholders.

The system dynamics model generates an integrated cost-benefit analysis that monetizes the following indicators for nature-based and grey infrastructure:

- Construction/planting costs
- Maintenance costs
- Tourism revenue
- Wages from construction and maintenance
- Fishing income
- Avoided water pollution
- Avoided carbon emissions
- Avoided flood and erosion damages

We report the cumulative value of these indicators over time both undiscounted and discounted. For the undiscounted results, we present the net benefits and benefit-to-cost ratio (BCR). The discounted analysis consists of three elements, namely the cash flow statement, the impact statement, and the integrated value statement. The cash flow statement includes only the costs and revenues that are actual cash flows to the project itself. The impact statement includes all other benefits generated by the implementation of the interventions. The integrated value statement combines the two.

At the integrated value statement level, we calculate the following three indicators:

- BCR in present value (PV) terms
- Internal rate of return (IRR)
- PV of the net integrated value

We also run the model excluding carbon emissions and water quality to produce the above same three indicators, as we assume that these benefits are unlikely to generate substantial cash flows for the stakeholders.

2.4 Financing Analysis

The objective of the financing analysis is to assess possible financing structures for the mangrove restoration project under different climate scenarios and tourism investments. To do so, we built a financing model that considers a combination of debt and a non-repayable grant (50% debt and 50% grant). In addition to this, a second financing scenario is modelled considering only a non-repayable grant withdrawn across 5 years. Based on these financing options, we included a total of 24 scenarios based on three tourism scenarios (high tourism, low tourism, or no tourism) and two climate scenarios (Representative Concentration Pathway (RCP) 4.5 and RCP 8.5).

To assess the capacity of the project to cover implementation costs and debt, we looked at the alternative revenue stream generated by the internalization of benefits and avoided costs. For this analysis, we include tourism benefits, wage benefits, fishing income, and avoided flood and erosion damage as factors that could be internalized. The outputs generated by the model allow us to quantify the portion of benefits and avoided costs that can be used to generate alternative revenue streams and fund the mangrove restoration, or in other words, ensure the project breaks even.

The concept of internalizing indirect benefits and avoided costs has been used in other financing mechanisms like outcome-based financing, which involves transforming benefits and avoided costs into revenue streams to fund projects and generate returns for investors (Brand et al., 2021). In our analysis, we aim to apply the same concept by incorporating the indirect benefits and avoided costs into project cash flow to repay debt and cover project expenses. While the way to generate revenue from these factors depends on the local context, the aim is to demonstrate how an effort to monetize indirect benefits and avoided costs can improve the financial viability of an NBI project. For example, an alternative revenue stream from tourism could be generated through hotels and local businesses, direct beneficiaries of mangrove restoration, who provide payments or contributions to fund the project. Likewise, landowners and property owners who benefit from avoided flood and erosion damages generated by the project could also be involved in financing project implementation.

Generally, the most common financing instruments for NBI are public grants and concessional loans. Grant funding which is generally provided by governments, public financial institutions, and foundations can improve the bankability of the investment and de-risk the NBI project. This can unlock additional financing enabling other entities to participate in the financing structure (Earth Security, 2021). In this context, multilateral development banks, impact investors, and private investors can play a relevant role by providing loans at favourable conditions to fund the project (United Nations Framework Convention on Climate Change, 2022).

Based on these assumptions, we developed a financing model that considers a straightforward combination of debt and a non-repayable grant. We also modelled a second financing scenario in which we assume the interventions are financed exclusively by a non-repayable grant disbursed over 5 years. This latter scenario allowed us to determine the amount of value required to be generated by indirect benefits and avoided costs to reach the break-even point for the project in the absence of debt financing.

3.0 Scenarios and Assumptions

3.1 Scenarios

We assess the costs and benefits of the NBI and grey infrastructure relative to a BAU scenario in which no interventions are made and degradation is allowed to continue. For grey infrastructure, we consider options that provide the same level of service as the NBI. We thus assume a wastewater treatment plant is built with the capacity to provide the same water quality benefits as the mangroves. We also look at installing enough photovoltaic solar panels to reduce carbon emissions to the same extent as the NBI, and an offshore breakwater with the same flood and erosion protection benefits. Note that these are hypothetical interventions that are not necessarily being considered for the area around the Mallorquín Swamp but are included for purposes of the analysis to demonstrate the value of NBI relative to comparable grey infrastructure.

We consider both the grey and the NBI options with and without new tourism infrastructure. When tourism infrastructure is built, we assess the benefits using both a high and low estimate for the number of visitors (Table 1).

Table 1. Scenarios. Details about the assumptions are provided in the technical appendix (part C).

Scenario name	Assumptions
NBI with high tourism	• Mangroves are planted on 2.89 hectares of swamp in 2019 and 5.75 hectares in 2021. • Informal developments are relocated out of the swamp. • Flow from the Magdalena River into the swamp is partially restored. • An eco-park is established, and ecotourism is promoted as a source of income, resulting in 2.53 million visitors per year.
NBI with low tourism	• Mangroves are planted on 2.89 hectares of swamp in 2019 and 5.75 hectares in 2021. • Informal developments are relocated out of the swamp. • Flow from the Magdalena River into the swamp is partially restored. • An eco-park is established, and ecotourism is promoted as a source of income, resulting in 900,000 visitors per year
NBI with no tourism	• Mangroves are planted on 2.89 hectares of swamp in 2019 and 5.75 hectares in 2021. • Informal developments are relocated out of the swamp. • Flow from the Magdalena River into the swamp is partially restored.
Grey with high tourism	• A seawall is built to protect against extreme climate events. • Wastewater treatment infrastructure is used to improve water quality. • Renewable power generation is used to avoid carbon emissions. • New tourism infrastructure is built, resulting in 2.53 million visitors per year.

Scenario name	Assumptions
Grey with low tourism	• A seawall is built to protect against extreme climate events. • Wastewater treatment infrastructure is used to improve water quality. • Renewable power generation is used to avoid carbon emissions. • New tourism infrastructure is built, resulting in 900,000 visitors per year.
Grey with no tourism	• A seawall is built to protect against extreme climate events. • Wastewater treatment infrastructure is used to improve water quality. • Renewable power generation is used to avoid carbon emissions.

3.2 Climate Scenarios

We use climate data as an input to the model to assess the climate adaptation benefits of the NBI. The climate indicators included in this assessment are precipitation, evaporation, sea level rise, and wave height. We consider two scenarios from two representative concentration pathways (RCPs): RCP 4.5, which we use as a low climate change scenario, and RCP 8.5, which we use as a high climate change scenario (Box 2). Each of the six scenarios in Table 1 is simulated for both climate scenarios, resulting in a total of 12 scenarios.

Box 2. Representative Concentration Pathway climate scenarios

The RCP scenarios are defined by atmospheric greenhouse gas concentrations. They specify the radiative forcing, that is, changes in the earth's energy budget that cause changes in climate. For example, RCP 4.5 assumes that the radiative forcing at the end of the 21st century is 4.5 watts per m2 (W/m2), whereas RCP 8.5 assumes a radiative forcing of 8.5 W/m2 in 2100. These radiative forcings are affected by greenhouse gas emissions, and each RCP scenario corresponds to a hypothetical emissions pathway (Intergovernmental Panel on Climate Change [IPCC], 2013). For this assessment, we use projections from the following scenarios:

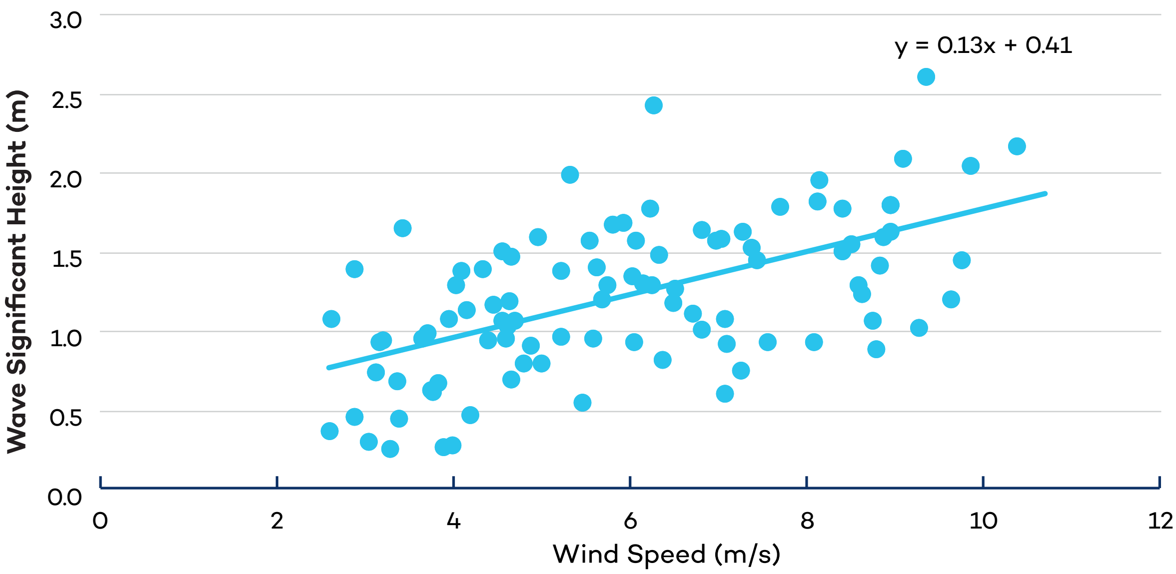
- RCP 4.5: A low climate change scenario, which assumes emissions peak in 2040 and then begin to decline.
- RCP 8.5: A high climate change scenario, which assumes continued high reliance on fossil fuel-based energy for the remainder of the century.

We use only one model run for each of these climate scenarios. Thus, the projections we use are neither central estimates nor most likely predictions for the climate indicators under each RCP. Nevertheless, we can use these projections to assess performance under two possible scenarios with different underlying assumptions about greenhouse gas emissions and to assess the impact of both extreme events and gradual changes.

For precipitation and evaporation, we use projections from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Copernicus Climate Change Service, 2018). Sea level rise data are taken from (Sweet et al., 2022).

For wave height, we rely on an observed relationship between historical wind speed and significant wave height. Historical wind data come from the European Centre for Medium-Range Weather Forecasts Reanalysis 5th Generation (ERA5) data product (Hersbach et al., 2019). We use historical significant wave height data from (EU Copernicus Marine Service Information, 2019). From these data, we estimate a linear relationship between wind speed and wave height shown in Figure 3. We use this relationship to predict future wave height from wind speed projections given by (Copernicus Climate Change Service, 2018).

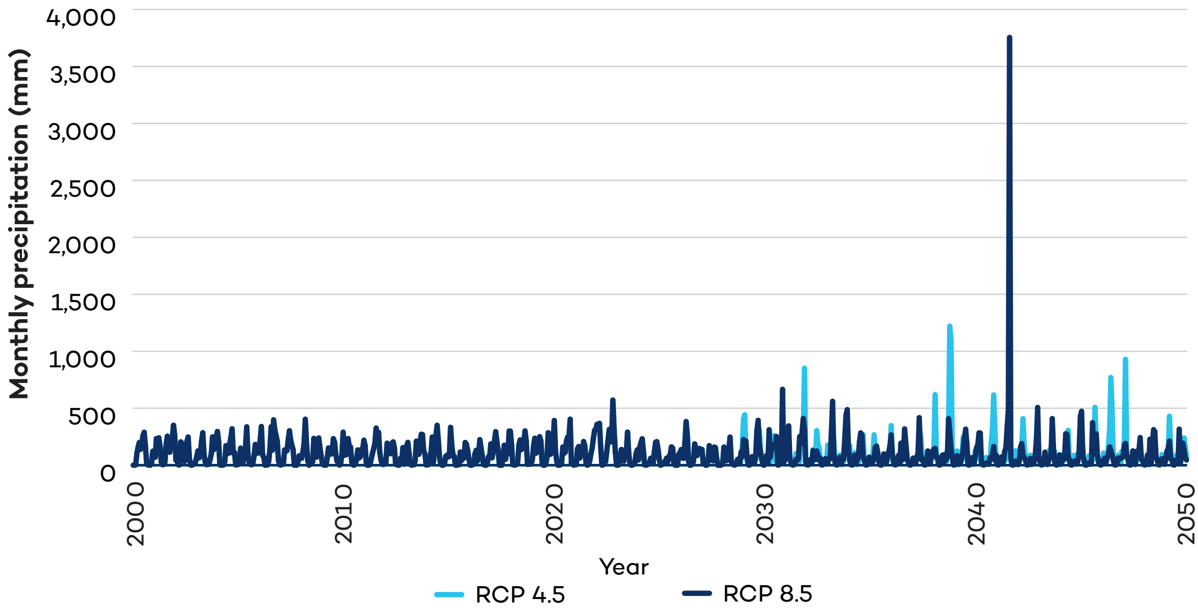
Figure 3. Historical significant wave height vs. wind speed. Linear regression results in a best fit line of wave height = 0.13 × wind speed + 0.41. We use this equation to predict future wave significant height.



Source: Authors' diagram based on data from E.U. Copernicus Marine Service Information, 2019; Hersbach et al., 2019.

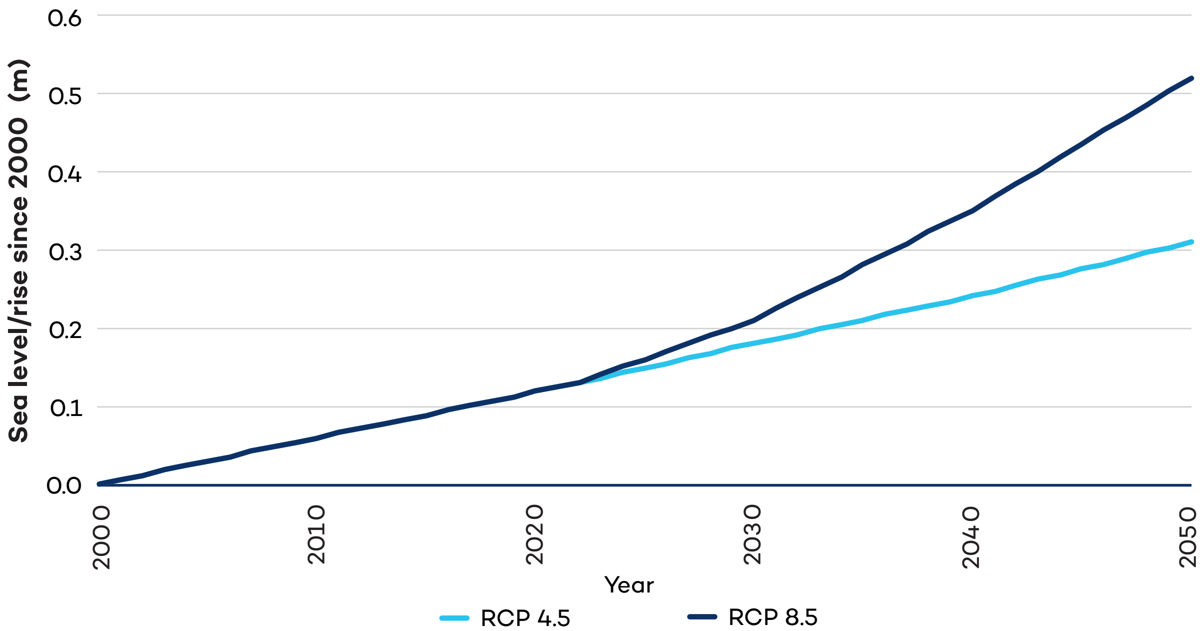
Comparing the two climate scenarios, RCP 4.5 shows more frequent moderately large precipitation events, but RCP 8.5 includes one much larger extreme event (Figure 4). Sea level rises approximately linearly under RCP 4.5 and accelerates under RCP 8.5 (Figure 5). Consequently, in 2050, sea level is approximately 20 cm higher under RCP 8.5 compared to RCP 4.5. Evaporation and wind speed are similar across the two scenarios (Figures 6 and 7).

Figure 4. Monthly precipitation under RCP 4.5 and RCP 8.5. The RCP 4.5 scenario shows an increase in large precipitation events. The RCP 8.5 scenario includes one extreme event in 2038.



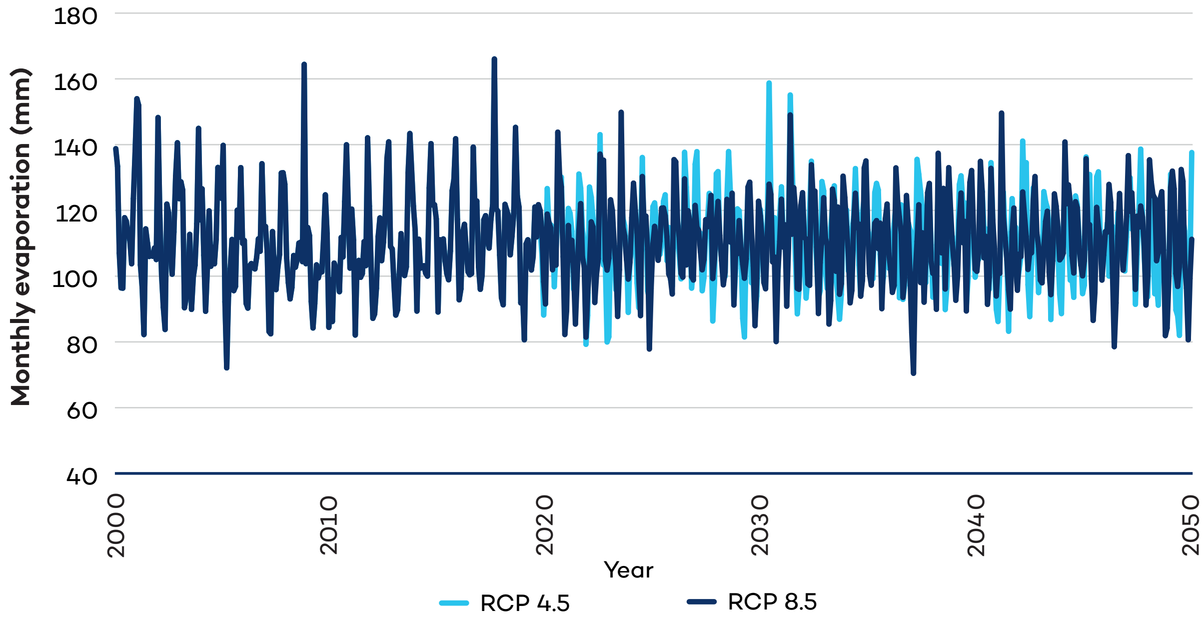
Source: Authors' diagram based on data from Copernicus Climate Change Service, 2018.

Figure 5. Regional sea level rise under RCP 4.5 and RCP 8.5. Under both scenarios, sea level rises. The rate of change is faster under RCP 8.5.



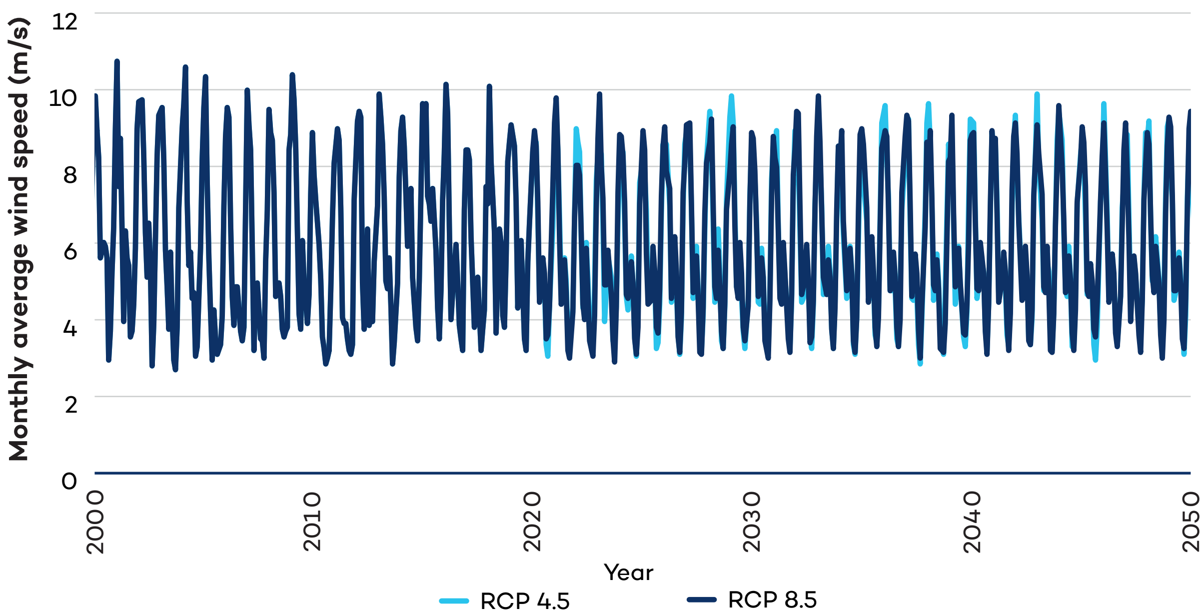
Source: Authors' diagram based on data from Sweet et al., 2022.

Figure 6. Monthly evaporation under RCP 4.5 and RCP 8.5. Evaporation is similar under the two scenarios.



Source: Authors' diagram based on data from Copernicus Climate Change Service, 2018.

Figure 7. Monthly average wind speed under RCP 4.5 and RCP 8.5. Wind speed is similar under the two scenarios.



Source: Authors' diagram based on data from Copernicus Climate Change Service, 2018

3.3 Integrated Cost-Benefit Analysis

Indicators included in the integrated cost-benefit analysis (CBA) and how they are calculated are shown in Table 2. We calculate the cumulative, undiscounted value over a 20-year timeframe of analysis (2019–2038).

Table 2. Indicators included in the CBA

	Economic Indicator	Assumptions and calculations
Direct costs	Construction costs	**NBI:** For planting and maintaining mangroves and building and operating the eco-park, we assume lifecycle costs of COP 530.6 billion (USD 141 million) (Monroy & Salazar, 2021). We assume that 16% of this is spent on construction in each year from 2019 to 2023. **Grey:** We assume that the cost to install solar panels is equal to the price of the solar panels (EUR 520 [USD 591] per kW) added to the labour price (EUR 43 [USD 49] per kW) (López et al., 2020). We calculate the cost of constructing a wastewater treatment plant based on the assumed capacity and efficiency using the relationship provided by (Jiang et al., 2018). We assume that constructing the breakwater costs USD 250,000 per km if waves are reduced 0.2 m (Narayan et al., 2016). We further assume that this cost scales linearly with the level of wave height reduction. If tourism is also included, we add 50% of the cost of NBI. All construction costs are spread evenly over 5 years, starting in 2019.
	Maintenance costs	**NBI:** We assume that 1.33% of the total USD 141 million is spent each year from 2024 to 2038 on maintenance. **Grey:** We calculate the cost to maintain a wastewater treatment plant based on the assumed wastewater flow and efficiency using the relationship provided by Jiang et al. (2018). We assume that the annual maintenance costs for the breakwater are 1% of the construction costs (Oppenheimer et al., 2019). If tourism is also included, we add 50% of the cost of NBI. All maintenance costs start in 2024

	Economic Indicator	Assumptions and calculations
Added benefits	Tourism revenue	We assume annual revenue of USD 11.16 per visitor per year plus an additional USD 266,000 per year (Monroy & Salazar, 2021). For the low tourism scenarios, the number of visitors does not include touristic train rides, so we also add USD 1.59 million per year (Monroy & Salazar, 2021).
	Wages	We multiply the number of jobs by wages using the following sector-specific full-time equivalent wages reported by the International Labour Organization (2022): • Planting and maintaining mangroves/eco-park: USD 226.3 per month (USD 2,715.6 per year) • Constructing and maintaining the wastewater treatment plant: USD 332 per month (USD 3,984 per year) • Constructing and maintaining the breakwater: USD 291.1 per month (USD 3,493.2 per year) • Installing solar panels: USD 291.1 per month (USD 3,493.2 per year) Wages for constructing and maintaining the conventional tourism infrastructure are assumed to be 10% of the tourism costs.
	Fishing income	We multiply fish landings by USD 2,298 per ton of fish (Organisation for Economic Co-operation and Development, 2021).
Avoided costs	Avoided water pollution	We assume that nitrogen has a cost of EUR 4.6 (USD 5.98) per kg per year and that phosphorus has a cost of EUR 7.5 (USD 9.75) per kg per year. These numbers are taken from a study in Spain considering the cost of pollutants that enter the sea (Hernández-Sancho et al., 2010).
	Avoided carbon emissions	We assume a value of USD 5 per ton of avoided CO_2 emissions. This is the value of a carbon tax introduced in Colombia that applies to all fossil fuel emissions (Climate Transparency, 2020).
	Avoided flood and erosion damage	Erosion damage is calculated as the product of area lost and the value per hectare (USD 1.32 million per hectare of formal development and USD 120,000 per hectare of informal settlements [Garza & Lizieri, 2015]). We calculate the value destroyed based on the total value of the settlement area and the percentage destroyed, which depends on the percentage destroyed at the flood threshold (10% for formal developments and 20% for informal developments) and the difference between the effective water level and the threshold (500 mm).

Discounting is done using a discount rate of 5.0% per annum. This is a "real" discount rate (i.e., excluding inflation to match the uninflated cost and benefit values). The date to which values are discounted is Dec 31, 2022.

3.4 Financing Analysis

For the purposes of the financing analysis, we assessed debt financing for the NBI and the grey infrastructure assuming that eligible costs are financed either by a combination of debt and a non-repayable grant (50% debt and 50% grant) or exclusively through a 100% grant (no debt).

Based on these two financing options, we developed a total of 24 financing scenarios based on the three tourism scenarios (high tourism, low tourism, or no tourism) and two climate scenarios (RCP 4.5 and RCP 8.5). In terms of debt repayment, we assumed a 0.25% front-end fee rate, a commitment fee of 0.25% and an interest rate of 2.01%. These assumptions are based on the financial terms from the International Bank for Reconstruction and Development flexible loans for Colombia (World Bank, 2023). The interest rate includes 1.41% real rate interest based on 10 years TIPS yield (US bonds) (Trading Economics, 2023) and 0.60% lending margin based on International Bank for Reconstruction and Development flexible loans for Colombia (World Bank, 2023). We also assumed a 5-year maturity based on other financing examples for NBI (Green Finance Institute, 2023).

In addition, we also calculated the percentage of indirect benefits and avoided costs that must be monetized to fund capital expenditure, operating expenses, and to repay the debt. For this analysis, we do not include carbon storage and water quality benefits, as these had a relatively negligible impact in generating revenue streams.

4.0 Results

Key findings from the assessment include:

- **Restoration can counteract degradation and address environmental concerns**. In the area surrounding Barranquilla, land-use/land cover change has reduced carbon storage, worsened habitat quality, and increased nutrient export. From 2017 to 2021, carbon storage decreased by 16%, habitat quality declined 8%, nitrogen export increased by 17%, and phosphorus export rose by 22%.
- **NBI in the Mallorquín Swamp creates more value for society at a lower cost than the grey infrastructure alternative**. Our analysis found that the undiscounted NBI net benefits are approximately USD 37.9–39.1 million greater than those of the grey infrastructure alternative. Furthermore, the undiscounted BCR of NBI is about 1.4-1.9 times larger and the discounted BCR is about 1.2–1.4 times larger than that of grey infrastructure. The benefits of NBI compared to grey infrastructure are higher when results are undiscounted because the benefits of NBI increase with time as the mangroves mature and climate change progresses. Nonetheless, even using a 5% per year discount rate, the net present value (NPV) of NBI is approximately USD 19.2–20.0 million larger than the NPV of the grey infrastructure.
- **The restored swamp could support the local economy and provide valuable climate adaptation benefits**. Specifically, the largest benefits of restoration are tourism income and avoided flood and erosion damages. In most scenarios assessed, these two indicators combined more than offset the cumulative construction and maintenance costs. When discounting the results, grey infrastructure is a worthwhile investment[2] only if tourism is also developed. Furthermore, the interventions generate higher values when potential climate damages are larger.
- **Supporting the local economy by providing a sustainable source of income increases the net value of the investment**. Although not necessary to justify restoration, investing in ecotourism makes the NBI project more economically attractive. This is true in both the undiscounted CBA and the discounted analysis. Despite the higher direct costs, including ecotourism increases the undiscounted net benefits of NBI by USD 114.9–363.7 million and BCR by a factor of up to 2.2. Applying a 5% per year discount rate, the NPV increases by USD 55.8–219.7 million, and the BCR is up to 2.3 times larger when tourism is included.
- **NBI can be an effective long-term climate adaptation strategy**. In the initial years after the project is completed, the amount of tourism has a large impact on net benefits, but after some time, the climate adaptation benefits become more important. Specifically, for approximately 15 years, the net benefits depend most strongly on the number of visitors. However, after 15 years, avoided climate damages play a larger role in determining the total value, and the NBI starts to outperform the grey infrastructure.

[2] In this context, the investment is considered "worthwhile" from a societal perspective as the analysis integrates monetized benefits and avoided costs.

- **Investing in tourism infrastructure has a strong impact on the financial viability of both the green and grey interventions**. Under the 50:50 debt-grant financing option, investing in ecotourism is critical, as the NBI actions alone would not generate the revenue streams required to cover project costs and repay the debt. Likewise, grey infrastructure investments are unable to generate enough revenue from monetized indirect benefits and avoided costs alone and require tourism revenues to be financially viable.
- **NBI is more favourable than the grey infrastructure from a financing perspective**. When limited financial resources require the municipality to seek out blended finance options, the NBI is a better investment choice, as it is less expensive and therefore requires less revenue to finance the project. Under the only-grant financing option, we observe that a much smaller portion of monetized indirect benefits and avoided costs is needed to make the NBI break even, ranging from 20% in RCP 4.5 with no tourism to 5.8% in RCP 8.5 with high tourism. The grey infrastructure investments require more revenue from the monetized indirect benefits and avoided costs to fund the intervention for both financing options.

4.1 Spatial Analysis

Compared to 2017, carbon storage and habitat quality were lower, and nutrient export was higher in 2019. From 2019 through 2021, these trends reversed, but 2021 carbon storage and habitat quality were still lower and nutrient export higher than 2017 levels (Table 3).

Table 3. Spatial analysis results summary

Year	Carbon storage (tons)	Mean habitat quality	Nitrogen export (kg)	Phosphorus export (kg)
2017	2,869,487	0.205	59,591	16,464
2019	1,902,819	0.183	83,902	25,051
2021	2,404,705	0.189	70,009	20,151

These results suggest that land cover carbon emissions, loss of habitat, and nutrient export may be problems in this area, with possible improvement in recent years. Although the Mallorquín Swamp, with an area of 694 ha in 2017, is a small part of this landscape (30,000 hectares are included in this spatial analysis of ecosystem services), the loss of ecosystem services since 2017 implies that restoration may address relevant environmental concerns in Barranquilla and the surrounding area.

4.2 Integrated Cost-Benefit Analysis

As shown in Table 4 (undiscounted values), all scenarios have positive net benefits and a BCR greater than one. The largest benefits are tourism income (in the scenarios that include tourism) and the avoided flood and erosion damages. In almost all scenarios, these two indicators combined are greater than the cumulative construction and maintenance costs. The one exception is grey infrastructure with no tourism investments under a climate scenario of RCP 4.5, for which the wages (from construction and maintenance) are necessary to justify the investment.

In addition to the full CBA, we present the results without including carbon storage and improved water quality, given that these had a relatively limited contribution to the net benefits and BCR. In contrast, the avoided flood and erosion damages and the tourism benefit (when present) were much larger than all other benefits and avoided costs. Specifically, avoided greenhouse gas emissions and water pollution had a total value of about USD 4 million, compared to over USD 120 million of avoided flood and erosion damages and up to USD 427.1 million in tourism revenue. The relatively small impact of the carbon storage and water purification benefits demonstrates that the project is economically viable even without considering these environmental benefits.

Investing in tourism infrastructure increases the net benefits of the project, despite the higher costs. This is true even when using the low estimate for the number of visitors. For example, under RCP 4.5, the NBI with no tourism has net benefits of USD 57.3 million and a BCR of 1.8. When tourism infrastructure is built, net benefits rise to USD 172.3 million, with a BCR of 2.2 using the low estimate for the number of visitors. With the high estimate, net benefits increase to USD 421.0 and the BCR is 4.0. This trend of improved economic performance with increased tourism also holds for grey infrastructure and under the high climate change scenario.

For each tourism and climate scenario, NBI has larger net benefits and a higher BCR than grey infrastructure. Specifically, NBI net benefits are USD 37.9–39.1 million greater than grey infrastructure, and the BCR of NBI is about 1.4–1.9 times larger than that of grey infrastructure. This is primarily because the 20-year cumulative direct costs of the grey infrastructure are over USD 100 million larger than those of the NBI, although the grey infrastructure generates more wages than the NBI. This is because building and maintaining the grey infrastructure require more labour than the NBI. Thus, when accounting for the full societal benefits of the investment, NBI performs better than the grey infrastructure.

Table 4. Integrated cost-benefit analysis. Values are undiscounted and cumulative over a 20-year timeframe of analysis (2019–2038).

	RCP 4.5						RCP 8.5					
	High tourism		Low tourism		No tourism		High tourism		Low tourism		No tourism	
	NBI	Grey	NBI	Grey	NBI	Grey	NBI	Grey	NBI	Grey	NBI	Grey
Costs (million USD)												
Construction	28.2	150.2	28.2	150.2	14.1	93.8	28.2	151.5	28.2	151.5	14.1	95.1
Maintenance	112.7	98.1	112.7	98.1	56.4	84.0	112.7	98.8	112.7	98.8	56.4	84.8
Total costs	140.9	248.3	140.9	248.3	70.5	177.9	140.9	250.3	140.9	250.3	70.5	179.9
Added benefits (million USD)												
Tourism value	427.1	427.1	178.4	178.4	-	-	427.1	427.1	178.4	178.4	-	-
Wages	7.2	78.2	7.2	78.2	0.1	71.2	7.2	78.9	7.2	78.9	0.1	71.8
Fishing income	0.2	0.0	0.2	0.0	0.2	0.0	0.2	0.0	0.2	0.0	0.2	0.0
Total added benefits	434.4	505.3	185.7	256.6	0.3	71.2	434.4	505.9	185.7	257.2	0.3	71.8
Avoided costs (million USD)												
Avoided flood and erosion damage	123.5	122.2	123.5	122.2	123.5	122.2	183.8	182.6	183.8	182.6	183.8	182.6
Avoided water pollution cost	3.9	3.8	3.9	3.8	3.9	3.8	3.9	3.9	3.9	3.9	3.9	3.9
Avoided cost of carbon emissions	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total avoided costs	127.5	126.1	127.5	126.1	127.5	126.1	187.8	186.6	187.8	186.6	187.8	186.6
Net benefits (million USD)	421.0	383.1	172.3	134.4	57.3	19.4	481.3	442.2	232.6	193.5	117.6	78.5
BCR	4.0	2.5	2.2	1.5	1.8	1.1	4.4	2.8	2.7	1.8	2.7	1.4
Net benefits excluding carbon and water quality (million USD)	417.0	379.1	168.3	130.4	53.4	15.5	477.3	438.2	228.6	189.5	113.6	74.5
BCR carbon and water quality	4.0	2.5	2.2	1.5	1.8	1.1	4.4	2.8	2.6	1.8	2.6	1.4

Exploring Net Value Over Time

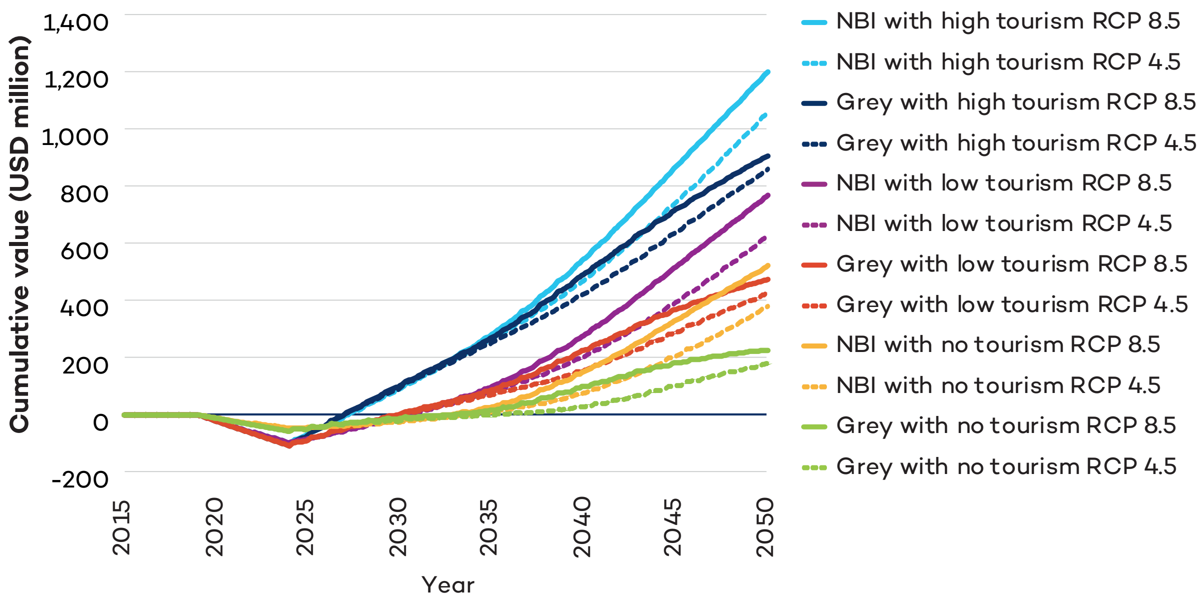
Figure 8 shows the net cumulative value for all scenarios simulated through 2050. As shown in this figure, scenarios are clustered by the amount of tourism until about 2035. This suggests that, initially, the costs and benefits, except for tourism, are similar across all scenarios. Thus, for approximately the first 15 years, the value created for society depends more strongly on the number of visitors than on a particular climate scenario or whether the intervention uses grey infrastructure or NBI.

Furthermore, the level of tourism has a large impact on how long it takes for the project to break even. Specifically, tourism has a larger impact than the interventions (NBI vs. grey infrastructure) in determining when the cumulative benefits outweigh the costs. In the high-tourism scenarios (light and dark blue lines in Figure 8), the cumulative net benefits become positive in 2027. In the low-tourism scenarios (purple and red lines in Figure 8), the cumulative net benefits are not positive until 2030. With no tourism (yellow and green lines in Figure 8), it takes another 2–5 years, depending on the type of intervention and climate scenario, to break even.

However, after 2035, the shape of the line depends more strongly on the type of infrastructure and climate scenario. Specifically, the net benefits of each intervention under RCP 8.5 are larger than those under RCP 4.5. This is because there are more potential damages under RCP 8.5, and so the avoided damages are greater, demonstrating the climate adaptation benefits of the project. This difference becomes more pronounced as climate change proceeds.

Furthermore, the grey infrastructure lines start to level off around 2035, while the NBI lines continue to increase at a fast rate. This suggests that, at this point, climate damages start to play a larger role in determining the total value. By design, the avoided damages with NBI are the same as the avoided damages with grey infrastructure when considering a 20-year time horizon. However, when looking at a longer timeframe, Figure 8 demonstrates that because the mangroves continue to grow, the capacity for NBI to provide climate adaptation benefits continues to increase, while that of the grey infrastructure does not. Thus, as the mangroves mature and climate change proceeds, the NBI provides more flood and erosion protection than the grey infrastructure. Due to these climate adaptation benefits, our results indicate that, by 2050, NBI provides considerably more value than grey infrastructure. For example, NBI without tourism may create more cumulative value than grey infrastructure with low tourism. This highlights that NBI can be an effective long-term climate adaptation strategy.

Figure 8. Cumulative net value for all scenarios



Source: Authors' diagram.

Applying a Discount Rate

Table 5 shows the performance of the NBI and the grey infrastructure under the two climate scenarios and tourism investments. The indicators are presented in discounted real terms (discount rate of 5.0%), excluding inflation to match the uninflated format of the cost and benefit values. All the values are discounted to December 31, 2022. In all scenarios, the net integrated values (PV) demonstrate that the NBI delivers better value for money compared to the grey infrastructure. We also note that the discounted PV and BCR are generally lower than the undiscounted net benefits and BCR in Table 4. This is because the benefits increase with time as climate change progresses and the mangroves mature. Discounting these future benefits by 5% per year therefore decreases the PV.

Both interventions generate higher values when potential climate damages are larger, demonstrating that both can address some impacts of climate change. Under the high climate scenario (RCP 8.5), the NBI generates better value for money compared to the grey infrastructure. This means that the NBI is more valuable, from a societal perspective, due to larger climate adaptation benefits.

The NBI and grey infrastructure benefit from the development of tourism under both climate scenarios. If tourism is not developed, the grey infrastructure has a negative net integrated value (-7.48). Conversely, the NBI remains a worthwhile investment from a societal perspective, even without tourism (net integrated value, 11.68). This demonstrates that the combined other benefits of NBI are larger than the cumulative costs.

As expected, excluding carbon emissions and the benefits of water quality have a negative impact on the performance of both the NBI and the grey infrastructure. However, this impact is small, suggesting that these benefits have a minimal impact on total value creation. Thus, the other benefits, such as flood and erosion protection, are more pronounced for these investment options.

Table 5. Discounted analysis

	RCP 4.5						RCP 8.5					
	High tourism		Low tourism		No tourism		High tourism		Low tourism		No tourism	
	NBI	Grey	NBI	Grey	NBI	Grey	NBI	Grey	NBI	Grey	NBI	Grey
IRR of net integrated value	20.2%	19.7%	10.6%	9.5%	6.9%	3.3%	21.2%	20.5%	12.3%	11.3%	10.7%	8.7%
IRR of net integrated value (excl. carbon emissions and water quality)	20.1%	19.6%	10.4%	9.3%	6.5%	2.7%	21.1%	20.4%	12.2%	11.1%	10.4%	8.3%
Net integrated value - PV at Dec. 22	231.32	212.16	67.45	48.30	11.68	-7.48	263.81	243.85	99.94	79.99	44.16	24.21
Net integrated value - PV at Dec. 22 (Excl. carbon emissions and water quality)	228.88	209.64	65.02	45.77	9.24	-10.01	261.35	241.30	97.48	77.44	41.71	21.66
BCR on PV at Dec. 22	2.69	1.95	1.49	1.22	1.17	0.95	2.92	2.09	1.73	1.36	1.64	1.16
BCR on PV at Dec. 22 (excl. carbon emissions and water quality)	2.67	1.94	1.47	1.21	1.13	0.94	2.90	2.07	1.71	1.34	1.61	1.14

4.3 Financing Analysis

The objective of this section is to evaluate possible financing structures for the mangrove restoration project under different climate scenarios and tourism investments. Thus, we looked at the alternative revenue stream generated by the internalization of tourism benefits, wage benefits, and fishing income, and avoided flood and erosion damages to cover project implementation and debt costs.

Under the 50:50 debt-grant ratio, we can observe that the NBI project requires between 85.5% to 42.6% of monetized indirect benefits and avoided costs to fund the project and repay debt costs. When larger tourism benefits are modelled, a smaller portion of total indirect benefits and avoided costs is required to make the project break even. If tourism is not developed, avoided flood and erosion damages are not large enough to cover project costs and repay the debt. The same holds true for the grey infrastructure intervention, which would not be financially viable without including tourism benefits.

As expected, under the grant-only financing option, fewer indirect benefits and avoided costs need to be monetized for the project to break even. The portion of required indirect benefits and avoided costs in the grant-only financing option ranges from 20% in the RCP 4.5 (assuming no tourism) to 5.8% in RCP 8.5 (assuming high tourism).

The difference in the required percentages between the two financing options is magnified by the short-term repayment period of the loan and the higher implementation costs and lower net benefits generated at the beginning of the NBI.

For the grey infrastructure intervention, a higher cash flow from the indirect benefits and avoided costs would be required under both financing options to cover the higher construction costs (Table 6).

Table 6. Debt financing analysis (50% debt–50% grant and 100% grant): "n.a." is used to indicate that the project is not financially viable for that scenario.

			NBI	Grey infrastructure
High tourism	RCP 4.5	50% debt–50% grant	43.0%	57.1%
		100% grant	5.8%	16.2%
	RCP 8.5	50% debt–50% grant	42.6%	55.3%
		100% grant	5.7%	15.7%
Low tourism	RCP 4.5	50% debt–50% grant	85.5%	96.6%
		100% grant	11.4%	27.4%
	RCP 8.5	50% debt–50% grant	83.7%	91.1%
		100% grant	11.2%	25.8%
No tourism	RCP 4.5	50% debt–50% grant	n.a	n.a
		100% grant	20.0%	46.9%
	RCP 8.5	50% debt–50% grant	n.a	n.a
		100% grant	18.6%	41.5%

5.0 Conclusions

This study has demonstrated that the proposed NBI project in the Mallorquín Swamp is investment worthy and will provide multiple benefits, such as income from ecotourism and climate adaptation, including avoided flooding and erosion. The restoration will also mitigate greenhouse gas emissions and improve water quality, although the magnitude of these benefits is relatively smaller.

Furthermore, through our integrated CBA, we have shown that the proposed NBI interventions create more value and cost less than grey infrastructure alternatives that provide similar services. Likewise, the financing analysis shows that restoration in the Mallorquín Swamp is more financially viable than the grey infrastructure because it requires a smaller portion of indirect benefits and avoided costs to be monetized to break even. In particular, the results highlight the importance of investing in ecotourism to complement the restoration and improve financial attractiveness.

More generally, the results demonstrate the value of restoration and ecotourism and can support decisions to fund restoration in Barranquilla and similar projects in other places.

6.0 References

Barranquilla Verde. (2021). *Contexto General*.

Brand, M. W., Seipp, K. Q., Saksa, P., Ulibarri, N., Bomblies, A., Mandle, L., Allaire, M., Wing, O., Puente, J. T. la, Parker, E. A., Nay, J., Sanders, B. F., Rosowsky, D., Lee, J., Johnson, K., Gudino-Elizondo, N., Ajami, N., Wobbrock, N., Adriaens, P., … Gibbons, J. P. (2021). Environmental impact bonds: A common framework and looking ahead. *Environmental Research: Infrastructure and Sustainability, 1*(2), 023001. https://doi.org/10.1088/2634-4505/ac0b2c

Calvo, R. N., & Arispe, S. (2021). *Evaluación Ambiental y Social Estratégica*. Inter-American Development Bank. https://www.barranquilla.gov.co/programa-de-biodiverciudad-y-equidad-urbana-en-barranquilla

Climate Transparency. (2020). *The climate transparency report 2020: Comparing G20 climate action and responses to the COVID-19 crisis*. https://www.climate-transparency.org/g20-climate-performance/the-climate-transparency-report-2020#1531904804037-423d5c88-a7a7

Copernicus Climate Change Service. (2018). CMIP5 monthly data on single levels. *Coupled model intercomparison project Phase 5*. https://cds.climate.copernicus.eu/cdsapp#!/dataset/projections-cmip5-monthly-single-levels

Earth Security. (2021). *The blended finance playbook for nature* [Strategic report]. https://www.earthsecurity.org/reports/the-blended-finance-playbook-for-nature-based-solutions

EU Copernicus Marine Service Information. (2019). *Global ocean waves reanalysis waverys*. https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=GLOBAL_REANALYSIS_WAV_001_032

Garza, N., & Lizieri, C. (2015). *An empirical approach to land monopoly: The case of Barranquilla, Colombia* (Working paper series no. 2015–03). University of Cambridge, Real Estate Research Centre. http://dx.doi.org/10.2139/ssrn.2807024

Green Finance Institute. (2023). *Blue Forest conservation forest resilience bond*. Greenfinanceinstitute.Co.Uk. https://www.greenfinanceinstitute.co.uk/gfihive/case-studies/blue-forest-conservation-forest-resilience-bond

Hernández-Sancho, F., Molinos-Senante, M., & Sala-Garrido, R. (2010). Economic valuation of environmental benefits from wastewater treatment processes: An empirical approach for Spain. *Science of The Total Environment, 408*(4), 953–957. https://doi.org/10.1016/j.scitotenv.2009.10.028

Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., Nicolas, J., Peubey, C., Radu, R., Rozum, I., Schepers, D., Simmons, A., Soci, C., Dee, D., & Thépaut, J-N. (2019). *ERA5 monthly averaged data on single levels from 1979 to present*. Copernicus Climate Change Service Climate Data Store. https://doi.org/10.24381/cds.f17050d7

International Labour Organization. (2022). Average monthly earnings of employees by sex and occupation—Annual. *ILOSTAT*. https://www.ilo.org/shinyapps/bulkexplorer13/?lang=en&segment=indicator&id=EAR_4MTH_SEX_OCU_CUR_NB_A

Jiang, Y., Dinar, A., & Hellegers, P. (2018). Economics of social trade-off: Balancing wastewater treatment cost and ecosystem damage. *Journal of Environmental Management, 211*, 42–52. https://doi.org/10.1016/j.jenvman.2018.01.047

López, A. R., Krumm, A., Schattenhofer, L., Burandt, T., Montoya, F. C., Oberländer, N., & Oei, P.-Y. (2020). Solar PV generation in Colombia—A qualitative and quantitative approach to analyze the potential of solar energy market. *Renewable Energy, 148*, 1266–1279. https://doi.org/10.1016/j.renene.2019.10.066

Monroy, L. E., & Salazar, A. M. (2021). *Recuperación Integral de La Ciénaga de Mallorquín Una estimación de impactos socioeconómicos*. Sectetaría de Planeación. Alcaldía Distrital de Barranquilla. https://www.barranquilla.gov.co/planeacion/documentos-tecnicos-preliminares

Narayan, S., Beck, M. W., Reguero, B. G., Losada, I. J., van Wesenbeeck, B., Pontee, N., Sanchirico, J. N., Ingram, J. C., Lange, G.-M., & Burks-Copes, K. A. (2016). The effectiveness, costs and coastal protection benefits of natural and nature-based defences. *PLOS ONE, 11*(5), e0154735. https://doi.org/10.1371/journal.pone.0154735

Natural Capital Project. (2019). *InVEST*. https://naturalcapitalproject.stanford.edu/software/invest

Oppenheimer, M., Glavovic, B. C., Hinkel, J., van de Wal, R., Magnan, A. K., Abd-Elgawad, R., Cai, R., Cifuentes-Jara, M., DeConto, R. M., Ghosh, T., Hay, J., Isla, F., Marzeion, B., Meyssignac, B., & Sebesvari, Z. (2019). Chapter 4: Sea level rise and implications for low-lying islands, coasts and communities. In H.-O. Portner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegria, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N. M. Weyer (Eds.), *IPCC special report on the ocean and cryosphere in a changing climate*. In press. https://www.ipcc.ch/srocc/chapter/chapter-4-sea-level-rise-and-implications-for-low-lying-islands-coasts-and-communities/

Organisation for Economic Co-operation and Development. (2021). *Fisheries and aquaculture in Colombia*. https://www.oecd.org/agriculture/topics/fisheries-and-aquaculture/documents/report_cn_fish_col.pdf

Rojas, F., Hobbs, J., Acevedo, P., Zambrano-Barragán, P., Piedrafita, C., Palacio, M., Chamas, P., Guzman, J., Sandoval, J. M., Salazar, C., Avila, J., Orellana, E., Navarrete, M. J., Cruz, P., Maragall, J., Zegarra, F., Bocarejo, D., Rojas, J., Catacoli, A., … Giraldo, A. (n.d.). *Project profile: Colombia*. https://www.barranquilla.gov.co/programa-de-biodiverciudad-y-equidad-urbana-en-barranquilla

Sweet, W. V., Hamlington, B. D., Kopp, R. E., Weaver, C. P., Barnard, P. L., Bekaert, D., Brooks, W., Craghan, M., Dusek, G., Frederikse, T., Garner, G., Genz, A. S., Krasting, J. P., Larour, E., Marcy, D., Marra, J. J., Obeysekera, J., Osler, M., Pendleton, M., … Zuzak, C. (2022). *Global and regional sea level rise scenarios for the United States: Updated mean projections and extreme water level probabilities along U.S. coastlines* (Technical report No. 1; p. 111). National Oceanic and Atmospheric Administration, National Ocean Service. https://aambpublicoceanservice.blob.core.windows.net/oceanserviceprod/hazards/sealevelrise/noaa-nos-techrpt01-global-regional-SLR-scenarios-US.pdf

Trading Economics. (2023). *United States 10 year TIPS yield—2023 data—1997-2022 Historical—2024 forecast*. https://tradingeconomics.com/united-states/10-year-tips-yield

United Nations Framework Convention on Climate Change. (2022). *Finance for nature-based solutions must triple by 2030*. United Nations Climate Change. https://unfccc.int/news/finance-for-nature-based-solutions-must-triple-by-2030

United Nations, Department of Economic and Social Affairs, Population Division. (2018). *World urbanization prospects: The 2018 revision, online edition*.

United Nations Environment Program. (2014). *Using models for green economy policymaking*. https://www.un-page.org/files/public/content-page/unep_models_ge_for_web.pdf

World Bank. (2023). *Lending rates & fees*. IBRD Financial Products. https://treasury.worldbank.org/en/about/unit/treasury/ibrd-financial-products/lending-rates-and-fees

World Economic Forum. (2022). *BiodiverCities by 2030: Transforming cities' relationship with nature*. World Economic Forum and Alexander von Humboldt Biological Resources Research Institute. https://www3.weforum.org/docs/WEF_BiodiverCities_by_2030_2022.pdf

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