Assessing the Benefits and Costs of Nature-Based Solutions for Climate Resilience:

A Guideline for Project Developers

GLOBAL PROGRAM ON
NATURE-BASED SOLUTIONS
FOR CLIMATE RESILIENCE

GFDRR
Global Facility for Disaster Reduction and Recovery

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A Guideline for Project Developers

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Foreword

The combined climate and biodiversity crises are urging the World Bank and other development financing institutions to think of ways to mainstream climate resilient and nature positive investments. Nature-based solutions (NBS) are becoming a key component in many investment projects in urban development, disaster risk management, natural resource management, transport, and water management. At the World Bank, we have seen an increase in NBS projects and financing commitments, which have surpassed $5 billion in the past 10 years.

Where in the past an urban flood risk management project would focus on engineered drains and culverts, nowadays investments in drainage infrastructure can be supplemented with bioretention areas and parks or wetlands that can function as flood storage areas. In coastal resilience projects, hard engineering such as sea walls, rock armoring, and groins are used with more caution and are complemented by marshes, coastal wetlands, and living breakwaters such as reefs for coastal protection and erosion prevention.

A key difference between traditional sectoral structural and non-structural investments and NBS is their multifunctionality. The aforementioned urban flood risk management becomes and urban park that not only functions as a flood retention area but also reduces the air temperature during heatwaves, provides opportunities for leisure and recreation, has health benefits for the community, and offers a habitat for flora and fauna. Therefore, to compare the value of NBS to gray infrastructure solutions, and to understand their complementarity, having the tools to value all benefits is imperative.

This guideline aims to provide a common ground for valuing the benefits and costs of NBS for climate resilience at the project level. With our partners, we consolidated approaches and methods to quantify nature-based disaster risk reduction, natural capital, and ecosystem services assessment from the global literature. We consulted over 20 leading World Bank experts to better understand the needs at the project level and to identify good practice examples. The result is a comprehensive guidance and eight case studies that have informed World Bank investment projects—featuring a range of different ecosystems and geographies.

We hope that this report will help project developers and technical experts at the World Bank and beyond with actionable approaches for valuing the benefits and the costs of NBS for climate resilience to unlock more funding and financing, to design projects with better development outcomes, and to improve our ability to measure the economic impact of investments in NBS for climate resilience.

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World Bank

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Abbreviations and Acronyms

Alt	alternative
ARI	average recurrence interval
ASA	Advisory Services and Analytics
BCR	benefit-cost ratio
BOQ	bill of quantities
BRIs	benefit-relevant indicators
CAPEX	capital expenditures
Cat DOO	Catastrophe Deferred Drawdown Option
CBA	cost-benefit analysis
CC	cooling capacity
CEA	cost-effectiveness analysis
CMP	Coastal Management Plan (Seychelles)
CVI	Coastal Vulnerability Index
DMDU	decision-making under (deep) uncertainty
DMU	decision-making under uncertainty
DRM	disaster risk management
DRR	disaster risk reduction
DTM	Digital Terrain Model
EbA	ecosystem-based adaptation
Eco-DRR	ecosystem-based disaster risk reduction
EDI	Effective Drought Index
EFA	economic and financial analysis
EIRR	economic internal rate of return
ENB	Environment, Natural Resources and the Blue Economy Global Practice
ENPV	expended net present value
ES	ecosystem services
ESVD	Ecosystem Services Valuation Database
EWS	early warning system
FAST	Flood Assessment Structure Tool
FEMA	Federal Emergency Management Agency (US)
GDP	gross domestic product
GFDRR	Global Facility for Disaster Reduction and Recovery
GHG	greenhouse gases
GIS	Geographic Information Systems
GPURL	Urban, Disaster Risk Management, Resilience and Land Global Practice
ha	hectare
IBRD	International Bank for Reconstruction and Development
ICR	implementation completion report
IDA	International Development Association
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IRR	internal rate of return
KfW	Kreditanstalt für Wiederaufbau
kg	kilogram
KGA	Kali Gandaki A Hydropower Plant (Nepal)
Kt	transmission coefficient
kWh	kilowatt hours
LiDAR	light detection and ranging
LSI	Landslide Susceptibility Index
LSO	landslide object
LULC	Land Use and Land Cover
MCA	multicriteria analysis
MgC	tonnes of carbon
n.a.	not applicable
NBS	nature-based solution
NEA	Nepal Electric Authority
NEPA	National Environment and Planning Agency (Jamaica)
NGO	nongovernmental organization
NPR	Nepalese rupees
NPV	net present value
NSI	National Structure Inventory (US Army Corps of Engineers)
NWA	National Works Agency (Jamaica)
ODPEM	Office of Disaster Preparedness and Emergency Management (Jamaica)
OLC	Open Learning Campus (World Bank)
OPEX	operating expenses
OSM	Open StreetMap
PAD	project appraisal document
PCN	project concept note
PDO	project development objective
PES	payments for ecosystem services
PIU	project implementation unit
PROFOR	Program on Forests
RDM	robust decision-making
RCP	Representative Concentration Pathway
RRB	risk reduction benefit
SCC	social cost of carbon
SDG	Sustainable Development Goals
SeyCCAT	Seychelles Conservation and Climate Adaptation Trust
SIDS	small island developing states
SL Rs	Sri Lanka rupees
SOC	soil organic carbon
SPI	Standardized Precipitation Index
SPEI	Standardized Precipitation-Evapotranspiration Index
SUDS	sustainable urban drainage systems
tCO_2e	tonne of carbon dioxide equivalent
TDR	triple dividend of resilience
UAV	unmanned aerial vehicle
UHII	Urban Health Island Index
USAID	United States Agency for International Development
US EPA	United States Environmental Protection Agency
USGS	US Geological Survey
WASP	Weighted Anomaly of Standardized Precipitation
WTP	willingness to pay
VSL	value of a statistical life

All dollar amounts are US dollars unless otherwise indicated.

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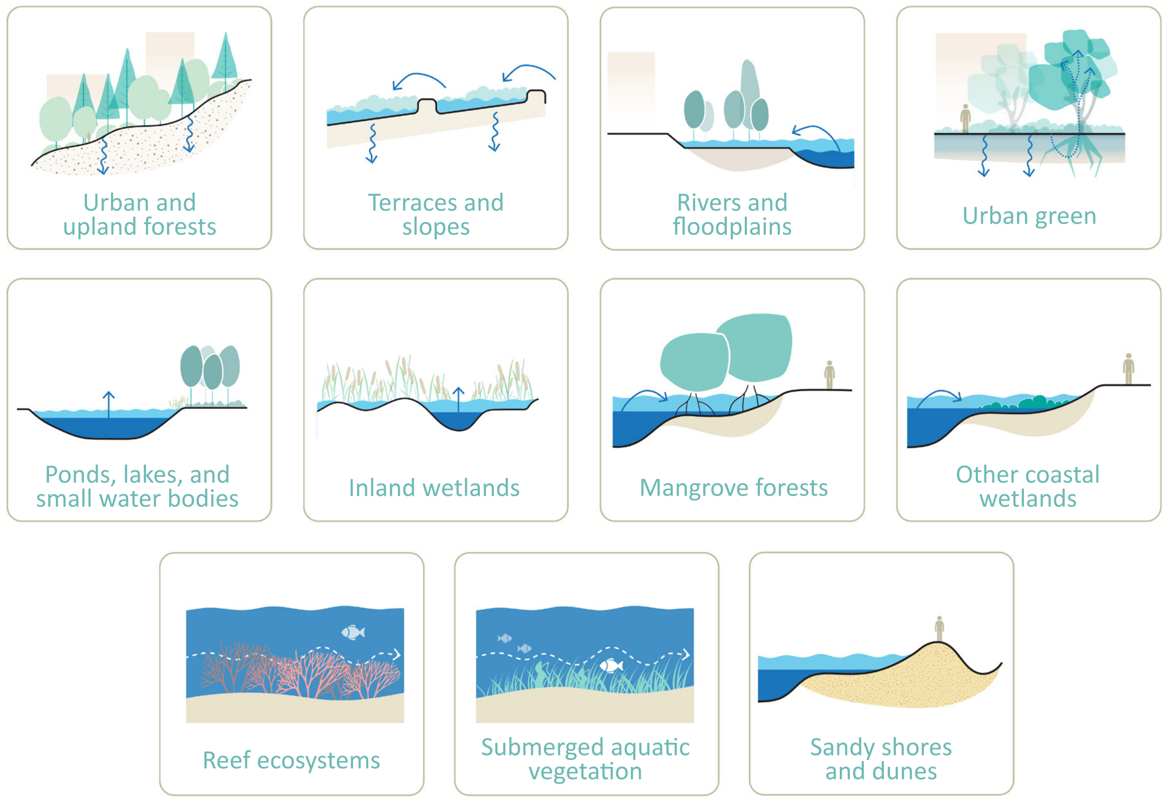
Overview

The challenge: How to make the economic case for investment in nature-based solutions

Countries are facing increasingly complex climate-related challenges that, in combination with unplanned growth and nature loss, are making them less resilient to climate shocks and more vulnerable to disasters. Nature-based solutions (NBS) for climate resilience are integrative strategies to reduce climate risks while at the same time enhancing biodiversity and ecosystem services. They include the protection or restoration of mangroves, urban green space, rivers and floodplains, reef ecosystems and wetlands (figure O-1). Whereas investment in NBS for climate resilience is gradually increasing, globally, funding needs are expected to triple by 2030 to effectively address the combined climate and nature challenges.

Figure O-1. NBS for climate resilience families



Source: Original figure for this publication.
Note: See chapter 2 for more details.

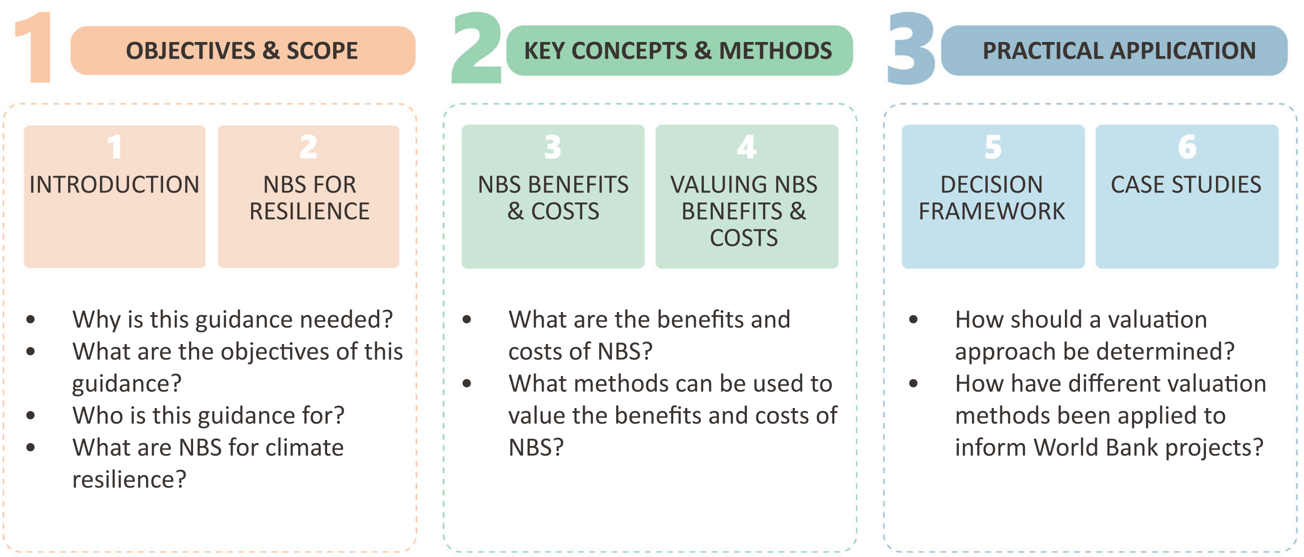
Global assessments show that the net benefits of NBS for climate resilience are significant. For example, benefit-cost ratios for protecting mangroves for coastal protection were estimated at more than five-to-one. And in a US Gulf Coast assessment, nature-based coastal risk mitigation options had higher benefit-cost ratios than gray infrastructure alternatives. Globally, the annual avoided damages due to the presence of mangroves and coral reefs have been estimated at $65 billion and $4 billion, respectively. The aforementioned benefits are a lower-bound estimate, as they quantify only climate and disaster risk reduction benefits and do not value other ecosystem services, which in many places provide additional benefits. For example, 30 percent of the world's reefs are of value for tourism, with a total annual value estimated at nearly $36 billion, whereas mangroves also contribute to nature-based tourism through the high-value, low-impact use of these important ecosystems.

However, one of the key barriers to scaling investment in NBS for climate resilience is the limited understanding of their benefits at project level. A better understanding of methods and approaches to value the costs and benefits of NBS for climate resilience may enable further uptake of NBS by articulating their value and beneficiaries across sectors and, thereby, pave the way for additional funding and financing options. However, many project developers lack the knowledge and tools to value NBS that substitute or complement gray infrastructure to reduce climate risks. In addition, knowledge, time, and resources are often limited for the identification and valuation of the other benefits that these solutions provide, such as climate regulation, food provisioning, and opportunities for recreation and enhancing biodiversity.

Providing practical guidance to valuing NBS for climate resilience

This guideline supports the design and execution of studies that can effectively inform NBS for climate resilience investment projects. It connects valuation methods to the different phases in NBS investment projects—from upstream analytics to impact evaluation—in a decision framework. This decision framework helps guide study design, considering the project context as well as time and budget constraints (figure O-2). Eight case studies on the benefits and costs of NBS for climate resilience that have informed World Bank projects—with interventions such as mangroves, urban green spaces, and watershed management—are included as practical examples.

Figure O-2. Structure of the guideline and questions addressed

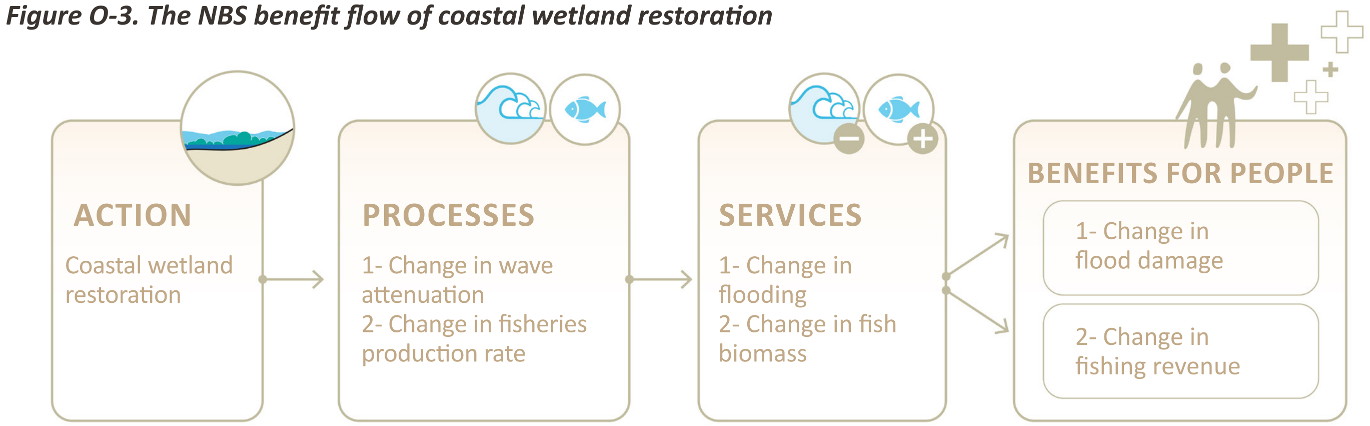


Source: Original figure for this publication.
Note: NBS = Nature-based solutions.

Valuing the benefits of NBS is typically approached through ecosystem service assessment. Such assessments link an action, such as wetland restoration, to benefits through an ecological or physical production function (figure O-3). The restoration of wetlands can reduce flood risk by reducing surges and waves through the frictional effects of vegetation blades, stems, and branches on water flow. The transformation of waves and surges influences the amount of water overtopping berms and other coastal structures, as well as the intensity of the force of water. The change in wave height and force results in a change in flood extent and height, and a change in related property damage. Importantly, an NBS project such as wetland restoration can also generate a wide range of potential other benefits—for example, an increase in fish biomass and revenues from fishing.

An assessment of the net benefits provided by an NBS project requires comparison to a without-project scenario, or to a scenario where a different project alternative is chosen. Doing nothing can still result in benefits, so even though an area may be degraded it is important to measure its service provision to contrast to the NBS project benefits.

Figure O-3. The NBS benefit flow of coastal wetland restoration



Source: Original figure based on **van Zanten et al. 2021.**
Note: See chapter 3 for more details.

Ingredients of a good assessment: Key steps in the analysis and principles for valuing NBS

What makes a good assessment? Chapters 3 and 4 take a deeper dive into the key benefits, main cost components, and how to value benefits and costs. Six steps are identified that should be part of each assessment of the benefits and costs of NBS for climate resilience (table O-1).

Table O-1. Six steps of each assessment of the benefits and costs of NBS for climate resilience

Step	Description
Scoping benefits	The first step in valuing NBS benefits is to **identify what the key benefits of the project are.** This is a critical step as the benefits to local communities vary from place to place. Identifying the three or four key other benefits of NBS can be done in several different ways, including through expert elicitation, stakeholder consultation, and participatory mapping.
Defining the decision support framework	The choice of decision support framework is an important step in valuing the benefits and costs of NBS as **it determines the way costs and benefits are compared**, and, therefore, it influences the choice of method in the next analytical steps. Commonly applied economic decision support analyses are cost-benefit analysis (CBA), multicriteria analysis (MCA), cost-effectiveness analysis (CEA), and robust decision-making (RDM) approaches.

Hazard and risk assessment	Hazard and risk assessment is required to **understand climate and disaster risk** at potential project locations. These risks could include, but are not limited to, flood, erosion, heat, drought, and landslide risk.
Risk reduction benefits valuation	Risk reduction benefits are services that **flow from NBS to regulate climate and disaster risk** as their primary design intention or goal. They are assessed using methods applied in disaster risk analysis. Such analyses employ process-based physical models and damage assessment to quantify risk and the risk reduction impact of an NBS.
Other benefits valuation	Other benefits, also referred to as *co-benefits*, are **other relevant societal benefits derived from NBS**, which may vary depending on the particular NBS intervention and may include food, raw materials, drinking water provisioning, biodiversity, tourism and recreation, and global climate regulation. A suite of valuation methods is available depending on the type of benefit and project context.
Cost valuation	**It is critical to understand the key cost components of an NBS.** Across the life cycle of an NBS for climate resilience project there are capital expenditures (CAPEX), including the costs design, planning, and construction; and operating expenses (OPEX). OPEX include monitoring, maintenance, and operation of the NBS to sustain benefits over time. Other NBS cost components include opportunity costs, transaction costs, and costs associated with negative externalities and disservices.

Source: Original table for this publication.
Note: NBS = nature-based solutions.

This guideline offers methods to execute the six steps described above in a way that serves the project's decision context. Which method is chosen for each of the steps may depend on (1) the type of NBS; (2) the level of rigor and granularity required at different project stages; and (3) the constraints related to the availability of data, time, knowledge, and resources. However, for all assessments, four principles apply:

- **Value both risk reduction and other benefits.** NBS are multi-benefit and therefore multistakeholder approaches. The other benefits such as biodiversity, climate regulation, and ecosystem services supporting local livelihoods are a crucial part of their value proposition. This implies that to accurately reflect the value of an NBS, both risk reduction and relevant other benefits should be considered in the assessment.
- **Engage stakeholders to scope locally relevant benefits of NBS.** NBS benefits are often context specific. This implies that the value of NBS varies widely from place to place. It is critical to consult and engage stakeholders to identify the relevant benefits to consider in project identification to ensure community buy-in and engagement.
- **Address uncertainty.** As the climate is changing, analytics based on historical climatic conditions at project initiation may not serve as a realistic projection of climatic conditions toward the end of the project lifetime. Uncertainties driven by both climate and socioeconomic conditions play an important role in the assessment of the benefits and costs of NBS.
- **NBS benefits (and cost) assessment should inform project identification, design, implementation, and impact evaluation.** Benefits assessment and cost assessment should be an integral part of NBS project identification and preparation to raise awareness, engage stakeholders, assess economic viability on investments, and evaluate impact of the NBS.

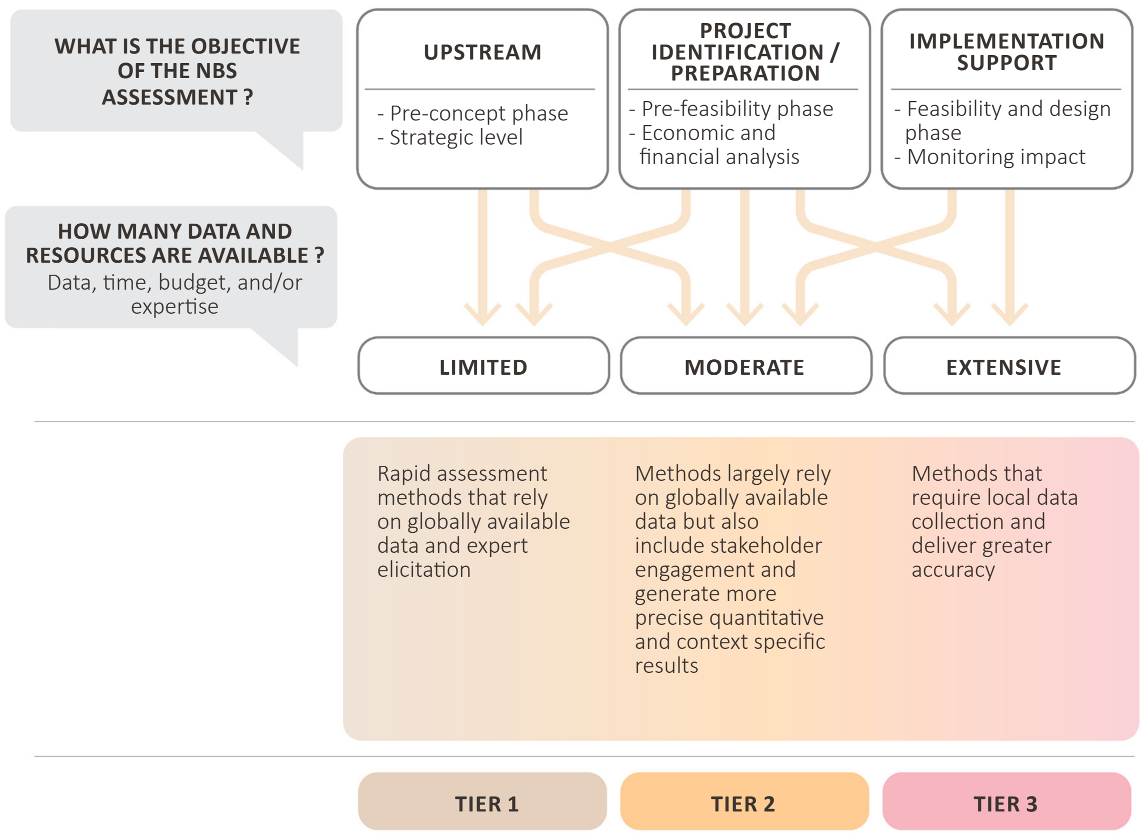
Actionable approaches for project-level assessment

To establish the right method to use for a decision context, a tiered approach is proposed (figure O-4). **Tier 1** includes rapid assessment methods that rely on globally available data and expert elicitation; **tier 2** methods largely rely on globally available geospatial/economic data but also include stakeholder engagement and generate more precise quantitative and context specific results; and **tier 3** includes methods that require local data collection (for example, interviews, focus groups, and field observations) and deliver greater accuracy. Tier selection is guided by the following questions:

1. **What is the objective of the assessment?** There can be different objectives. For example, the objective can be advocacy and raising awareness of NBS among clients, experts, funders, and other stakeholders; or the objective can be to provide part of technical studies to locate or design NBS. Naturally, feasibility and design studies of NBS interventions will require more granular results and greater methodological rigor and robustness than an advocacy piece or a country-level strategic assessment.

2. **How much data, time, and resources are available?** In a project context, the availability of time, funding, data, and expertise for assessing the benefits and costs of NBS will often dictate which methods are feasible. Benefit assessments and cost assessments of NBS in many cases rely on data from previous studies across disciplines and sectors, such as flood risk assessments or natural capital accounts. Therefore, careful screening of available data is essential for developing high-quality assessments in a cost-effective way.

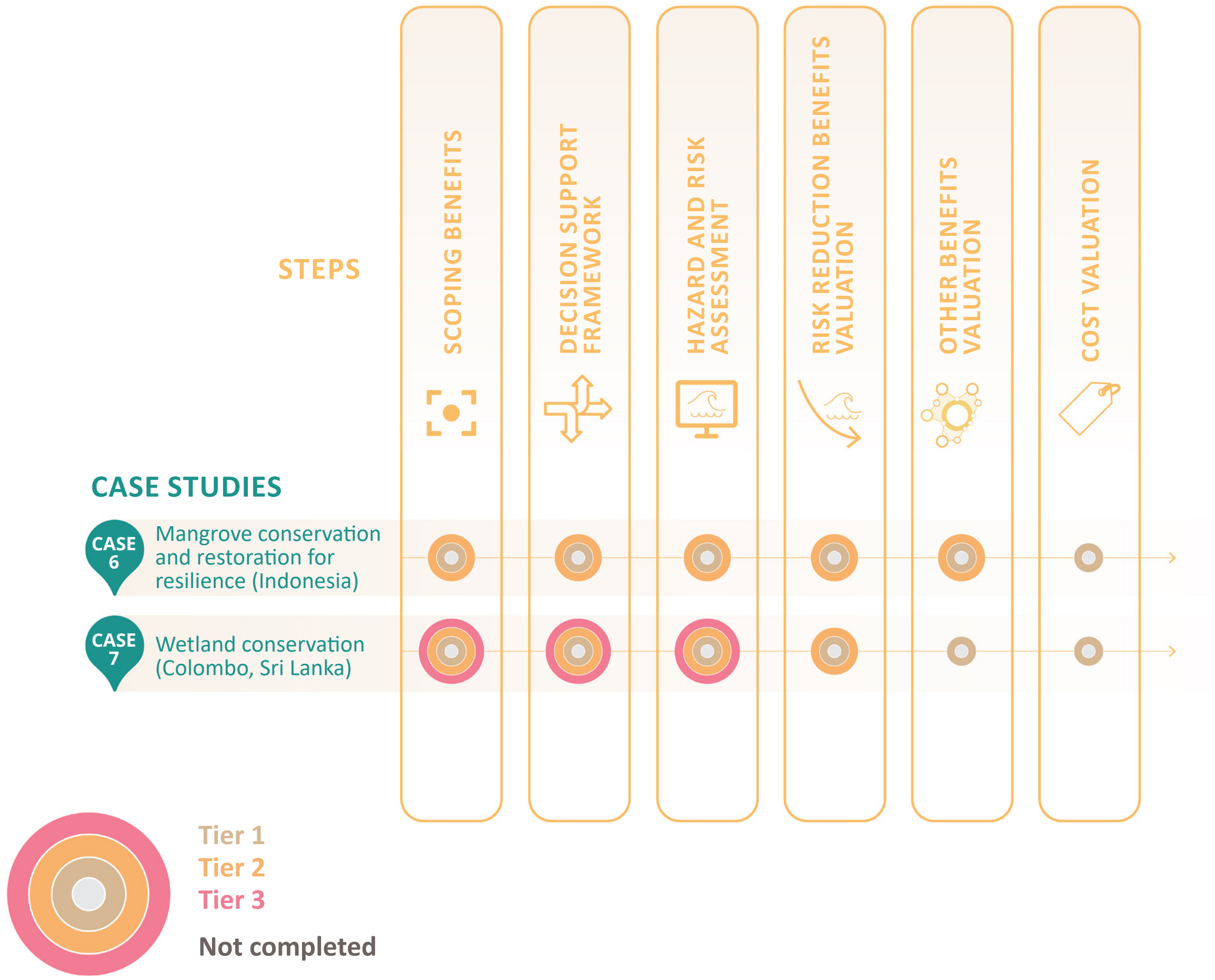
Figure O-4. The decision context, resource availability, and tiers of analysis



Source: Original figure for this publication.
Note: See also figure 5-2 for further details.

The case studies at the end of this guideline show how **assessing the economics of NBS has successfully informed investments,** and which tier selection was made by the respective teams. For example, in Colombo (case study 6) the economic case was made for wetland conservation in the city, showing that the benefits of flood management and recreation outweigh the opportunity cost of land development. In Indonesia (case study 7), a national-level cost-benefit analysis showed the economic viability of mangrove conservation and restoration in large parts of the country and helped identify priority areas for $400 million worth of investment in mangroves supporting coastal protection and livelihoods. Different methodological choices were made in the eight case studies that are evaluated (figure O-5), with potential for replication in future projects

Figure O-5. Tiers of analysis applied in two case studies



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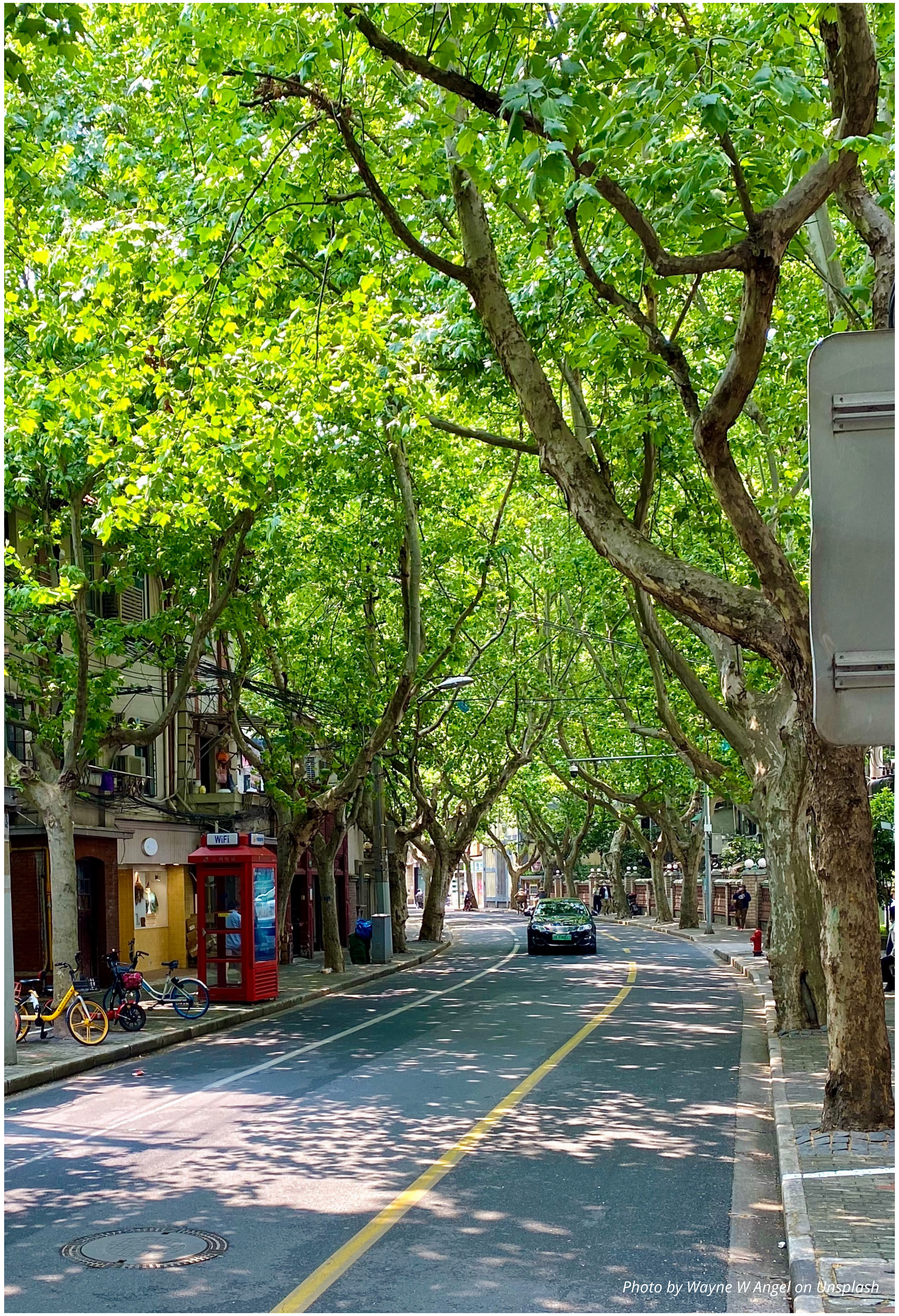
Note: See also figure 6-2 for further details.



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1

Introduction

1.1 Background

Communities and governments are facing increasingly complex climate-related challenges, which undermine resilience and require integrated and innovative solutions. The interactions among the coupled climatic, natural, and human systems are the basis of emerging risks from climate change, ecosystem degradation, and biodiversity loss (IPCC 2022). Preserving or restoring natural features at scale has the potential to be an important part of the solution to the combined challenge of mounting climate risk and nature loss. For example, mangroves help to protect coastal communities and infrastructure against the effects of storms, tidal surges, and sea-level rise, while wetlands and natural forests play an important role in maintaining dry season waterflow and creating water storage.

Nature-based solutions (NBS) are defined by the United Nations as "actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits" (UNEP 2022). Under this umbrella term, this document focuses on NBS for climate resilience, which are solutions aiming to reduce climate and disaster risk. This concept includes related approaches, such as ecosystem-based disaster risk reduction (Eco-DRR), NBS for disaster risk management, ecosystem-based adaptation (EbA), and green infrastructure. Climate-smart agriculture and other NBS typologies in the agricultural landscape are not within the scope of this report. However, NBS for climate resilience are viewed through a holistic lens, also valuing the other important benefits they provide beyond climate and disaster risk reduction, such as the provisioning of food or drinking water, opportunities for recreation, and climate regulation.

The potential benefits of NBS for climate resilience are significant, evidence suggests. For example, global benefit-cost ratios for protecting mangroves for coastal protection were estimated at more than five to one (GCA 2019). And in a US Gulf Coast assessment, nature-based coastal risk mitigation options had higher benefit-cost ratios than gray infrastructure alternatives. Globally, the annual avoided damages due to the presence of mangroves and coral reefs have been estimated at $65 billion and $4 billion, respectively (Losada et al. 2018; Menéndez et al. 2020). The benefits in these assessments are underestimated, as they quantify only climate and disaster risk reduction benefits and neglect other ecosystem services, which in many places provide additional benefits. For example, 30 percent of the world's reefs are of value for tourism, with a total value estimated at nearly $36 billion (Spalding et al. 2017), whereas mangroves also contribute to nature-based tourism through a high-value, low-impact use of these important ecosystems (Spalding and Parrett 2019).

Despite the potential of NBS to address climate-related risks and provide important other benefits, funding and financing remain limited. Between 2012 and 2018, global funding for EbA projects increased from $2.1–4.1 billion to $3.8–8.7 billion (Swann et al. 2021). In perspective, for 2018 this funding represents ~0.6 to 1.4 percent of total climate finance flows and 1.5 to 3.4 percent of public climate finance flows (Swann et al. 2021). By another estimate, NBS for adaptation accounted for 13 percent of the total $18.8 billion invested in climate mitigation and adaptation by the Global Environment Facility, the Green Climate Fund, the Adaptation Fund, and the International Climate Initiative (Germany) combined over the last 30 years (UNEP 2021a). To tackle the intertwined climate, nature, and land degradation challenges, the *State of Finance for Nature Report* (UNEP 2021b) estimated that investment in NBS needs to triple by 2030 and increase fourfold by 2050 if it is to be successful.

The lack of quantitative evidence on the benefits of NBS for climate resilience is considered one of the key barriers to implementation at scale. A first constraint has been an inability to fully model the effectiveness of NBS to substitute or complement gray infrastructure's services. The economic viability of dikes, dams, and drainage systems is traditionally modeled by comparing expected impacts of natural hazards with and without project intervention. To evaluate NBS at the same level as gray infrastructure alternatives, process-based models to assess the capacity of NBS to dissipate wave energy, adapt to sea-level rise, and reduce runoff have improved greatly in recent years. Despite these advancements, some knowledge gaps remain, and successful modeling and valuation approaches have not yet fully permeated throughout the industry. A second constraint is that, even though a variety of methods is available to quantify the other benefits (or ecosystem services) provided by NBS, these have seen little application in the context of NBS for climate resilience projects. As a result of these knowledge and information gaps, many project developers and policy makers remain unconvinced or unaware of the potential benefits of integrating NBS for climate resilience in strategies for urban development, water management, and climate adaptation.

Hence, a framework and a comprehensive set of methods is needed to measure, compare, and communicate the benefits and costs of NBS to support better-informed projects by World Bank task teams and project developers elsewhere. Valuation of benefits and costs can support NBS project preparation, implementation, impact evaluation, and operation. NBS provide benefits to different stakeholders, across sectors and spatial scales. An urban forest might provide flood protection, health benefits, and recreation to local communities and governments while sequestering carbon that is regulating the global climate. Valuing these benefits and identifying their beneficiaries will help (1) identify locations where NBS can be effective, (2) raise awareness among stakeholders, (3) inform design of the NBS to ensure optimal outcomes, and (4) identify indicators to evaluate impacts. In addition, the valuation of benefits of NBS is critical to leverage additional financing for NBS from third parties, such as private sector actors or carbon markets.

1.2 Objectives

This document aims to guide the design, implementation, and use of studies to value the benefits and costs of NBS for climate resilience projects. Reliable quantification of the costs and benefits of NBS for climate resilience can facilitate further mainstreaming of NBS by articulating the value proposition of NBS across sectors and identifying additional funding and financing for projects. This report by no means presents a comprehensive manual of all valuation methods, tools, and data. Rather, it provides an overview of methods and approaches, along with a decision framework to guide the design of NBS cost and benefit assessment. To avoid an overwhelming level of technical detail that might be less relevant for a nonexpert audience, the authors have incorporated key references to expand the guidance of main economic methods and approaches. The decision framework presented should also enable project developers to come up with a cost-effective approach for quantifying the benefits and costs of NBS that is effective and convincing in the context of climate resilience projects.

The report consolidates lessons from existing guidelines applied to a World Bank project context. It adopts the main NBS typologies from the *Catalogue of Nature-Based Solutions for Urban Resilience* (**World Bank 2021**), while the valuation methods and framework build on the international NBS guidelines for flood risk management (**Bridges et al. 2021**; **van Zanten et al. 2021**). It also leverages approaches from World Bank guidelines for assessing the benefits of specific NBS types, such as coastal protection by mangroves and coral reefs (**Beck and Lange 2016**) and landslide risk (ADPC 2009).

1.3 Target audiences

This guidance manual targets multiple audiences. While most of the content is useful and valuable for project developers and economic experts outside the World Bank, the main audience of this resource are World Bank task teams, their technical staff, and government clients. The document is primarily targeted at the professionals who are responsible for commissioning, supervising, and using the results of such studies to inform and influence project identification, design, appraisal, and implementation. Hence, it addresses the importance of valuing benefits and costs of NBS at different phases in the World Bank project cycle and provides case studies as examples linked to World Bank investment projects.

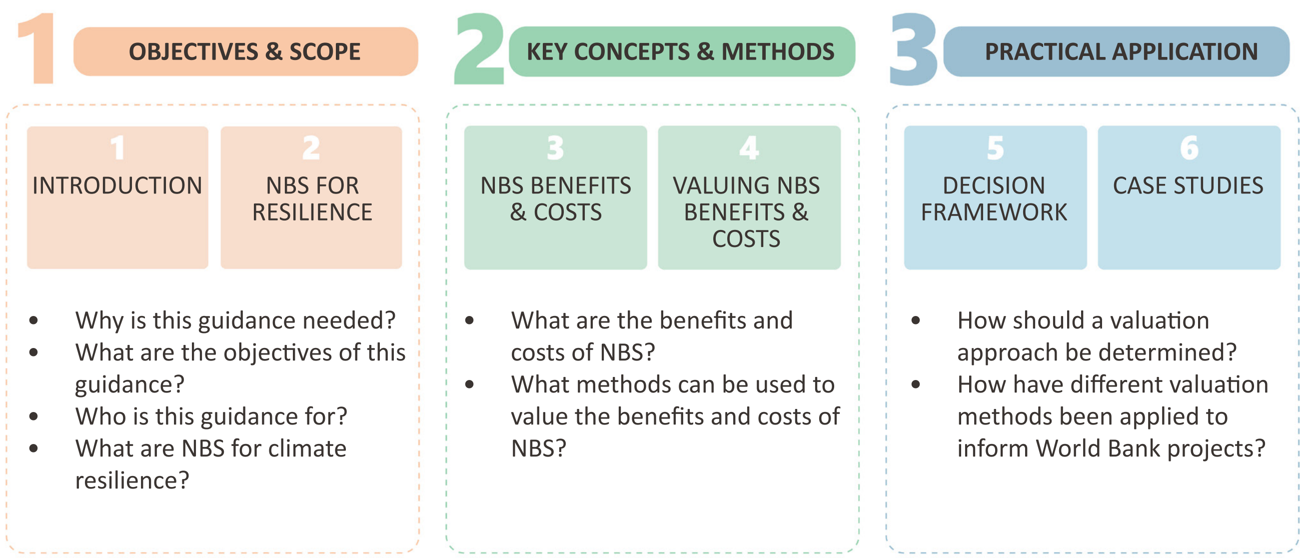
At the World Bank, NBS for climate resilience investments are integrated in projects across Global Practices, including Urban, Disaster Risk Management, Resilience and Land (GPURL); Environment, Natural Resources, and the Blue Economy (ENB); Water; Agriculture; and Transport (World Bank 2023).

The users of this guideline are assumed to have a basic understanding of concepts and implementation principles of NBS for climate resilience. For general background and implementation guidance, we refer to the C*atalogue of Nature-Based Solutions for Urban Resilience* (**World Bank 2021**) and the flagship report entitled *Integrating Green and Gray: Creating Next Generation Infrastructure* (Browder et al. 2019). This current guideline focuses on the valuation of the NBS for resilience benefits and costs exclusively; however, additional key references of relevant economic valuation methods and concepts are also highlighted through the document to advise on important questions and expand technical guidance.

1.4 Content structure

This guideline consists of six chapters divided into three main sections (figure 1-1) aiming at presenting a comprehensive overview of the valuation of NBS costs and benefits (section 2) and connecting the theory of these analytical approaches with the context of World Bank projects (section 3).

Figure 1-1. Structure of the guideline and questions addressed



Source: Original figure for this publication.
Note: NBS = Nature-based solutions.

Context, objectives, and scope:

- Chapter 1 presents an introduction to the context, objectives, target audiences, and structure of the report.
- Chapter 2 provides information on the scope of NBS for climate resilience to which the guideline applies, including the NBS types it covers and the scale and context in which the NBS are applied.

NBS concepts and valuation methods:

- Chapter 3 leverages current literature to identify and describe the benefits and costs associated with NBS for climate resilience.
- Valuation methods for estimating the benefits and costs associated with NBS for climate resilience are described in chapter 4.

Decision framework and case studies:

- Chapter 5 proposes a decision framework and different economic valuation methods depending on project contexts and available resources taking into consideration the specificities of the World Bank project cycle.
- To illustrate this in practical applications, chapter 6 presents eight case studies from World Bank projects with examples of valuation benefits and costs of NBS in different phases of the project cycle. The case studies (index in table 1-1) are also referenced throughout the document to better show how different valuation methods are applied in real projects.

Table 1-1. Index of case studies included in the guidance with key characteristics

Case study (country)	NBS type	Scale	Risk reduction benefits (RRB)	Other benefits	Main analytical approaches applied for RRB	Project cycle stage
1. Coral Reef Restoration (Seychelles)	Reef ecosystems	National (scoping phase) and site specific (pre-feasibility phase)	Flooding and erosion	Biodiversity Tourism and recreation Climate regulation (only identification)	Multicriteria analysis Avoided damages and costs	Upstream
2. Urban Wetlands for Heat Reduction (China)	Urban green Inland wetlands	City	Extreme heat reduction	Health Climate regulation	Cost-benefit analysis Avoided damages and costs	Upstream
3. Nature-Based Flood Protection (Mozambique)	Urban green Ponds, lakes, and small water bodies	City	Flooding and erosion	Provisioning of food and raw materials Climate Regulation	Cost-benefit analysis Avoided damages and costs	Upstream
4. Green Infrastructure for Landslide Risk Reduction (Nepal)	Urban and upland forests Terraces and slopes Rivers and floodplains	Watershed	Landslide risk reduction	Provisioning of food and raw materials Climate regulation	Cost-benefit analysis Avoided lives lost Avoided damages and costs	Upstream Project Identification and preparation
5. Mangroves for Coastal Protection (Jamaica)	Mangrove forests	National and site specific	Flooding and erosion	Climate regulation, Provisioning of food and raw materials	Avoided damages and costs	Upstream Project identification and preparation
6. Mangrove Restoration for Resilience (Indonesia)	Mangrove forests	National	Flooding and erosion	Climate regulation Provisioning of food and raw materials Tourism and recreation	Spatial cost-benefit analysis Avoided damages and costs	Project identification and preparation Project appraisal
7. Wetland Conservation in Colombo (Sri Lanka)	Inland wetlands	City	Flooding and erosion Extreme heat reduction	Climate regulation Tourism and recreation Wastewater treatment	Cost-benefit analysis; Decision-making under uncertainty Avoided damages and costs	Project identification and preparation Project implementation and support
8. Coastal Resilience in Emergency Recovery (Mozambique)	Sandy shores and dunes Mangrove forests	Site specific	Flooding and erosion	Tourism and recreation Biodiversity Job creation Health	Cost-benefit analysis Avoided damages and costs	Project implementation and support

Source: Original table for this publication.
Note: NBS = nature-based solutions.

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2

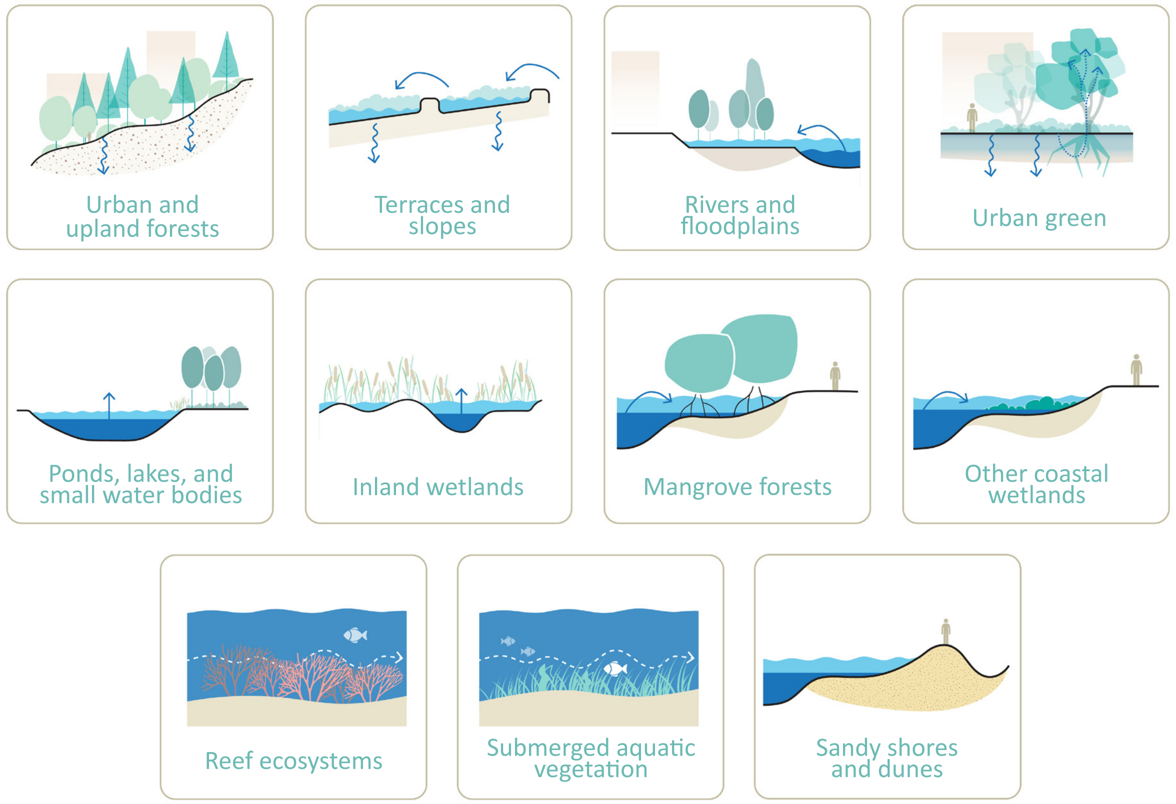
Nature-Based Solutions for Climate Resilience

Nature-based solutions (NBS) for climate resilience are a subset of interventions under the NBS umbrella that, alongside other benefits, contribute to climate resilience and adaptation. Specific types of NBS can increase resilience as climate change is increasing the exposure of people to natural hazards—such as flooding, extreme heat, droughts, and landslides—around the globe. For instance, an intervention that focuses only on protecting or restoring forests to store and sequester carbon from the atmosphere is *not* an example of an NBS for climate resilience. If, however, the forest happens to be a protective forest—there is evidence that it protects communities in the valley against the impacts of landslides and avalanches—it can be considered an NBS for climate resilience after all. To complement or even substitute for the services of gray infrastructure, it is essential that the resilience and adaptation benefits of NBS are quantifiable and based on sound analytics, with an evidence base accepted across infrastructure sectors.

The identification, design, and implementation of NBS for climate resilience requires a systems approach that considers the landscape ecology, functions of gray infrastructure, and location of the project site in the watershed. The value proposition of NBS for climate resilience—alongside gray infrastructure—is often best understood when analyzed at the landscape, city, or watershed level (**World Bank 2021**). For example, runoff reduction of many green spaces can be combined effectively to reduce stormwater flooding as part of a city's drainage system; mangroves along coastlines may together reduce wave energy and storm surge height, reducing the cost of embankments (Dasgupta et al. 2019).

Building on the World Bank's *Catalogue of Nature-Based Solutions for Urban Resilience* (2021), this guidance, identifies 11 main "families" of NBS for climate resilience (figure 2-1). These 11 types of interventions provide benefits for climate resilience and adaptation in different ways and, therefore, require different approaches to quantify their benefits and costs. For example, an urban forest may reduce stormwater runoff and reduce heat through shading, while coastal wetlands may reduce wave energy and prevent erosion by stabilizing sediments. Moreover, valuing the other benefits provided by forests and coastal wetland—such as climate regulation (through carbon sequestration), biodiversity, and recreation—may require different analytical approaches.

Figure 2-1. NBS for climate resilience families



Source: Original figure for this publication.
Note: This group of intervention types is not a comprehensive list of all NBS for resilience types but instead focuses on NBS interventions for adaptation and disaster risk reduction applications. The *rivers and floodplains* family includes riparian buffers, oxbows/side channels/diversion channels, floodplains/swales, stream biofilters/leaky and woody barriers, and removal of invasive species that affect flooding. The *urban green* family includes green buildings and roofs, urban parks and open green space, green corridors, urban farming, bioretention areas, and sustainable urban drainage systems (SUDS). The *coastal wetlands* family excludes mangroves. *Submerged aquatic vegetation* includes seagrasses and kelp. NBS = nature-based solutions.

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Key references


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3

Benefits and Costs of Nature-based Solutions for Climate Resilience

3.1 Defining benefits and costs

This section provides a definition and an overview of the benefits and costs of nature-based solutions (NBS). The definition of *benefits* used in this guideline is based on concepts of ecosystem services and natural capital (Guerry et al. 2015; IPBES 2019). *Ecosystem services* are defined as the contribution of nature to people (Diaz et al. 2018; IPBES 2019). By employing natural or nature-based features, NBS are linked to regulating the impact of natural hazards and the provision of other ecosystem services that contribute to human well-being. This guideline distinguishes two types of benefits provided by NBS for climate resilience: risk reduction benefits and other benefits.

- ***Risk reduction benefits*** are services that flow from NBS to regulate climate and disaster risk as their primary design intention or goal. The reduced risks include flood, erosion, heat, drought and water supply regulation, and landslide risk.

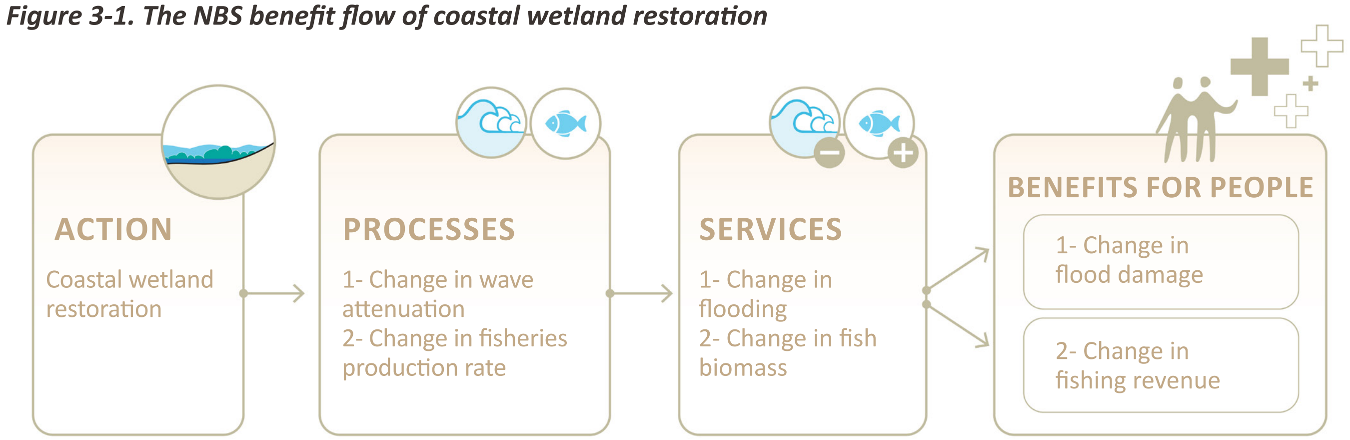
- ***Other benefits*** are other relevant societal benefits derived from NBS, which may vary depending on the particular NBS intervention and may include the provisioning of food, raw materials, and drinking water, and the enhancement of biodiversity, tourism and recreation, and global climate regulation.

Measuring the benefits of NBS is typically done through ecosystem service assessments (de Groot et al. 2002; Olander et al. 2017; figure 3-1). Ecosystem service assessments translate an action (that is, an NBS project) into impacts on valued ecosystem services through an ecological or physical production function (shown in the first three boxes of figure 3-1). This function is an expression or model of the processes by which an action relates to environmental outcomes (Bruins et al. 2017; Ruckelshaus et al. 2020). For example, the restoration of wetlands can reduce flood risk by reducing surges and waves through the frictional effects of vegetation blades, stems, and branches on water flow (for example, see Narayan et al. 2016). The transformation of waves and surges influences the amount of water overtopping berms and other coastal structures, as well as the intensity of the force of water (Tsihrintzis and Madiedo 2000).

The ecological production function is then connected to a measure of the change to human well-being to complete the ecosystem service assessment. In the case of coastal wetland restoration, this could mean assessing how the change in wave height and force results in a change in flood extent and height and a change in related property damage. Importantly, a single action or NBS project such as wetland restoration can also generate a wide range of potential other benefits. Therefore, tracing all of these out through their own ecosystem service assessments is necessary for a full accounting of the effects of an NBS project.

It is important to note that an assessment of the benefits provided by an NBS project requires comparison to a without-project scenario, or to a scenario where a different project alternative is chosen. In the wetland restoration context, this means values are estimated as changes (see boxes 2–4 in figure 3-1) from an alternative state. This alternative state generally reflects the current and anticipated outcomes from doing nothing. Doing nothing can still result in valued ecosystem goods and services for people, so even though an area may be degraded it is important to measure its service provision to contrast the NBS project benefits against.

Figure 3-1. The NBS benefit flow of coastal wetland restoration



Source: Original figure based on **van Zanten et al. 2021.**
Note: The benefit flow links the production function to risk reduction benefits and other benefits for people.

The structure of ecosystem service assessments should be familiar to those who have experience conducting project-level assessments of civil infrastructure. The assessment framework simulates how an action leads to an outcome and then evaluates physical and social metrics of interest to planners, in much the same way traditional gray infrastructure is evaluated (Lallemant et al. 2021). Thinking of this approach as distinct from traditional infrastructure evaluation can lead to inconsistent comparisons with NBS. While it is not often currently assessed, gray infrastructure can have impacts on the environment that would also require ecosystem service assessment models to measure. For example, if a levee prevents wetland migration in response to sea-level rise, then the loss of fisheries habitat and resulting losses to commercial and recreational fishers should be measured as an impact of the project. NBS and gray infrastructure can also provide the same benefit in potentially different amounts. For example, recreational birding may be associated with a wetland, whereas recreational fishing may be associated with a seawall, and both benefits should be assessed using the same methods. While a thorough accounting of all project impacts is not always feasible, it is important to realize that consistency in estimating project costs and benefits allows NBS to be compared directly to hybrid or gray approaches.

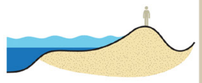
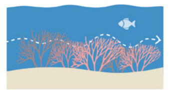
Some benefits provided by NBS are traded in markets. Such benefits have a market price and include the provisioning of food, water, timber, and nature-based tourism. In contrast, global climate regulation and disaster risk reduction benefits of NBS for climate resilience are generally considered public goods. Their value is to a lesser extent incorporated in market prices and only becomes "visible" if the NBS no longer regulates the climate, reduces flooding, or provides water. The difference between marketed and non-marketed benefits is made explicit by conducting economic or financial assessment. The economic assessment quantifies all relevant benefits and costs, including public goods, for assessing the economic viability of an NBS through a societal lens. Financial assessment shows the part of the benefits and costs of NBS that is reflected in market prices. Financial assessment helps project teams understand the financial viability of a project, "sheds light" on existing incentive structures (that is, why is deforestation happening or disaster risk increasing?) and might support the design of instruments to sustainably finance NBS for climate resilience. Governments can create a market for public good–type NBS benefits—for instance, through payments of ecosystem services programs, resilience credits, or carbon markets.

3.2 Risk reduction benefits

NBS can mitigate climate and disaster risk by taking advantage of the biological and physical properties of natural features (figure 3-1). The processes through which hazards are mitigated by an NBS project vary widely and depend on the type of hazard, the NBS approach, and the ecosystem or landscape context. Importantly, climate risk also depends on the configuration of exposed people, property, and other valued assets within the hazard zone, not just the physical changes of the hazard attributable to the NBS. Table 3-1 provides an overview of processes by which the key NBS types addressed in this report regulate natural hazards.

Table 3-1. Processes by which key NBS types regulate hazards

	Hazard regulation processes				
NBS Type	**Flooding**	**Erosion (coastal & riverine)**	**Drought (water flow regulation)**	**Heat**	**Landslides**
Urban and upland forests[a]	Reducing runoff, reflecting energy, slowing water flow, reducing wave height	Stabilizing soil with a root network	Regulating water storage and flow, affecting evapotranspiration, shading, recharging groundwater	Shading, affecting evapotranspiration	Stabilizing soil with a root network, delaying and reducing runoff
Terraces and slopes	Delaying runoff, enhancing infiltration	Stabilizing soil	Enhancing infiltration, affecting evapotranspiration, storing water	Shading, affecting evapotranspiration	Stabilizing soil with a root network, delaying runoff
Rivers and floodplain restoration[b]	Storing water, slowing water flow, enhancing infiltration	Rebalancing sediment supply and processes	Enhancing infiltration, affecting evapotranspiration, shading, storing water	Shading, absorbing heat, affecting evapotranspiration	Stabilizing riverbanks
Urban green[c]	Storing water, enhancing infiltration	Stabilizing soil with a root network	Affecting evapotranspiration, shading, infiltration, storing water	Shading, affecting evapotranspiration	Stabilizing soil with a root network
Ponds, lakes, and small water bodies	Storing water	Regulating sediment flows	Storing water	Absorbing heat, reducing evaporation	n.a.
Inland wetlands	Storing water, slowing water flow, reducing wave height	Regulating sediment flows	Recharging groundwater	Affecting evapotranspiration	n.a.
Mangrove forests	Reflecting energy, slowing water flow, reducing wave height	Regulating water and sediment flows	n.a.	n.a.	n.a.
Other coastal wetlands (excluding mangroves)	Storing water, slowing water flow, reducing wave height	Stabilizing soil and sediment	n.a.	n.a.	n.a.

 Sandy shores and dunes	Reflecting energy, slowing water flow	Rebalancing sediment supply and processes (morphodynamic adaptation)	n.a.	n.a.	n.a.	
 Reef ecosystems [d]	Reflecting energy, slowing water flow, reducing wave height	Affecting surf zone dynamics and sediment transport	n.a.	n.a.	n.a.	
 Submerged aquatic vegetation [e]	Slowing water flow, reducing wave height	Regulating water and sediment flows	n.a.	n.a.	n.a.	

Source: Original table for this publication.
Note: n.a. = not applicable; NBS = nature-based solutions.
a. Forests NBS considered in this guideline include urban forests and upland forest areas.
b. Rivers and floodplains NBS considered in this guidance include riparian buffers, oxbows/side channels/diversion channel, floodplains/swales, stream biofilters/leaky and woody barriers, and removal of invasive species that affect flooding.
c. Urban green NBS considered in this guidance include green buildings and roofs, urban parks, open green space, green corridors, urban farming, bioretention areas, and sustainable urban drainage systems (SUDS).
d. Reefs considered are coral and oyster.
e. Vegetation considered are seagrass and kelp.

Following the NBS benefit flow (presented in figure 1-3), the sections below summarize key processes and examples of quantified risk reduction benefits.

Flooding

Process and services. Employing nature to reduce the risk of flooding relies on a variety of different physical processes that depend on the interaction of water and ecosystems, including trapping sediments, dampening waves, storing water, and physically impeding water movement (Arkema et al. 2017). As a result, the value of NBS for flood risk mitigation is highly site-specific (Ruckelshaus et al. 2016).

Benefits. Recent advances in modeling have increased our understanding of the value of flood risk reduction benefits. Storlazzi et al. (2019) estimate that coral reefs in the United States provide over $1.8 billion per year in flood risk reduction benefits, while Sun and Carson (2020) and Menéndez et al. (2020) estimate that wetlands and mangroves provide widely varying but significant flood protection value, with an average value of \$91,000/km^2/year and $461,000/km2/year, respectively. Lallemant et al. (2021) found that forest protection reduces average annualized losses by 14 percent by decreasing peak discharge, flood volume, and flood extent in simulations in the Chindwin River basin in Myanmar. Cutler, Gouett, and Guzzetti (2022) estimate that planting trees in Addis Ababa, Ethiopia, can increase runoff retention between 2.4 percent and 9.3 percent, depending on the tree-planting scenario (11 million or 25 million trees with low or high survival rate, respectively). This can help to avoid flood damages to property between $436,000 and $1,587,000 under a Representative Concentration Pathway (RCP) 8.5 climate scenario and based on a 20-year lifetime of the intervention. In comparison with gray infrastructure, NBS may provide more resilient flood risk reduction benefits because they are able to adapt to changing conditions such as sea-level rise, or land subsidence such as salt marsh migration (Smith 2020).

Erosion (coastal/riverine)

Process and services. NBS can help reduce erosion by stabilizing coastal shorelines and riverbanks (Reguero et al. 2018) and trapping sediment that would otherwise reach waterways in upland riparian areas (Pandey et al. 2021; Willemen et al. 2019).

Benefits. Erosion has a direct effect on land by reducing its quality and quantity for residential, agricultural, recreational, or infrastructure purposes. Several studies have valued the benefits of avoided beach erosion for recreational use (Landry, Shonkwiler, and Whitehead 2020; Whitehead et al. 2008). Secondary effects relate to the transport of eroded materials into waterways that affect water services, such as drinking water, recreation, and hydropower. For example, Yoo et al. (2014) found that thinning of existing tree stands around an upland lake by 10 percent can cause lake sedimentation that can reduce house prices (0.3 percent per house, or over $6 million in aggregate for their study area). While erosion in these contexts is largely considered to have negative effects, the transport of sediment from upland areas through erosion can be a key part of a shoreline's ability to accrete sediment for beaches (Pranzini et al. 2013).

Drought and water flow regulation

Process and services. Differences in evapotranspiration from incorporating NBS into landscape management is the main environmental function through which these solutions can affect the provision of water for all potential end uses. *Evapotranspiration* refers to the process by which water moves from the land to the atmosphere through evaporation from surfaces and transpiration by plants, which includes subsurface water uptake by plants through their roots and transport to their foliage where water then transpires. Variation in trees, herbaceous plants, and other types of land cover can affect evaporation and transpiration, holding all else equal, leading to changes in water availability throughout the year (Mandle et al. 2017; Yang et al. 2018). Adaptation to water and drought risk are often assessed as a compound risk alongside heat risk (Turek-Hankins et al. 2021). Enhancement of infiltration capacity is also an important function linked to NBS implementation. In cities, NBS can reduce imperviousness and allow the infiltration of runoff into the soil; outside cities NBS can change soil structure and improve infiltration capacity. Aquifer recharge techniques and reforestation are examples of NBS that help these processes (Gómez Martín et al. 2021; López Gunn et al. 2021).

Benefits. Research (Spinoni et al. 2013) has found evidence of an increase in drought risk over recent decades, that this risk is linked to anthropogenic climate change (Chiang, Mazdiyasni, and AghaKouchak 2021), and that we should expect more risk as the climate continues to change, with spatial heterogeneity in effects (Balting et al. 2021; Dai 2012). Depending on the type of trees or plants involved in the intervention, the net overall effect of NBS on water provisioning across a year can vary, and can often be negative; however, for locations prone to drought, the timing of water availability is often the most important factor and so tracking interannual availability is important for understanding service delivery. Valuing a marginal change in water provisioning is highly context dependent and is contingent on the end uses for that water and their distribution across space, as well as the public policy setting for water where markets can be distorted through subsidies and public provisioning of water (Grafton, Chu, and Wyroll 2020). The number of studies that value a change in water provisioning from NBS appears very limited (Yang et al. 2018), though there is some research to draw from for hydropower end users (Vogl et al. 2017). Bassi et al. (2021) estimated that forest restoration and improved land management on a large scale in the upper Brantas River Basin in East Java, Indonesia, could increase groundwater recharge by up to 6.1 percent a year, thus contributing to a reliable water supply for industrial activities in the watershed.

Heat

Process and services. NBS to extreme heat events in urban areas include a variety of measures such as urban forests, green roofs, and ponds to reduce heat extremes and human exposure in built environments (**World Bank 2021**). NBS such as tree canopy, green open spaces, water bodies, green roofs, and vertical greenery in cities can mitigate the urban heat island effect through shading, evaporation, and convection. The thermal properties of vegetation are influenced by physical and other contextual characteristics and therefore require detailed assessment (Koc, Osmond, and Peters 2018).

Benefits. Severe heat–related mortality is projected to increase significantly toward the latter half of the century, with areas near the equator experiencing the largest impacts in the absence of any adaptation (Guo et al. 2018). The principal benefits of NBS cooling include improved productivity and reduced health impacts. Carleton et al. (2022) estimate that the mean global increase in mortality risk due to climatic temperature change, accounting for adaptation benefits and costs, is valued at roughly 3.2 percent of global GDP in 2100 under a high emissions scenario. As an example of the heat risk reduction benefits that NBS can provide, a recent study found that a change of 10 percent tree cover in the city of Baltimore is associated with a change of 80–250 annual deaths citywide, at a value of $0.7 to $2.0 billion estimated via the value of a statistical life (Sinha et al. 2021). Another study, in the City of Tshwane, South Africa, found that green roofs can reduce the impacts of extreme heat on energy consumption for cooling. Covering 10 percent of the buildings with green roofs could save 688,425 kilowatt hours (kWh) in annual building's energy, corresponding to more than $21 million in energy costs over 40 years. Similarly, planting 1,000 additional trees would cool down temperatures and cut energy needs for air conditioning by 156,000 kWh per year, or almost $5 million over 40 years (WWF 2021).

Landslides

Process and services. Vegetation on slopes, particularly trees and shrubs, regulate landslide risk by building root structures that reinforce soil and by reducing water content through evapotranspiration (Endo and Tsuruta 1969; Kalsnes and Capobianco 2019; Megahan, Day, and Bliss 1978; Wu and Swanston 1980).

Benefits. The benefits of NBS to regulate landslide risk are the reduction in severe destructive impacts of landslides on infrastructure, agriculture, human life, and ecosystems. There are relatively few studies that estimate the economic value of landslide regulation by NBS. In a study of upland grazing land in New Zealand, Dominati et al. (2014) find that a single shallow landslide on steep hills can decrease the total value of ecosystem services by 64 percent, and that trees planted for slope stabilization can increase the value of ecosystem services by 23 percent after 20 years. In a study of forest management in Adjara, Autonomous Republic of Georgia, Brander et al. (2018) show that forest restoration can reduce landslide damage to properties by $116,000 per year in that region.

3.3 Other benefits

In addition to risk reduction benefits, the valuation of NBS for climate resilience should also address the impacts on the provision of other goods and services (Guerry et al. 2022; Pagiola, von Ritter, and Bishop 2004). For example, many NBS not only provide risk reduction benefits but also provide climate regulation benefits through carbon sequestration into the soil and biomass (Canadell and Raupach 2008). There are many other potential benefits of NBS. For example, salt marsh restoration for flood risk reduction can also enhance fish harvests by providing additional fish habitat as well as recreational and non-use value by enhancing bird habitat (Barbier et al. 2011; Interis and Petrolia 2016). These benefits can extend beyond the spatial footprint of the risk reduction impact based on the physical process that links the service to people: Fish harvest benefits may accrue to fishers and consumers well beyond the localized area of salt marsh flood protection (Mandle et al. 2015), and NBS often contribute to global public goods such as sustaining biodiversity.

Tracking other benefits and their beneficiaries is also important for comparing distributional impacts of alternative NBS actions, as well as for identifying where an NBS project can generate revenue streams from fishing or tourism. Table 3-2 provides a sample of important benefits of NBS that is consistent with the UN System of Environmental Economic Accounting ecosystem service classification framework (UN 2021).

Table 3-2. Other benefits of NBS for climate resilience

Benefit or ecosystem service	Description
Provisioning of food and raw materials (See case studies 3,4,5, and 6.)	Food and raw materials are benefits that support economic activity and are typically traded in markets for consumptive use. NBS can serve as habitat that aids in the provision of these resource stocks (for example, fish) or can itself be harvested directly as a renewable resource (for example, agricultural products, timber).
Tourism and recreation (See case studies 1,6,7, and 8.)	Tourism and recreation are tied closely to the natural environment. Often these recreational experiences are jointly produced with built capital—for example, a nature area may have constructed pathways, benches, or restrooms (Boyd and Banzhaf 2007). A careful articulation of the NBS intervention is necessary to evaluate its impact versus other factors that comprise a recreational experience.
Climate regulation (See case studies 3,4,5,6, and 7.)	Many NBS types mitigate climate change by sequestering greenhouse gasses in biomass and soil (Harvey et al. 2013). Globally, it is estimated that the explicit carbon price should be at least $40–$80/tCO_2e by 2020 and $50–$100/tCO_2e by 2030 to reach the Paris Agreement targets (High-Level Commission on Carbon Prices 2017). Across jurisdictions, different instruments are used to price carbon, including carbon taxes, emissions trading systems, and voluntary markets.
Biodiversity (See case studies 1 and 8.)	A diversity of species can provide benefits by supporting the functioning of ecosystems and thereby the provision of all other benefits (Mace, Norris, and Fitter 2011). In green-gray and hybrid systems, where NBS are complementing gray infrastructure, it is critical that biodiversity considerations are part of the design to sustain biodiversity as a public good and the provision of other benefits.

Water quality	Watershed NBS and dune systems can have a meaningful impact on water quality and associated benefits by mitigating the flow of nutrients and sediment into streams and water bodies (Keeler et al. 2012). Even in the water, NBS such as oyster reefs feed on particulate organic matter, such as detritus and phytoplankton. By pulling these particulates out of the water column, they can improve water quality with effects on fish stocks, recreational experiences, adjacent house prices, and more.
Health (See case study 2.)	Nature and green spaces affect people's health in multiple ways, including by providing a place for physical or experiential activity, which can increase both physical and mental health (Remme et al. 2021). Health is also supported through nutritional diets from enhanced crop, livestock, or wild harvest provisioning, though it is important not to double count this benefit in NBS valuation with the food provisioning service itself.

Source: Original table for this publication.
Note: NBS = nature-based solutions; tCO_2e = tonnes of carbon dioxide equivalent.

Considering the full suite of risk reduction and other benefits in an NBS project may lead to better development outcomes. It is often vulnerable groups that are dependent on local livelihood benefits of NBS, such as the provision of food and raw materials. Investment in NBS can increase the value of these benefits and offer additional opportunities for economic development through job creation (see box 3-1). In addition, the benefits of tourism, recreation, health, and water quality produced through NBS can generate additional revenue streams for governments, for instance through land value capture or user fees for protected areas.

Identifying the comprehensive range of benefits from climate adaptation generally, and NBS in particular, has been framed as the *triple dividend of resilience* (TDR), in which the first dividend is the reduction in damage costs, the second dividend is induced economic or development benefits, and the third dividend comprises the social and environmental benefits (Heubaum et al. 2022).

BOX 3-1. The potential of NBS to create and protect sustainable jobs

Natural systems can also provide opportunities for stimulating the economy and creating jobs. The World Economic Forum identified three key socioeconomic systems (infrastructure and the built environment; food, land and ocean use; and extractives and energy), where a shift toward nature-positive models could add up to $10.1 trillion in annual business value and create 395 million jobs by 2030 (World Economic Forum 2020).

NBS often create jobs, directly and indirectly. Because they typically require construction and long-term operations and maintenance work, the implementation of NBS investments can be important engines of direct job creation. The types of jobs that might be created around the development of an NBS project may include short-term jobs for tree planting for reforestation, vegetation planting, and invasive species removal; and longer-term jobs for the maintenance of these natural features through continued retreatment of invasives, pruning, and replanting. NBS projects can be designed to both engage and employ local workers. At the same time, NBS create important benefits for human and ecosystem health that further bolster local livelihoods and security and indirectly protect jobs. For example, NBS can indirectly protect and sustain jobs by reducing the disruptive nature of natural disasters such as floods and landslides.

The evidence for the job creation of NBS projects is significant and increasing. An increasing number of diverse projects around the world are demonstrating that a range of practical and implementable NBS can be deployed to help address the biodiversity and climate crises while simultaneously creating sustainable jobs and long-term prosperity. One study, focusing mostly on developing economies, estimated direct job creation benefits per million US dollars of investment in some typical activities required in the implementation of NBS approaches: 275 to 625 direct jobs for afforestation, reforestation, and desertification control; 166 to 500 direct jobs for watershed improvement-related activities; and 24 to 250 jobs for creation and management of urban green spaces (WWF 2020). In the United States, it has been estimated that for every dollar spent on nature restoration–related work, at least $9 of economic benefits can be expected in return; this is in addition to the creation of 10 times more jobs than investments in coal and nuclear power (Nature4Climate 2020; UNEP 2020). Another study estimated that restoration and sustainable forest management in the United States had higher job creation benefits (~39.7 direct and indirect jobs per million US dollar investment) than other sectors such as transportation and agriculture (Heintz, Pollin, and Garrett-Peltier 2009). Studies have also suggested that NBS projects such as the protection of coastal ecosystems have the potential to create 17 jobs per $1 million spent, which is similar to other land conservation industries and much higher than traditional industries including coal, gas, and nuclear energy generation (Edwards, Sutton-Grier, and Coyle 2013). Such job creation can also have spillover and ripple effects in the local and regional economy.

3.4 Costs

Evaluating the costs of any intervention, including NBS, is critical when comparing potential alternative solutions. Across the life cycle of a NBS for climate resilience project, there are capital expenditures (CAPEX)—including the costs of design, planning, and construction—and operating expenses (OPEX). OPEX include the costs of monitoring, maintenance, and operation of the NBS to sustain its benefits over time. Other NBS cost components include opportunity costs, transaction costs, and costs associated with negative externalities and disservices (table 3-3). Although these cost components are similar to those for gray infrastructure projects, there are some key distinctions between cost profiles of NBS and gray infrastructure alternatives.

Table 3-3. NBS cost components

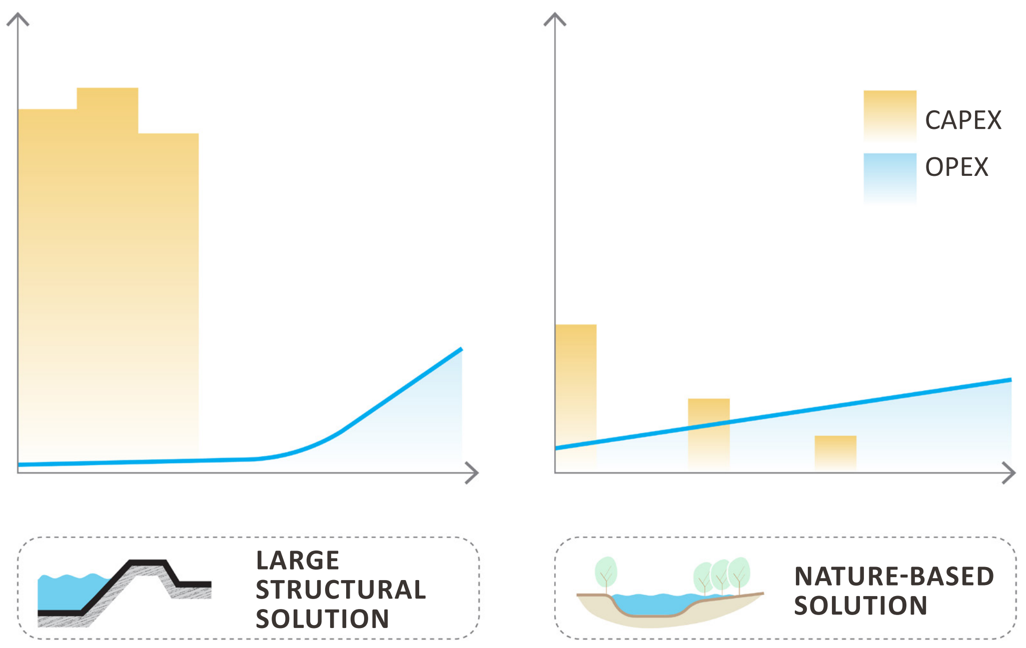
CAPEX	OPEX	Transaction costs	Opportunity costs [a]	Disservices
- Design and planning - Securing permits - Land acquisition - Community resettlement - Site preparation - Construction - Tree planting	- Monitoring labor and technology - Tree and vegetation maintenance - Invasive species removal - Land use (for example, rent or other payments to landowners) - Land protection, including managing and controlling access	- Scoping studies and other technical assistance - Community engagement / stakeholder outreach - Goal setting and prioritization	- Value of using land for other purposes such as agriculture or residential/ commercial development - Opportunity cost of local labor and materials used for implementing the NBS project	- Negative impacts from NBS (for example, mosquitoes, pests)

Source: Original table for this publication.
Note: CAPEX = capital expenditures; NBS = nature-based solutions; OPEX = operating expenses.
a. Avoid double counting between opportunity cost and CAPEX/OPEX cost components. For example, do not include land acquisition costs in CAPEX and the opportunity cost of land.

Capital expenditures (CAPEX) include many of the up-front costs associated with NBS investments. CAPEX include components such as design and planning by professionals such as engineers and landscape architects; securing required permits from various public entities; land acquisition costs; community resettlement where necessary and appropriate; and site preparation and construction by a contracted third-party entity, including planting trees and vegetation and installing other elements of the NBS solution. In general, NBS investments may require larger land footprints than gray solutions to achieve desired benefits (**Bridges et al. 2021**), as in the case of using landscape-scale NBS such as upstream forest protection or room for the river interventions for flood risk reduction. Such interventions require timely consideration of land ownership.

Operating expenses (OPEX) include costs incurred throughout the life cycle of the NBS. These costs take account of the operation and maintenance of NBS. This includes the management of protected areas, maintenance of urban green spaces, monitoring air and water quality, removal of invasive species, fertilizing, and distributing land use payments to landowners if needed, among other activities. Ideally, projects will identify long-term sources of funding and responsible entities to govern and implement maintenance and monitoring after project closing.

Figure 3-2. Illustrative cost and benefit timelines for NBS and gray infrastructure solutions



Source: Adapted from **Wishart et al. 2021**.

While cost components may be similar across NBS and other types of infrastructure projects, the costs of NBS investments differ from costs associated with traditional gray infrastructure in the distribution of capital and operating expenses over time (figure 3-2). For example, gray infrastructure solutions such as seawalls and levees have relatively lengthy construction periods and high up-front capital expenditures, but operating expenses are not incurred in the first years of operation. In contrast, NBS—such as mangrove restoration or watershed forest protection—may have lower CAPEX but require sustained operational expenditures to manage restoration efforts over time and protect areas from encroachment.

Transaction costs are those costs associated with making an economic exchange or transaction happen, in this case an investment in NBS for climate resilience. Transaction costs for NBS investments may include the cost of upstream studies, other technical assistance, and stakeholder engagement. Stakeholder engagement activities include scoping benefits and related goal setting and prioritization exercises with the community and on the project team to determine specific investments to move forward for implementation. Because they are integrated and multisectoral approaches, transaction costs for NBS projects may be relatively high. Extensive community/stakeholder engagement is often required to properly scope, design, and involve all stakeholders in the project, both to raise awareness of the benefits and to achieve sustainability (see case study 8).

Opportunity costs of a good, service or resource is its value to the economy in its next best alternative use. In the context of NBS projects, it is important to understand the opportunity cost of alternative land uses such as agricultural cultivation or residential development. Often, such opportunity costs are important considerations for policy makers. In the process of identifying opportunity costs of an NBS, it is also important to identify the stakeholder groups that incur those costs, such as farmers, local communities, commercial developers, or government.

Disservices are found where NBS have negative impacts on human welfare. Such effects are referred to as *disservices*. A well-known example is the perceived negative effect of mosquitoes around wetlands. In cities, trees and vegetation can also exacerbate allergies by releasing pollen; fall on cars, buildings, and people; and destroy sidewalks through root growth (Delshammar, Östberg, and Öxell 2015). Accounting for important disservices is recommended to understand the impacts on different parties and the distributional consequences of an NBS intervention.

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Key references

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4

Valuing the Benefits and Costs of Nature-based Solutions for Climate Resilience

4.1 Identifying benefits

The first step in valuing nature-based solutions (NBS) benefits is to identify the key benefits of the project. This is necessary and important because there can be substantial variation in which NBS benefits are relevant, depending on the type of NBS and the specific context in which it is implemented. Identifying the key benefits of an NBS investment can be done in several different ways, including through expert elicitation and stakeholder consultation.

Expert elicitation involves contacting relevant experts with knowledge of NBS implementation and/or the project site and asking them to identify the most important impacts and benefits of the NBS. Experts may be drawn from different fields of expertise (for example, climate impact modeling, engineering, ecosystem service assessment). The elicitation process can take many forms, including informal discussion, semi-structured interviews, and structured protocol. Hemming et al. (2017) provide a practical guide to structured expert elicitation. A general advantage of expert elicitation over broader stakeholder consultation is that it generally requires less time and fewer resources to complete.

Stakeholder consultation can take many forms, and may include surveys, interviews, focus groups, and workshops through which stakeholders can be presented with plans and information and asked to identify the key issues and impacts (both positive and negative). A *stakeholder* is any person, group, or organization with direct or indirect interests in disaster risk reduction and NBS (for example, business owners, government, indigenous people, and local communities). Engaging stakeholders in the initial phase of developing an NBS also offers an opportunity to raise awareness about the project, understand local contexts and concerns, facilitate ownership and support, and ensure uptake in decision-making. Ferreira et al. (2020) provide a review of stakeholder engagement in NBS.

A potentially useful form of stakeholder participation to identify NBS benefits is participatory mapping. The process of *participatory mapping* (or participatory Geographic Information Systems, or GIS) creates a map that integrates perceptions and knowledge from multiple stakeholders. Useful information that can be recorded in this exercise includes changes in land use, ecosystems, infrastructure, services important to the community, climate impacts, other benefits, areas of most concern, associated costs, and potential solutions, among others. Participatory formats can also be useful to allow discussion and reach consensus, but care needs to be taken regarding dominant relationships between stakeholders and restrictions on the expression of different opinions.

4.2 Selecting a decision support framework

The costs and benefits of a project generally vary across space and time as a result of the physical and biological processes of the different services and the spatial distribution of affected stakeholders (Lourdes et al. 2022). Making decisions between alternative investment options for climate and disaster resilience, including NBS, therefore involves trade-off among competing objectives and requires deliberate consideration of project goals, decision processes, and evaluation criteria prior to project evaluation. This section provides an overview of methods to evaluate project alternatives and scenarios that are commonly used across a range of decision contexts.

Decision support frameworks are systems for structuring information and factors relevant to decision-making. Decision objectives may range from maximizing net benefits, to labor and employment considerations and to distributional climate justice considerations and beyond, all potentially measured in different units. Organizing, gathering, comparing, and aggregating information on such a complexity of impacts—and subsequently choosing between alternative options with different impact profiles—benefits from a structured approach for evaluating alternatives. Articulating a vision and process for decision-making is a central aspect of the development process of designing project alternatives (Howard 1988).

The most applied decision support frameworks include cost-effectiveness analysis (CEA), cost-benefit analysis (CBA), spatial prioritization, multicriteria analysis (MCA), and decision-making under uncertainty (DMU). A summary of these frameworks and their applicability for evaluating NBS is provided in (table 4-1), and each framework is described in further detail below. Note that these frameworks are not mutually exclusive—for instance, it is possible to implement spatial prioritization within a CBA. The choice of decision support framework is a critical step in valuing the benefits and costs of NBS as it defines the methodology and scope of valuation.

Table 4-1. Decision support frameworks

Decision support framework	Application	Strengths	Challenges
Cost-effectiveness analysis	Identifies lowest cost NBS options to achieve a given risk level	Does not require assessment of benefits and is analytically less complex	Limited applicability given the multi-benefit nature of NBS and the challenges of establishing identical risk levels across options
Cost-benefit analysis	Estimates the societal net benefit of NBS options in monetary units	Rigorous framework for directly comparing benefits and costs	Requires that all costs and benefits be quantified in monetary terms; important other objectives (nonmonetary) may be omitted
Spatial prioritization	Maps the spatial distribution of objectives (could be monetized or benefit relevant indicators)	Enables spatial prioritization of NBS	Requires GIS expertise
Multicriteria analysis	Ranks alternative NBS options	Allows the inclusion of qualitative effects and plural values	Potentially relies on the subjective judgment of the analytical team
Addressing uncertainty (for example, robust decision-making)	Incorporates deep uncertainties in evaluation of NBS	Addresses unquantified uncertainties	Requires technical modeling expertise

Source: Original table for this publication.
Note: GIS = Geographic Information Systems; NBS = nature-based solutions.

Cost-effectiveness analysis (CEA). CEA is a method for decision-making that involves selecting between alternative options to achieve a single specific goal (for example, a target flood protection standard) for the lowest cost over a project lifetime, which is typically 30 or 40 years for infrastructure assets. CEA requires that all costs be measured in monetary terms. Different NBS and gray infrastructure options are, however, unlikely to deliver identical risk reduction benefits and other benefits, which limits the applicability of CEA for the evaluation of NBS. Another key shortcoming in the use of CEA for NBS economic assessment is that it is impossible to know whether the net benefit from any option is positive without measuring benefits, so the best option may still result in a net loss. In practice, this approach can be useful when the scope of the impacts of an NBS intervention is limited.

Cost-benefit analysis (CBA). CBA is a common method for evaluating and comparing investments, projects, and policies. CBA involves computing the costs and benefits of a project in monetary terms, relative to a baseline or "without project" scenario. The total economic benefit of an NBS includes both the risk reduction and other benefits. For NBS that deliver multiple benefits to multiple stakeholders, CBA can become challenging and requires care to define and model the geospatial extent of impacts, as well as care to avoid double counting or mis-categorizing costs and benefits. Costs and benefits that are incurred at different points in time are made comparable by converted to "present values" using a relevant discount rate to reflect society's time preference and the opportunity cost of capital. In a CBA, the economic performance of projects can be expressed in three different statistics: (1) the net present value (NPV), which is the difference between present value benefits and present value costs—positive NPV indicates that implementing a project will improve social welfare; (2) the benefit-cost ratio (BCR), which is the ratio of present value benefits and costs—a BCR greater than one indicates that the benefits of a project exceed the costs; and (3) the internal rate of return (IRR), which is the discount rate at which a project's NPV becomes zero—an IRR exceeding the discount rate indicates that the project generates returns in excess of other investments in the economy. **OECD (2018)** provides guidance on CBA for environmental investments. Examples of CBA applied to NBS can be seen in case studies 2, 3, 4, 5, 6, and 7.

Spatial prioritization. In some cases it is especially important to map how alternative decisions affect benefits, costs, and/or other benefit-relevant indicators (Olander et al. 2018). Spatial prioritization involves spatial targeting or optimization, with decisions made about where best to allocate limited resources for specific or maximum benefits. Spatial variation in NBS outcomes can be reflected in monetary terms or benefit-cost ratios in CBA (see case study 6), or other decision-relevant criteria from an MCA (see case study 1).

Multicriteria analysis (MCA). MCA provides a framework for integrating and comparing information that is measured in different metrics; it is particularly useful when considering effects that cannot be expressed in monetary terms (**OECD 2018**). MCA uses individual criteria to provide indicators of the overall performance of alternative options, which can be aggregated and compared on a common basis. In the most generic formulation of MCA, decision-makers and stakeholders identify relevant criteria of importance, determine scores for each criterion, assign relative weights to the criteria, and create an aggregate score for each alternative using a linear summation of weighted scores. Alternative options can then be ranked and the option(s) that perform best are selected. An example application of MCA for NBS is described in case study 1 on coral reef restoration in the Seychelles.

Addressing uncertainty. Investments often face significant uncertainties regarding future costs and benefits. Variability in future climate risks, natural processes, and human development are all relevant sources of uncertainty that may affect NBS outcomes. There are multiple methods for incorporating uncertainty into decision support frameworks. The three most common approaches are sensitivity analysis, the use of probabilities and expected values, and robust decision-making (RDM) using simulation modeling.

- *Sensitivity analysis* involves testing the robustness of the analytical results by varying the input parameters, values, and assumptions. Sensitivity analysis is often applied as a stress test to verify the robustness of results under different scenarios of future economic development, climate change, or the assumed discount rate.
- *Expected value analysis* builds on the presumption that uncertainties can be quantified as probabilities, which can be used to compute or model expected values of parameters in the analysis. This approach seeks to identify the best expected return on investment given the underlying uncertainties.

- *Robust decision-making (RDM)* recognizes different types of uncertainty and that not all uncertainties can be quantified (that is, for some uncertain factors there is no reliable probability distribution). RDM is a decision-making under (deep) uncertainty (DMDU) approach, which aims to answer the question "under which conditions is the decision or project considered a good investment?" Key components of the DMDU approach are: (1) stakeholder consultations to identify potential options, performance metrics, and key uncertainties; and (2) the use of simulation models to generate hundreds of alternative futures and evaluate the performance of options. See case study 7 for an example application in the context of wetland conservation in Colombo, Sri Lanka.

4.3 Valuing the risk reduction benefits of NBS

Risk reduction benefits of NBS can be assessed using methods applied in disaster risk analysis. Such analyses employ process-based physical models and damage assessment to quantify risk. Similarly, the models can be used to evaluate the impact of risk reduction investments. For certain applications, the impacts of risk reduction investments can be assessed through nonmonetary indicators. Therefore, the metrics for assessing risk reduction benefits can include both monetary and nonmonetary values. Choosing the right metric would depend on the approach and framework used for decision-making (see table 4-1).

This section describes an approach for valuing risk reduction benefits primarily through the estimation of avoided damages attributed to NBS investments. This approach is a widely used in World Bank projects to assess climate and disaster risk and is an established method that provides actuarially appropriate estimates of risk change for property damages that are comparable to analyses done for NBS and gray infrastructure assets (see box 4-1; see also World Bank case studies and appendix B for external examples). A brief description of specific application to five different hazards—flooding, erosion, landslides, heat, and drought—is provided. For some hazard types, avoided damage assessments are not typically used; for these, other valuation approaches are introduced below and then expanded on later in section 4.3.2. These alternative valuation approaches and indicators may be used to complement or substitute for avoided damage assessments depending on research questions, data availability, and project resources.

BOX 4-1. Calculating disaster risk from natural hazards

In its most simple form, disaster risk is a function of three components: hazard, exposure, and vulnerability (GFDRR 2014). Hazard refers to the likelihood, probability, or chance of a potentially destructive phenomenon; exposure indicates the location, attributes, and values of assets important to communities; and vulnerability indicates the likelihood that assets will be damaged when exposed to the hazard event. Therefore, risk can be calculated from the statistical distribution of (socioeconomic) losses or damages produced by hazard events such as floods, windstorms, or heatwaves (a damage function describes risk as a relationship between the expected damages and the hazard intensity).

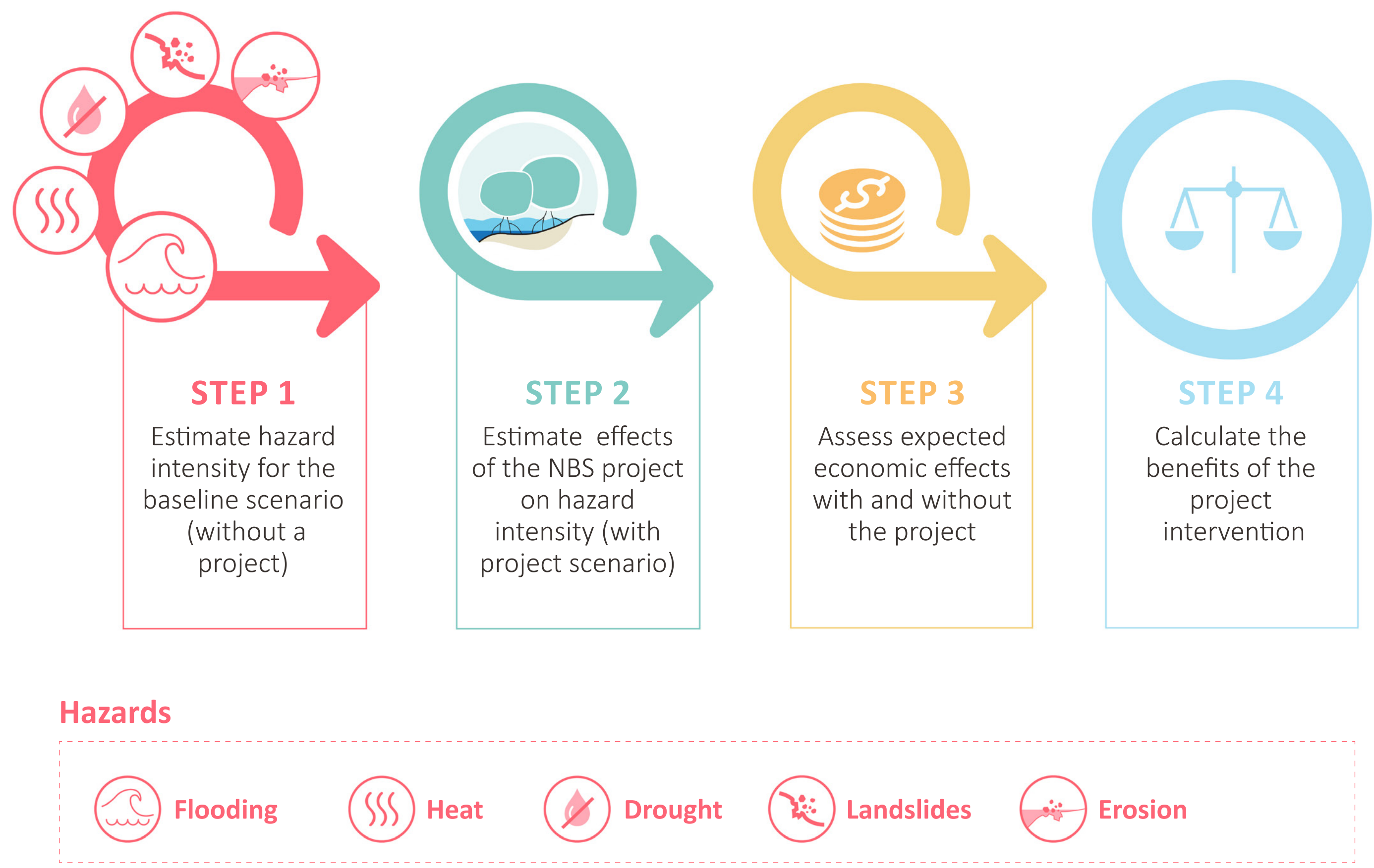
Hazards can be simulated for individual events or determined based on frequencies of occurrence (for example, a hazard can be characterized as a return interval, the likelihood that extreme conditions occur on average once every certain number of years—for instance, a storm having a once in 10-year recurrence). The hazard intensity—for example, flood depth—is usually converted to economic impacts and people affected by calculating the buildings, infrastructure, and people impacted using damage functions, which depend on the affected party (people, buildings, and so on).

Hazard information can be developed for present-day conditions, based on historic information, or for scenarios of future climate (effects of sea-level rise on flooding, or rising temperatures on heatwaves), but also other changes in the other components of risks through changes in buildings or population distribution (socioeconomic exposure), policy interventions, physical infrastructure projects, and so on.

4.3.1 Quantifying avoided damage cost to value risk reduction benefits

The risk reduction benefits of a project, including NBS, can be determined based on established approaches to quantify disaster risk (see, for example, **GFDRR 2014**) and by comparing risk between two situations: with the project and without the project (or the baseline scenario). This approach builds from previous guidance proposed for coastal and fluvial NBS as described in **Beck and Lange (2016)** and **Bridges et al. (2021).** The methodology described below has been applied in different contexts and across spatial scales—for example, to determine the flood risk reduction benefits of coral reefs (Beck, Losada et al. 2018) or mangroves (Menéndez et al. 2020), or the cost-benefit analyses of nature-based adaptation strategies (Reguero, Beck, Agostini, et al. 2018). The process can be described in four sequential steps (figure 4-1).

Figure 4-1. The four-step process of valuing risk reduction benefits using the avoided damages method



Source: Original figure for this publication.

STEP 1. Estimate hazard intensity for the baseline scenario (without-project scenario)

The effects of a natural hazard should be estimated based on a description of the hazard intensity (for example, flood depth or extent) with the probabilities of occurrence, based on historical observations and/or statistical and numerical modeling. Brief descriptions of how to study the hazards of flooding, erosion, landslides, heatwaves, and droughts are provided in table 4-2. For more detailed descriptions, we refer to disaster risk modeling resources (for example, **GFDRR 2014**).

Table 4-2. Step 1: Estimating hazard intensity

Hazard	Description
Flooding	In coastal flooding, water levels vary along shorelines depending on the effects of bathymetry, coastal features, and ecosystems. Coastal flood hazard is often determined based on numerical models or previous local studies and observations that provide information on different contributors to flooding such as wave action, mean sea levels, surges, and other sea-level components (Losada et al. 2013). Flood hazard zones can be defined by mapping flooded zones and water depths through modeling and elevation data (for example, applying numerical models or geospatial approximations such as a spatial intersection with a digital elevation model, known as a "bathtub model"). In riverine environments, hydrological data and models can be used to derive runoff information that serves as an input to flood models for determining the flood hazard zones (Teng et al. 2017). Hydrological models also need information on soil properties, vegetation, and land uses to correctly determine the amount of water that is intercepted as well as to determine evapotranspiration. Flood modeling should also include information on river routing and other hydraulic features (for example, Bulti and Abebe 2020). For flash floods and tsunamis, other detailed hydrodynamic models are required. Pluvial flood modeling is estimated using hydrodynamic models that are validated using observations or previous studies. To model flood damage, a two-dimensional hydrodynamic model is needed; these models are able to represent overland multidirectional flow, providing flow depths and velocities. However, these models are data intense and require long computational time (Kumar et al. 2021). Therefore, often approximations using one-dimensional models are applied (Bulti and Abebe 2020).
Erosion	Erosion impacts can be assessed using numerical modeling of sediment transport or using satellite or aerial imagery to detect historical changes in the coastline or riverbanks (Vos et al. 2019). Erosion can occur associated with extreme events (extreme erosion) or over longer periods of time (long-term erosion), creating chronic erosion. Numerical modeling can be used to project future erosion and geomorphological changes, including the effects of climate change (Cooper et al. 2020; Toimil et al. 2017; Vousdoukas et al. 2020). However, modeling morphodynamic changes over long periods of time is a very complex task. As an alternative in situations where historical erosion impacts may justify an intervention, projecting historical observed trends (for instance, from satellite imagery) into the future can be considered a first estimate of potential future erosion. However, this approach should not be extended very far into the future, typically not exceeding the historical period of observations.
Landslides	Several methods are available for landslide hazard zonation, although there is no universally accepted method (Pardeshi, Autade, and Pardeshi 2013). Advanced multivariate techniques and physical process–based models perform well to define landslide hazards. However, one of the most used models is a deterministic model that defines the hazard level of a landslide as a function of the slope of the site, its lithological composition, the moisture conditions of the soil at the site, and the precipitation and seismic conditions at the site (Mora and Vahrson 1994; Nadim et al. 2006). Aerial photographs and high-resolution satellite data are also useful for detecting, mapping, and monitoring landslide processes. A review of different methods can be found in Corominas et al. (2014) and Pardeshi, Autade, and Pardeshi (2013).
Heat	The risk of extreme heat is increasing in many regions as temperatures rise with global warming. Heat intensity is reported in a variety of metrics, depending on the area's potential use. These metrics include temperature but also measurements of heat stress that reflect the role of temperature and humidity together. Heat waves are often measured through a heat index: what the temperature feels like to the human body when relative humidity is combined with the air temperature (NOAA, no date). The heat intensity usually refers to the average daily maximum heat index value in the month the event occurred. To calculate it, atmospheric temperature and humidity can be obtained from historical data from satellites, models, or in situ measurements. Many urban and suburban areas are also experiencing urban heat island effects, which refer to higher temperatures in urbanized environments compared to rural surroundings. By one estimate, the annual mean air temperature of a city with 1 million or more people can be 1°C to 3°C warmer than its surroundings, whereas on a clear, calm night, such difference can reach up to 12°C (Oke 1997). Urban heat islands are caused by development and the changes in radiative and thermal properties of urban infrastructure as well as the impacts of buildings on the local micro-climate (for instance, tall buildings can slow the rate at which cities cool off at night). The warming over small areas through urban heat islands is an example of local climate change, which fundamentally differs from global climate changes in that their effects are limited to the local scale and decrease with distance from their source. Heat islands are influenced by a city's geographic location and by local weather patterns, and their intensity changes on a daily and seasonal basis. Models exist to define this heat island effect as a function of the surface temperature, urban fabric, and distance to buildings, which include direct and indirect methods, numerical modeling, and estimates based on empirical models. Remote sensing can also be used to estimate surface temperatures, as can thermal images and other technology.
Drought	Droughts (meteorological, agricultural, hydrological, and socioeconomic droughts) can be modeled from precipitation and temperature historical records, but also by generating stochastic climate simulations. For example, drought hazard can be estimated as the probability of exceeding the median severe precipitation deficits for a historical reference period. The severity of the precipitation deficit can be computed from Weighted Anomaly of Standardized Precipitation (WASP) (Lyon and Barnston 2005) or other drought indexes, such as the Standardized Precipitation Index (SPI) or the Effective Drought Index (EDI) (IDMP, no date; IDMP 2016; Jain et al. 2015). There are different software and tools for assessing drought hazard and risk, including global data sets and tools, as well as specific models developed for different regions (for a review of tools, see Deltares 2017).

Source: Original table for this publication.

STEP 2. Estimate effects of the NBS project on hazard intensity (with-project scenario)

Using approaches similar to the assessment of hazards (step 1), the effect of the NBS project can be determined by including the effects of natural features in the models and assessing changes in the hazard intensity (table 4-3). Assessing the effectiveness of the project will typically require modifying variables in the models such as elevation, friction to water flow, temperature, humidity, or water retention or availability, which depend on the type of NBS. The effectiveness of the project will also depend on the project's characteristics, geophysical and atmospheric processes, and other local factors. Whereas modeling is preferred because it provides direct quantification and spatial description of the project benefits, in the absence of other information, an alternative approach can assume a representative effectiveness of the project (for example, percent flood mitigation) based on information obtained from previous projects, experts, or other sources. However, this approach involves important caveats about the real effectiveness of the project that should be taken into account in the decision process.

Table 4-3. Step 2: Estimating the effect of NBS on hazard intensity

Hazard	Assessing the NBS effect
Flooding	The effect of coastal NBS on flooding can be assessed through models that simulate the frictional drag of vegetation, changes in depths and elevation, ecosystem density and distribution, and physical extent. However, the models for estimating the effects of NBS depend on the physical landscape; for example, models for coastal NBS are different for reefs and wetlands, depending on each type of habitat. Whereas coral reefs attenuate waves mainly through breaking and wave energy dissipation—which depends on the relative depth, rugosity, and reef geometry (see **Beck and Lange 2016**)—mangrove forests can attenuate both short-wave energy and storm surges through frictional drag. Beach and dune systems also provide flood protection through elevation allowance. Similarly, for freshwater flooding, flood models can be used to account for the changes in elevation (water retention) and frictional effects of changes in land uses to model NBS within the watershed or in an area. Incorporation of temporal changes in land cover and form in approach can also simulate the impact of NBS and conservation measures (for example, reforestation) (Zhang et al. 2015). The modeling of the impact of NBS on rivers and streams is widely based on hydraulic models, which are able to determine inundation extent, simulate scenarios at high spatial and temporal resolution, and model the effect of different NBS. Examples of NBS that can be simulated with such models are floodplain restoration, wetlands and reservoirs, changes in the cross-section, woodland changes at the catchment level, and so on. Moreover, these solutions can be combined with gray infrastructure such as levees (Kumar et al. 2021). To assess the impact of NBS on pluvial flooding, several integrated hydrologic-hydraulic models can simulate different nature-based stormwater infrastructure, considering processes of evaporation, infiltration, runoff retention, and ponding. These models are also able to model gray approaches and hybrid (green-gray) rainwater control measures (Kumar et al. 2021). Urban flood models can also include the effects of large and small stormwater management features such as rain gardens, green streets, flood parks, and bioswales through the effect of storing water volume, reducing runoff, or increasing permeability (Natural Capital Project, no date; Whelchell et al. 2018; World Bank 2019). Ample examples of case studies that simulate such effects in coastal and riverine environments are described in **Bridges et al. (2021).**
Erosion	NBS can help reduce the risk of erosion by stabilizing shorelines and trapping sediment that would otherwise reach waterways in upland riparian areas (Pandey et al. 2021). The effects of coastal NBS on erosion can be modeled by projecting morphodynamical changes in the shoreline associated with storms or long-term erosion processes (Reguero, Beck, Agostini, et al. 2018). These models allow for assessing the effects of a project by modeling sediment transport after the project is implemented—for example, a beach restoration project.
Landslides	Landslide hazard can be influenced by natural resource management and rural development–related activities, such as forest management, road construction, agricultural practices, and river management (Dolidon et al. 2009). Forests and vegetation are common NBS for landslide risk management. Forests and vegetation can increase soil strength and stabilize slopes, absorb precipitation before it infiltrates the soil, and move water away from slopes (Collison, Anderson, and Lloyd 1995; Vanacker et al. 2003). The effectiveness of forests and other forms of vegetation in reducing landslide risk depends on various factors such as topography, hydrology, and soil conditions. Models that estimate the impact of NBS on landslide risk can manipulate values that change landslide risk such as values for root cohesion and soil moisture to simulate the reduction in landslide risk as these values change. NBS may often be required in hybrid solutions for landslide risk, especially in areas of higher risk and deeper landslides, where piles and retaining walls may also be necessary.
Heat	NBS in cities—such as tree canopies, green open spaces, water bodies, green roofs, and vertical greenery—can mitigate the urban heat island effect through shading, evaporation, and convection. The effect of these can be modeled empirically—for example, Lonsdorf et al. (2021) used a multiple regression to relate temperature to various landscape features, including urban greenspace, within a radius. The radius was varied, and stepwise regression was used to select the radius and function with the best empirical fit for predicting the relationship between urban greenspace and temperature using different development scenarios. Composite indexes are also used to derive a relative measure of NBS effectiveness for spatial prioritization. For example, Zawadzka, Harris, and Corstanje (2021) investigated a heat mitigation index for NBS based on evapotranspiration from vegetation, cooling distance of large urban parks, and albedo assigned to a land/water cover map. Changes in temperature from NBS may also need to be combined with other information such as effects on humidity to assess changes in the heat index (Koc, Osmond, and Peters 2018), as described in step 1. There are also modeling tools to assess the effectiveness of NBS for mitigating the impacts of heatwaves or heat stress. Different modeling techniques for urban heat studies include micro-scale fluid dynamics models, nonhydrostatic regional climate models, and urban canopy layer models. These types of approaches have been utilized to simulate the effects of vegetation to relieve heat stress in the microenvironment, modeling changes in landscape design, parks and grasslands, urban trees, green roofs and walls, and so on (see Kumar et al. 2021).

Drought	The effects of NBS can be introduced in drought models by simulating the effects of the project on water availability, quality, or access. Since the value of water in a drought context is often dependent not just on the amount of water available, but also on its timing and spatial distribution, understanding the impact of NBS on water provisioning requires characterizing seasonal and subseasonal changes in water provisioning. For example, the InVEST seasonal water yield model is an example of a model that can assess changes in water resources and include NBS (Gaglio et al. 2019; Mandle et al. 2017; Yang et al. 2018) under drought and dry season conditions. The Soil and Water Assessment Tool is another example of a tool that can include the effects of NBS on water resources (Arnold et al. 1998; Vogl et al. 2017). Other modeling approaches can also be utilized for evaluating the effects of NBS. These include hydrological models that combine groundwater and plant hydrology and hydraulics to evaluate the response of forest to drought at the watershed scale; models that mimic river discharges, evapotranspiration, and the impact of water abstractions on the aquifer at catchment scale; and models that simulate surface and groundwater in the saturated and unsaturated zone, both horizontally and vertically at regional scales. Kumar et al. (2021) provide several examples of these tools.

Source: Original table for this publication.

STEP 3. Assess expected economic effects with and without the project

After assessing the effects of the NBS intervention on the hazard, the next step is calculating the socioeconomic effects or damages under both scenarios—with and without the project intervention. This assessment requires calculating exposure and vulnerability through damages to buildings and infrastructure; and changes in yields, uses, agricultural land, people affected, and other assets relevant for the project. Therefore, the methods will vary depending on the hazard, NBS features, and socioeconomic contexts. Damages to structures and land from floods, for example, are generally calculated using vulnerability functions that relate the flood depth to a repair or replacement cost for each asset type. In a social context, social vulnerability factors can also influence the degree of impact and effects of a certain hazard and may influence the benefits of the project too. For each asset class exposed to the hazard, vulnerability functions generally can provide the total repair costs, the loss in yield, or other metric that can be converted into monetary value or other metrics of socioeconomic consequences. These physical direct effects on assets can be valued using market prices, restoration costs, or replacement costs. Human life and health effects can also be valued using cost of treatment, productivity loss, hedonic pricing, or stated preference methods. Information and valuations of the socioeconomic effects of historical events can also be a useful resource to estimate the effect of future disasters.

In addition to direct damages (property damage), indirect impacts, which refer to changes in economic activity that follow the disaster, can be significant. For estimating indirect effects, historical valuations of previous disasters can help estimate such effects, but there are also theoretical models that provide a mathematical representation of the most pertinent causal chains to trace the impacts on the economic system. In such models, typically the disaster is modeled through the sudden loss of production factors (such as labor and capital), to which the economic system adjusts (Botzen, Deschenes, and Sanders 2019). These models often lack spatial detail and are not considered in this section, which is focused on direct effects. The list below provides an initial description of the possible approaches for each hazard type (table 4-4).

Table 4-4. Step 3: Assessing the economic effects for both scenarios

Hazard	Estimating economic effects
Flooding	Two common flood damage estimation approaches are unit loss models and model applications. Whereas a unit loss approach is based on an assessment of effects property by property, either actual or potential, model applications focus on estimating the linkage effects, or intersectoral relationships of floods within the economy (see, for example, Botzen, Deschenes, and Sanders 2019). Flood damage to individual assets can be estimated using depth-damage functions that relate flood depth to damage degree (Huizinga, de Moel, and Szewczyk 2017). For example, such a function would indicate that a structure flooded by 0.5 meters of water will have a lower damage percentage than a structure flooded by 2 meters of water (for example, Scawthorn et al. 2006). For each asset type, total cost can be calculated as a fraction of the asset value. The spatial intersection of the inventory of assets and the flood depths and extent (estimated in steps 1 and 2) using the respective depth-damage function for each asset type (for example, type of building) provides a value of the damage of that specific flood event. Different damages from possible flood events can then be aggregated to calculate a total damage level from a series of flood events. In the absence of spatial distribution of assets, normalized damage functions can be combined with built-up area information, land uses, and other correction factors of building density to estimate spatial distribution of economic damages in different countries (see a review of damage functions for different countries and regions and guidelines for flood damage calculation in Huizinga, de Moel, and Szewczyk 2017). Other useful information is found by using historical events and valuations of losses as well as economic effects.
Erosion	Erosion damages can be determined based on land value loss in a way similar to determining flooding damages—considering permanent value loss (for example, buildings or agricultural land) but also other services associated with the beach such as recreation value, housing market, and so on (see Gopalakrishnan et al. 2016 for a review of economic models). For example, the effects of erosion on the recreation value of beaches is also a key indicator for the tourism sector (Toimil et al. 2018). The eroded beach extent can be related to geographic and socioeconomic aspects, as well as to other physical settings—including beach type, quality, and access—to yield monetary estimates of risk in probabilistic terms. The expected value per unit of surface loss can be calculated by multiplying the area required by a user by the number of hours of beach use and the value of the recreation use per user. The values can also be calibrated to represent access points, length, quality, tourism intensity (remote locations versus urban beaches), and other factors affecting beach usage. Alternatively, estimates from coastal tourism can be used to estimate beach value and erosion effects (for example, see Houston 2008 for an economic value of beaches in the United States).
Landslides	Relevant approaches for valuing avoided landslide damages as a result of NBS are determined by the impacted assets under consideration. Assessing the extent of damage from landslide events requires an understanding of the interaction between a landslide and impacted assets (de Ruiter et al. 2017). As with other hazards, exposure data and vulnerability models can be used to calculate the extent of potential damage or degree of loss for a given asset subject to a landslide of a given intensity, whereas the impacted assets can include infrastructure, buildings,

	agricultural land, and people. For example, information on the economic value of forests in regulating landslides can inform forest management decisions (Langner et al. 2017). Quantification of the damage costs of deforestation (or avoided damage costs resulting from reforestation) can provide input for the appraisal of investments in conservation and restoration (Brander et al. 2018).
Heat	Effects of heat stress can be translated to productivity-based estimates by valuing the labor productivity losses/gains due to an increase/reduction in temperature from NBS. The change in productivity with the project can be estimated using local data on temperature, productivity, and other factors, or could make use of more generalized known relationships between human biology and temperature (Kjellstrom, Holmer, and Lemke 2009). A related and additional category is the change in value associated with heat-related illness and mortality. Several measures are available for this estimation, including the value of a statistical life for premature mortality and the value of a life year for displaced mortality (Chiabai, Spadaro, and Neumann 2018). Furthermore, the benefits of NBS for reducing heat are expressed by quantifying the avoided cost of cooling buildings and public spaces.
Drought	Drought exposure can be computed and validated on the basis of geographic layers by considering the spatial distribution of physical elements from agriculture and primary sector activities such as crop areas (agricultural drought), livestock (agricultural drought), industrial/domestic water stress (hydrological drought), and human population (socioeconomic drought) (Carrão, Naumann, and Barbosa 2016; Vogt et al. 2018). Vulnerability to droughts also depends on social, economic, and infrastructural factors. Therefore, the economic effects of droughts depend on the specific water use, and the effects of a project can include changes in agricultural output, other water-dependent productivity, direct human water consumption, hydropower, or other water uses. Grafton, Chu, and Wyrwoll (2020) summarize the complexity of originating a water provisioning valuation study and is a good reference in the absence of more concrete examples of valuing the water provisioning service of NBS.

Source: Original table for this publication.

STEP 4. Calculating the benefits of the project intervention

The benefits of risk reduction from an NBS intervention (or other investment focused on disaster risk reduction) can be calculated as the difference of the total damages (using models in step 3) between the scenarios with and without NBS intervention. The benefit of the NBS project can be calculated from the differences between scenarios, measured as the prevented costs from investing in the project: the avoided damages associated with the effect of the NBS on the baseline situation. However, such benefits from the project can be reported using different metrics depending on the context of the investment decision:

- **Risk reduction benefit calculated from a single event.** This approach provides a measure of the differences in damages by comparing the situation with and without the project, but considering only a single event, typically an historic, representative event (for example, see Narayan et al. 2017 for wetlands and Hurricane Sandy). Assessments for individual events are often useful in demonstrating the value of new technologies (proof of concept), or in indemnity valuations (post-storm), as they require less effort than estimating annual benefits or the net present value of annual expected benefits.

- **Annual benefit.** This approach extends the single-storm benefit calculation to other hazard events by incorporating into the calculation the frequency of different events. The expected annual change in damages from an NBS project is calculated as the difference between the expected annual damages for any given year with and without the project. These annual values are calculated for each scenario by integrating the damage-probability curve. The difference between annual expected damages represents the annual expected benefit of the project. Reguero et al. (2021) provides a national example for coastal flooding; see also Olsen et al. (2015) for further details on estimating annual expected damages.

- **Net present value of annual expected benefits.** The NPV of benefits of the project can be calculated by discounting the future benefits of the project over a typical project lifespan. This requires information about the time preference for money (discount rate or weighted average cost of capital) and other changes in the benefits over time. Examples include changes in exposed assets or population composition through time and changes (deterioration or improvement) in the performance or reliability of the hazard mitigation investment. However, it may also consider changing environmental conditions such as sea-level rise and other climate change factors. For example, in a comparison of adaptation strategies for the US Gulf Coast, including NBS options, costs, and benefits of each measure, were compared in 20- and 40-year life cycles, accounting for (1) the effect of relative sea-level rise and future storms and (2) changes in population and economic exposure (Reguero, Beck, Bresch et al. 2018).

4.3.2 Alternative approaches for valuing risk reduction benefits of NBS

Index-based approaches for risk and nonmonetary risk reduction indicators

The quantification of risk reduction benefits through biophysical, process-based hazard models and the avoided damage approach is the recommended approach in the context of disaster risk and adaptation investments because it provides a direct way to quantify risks spatially, rigorously, and in metrics that can be directly incorporated in economic and financial assessments. However, modeling risk can be a complex task that requires time, resources, and technical capacity. In situations where a swifter approach is desired or where resources are limited, alternative methods can provide sufficient information for continuing the planning process. This section describes simplified models and index-based approaches that can be used as an alternative to evaluate the hazards.

Index-based assessments of hazard vulnerability and exposure can represent an alternative approach to quantitative disaster risk assessment in contexts where data or characterization of people and communities at risk can rely on proxy information, or when social vulnerability indexes can provide additional information to the assessment of disaster risk. More broadly, indexes that are representative of ecosystem condition can also be used as part of measuring other benefits of NBS (see benefit-relevant indicators, section 4.4.2).

In general terms, index-based approaches use estimates of exposure and hazard vulnerability to assess risk and risk reduction benefits. These indexes can be calculated considering with and without the project situation to estimate potential changes in risk, relying on assumptions about their effectiveness. For example, the Coastal Vulnerability Module of InVEST (Arkema et al. 2013) uses an index-based approach to create a flood vulnerability index by scoring seven relevant variables (related to exposure to winds, wave action, bathymetry type, sea-level rise, coastal morphology, habitat type, and topography type) on a scale of one to five to indicate exposure of the shoreline to flooding. These indexes can then be combined with information on exposure—such as a geospatial inventory of structures, people and their demographics, or other assets—to provide information for screening areas for more in-depth study; they can also be used directly for decision-making in lieu of available effort for in-depth studies (Ruckelshaus et al. 2020). By changing the values of some scores after introducing the effect of an NBS project or other intervention, the index may also allow comparison of changes in the habitats and the exposure variables. Similar indexes exist for erosion (Gornitz 1991), droughts, landslides, and other hazards. A list of examples for different hazards is provided below (table 4-5), but a comprehensive catalogue of tools can be consulted at Climate-ADAPT's database, available at https://climate-adapt.eea.europa.eu/#t-database.

Table 4-5. Indexes for hazard quantification

Hazard	Index	Description	References and additional information
Coastal flooding	Coastal Vulnerability index (InVEST)	The Coastal Vulnerability Index from the open-source Integrated Evaluation of Ecosystem Services and Trade-off (InVEST) model, developed by the Natural Capital Project, uses geophysical and natural habitat characteristics of coastal landscapes to compare their exposure to erosion and flooding in severe weather. The model provides a numeric index ranking coastal vulnerability; when overlaid with data on coastal population density, economic exposure, or social vulnerability, it can be used to identify coastlines with higher risks of damage from storm waves and surge.	More information about index: Stanford University, no date- a Application examples: Arkema et al. 2013 Silver et al. 2019
Coastal erosion	Coastal Vulnerability Index (CVI)	The Coastal Vulnerability Index (CVI) is one of the most commonly used and simplest methods to assess coastal vulnerability to sea-level rise, in particular caused by erosion and/or inundation (Gornitz, White, and Cushman 1991). The CVI uses key variables representing driving processes of coastal evolution. The version developed by the US Geological Survey (USGS) considered six variables: geomorphology, shoreline change rates, coastal slope, relative sea-level rise, mean significant wave height, and mean tidal range. Various methodologies are available for the scoring; quantification is generally based on the definition of semiquantitative scores according to a 1–5 scale, which are then integrated into an overall index. The final CVI values are then classified into groups using *n*−1 percentiles as limits. While the CVI index can be useful for characterizing physical vulnerability to erosion, its greatest limitation is its incapacity to reflect socioeconomic aspects (such as the number of people affected, infrastructure potentially damaged, and economic costs) (Ramieri et al. 2011). Two main possible solutions are (1) using the CVI in association with other indexes related to socioeconomic aspects, and (2) modifying the original formulation to take into account variables representing the socioeconomic systems.	More information about index: Climate ADAPT 2016 Application example: Koruglu et al. 2019 More information on other methods for assessing coastal vulnerability: Ramieri et al. 2011
Urban floods	Urban Flood Risk Mitigation model (InVEST)	The Urban Flood Risk Mitigation model by InVEST estimates the runoff due to two extreme rainfall events for watersheds and calculates an attenuation index based on natural water retention measures as a function of land-use types. The runoff reduction index provides a metric of the amount of runoff retained per pixel compared to the storm volume with and without the measures. It can be used for determining economic damages by overlaying information on flood extent and exposure.	More information about index: Natural Capital Project, no date Application example: Quagliolo, Comino, and Pezzoli 2021
Stormwater retention	Urban Stormwater Retention (InVEST)	This model calculates annual stormwater retention volume and the associated water quality benefits (that is, avoided transport of nutrients or pollutants to lakes, streams, or estuaries that receive runoff). The value of the retention service may be calculated using a replacement cost of stormwater infrastructure. Optionally, the model can also provide estimates of potential groundwater recharge to the aquifer, as well as the stormwater exported in surface runoff (as volume and mass of pollutants or nutrients).	More information about index: Natural Capital Project 2022
Droughts	Standardized Precipitation-Evapotranspiration Index (SPEI)	The SPEI is a multiscalar drought index based on climatic data that can be used for determining the onset, duration, and magnitude of drought conditions with respect to normal conditions in a variety of natural and managed systems such as crops, ecosystems, rivers, water resources, and so on. The index uses information on monthly time series of precipitation and mean temperature with the geographic coordinates of the site.	A global real-time drought monitoring system based on the SPEI is operative. It provides global SPEI maps and data for the entire Earth at a spatial resolution of 1º at https://spei.csic.es/map/maps.html

			See also the SPEI Calculation of the Standardized Precipitation-Evapotranspiration Index at https://cran.r-project.org/web/packages/SPEI/index.html and the SPEI calculator, available at https://digital.csic.es/handle/10261/10002
Heat island effect	Urban Heat Island Index (UHII), California	The urban heat island effect occurs when large urban areas experience higher temperatures, greater pollution, and more negative health impacts during hot summer months than rural areas. This phenomenon is created by a combination of heat-absorptive surfaces (for example, dark pavement and roofing), heat-generating activities (for example, engines), and the absence of vegetation (that is, lack of evaporative cooling). In 2012, the California State Legislature required the development of an Urban Heat Island Index (UHII) given the lack of a consistent way to determine and map locally the urban heat island effect. The UHII is calculated as a temperature differential over time between an urban census tract and nearby upwind rural reference points at a height of 2 meters above ground level, where people experience heat. Since 2020, the index is also reported in degree-hours per day on a Celsius scale—a measure of heat intensity over time, calculated by dividing the UHII by 182 days.	Application example: CalEPA 2015 CalEPA 2015's Urban Heat Island Interactive Maps, available at https://calepa.ca.gov/urban-heat-island-interactive-maps-2/, showing the urban heat island effect for each census tract in and around most urban areas throughout the state of California.
Urban cooling effect	Heat Mitigation Index (InVEST)	The InVEST urban cooling model calculates a cooling capacity (CC) index for each pixel based on local shade, evapotranspiration, and albedo, as well as distance from cooling islands (for example, parks). The cooling effect of large green spaces (>2 hectares) on surrounding areas is calculated through an urban Heat Mitigation Index as a distance-weighted average of the CC values from the large green spaces and the pixel of interest.	More information: InVEST's Urban Cooling Model, available at http://releases.naturalcapitalproject.org/invest-userguide/latest/urban_cooling_model.html Application examples: Zawadzka, Harris, and Corstanje 2021
		The model also allows for calculating benefits from the temperature reduction by vegetation using two (optional) valuation methods: energy consumption and work productivity.	Bartesaghi, Osmond, and Peters 2018 Zardo et al. 2017
Landslides	Landslide susceptibility Index (LSI)	The LSI can be calculated using six relevant landslide-controlling factors derived from geospatial remote sensing data and weighted based on their relative significance to the process of landslide occurrence (for example, slope is the most important factor and soil types and soil texture are also primary-level parameters; while elevation, land cover types, and drainage density are secondary in importance). Finally, the index is mapped by classifying the values into six susceptibility categories. Other implementations have used artificial neural networks and statistical methods to generate an LSI using training data based on geomorphic (for example, altitude, slope, and aspect) and geologic parameters (for example, rock type, distance from geologic boundary, and geologic dip-strike angle) and previous landslides. Data from areas with and without landslide occurrences are also used for training the models.	Application examples: Lee et al. 2003 Hong, Adler, and Huffman 2007

Source: Original table for this publication.

Alternative monetary valuation approaches

As an alternative to calculating avoided damages as the valuation method, other valuation approaches include stated preference, hedonic pricing, averting expenditure, and value transfer. Their application for quantifying risk reduction benefits is described in more detail below (see also box 4-2).

Stated preference. Often prices and quantities of a good or service are unavailable because there is no direct exchange for the good or service; this is often the case with ecosystem-provided goods and services. Creative valuation methods have been devised to infer values in such cases. One example is stated preference methods. *The stated preference method* is an alternative approach that relies on survey questions that ask individuals to make a choice between scenarios (choice experiments) or state (contingent valuation) what they would be willing to pay for specified changes in non-market goods or services. These methods can be applied in the context of NBS for risk reduction. In this case, the survey would ask households about their willingness to pay for risk reduction benefits of NBS and, potentially, other benefits. For example, Kim, Ahn, and Kim (2016) employed a contingent choice survey and found that urban residents in the Republic of Korea are willing to pay $374 to increase urban forests from 0.4 to 7.0 square meters/capita. These surveys can be advantageous for several reasons: first, since these other benefits are often non-market goods themselves, this method represents a way to include multiple NBS benefits, in addition to risk reduction (Morawetz and Koemle 2017). Second, surveying allows for identifying and valuing preferences not considered by the avoided damage method, as it assumes that people are risk-neutral and consider damage repair to be the only relevant cost (Barbier 2015) even though evidence suggests a lack of risk neutrality (Petroila, Landry, and Coble 2013) and other damage pathways—such as psychological distress and damage to cultural heritage—that cannot be readily repaired (Merz et al. 2010). Third, surveying can also help address the fact that affected parties may have a poorly informed estimate of risk or other deviations from standard economic assumptions (ambiguity aversion, and so on). While avoided damage approaches may be more actuarially accurate, understanding these deviations can be an important part of understanding the perceived benefits of NBS.

Hedonic pricing. Another approach for valuing non-market goods is hedonic pricing, which estimates value based on adjacent markets and ecosystem characteristics. The canonical example uses data on house prices and house attributes to value each attribute's marginal value. This can be for an additional bathroom or bedroom, but it can also extend to adjacent environmental (dis)amenities such as neighborhood air quality, ocean views, flood risk, and more. For example, Dundas (2017) estimates the value of the protective effect of coastal dunes while simultaneously estimating their disamenity value of blocking ocean views from properties, disentangling these confounding variables and valuing each. With data on NBS and housing attributes, risk reduction by NBS can be estimated empirically for a study area and then the estimated regression function can be used to simulate the effects of alternate NBS projects. Changes in property prices that are attributable to the implementation of NBS can be a useful means of communicating the benefits and potentially for designing "beneficiary pays" funding mechanisms (for example, property taxes).

Hedonic pricing can be used to value NBS risk reductions and other benefits simultaneously if data are available. In principle, all perceived improvements in property characteristics (for example, reduced flood risk, increased productivity, lower cooling costs, recreation opportunities) will be reflected in the property price. Hedonic pricing has an advantage over stated preference methods in that it is based on actual market behavior (revealed preferences) rather than statements of what people might be willing to pay. In general, values estimated through revealed preference are considered more reliable than those elicited through stated preference approaches (Kling, Phaneuf, and Zhao 2012).

BOX 4-2. Land value creation through flood risk reduction in Buenos Aires

Reduction of flood risks can potentially stimulate investment and development, particularly in urban areas, resulting in economic benefits that extend beyond the direct reductions in flood damages. A study by Avner et al. (2022) provides an example of how such benefits can be quantified using a model of urban land values in an application in Buenos Aires, Argentina. The planned flood mitigation interventions consist largely of stormwater drainage and retention capacity investments in the three water basins of the city. The model enables the estimation of aggregate effects on land values, taking into account that the location of flood protection will change the relative attractiveness of land within the urban area and potentially reduce the value of land that remains unprotected. Because of this consideration, this approach is superior to the use of hedonic pricing, which does not capture the net market effects of displacing demand from unprotected areas. The application of the model is data, expertise, and time intensive; so, to facilitate the use of this approach, the authors provide an approximation of localized and aggregate land value changes with reduced details that can be more easily applied than the original model.

The results show that the potential for land value creation from resilience investments can be substantial, particularly when the flood-prone areas that are protected are proximate to employment centers. Under central and conservative modeling assumptions, net land value creation in this case is in the range 0.1–0.52 percent ($379–$1,929 million), which alone is of sufficient magnitude to justify the upfront investment costs.

The authors note that estimates of land value creation should not be added to estimates of reduced flood damage—for example, in a cost-benefit analysis—because of the potential for double counting, since the land value effect is at least partially a reflection of expected reduced damage costs. They argue, however, that providing information on the benefits of flood risk mitigation in terms of land values is useful and tangible to decision-makers and facilitates the use of land taxes as a mechanism for financing resilience investments.

Averting expenditure and replacement costs. Risk reduction can also be proxied based on expenditures to mitigate damage incurred by a change in environmental conditions. These averting expenditures—such as flood-proofing roads, improving drainage capacity, raising the foundation of a house to avoid flooding, or digging a deeper well to prepare for drought conditions—can be considered a lower bound of the change in value (Tietenberg and Lewis 2018), as people would not spend more on the averting behavior than on the expected damage itself. A closely related approach estimates value using the replacement costs for non-marketed goods and services, assuming that these can be replaced by manufactured goods and services. Although its calculation is relatively simple—as the sum of market-based prices for engineering, construction, and maintenance of the replacement—in general this cost does not represent the value of the services it may be replacing as it is based on technological aspects of design and construction costs, not service values (Heal 2001). As such, it is not generally recommended for cost benefit analysis unless used as a lower bound for value in a retrospective analysis.

4.4 Valuing other NBS benefits

In addition to risk reduction benefits, NBS provide other benefits (see section 3.3), which should be valued and added to the disaster risk reduction benefits to include an integrated measure of NBS benefits in the decision framework. A diverse set of economic methods is available for estimating the other benefits of NBS for climate resilience in monetary terms (table 4-6; the valuation methods are described in section 4.4.1). Although it is beyond the scope of this guideline to provide a complete manual on how to apply each valuation method, section 4.4.1 outlines (1) which valuation methods are relevant for valuing each benefit; and (2) the general approach, strengths, and challenges of each method. In some cases, it may not be feasible to quantify all NBS benefits in monetary terms. In such cases, benefit-relevant indicators can be applied, which are introduced in section 4.4.2.

Table 4-6. Links from NBS benefits to valuation methods

	Valuation method					
NBS benefit	**Market prices**	**Net factor income**	**Avoided damages**	**Replacement cost**	**Stated preferences**	**Value transfer**
	NBS benefits that are directly observed in markets	Revenue from a marketed good with an NBS benefit input minus the cost of other inputs	Damage costs avoided due to NBS	Estimate the cost of replacing an NBS with an engineered solution	Ask people to state their WTP for an NBS benefit through surveys	Use results from existing valuation studies for similar NBS and socioeconomic contexts
Food and raw materials	✓	✓				✓
Tourism and recreation		✓			✓	✓
Climate regulation	✓		✓			✓
Biodiversity	✓				✓	✓
Water quality			✓	✓		✓
Health					✓	✓

Source: Original table for this publication.
Note: The green check mark indicates which valuation method is commonly applied for each NBS benefit; NBS = nature-based solutions.

4.4.1 Valuation approaches for other benefits of NBS

The choice of which valuation method to use is largely determined by which NBS benefit is being valued. For each of the key other benefits from NBS identified in section 3.3, the most relevant valuation method(s) are indicated in table 4-6 and explained in more detail below.

The set of valuation methods described in this section is selective; a more comprehensive overview of primary valuation and value transfer approaches that are potentially relevant to NBS benefits is provided in table A1 in appendix A.

Market prices

Market prices can be used to value NBS benefits that are directly traded in markets. This approach is particularly relevant for valuing the provisioning of food such as fish catch, raw materials, and global climate regulation.

The most straightforward and commonly used method for valuing any good or service is to look at its market price—that is, how much it can be bought or sold for. In a competitive market without distortions, price is determined by the relative demand for and supply of the good or service and reflects its marginal value (the value of a small change in the provision).

The major advantage of using this valuation method is that it is relatively easy to apply since it makes use of generally available information on prices and requires only simple modeling of quantities. A major disadvantage is that many ecosystem services are not traded directly in well-functioning markets, so readily observable prices for them are not available. If markets for ecosystem services do exist but are highly distorted, the available price information will not accurately reflect economic values and cannot be used. The main sources of market distortion are taxes and subsidies, noncompetitive markets, imperfect information, and government-controlled prices.

The market price approach is used in the case study on Indonesian mangrove restoration (case study 6) to value carbon storage and sequestration attributable to restoration and conservation. The quantities of carbon stored over the 30-year project lifetime were derived using mangrove extent accounts and valued using a voluntary carbon market price of \$5–\$9/tonne of carbon dioxide equivalent (tCO_2e).

Net factor income

The net factor income (or residual value) method is useful for valuing ecosystem inputs into the production of marketed goods and services. Ecosystem inputs to production are often unpriced, and the net factor income method estimates the value of such inputs by subtracting all other costs from the price of the final good or service. In the context of other benefits from NBS, this is a useful method for valuing ecosystem inputs to food production and tourism.

This method can be made more sophisticated to measure the marginal or incremental effect that the ecosystem input has on production. This *production function* method requires building a mathematical function to model the production of a good or service. Mangroves, for example, can serve as habitat for young fish. Given data on the extent and density of mangroves, quantities, and costs of other inputs (fishing effort), along with the quantity and price of fish caught, it is possible to estimate the relationship between mangroves and the productivity of a fishery. The contribution of mangroves to the productivity of the fishery as a proportion of total fish harvest can then be converted to monetary units based on the market value of those fish. A general limitation of this method is that it requires more detailed data than are commonly available for many ecosystem services.

Avoided damage cost

The avoided damage cost approach is described in detail in section 4.3 for valuing the direct risk reduction benefits of NBS. This method is also applicable for valuing other NBS benefits—in particular, global climate regulation.

By sequestering and storing carbon, NBS help to mitigate climate change and the resulting global damage costs, termed the social cost of carbon (SCC). The SCC is the monetary value of damages caused by emitting one additional tCO_2e in a given year; therefore, it also represents the value of damages avoided for a small reduction in emissions—in other words, the benefit of a CO_2 reduction of 1 tonne from the atmosphere. The estimated SCC used by the US Environmental Protection Agency (US EPA) and other US agencies for appraisal of emissions reductions in 2020 is \$51/tCO_2e (United States Government 2021).

The SCC is intended to be a comprehensive estimate of climate change damages, but because of current limitations in the integrated assessment models and data used to estimate it, it does not include all important damages and is likely to underestimate the full damages from CO_2 emissions.

Applying the avoided damage cost approach to value carbon storage by NBS involves quantifying the quantities of carbon sequestered (or emissions avoided) by the project over time and multiplying by the SCC for the relevant year. Several potentially useful tools exist for quantifying quantities of carbon sequestered and stored under alternative land uses and management scenarios. InVEST includes modules for measuring carbon storage in terrestrial and coastal ecosystems (Stanford University, no date-b; Stanford University, no date-c).

The avoided damage cost approach is applied in the case study on mangrove conservation in Jamaica (case study 5) to value climate regulation. The avoided emissions of carbon are estimated by multiplying the area of mangrove by the mean carbon stock per hectare and by a potential emissions factor. Avoided emissions are then valued using a SCC of \$48–\$51/tCO_2e.

The avoided damage cost method is also used in the case study on forest restoration to control landslides in Nepal (case study 4) to value reduced sediment arriving at a hydropower plant. Avoided costs include damage to equipment, efficiency loss, repairs, de-sanding, preventative measures, and maintenance of storage capacity.

Replacement cost

The replacement cost method estimates the value of an ecosystem service as the cost of replacing the service with human-built infrastructure. This valuation method has been described in section 4.3 in the context of valuing risk reduction benefits and can also be used to value other NBS benefits, particularly water quality regulation. In this case, the replacement infrastructure might be a water treatment facility.

The replacement cost method can provide lower-bound estimates of the value of an ecosystem service, but only if the following conditions are met: (1) the human-built infrastructure provides the same level of service as the ecosystem being replaced; (2) the human-built infrastructure should be the least-cost alternative; and (3) there should be substantial evidence that the service delivered by the infrastructure would be demanded by society if it were provided at cost (Shabman and Batie 1978). In practice, most applications of the replacement cost method do not meet these conditions and tend to overestimate the value of ecosystem services (Barbier 2016). This is because the cost of infrastructure is not a good proxy for the benefits that it delivers (benefits can be lower than costs if the infrastructure is redundant); moreover, the selected replacement infrastructures used in many studies are not the least-cost alternative. The replacement cost method is widely used because of its relative convenience (costs of human-built infrastructure are widely available) (**Beck and Lange 2016**), but when used inappropriately, it may deliver misinformation on the value of ecosystem services.

The replacement cost method is used in the case study on Metro Colombo inland wetland conservation (case study 7) to value nutrient retention and wastewater treatment by wetlands. Secondary data were used to quantify the volume of water filtered by wetlands and the costs of replacing that service with wastewater treatment infrastructure.

Stated preferences

Stated preference methods involve asking respondents in a public survey to state their willingness to pay for a specified good or service. Stated preference methods (contingent valuation and choice experiments) were introduced in section 4.3 in the context of valuing risk reduction benefits of NBS and can also be used to value other NBS benefits, particularly biodiversity and health benefits.

The economic value of biodiversity conservation is largely derived from people's preferences for the continued existence of diverse and charismatic species (existence value) and to leave such resources for future generations (bequest value) (see box 4-3 for more details on valuing biodiversity). Biodiversity conservation is largely not a marketed service and its value has been widely measured using stated preference methods. Amuakwa-Mensa, Bärenbold, and Riemer (2018) and Subroy et al. (2019) provide global reviews of stated preference valuations for biodiversity; and Johnston et al. (2017) provide guidance for stated preference studies.

The value of health benefits from access to green space includes both physical and mental health endpoints, which can be valued using stated preference methods. In this case, the question is what the survey respondents are willing to pay to obtain a reduction in the risk of ill health due to the increased availability of green space. Lindhjem et al. (2011) provide and global meta-analysis of stated preference studies that value mortality risk reductions.

BOX 4-3. Valuing biodiversity

It is widely recognized that biodiversity contributes substantially to human well-being (**Dasgupta 2021**; IPBES 2019). Biodiversity is a characteristic of ecosystems. It enables ecosystems to flourish and supply the wide variety of ecosystem services that underpin societies and economies—and of course nature-based solutions (NBS). Biodiversity increases nature's resilience to shocks, and thereby reduces risks to ecosystem services (**Dasgupta 2021**). Thus, there are compelling reasons to take biodiversity into consideration when designing NBS interventions.

There are, however, challenges to measuring biodiversity, and even more to valuing it. Biodiversity dynamics are complex, nonlinear, at times unpredictable, and frequently irreversible. Furthermore, the characteristics of biodiversity dynamics and the prevailing data gaps still pose modeling challenges that require further research (Power, Dunz, and Gavryliuk 2022). Biodiversity can benefit people as a supporting service underpinning other benefits and as a direct benefit to people (that is, in the form of medicine, spiritual or cultural value, and recreational value) (Mace, Norris, and Fitter 2012). Valuation methods exist for both types of benefits (Hanley and Perrings 2019).

Information on the impact of activities on biodiversity can also be incorporated into economic decision-making using a range of non-monetary indicators. Examples of guidance on the use of biodiversity indicators include the UK's Triple Win Toolkit (JNCC 2021) for development finance, the WWF's overview of tools to measure biodiversity and SDG footprints of financial portfolios (Hilton and Lee 2021).

The criticality of biodiversity as the foundation for human well-being, society, and the economy is becoming better understood by public and private actors. For example, in response to this growing awareness and the development of corporate nature strategies, a market for biodiversity credits has emerged. Two of the large carbon credit accreditation bodies are developing standards for biodiversity and nature credits and some project developers already have projects underway and have sold credits to corporates that have an impact on biodiversity through their operations. The voluntary biodiversity credit market is building on the compliance biodiversity offset markets that many countries have had for decades. Biodiversity offsets are actions intended to compensate for the unavoidable harm to biodiversity caused by development projects—their objective is to ensure no net loss of biodiversity. Biodiversity offsetting involves replacing damaged biodiversity by creating the same amount, type, and quality of habitat at other locations; these can also be credited, banked, and traded to offset the impacts of other development activities (Kerry ten, Bishop, and Bayon 2004).

Value transfer

Value transfer (also termed *benefits transfer*) is the use of research results from existing primary valuation studies at one or more study sites to predict welfare estimates or related information for other locations or policy sites (**Brander 2013**). In cases where study and policy sites are highly similar, simple unit value transfer may be sufficiently reliable.

In cases where study sites and policy sites are different, or the application is at a landscape scale for multiple ecosystem units, value function or meta-analytic function transfer offers a means to systematically adjust transferred values to reflect variation in factors determining demand for and supply of the valued service.

Value transfer can potentially be used to estimate values for any NBS benefit, provided that there are primary valuations of that benefit from which to transfer values. A potentially useful resource is the Ecosystem Services Valuation Database (ESVD, no date), which currently contains over 8,000 value estimates covering all biomes, ecosystem services, and regions.

The use of value transfer methods is generally lower cost, requires less time, and can be applied at scales that are not feasible for primary valuation methods (for example, in national, regional, and global assessments). Value transfer is widely applied in policy and investment appraisals but requires careful application since the estimated values can be less accurate and result in transfer errors.

Value transfer methods are used in the case study on Indonesian mangrove restoration (case study 6) to value tourism and provisioning services. Tourism is valued using a unit transfer of the median value of mangrove-related tourism in Southeast Asia ($876//hectare/year) combined with information on mangrove tourism sites from secondary sources. The provision of raw materials and support to fisheries by mangroves is valued using a meta-analytic value function that adjusts the values of these services to the characteristics of the mangrove, local beneficiaries, and availability of substitute sites. Value transfer using a meta-analytic value function was also used to value non-wood ecosystem services delivery by forests for the *World Bank's Changing Wealth of Nations* report (World Bank 2021).

4.4.2 Benefit-relevant indicators

A strength of the methods described above is that they provide a way to monetize benefits. Monetization allows benefits and costs to be compared in common units and combined as part of a cost-benefit analysis and provides a nominally meaningful measure of the strength of people's preferences for services provided by an NBS project. In cases where nonmonetized benefits are an important part of the decision process, or when monetization requires effort that extends beyond the dedicated resources for the project, benefit-relevant indicators can be a useful alternative that does not forgo the measurement and inclusion of benefits. *Benefit-relevant indicators* (BRIs) are measures that are demonstrably and directly relevant to human welfare, going beyond ecological indicators to connect the environment to those who depend on it (Olander et al. 2018). BRIs can be used to describe both risk reduction benefits and other benefits.

Assessments that rely on ecological values/indicators only are widespread (Mandle et al. 2021) and can be useful for assessing the provision of a potential service, such as the change in fruit produced from an urban orchard installation. In lieu of monetization, BRIs extend this to incorporate facets of the demand for this service—such as the number of people within walking distance of this orchard, or information about the number of households adjacent to the orchard that are considered to be in a "food desert" and could use easy access to nutritious produce. Linking the ecological change to these social outcomes stops short of estimating the strength of people's preferences for an urban orchard, but it provides a proxy for that based on related metrics that summarize the potential for demand. In principle, BRIs that indicate the intensity of human enjoyment of a good or service are most closely aligned with the underlying preferences and values of affected people.

Given the breadth of potential benefits associated with NBS for climate resilience, it is impossible to comprehensively catalogue BRIs. Some common BRIs are noted below:

- *Change in jobs.* Jobs are typically considered costs in a cost-benefit assessment but may also be seen positively by decision-makers and stakeholders as part of providing meaningful livelihoods to local communities. This can readily be incorporated into an MCA decision framework. NBS have the potential to create more lasting jobs than gray infrastructure alternatives (see also box 3-1).

- *Change in the number of visitors.* Recreation is often a valuable aspect of NBS projects that should be captured in some way if possible, and measuring visitation changes is often more feasible than monetizing the recreational value.

- *Disability-adjusted life years.* These measure the life years lost from premature death as well as the equivalent years of diminished quality of life, combining mortality and morbidity into a single measure. It is useful for assessing the health impacts of changes in environmental risk.

4.5 Assessing costs of NBS

During the identification, preparation, and implementation of an NBS project, it is important to gain an understanding of its life-cycle cost, accounting for the sum capital expenditures (CAPEX) and operating expenses (OPEX) and the other cost components. Between NBS for climate resilience and gray infrastructure projects, what differs is the timeline at which costs are incurred (see figure 3-2 in section 3.4). NBS implementation typically takes more time than the construction of gray infrastructure, and its successful implementation typically requires an institutional framework and funding to secure management, maintenance, and operation over time (**Wishart et al. 2021**). The cost components of NBS for climate resilience can be assessed with different levels of rigor.

Value transfer

Typically, rapid cost valuation in early stages of a project uses value transfer of unit cost from similar projects to estimate CAPEX and OPEX. For example: if a team is planning a wetland restoration project in a city, for a first indication of the CAPEX it should look at the per unit area cost of a similar project in a similar socioeconomic context. Some meta-studies and databases exist with unit cost estimates of ecosystem restoration (Aerts 2018; Bayraktarov et al. 2016; Narayan et al. 2016). These studies report a very large variation of unit cost for coastal NBS, with mangrove restoration costing $1,000–$9,000 per hectare, coastal marshes $11,000–$230,000 per hectare, and coral reefs $165,600–$300,000 per kilometer (**Bridges et al. 2021**). It is important to note that observations from high-income countries are overrepresented in these studies.

Adjusting unit costs to local conditions

The accuracy of unit cost transfer can be improved by adjusting the cost estimate to local conditions and specific characteristics of the NBS. If it is known that the material cost, labor, or land of a wetland restoration project is much higher or lower than in the project where the cost data were sourced, the difference in local market prices (of labor, land, or materials) can be used to adjust the cost estimate. If more project-level NBS cost data are or become available, more sophisticated approaches can be used to adjust CAPEX and OPEX per unit. For instance, cost functions can be developed by running regression analysis on NBS cost databases to understand the predictors of NBS CAPEX and OPEX. This approach has been used widely to adjust value transfer of NBS benefits/ecosystem services (for example, Brander and Koetse 2011), and it will become increasingly available as more geographically representative project-level NBS cost estimates are published.

Bill of quantities

A bill of quantities (BOQ) approach is especially suitable for NBS types with a substantial engineering component, such as bioretention areas, urban parks, and hybrid coastal solutions such as living breakwaters. Based on design sketches, material quantities can be estimated; labor quantities are estimated through stakeholder engagement. Subsequently, CAPEX and OPEX are calculated using local market prices of labor, land, and construction materials. In case study 8, the bill of quantities approach was used to cost coastal NBS in Beira, Mozambique.

Valuing opportunity costs

Opportunity costs include the cost of not using land for agriculture, residential development, or recreation. In a decision support framework, such as a CBA or MCA, opportunity cost can be defined as benefits—for instance, as income from agriculture in a baseline scenario—or as the cost of an NBS investment scenario. Depending on the type of opportunity cost, they can be valued using one of the valuation methods presented in table 4-6. If the opportunity cost associated with investing in NBS is a loss of income due to the protection of land for agricultural or residential development, such cost can be valued using a net factor income method. A net factor income method has been applied in both case studies 6 and 7.

Valuing externalities and disservices

Different valuation methods can be used to assess the costs of externalities and disservices. For example, additional costs associated with health issues and artificial watering costs required for the maintenance of an NBS can be calculated for health impacts and water quantity reductions resulting from NBS investment. Loss of recreational opportunities and other cultural disservices can be valued by estimating the loss of revenue from reduced visitation and/or a decrease in the willingness-to-pay for cultural services (Wu, Li, and Li 2021).

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5

How to Decide on a Valuation Approach

5.1 Principles for valuing NBS for climate resilience

Deciding on the approach to use to assess the benefits and costs of nature-based solutions (NBS) is not always straightforward. First, the objectives and thus the choice of methodology will depend on the stage of an engagement. A different level of rigor and granularity is required for upstream analytics, a project's economic and financial analysis (EFA), and detailed feasibility studies. Second, in practice, constraints related to the availability of data, time, knowledge, and resources often determine the NBS valuation approach. This chapter provides a framework to guide the selection of an appropriate and feasible approach to value the benefits and costs of proposed investments in NBS for climate resilience, adopting insights from the global literature and guidelines (**Bridges et al. 2021**).

The intention of this guideline is not to be prescriptive but instead to allow flexibility in the selection of methods to fit the diversity of NBS projects to the method of choice. There is no single "right" way to assess the benefits and costs of NBS, and each analysis should be tailored to the context and the specific needs and resources of the project at hand. However, four main principles, specific to valuing NBS, apply (Bouw and van Eekelen 2021; **Bridges et al. 2021**; **World Bank 2021**):

- **Principle 1: Value both risk reduction and other benefits.** NBS are multi-benefit and therefore multistakeholder approaches. The other benefits—such as biodiversity, climate regulation, and livelihoods—are a critical part of their value proposition. This implies that to accurately reflect the value of NBS, both risk reduction and relevant other benefits should be considered in the economic assessment. Moreover, quantification of other benefits is critical for the design of sustainable financing mechanisms for NBS, such as carbon financing mechanisms and broader payments for ecosystem services (PES)-schemes. As a rule of thumb, it is advised to value the three or four most important of the other benefits in addition to the risk reduction benefits to approximate the total economic value of the NBS.

- **Principle 2: Engage stakeholders to scope locally relevant benefits of NBS.** NBS benefits are often context specific. This implies that the value and socioeconomic importance of NBS widely varies from place to place. Depending on where you are, river floodplains might benefit communities as spaces for agricultural production, as communal places for washing and bathing, or as water storage to prevent flooding downstream. It is critical to consult and engage stakeholders to identify the relevant benefits to consider in project identification to ensure community buy-in and engagement.

- **Principle 3: Address uncertainty.** As the climate is changing, analytics based on historical climatic conditions at project initiation may not serve as a realistic projection of climatic conditions toward the end of the project's lifetime. Uncertainties driven by both climate and socioeconomic conditions play an important role in the assessment of benefits and costs of NBS.

- **Principle 4: NBS benefits assessment should inform project identification, design, implementation, and impact evaluation.** Benefit and cost assessment should be an integral part of NBS project identification and preparation to raise awareness, engage stakeholders, assess economic viability on investments, and evaluate impacts of NBS.

5.2 Assessing benefits and costs of NBS in the World Bank project cycle

Assessing the benefits and costs of NBS can play a key role in different phases of the World Bank's project cycle, from upstream analytics to detailed assessments that support project implementation and to natural capital indicators that enable impact evaluation upon project completion and beyond. Figure 5-1 summarizes how the economic value of NBS could be considered at each step in the project cycle:

- **Upstream.** In the pre-concept phase, strategic national- or regional-level economic assessments of NBS have proven to be a useful tool to raise awareness among clients and stakeholders and to identify potentially feasible solutions. In many countries, NBS are new and innovative and there is limited awareness of their benefits among stakeholders and across sectors. Upstream advisory services and analytics often also bring capacity-building outcomes through collaboration with local partners. Case studies 1, 2, 3, and 4 are examples of upstream analytics, assessing the benefits of NBS for coral reefs in Seychelles, urban wetlands in China, urban green spaces and small water bodies in Mozambique, and preventing landslides in Nepal, respectively.

- **Project identification and preparation.** In the identification and preparation phase, NBS investment ideas are subjected to technical and economic assessment. For the assessment of NBS for climate resilience, this often means evaluating NBS interventions using biophysical models (for example, hydrology, land use, and land cover) linked to benefit and cost assessment at the pre-feasibility level. In addition, at this stage, the economic assessment is a critical input for the identification of sustainable financing options. Nature or climate positive outcomes of an investment can attract additional financing on top of International Development Association (IDA) or International Bank for Reconstruction and Development (IBRD) commitments. Case studies 5, 6, and 7 are examples of analyses conducted to support project identification and preparation, showcasing economic analysis of NBS interventions for mangroves in Jamaica (case study 5) and Indonesia (case study 6), and urban wetlands for flood mitigation in the Colombo metropolitan area (case study 7).

- **Project appraisal.** Economic and financial analysis (EFA) of project components is a requirement for the project appraisal document (PAD) of all World Bank investment projects. Although most task teams conduct cost-benefit analyses, World Bank guidelines for the EFA allow for other analytical approaches—such as multicriteria analysis (MCA) and cost-effectiveness analysis (based on consultations with World Bank colleagues; see also World Bank 2013)—to be applied as well. To ensure a high-quality EFA, it is critical to build on technical and economic assessments of NBS components conducted in the project identification and preparation phase (see case study 6).

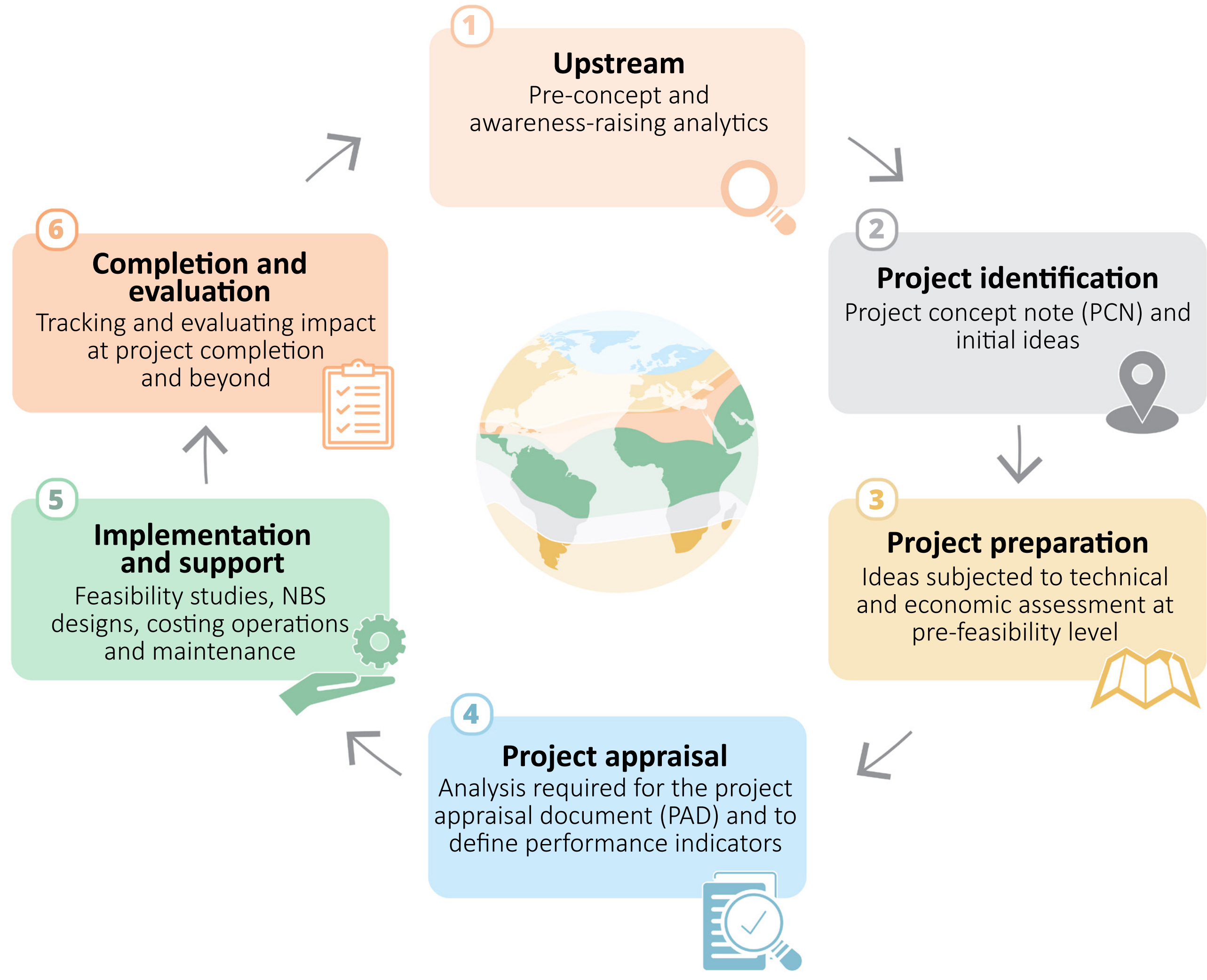
  Resilience rating system. This is a system to score the performance of World Bank projects in achieving resilience. The resilience rating of a project depends on the analytical approach used for the EFA. Projects with an EFA informed by a probabilistic assessment of climate impacts or an approach adopting robust decision-making achieve a higher resilience rating (World Bank Group 2021).

  Besides the EFA, the PAD defines project indicators linked to the project development objective (PDO) that are used to monitor performance during implementation and upon completion of the project. Task teams are strongly encouraged to include indicators that describe the benefits (that is, the outcomes) that NBS investments of the project deliver. For instance, such indicators could describe the "avoided expected flood damages as a result of investment in urban wetlands" or the "number of people protected by coastal mangroves protected by the project."

- **Implementation and support.** During project implementation, task teams support the client's project implementation unit (PIU) conducting detailed feasibility studies, designs and works. Feasibility studies should include preliminary designs of NBS and other interventions and a detailed costing considering both capital expenditures (CAPEX) and operating expenses (OPEX). Moreover, the feasibility study should scope and assess other benefits provided by NBS through engaging with local communities. Case study 8 is an example of implementation support, with a detailed feasibility study assessing the costs and benefits of gray, hybrid, and nature-based coastal protection investments for coastal sites in Beira, Mozambique.

- **Completion and evaluation.** Well-defined project indicators describing natural capital outcomes are critical to evaluate the impact and benefits of investments in NBS at project completion and beyond. As investments in NBS often require more time than gray infrastructure alternatives, tracking and evaluating impact is even more important beyond project completion. The implementation completion report (ICR) provides a narrative of project performance and reports progress on indicators.

Figure 5-1. Assessing the benefits and costs of NBS at different stages of the project cycle



Source: Adapted from World Bank Project Cycle, https://projects.worldbank.org/en/projects-operations/products-and-services/brief/projectcycle.
Note: NBS = nature-based solutions.

5.3 Decision framework

The choice of analytical methods for valuing NBS benefits and costs depends on several considerations regarding the objectives in the context of the project, as well as practical aspects such as the availability of time and funding. Two questions are used to structure the decision process (figure 5.2):

1. **What is the objective of the NBS assessment?** The objective of the analysis may include a broad range of decision contexts in the World Bank's project cycle (see section 5.2), such as advocacy and raising awareness of NBS among clients, experts, funders, and other stakeholders; and technical studies to support project identification and preparation or designing and locating NBS. Naturally, assessing the feasibility and design of NBS interventions will require more granular results, methodological rigor, and robustness than an advocacy piece or a country-level strategic assessment.

2. **How much data, time, and resources are available?** In World Bank project context, the availability of time, funding, data, and expertise for assessing the benefits and costs of NBS will often dictate which methods are feasible to apply. Economic assessments of NBS in many cases rely on data from previous studies across disciplines and sectors, such as flood risk assessments or natural capital accounts. Therefore, careful screening of available data is essential for developing high-quality assessments in a cost-effective way.

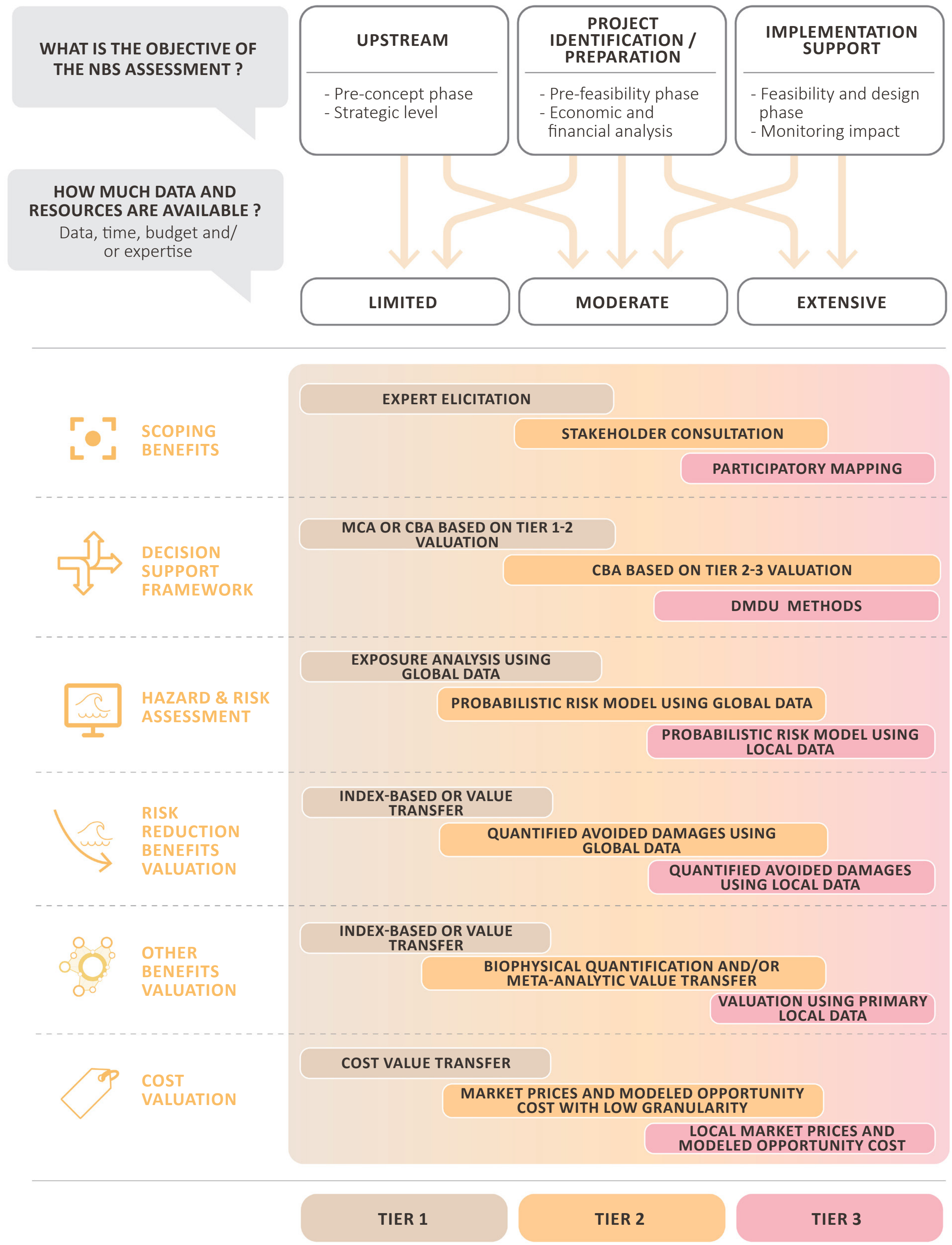
Answering the questions above will provide an indication of which methods for valuing NBS are relevant and feasible. A tiered approach is proposed to provide a broad indication of which analytical approach is the best fit for a project context. Higher-tier methods will provide more detailed and precise output, and they typically require more input data, time, resources, and expertise to implement.

- **Tier 1.** This tier consists of rapid assessment methods that rely on expert elicitation for scoping benefits; value costs and benefits using value transfer, global data analysis, and index-based valuation approaches; and typically employ MCA or a simple cost-benefit analysis (CBA) as a decision support framework.

- **Tier 2.** Tier 2 methods largely rely on globally available geospatial/economic data, but these methods generate more precise quantitative and context-specific results. For instance, more precise and context-specific results are obtained by engaging stakeholders to scope relevant NBS benefits; by quantifying disaster risk reduction by NBS considering hazard, exposure, and vulnerability; and by using value functions to adjust costs and benefits to the local project context (considering local NBS features, local income levels, and material costs). Typically, such an analysis would adopt a CBA with sensitivity analysis.

- **Tier 3.** Tier 3 methods require local data collection (for example, interviews and field observations) and deliver greater accuracy. This includes participatory approaches for scoping benefits and solutions; high-resolution risk assessment using locally obtained data (for example, a light detection and ranging [LiDAR]-based digital elevation model); local modeling of risk reduction processes and the economic impact of NBS; valuation of other benefits using local primary data (for example, stated and revealed preference methods and the analysis of local market prices); and opportunity costs estimated using primary local data. For decision support, robust decision-making (RDM) can be considered to account for deep uncertainties caused by climate change.

Figure 5-2. The decision context, resource availability, and tiers of analysis



Source: Original figure for this publication.
Note: CBA = cost-benefit analysis; DMDU = decision-making under (deep) uncertainty; NBS = nature-based solutions.

The tiered approach is applied to six sequential steps in the economic assessment of NBS for climate resilience, following the structure of chapter 4 (see table 5-1 for more details on data requirements). These steps include:

1. **Scoping benefits.** The first step in valuing NBS benefits is to identify what the key benefits of the project are. This is necessary and important because there can be substantial variation in which NBS benefits are relevant (**World Bank 2021**; see also the NBS Benefit Explorer, available at https://nbsbenefitsexplorer.net/). The three or four other key benefits of NBS can be identified in several different ways, including through expert elicitation, stakeholder consultation, and participatory mapping. Particularly for studies supporting project preparation and implementation, engaging with local stakeholders and communities is strongly advised (see the discussion of the four principles in section 5-1).

2. **Decision support framework.** If risk reduction and/or other benefits are valued using index-based approaches (tier 1), such as in case study 1, the decision support framework of choice should be an MCA. Monetary tier 1 or 2 valuation might apply a simple CBA to estimate a net present value (NPV) and economic rate of return of the NBS over the project lifetime. With a tier 1 or 2 approach, the CBA should address uncertainty by applying sensitivity analyses to two or three key variables that are considered uncertain, including the discount rate. A tier 2 or 3 CBA builds on higher resolution and precision valuation data and could be applied in combination with spatial prioritization (that is, Geographic Information Systems, or GIS, analysis) and more sophisticated sensitivity analysis or expected value analysis. In tier 3, CBA can also be combined with RDM, as shown in case study 7.

3. **Hazard and risk assessment.** This type of assessment is required to understand climate impacts and disaster risk at potential project locations. Hazard and risk assessment can be conducted with different levels of precision, ranging from exposure analysis using globally available hazard and exposure data to risk modeling relying on high-resolution local hazard data and locally calibrated damage assessment (figure 5.2). Ideally, steps 3 and 4 are combined in a single study to quantify the avoided damages of planned NBS investments in the project. However, in this framework, steps 3 and 4 are treated separately for practical reasons since, in most project contexts (for example, in case studies 7 and 8), output data of a risk assessment conducted earlier in the project are used as input for valuing risk reduction benefits of the NBS.

4. **Risk reduction benefits.** These NBS benefits can be valued using process-based physical models and damage assessment to quantify the avoided damages of climate impacts and natural hazards. Rapid assessment (tier 1) methods to value risk reduction benefits include index-based approaches and value transfer. Quantifying the avoided damage cost is the preferred approach for tiers 2 and 3, where tier 3 relies on local high-resolution data and modeling. In some cases, other valuation methods can be considered, such as stated preferences and hedonic pricing (see section 4.3.2).

5. **Other benefits valuation.** Methods of valuing other benefits vary widely across projects (table 4.6 and table A1 in appendix A). Rapid tier 1 methods include value transfer and index-based approaches, while tier 2 methods include meta-analytic value transfer and market prices linked to biophysical quantification (such as estimating carbon sequestration or timber production based on land use/land cover maps). Tier 3 approaches for valuing other benefits include methods that rely on local primary data such as on-site stated preferences and local net factor income assessment for tourism revenues and food and fisheries.

6. **Cost valuation.** Typically, rapid cost valuation (tier 1) uses the value transfer of unit cost from similar projects to estimate CAPEX and OPEX. Tier 2 cost assessment might use simple unit cost functions to estimate CAPEX and OPEX, using a bill of quantities to adjust unit costs to country-level wages and, if possible, material cost. In addition, tier 2 cost assessment should consider other cost components, such as opportunity cost modeled based globally geospatial data sets (see case study 6). Tier 3 cost valuation includes detailed cost functions based on local wages and material cost estimation, locally assessed opportunity costs, and, if relevant, disservices of the NBS.

It is possible to mix methods in different tiers across the analytical steps to reflect the needs of the project and choices made based on available data and resources (for example, to use a tier 3 method for hazard modeling and tier 1 or 2 methods for other steps in the analysis). As an illustration, chapter 6 describes how the case studies ranked for each analytical step.

Table 5-1. Data collection suggestions for tiers 1, 2, and 3 per analytical step

Analytical step	Tier 1	Tier 2	Tier 3
Scoping benefits	Expert elicitation	Stakeholder interview/ workshop	Stakeholder/community participatory mapping
Decision support framework	Consult experts to assign weights in MCA (if MCA is used)	Consult stakeholders to validate selection of benefits and sensitivity analysis	Stakeholder consultation series to set objectives for RDM
Hazard & risk assessment	Global hazard and exposure data sets,[a] including climate change scenarios	Tier 1 and regional socioeconomic statistics, damage models	Local data sets to improve the risk assessment, including high resolution Digital Terrain Model (DTM), precipitation, soil, gray infrastructure, building classes, local damage models.
Risk reduction benefits valuation	Global ecosystem and/ or land cover data Global (geospatial) risk reduction value datasets (monetary or index based)[b]	Tier 1 data sets and natural capital accounts (ecosystem extent and condition data sets)	Data for hazard and risk modeling and high-resolution ecosystem extent and condition data sets, environmental conditions such as water/ air quality, diseases
Other benefits valuation	Ecosystem services/ NBS benefits value databases[c] Global ecosystem and/ or land cover data	Tier 1 data sets and natural capital accounts (ecosystem extent and condition data sets) or other geospatial national/local ecosystem extent and/or condition data	High-resolution ecosystem extent and condition datasets (and full natural capital account if available), local market prices of NBS benefits/ecosystem services (agricultural output, nature-based tourism, fish), and stated preference surveys
Cost valuation	NBS CAPEX and OPEX unit cost estimations from other case studies/projects to inform value transfer	Modeled opportunity cost data sets (spatially explicit or regional statistics), national/ regional statistics on wages, and/or material cost to refine CAPEX and OPEX cost estimates	Estimate local wages/ labor cost; estimate material and land cost based on local market prices; value disservices (if any) using stated preference survey

(*Source* and *Note* on the next page)

Source: Original table for this publication.
Note: CAPEX = capital expenditures; DTM = Digital Terrain Model; MCA = multicriteria analysis; NBS = natured-based solutions; OPEX = operating expenses; RDM = robust decision-making.
a. See the World Bank Climate Change Knowledge Portal, available at https://climateknowledgeportal.worldbank.org/.
b. For example, see Menéndez et al. 2020; see also the Mapping Ocean Wealth Explorer, available at https://maps.oceanwealth.org/.
c. For example, see the Ecosystem Services Valuation Database (ESVD) at https://www.esvd.net/ and the SEPAL Benefits data layers at https://docs.sepal.io/en/latest/modules/dwn/seplan.html#benefits-data-layers.

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Key references

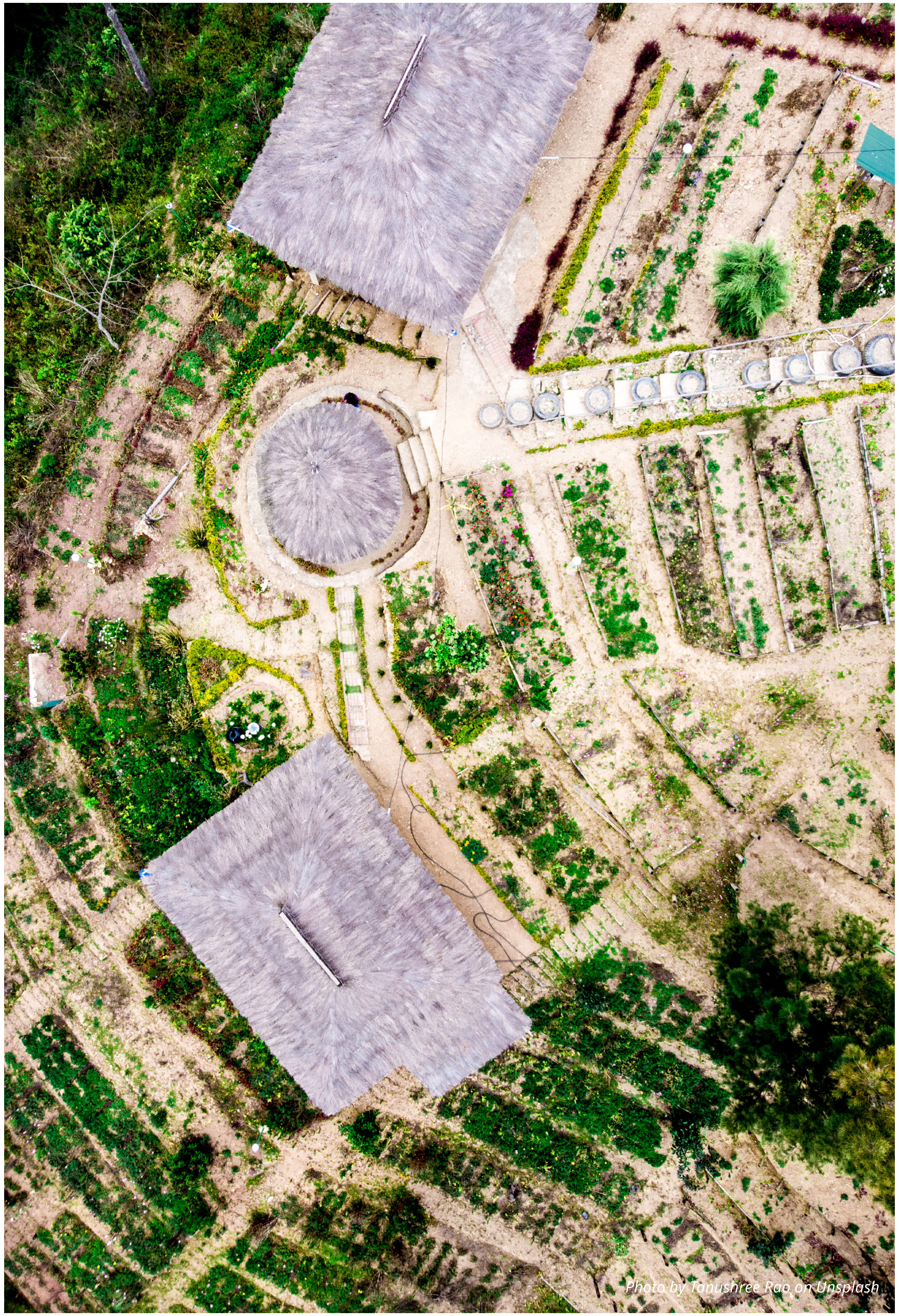

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Photo by Simone Lee

6

Overview of the Case Studies

6.1 Case study selection and template

A series of case studies of economic assessments are included in this guideline to illustrate how different valuation approaches have been applied for nature-based solutions (NBS) in World Bank projects (a more extensive list of examples can be found in appendix B). Case studies were identified through expert consultations. The case study profiles contain information on data sets, economic valuation methods adopted, and main results obtained. In addition, each study specifies how the results were used operationally by World Bank task teams and/or clients, and how the study could have been improved. Among other things, the practical information provided is intended to help both World Bank teams and external project developers to better understand, prepare, and implement similar studies. The case study descriptions include information that can be used for the preparation of terms of references for similar studies, such as the required budget and time, expertise, replicability of the study, and data requirements (figure 6-1).

Figure 6-1. Visual representation of the structure and main components of the case studies

PROFILE AND CONTEXT	METHODS AND RESULTS	PRACTICAL INFORMATION
[0] **Recap of main characteristics of the study**	**[2]** **Analytical approaches**	**[5]** **Operational use of results**
[1] **Background**	**[3]** **Methods and data**	**[6]** **Practical considerations** Budget, timeline, expertise, replicability and data requirements
	[4] **Results**	**[7]** **Areas for improvement**

Source: Original figure for this publication.

The eight case studies in this guideline were selected to be representative of several types of NBS, natural hazards, and geographies (table 1-1), and also to show how diverse analytical methods and approaches can be applied and combined in different decision contexts.

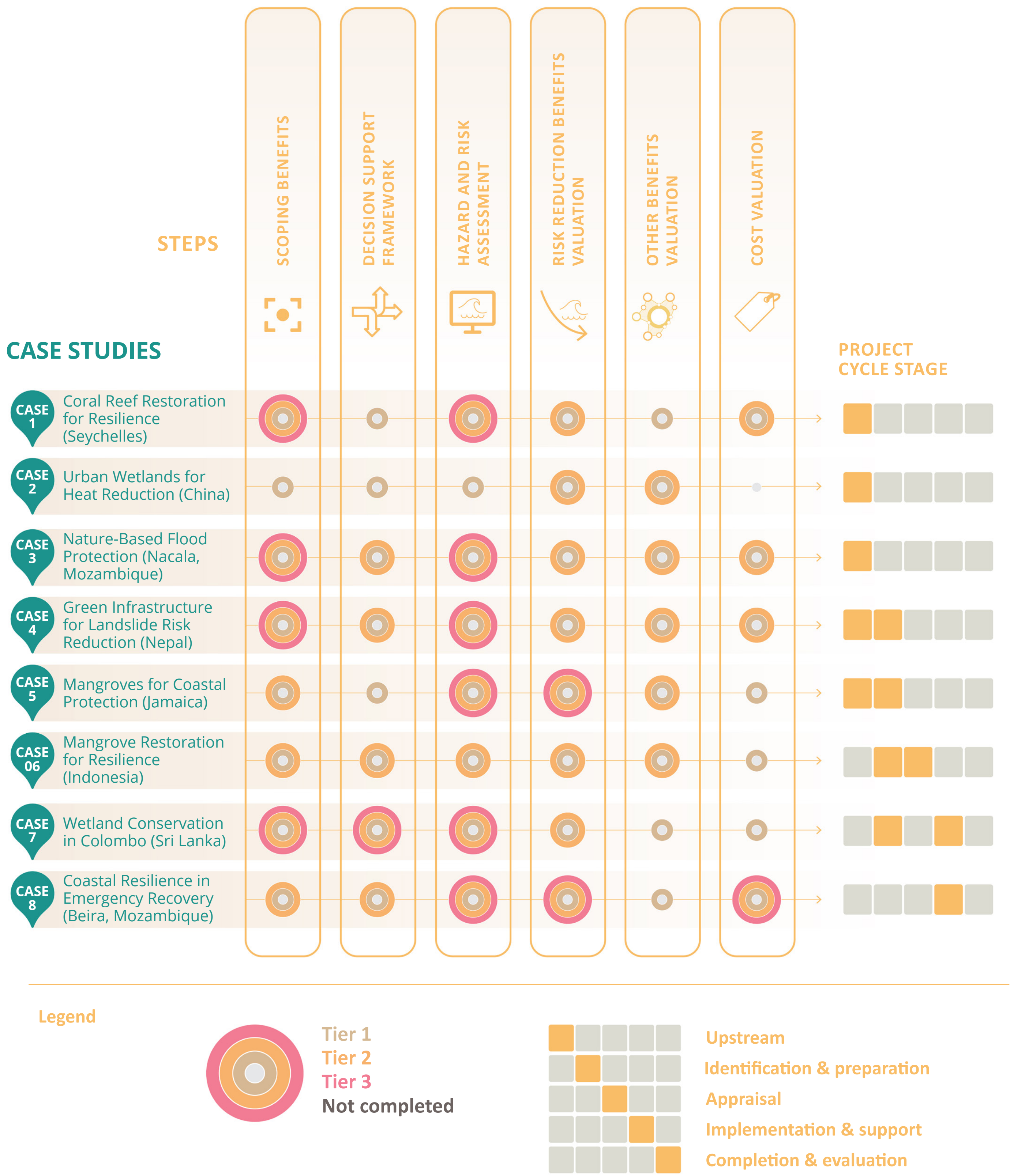
- *Case study 1* describes a series of consecutive studies focusing on identifying coral reefs as a key natural infrastructure in the three main islands of Seychelles, assessing their role for coastal protection and keeping in view other benefits such as tourism and marine biodiversity.
- The *second case study* shows a cost-benefit analysis (CBA) estimating the value of the Haizhu Urban Wetland Park in China, comparing the existing state of the park to an alternative state where the wetland is developed into residential housing. Throughout the analysis, ecosystem service models are employed to estimate human well-being changes due to changes in urban cooling, mental health, physical health, greenhouse gas emissions, and damages.
- *Case study 3*, located in the coastal city of Nacala (Mozambique), assesses the benefits of nature-based flood protection solutions and quantifies the potential costs and benefits in monetary terms to help determine whether one adaptation option would be preferable in the study areas.
- In Nepal (*case study 4*), the World Bank conducted a study to value watershed management practices for erosion and sediment reduction in the Kaligandaki watershed. The analysis focuses on the benefits that result from avoided erosion and sedimentation and looks secondarily at some of the co-benefits that arise from activities employed to control sediment.
- *Case studies 5 and 6* are both good examples of projects quantifying the contribution of mangrove forests to flood protection and climate resilience, accounting not only for disaster risk reduction benefits but also for the ecological and social value of these coastal ecosystems. In Jamaica, the study combines global and local data to assess the services of mangroves for flood risk reduction at a national scale and estimates the values for blue carbon and nearshore fisheries based on literature and benefit transfer approaches. The analytical approach in Indonesia is also applied at national scale, but in this case a spatial CBA is used to measure the net benefits of mangrove restoration and conservation identifying high net returns from investments around the country.
- *Case study 7* considers the use of wetlands as green infrastructure to complement a gray infrastructure investment package in the metropolitan region of Colombo (Sri Lanka) using decisions support tools for complex problems under deep uncertainties.
- Finally, *case study 8* describes the CBA of the feasibility study conducted for the coastal resilience component of the Cyclone Idai & Kenneth Emergency Recovery Project. The study evaluates different design alternatives for four coastal sections in the city of Beira to select the preferred intervention.

6.2 Tiers of analysis in the case studies

To better understand how the tiered approach (section 5.3) is implemented at the World Bank, figure 6-2 shows which tier was applied at each sequential step for all the case studies included in this report.

This practical exercise demonstrates that the choice of analytical methods for valuing NBS benefits and costs is not rigid. A diversity of methods and tiers can be applied and combined across the analytical steps, adapting to each project's needs. As stated in chapter 5, the assessment of the case studies confirms that deciding on the most adequate approach not only depends on the objective of the analysis but is also greatly influenced by the availability of time, data, and other resources. Figure 6-2 also confirms that those studies supporting the project implementation stage—usually assessing the feasibility or design of NBS interventions (case studies 7 and 8)—tend to apply methods requiring more local data and methodological rigor (tiers 2 or 3) than other types of upstream assessments. This trend is particularly evident in the analytical methods applied during the cost valuation and decision support framework steps.

Figure 6-2. Tiers of analysis applied in the case studies



Source: Original figure for this publication.
Note: The eight case studies are mapped based on the level of analysis (tier 1, 2, or 3) applied at each sequential step. The project cycle stage flows from upstream (top of the figure) to implementation support (bottom of the figure).

6.3. Lessons learned

The following observations and conclusions have been drawn from the analysis of the case studies and expert consultations:

1. **Clearly communicating the benefits of NBS can successfully inform project design.** Case studies 6 and 7 are a testament to this observation. However, we also observe that not all case studies have resulted in investment projects, likely because of circumstances that have nothing to do with the case study results but instead are due to other external causes. What can be concluded, though, is that timing is critical: Case studies 6 and 7 are rapid assessments that managed to inform the project on time. Looking at the portfolio of NBS projects financed by the World Bank teaches that most teams do not assess the benefits of NBS during project identification and preparation. Consulted experts indicated that this is often due to the lack of certainty and concrete details on the final intervention design and scale.

2. **Teams do not always make use of the available approaches for valuing NBS benefits.** There seems to be a preconceived idea among the various task teams about the high costs and time associated with the valuation of the benefits of NBS. However, as this guideline highlights, there exists a diversity of methods that can be adapted to a broad range of project requirements. In addition, the assessment of NBS studies conducted at the World Bank (figure 6-1) demonstrates that most economic assessments are able to combine different methods and approaches adapting to the objectives, uncertainties, and resources available across the different sequential steps of a study.

3. **Successful studies optimize the use of available data.** Data are crucial to shape benefit and cost assessments and help practitioners make informed decisions that are relevant for the development contexts in which projects are being implemented. However, project teams still encounter significant challenges (logistical, financial, and capacity-wise) they must overcome to collect the data needed for the estimation of different potential benefits and costs, especially in data-scarce contexts where projects are usually developed. Two learning points have been extracted from the analysis of the case studies that can help to overcome these data challenges. First, stakeholder participation throughout the project identification process is fundamental and should involve both local communities and expert consultation. Data collection and methods properly involving the appropriate stakeholders will help to identify the full scope of benefits and costs, reveal potential indirect impacts, and connect NBS interventions to broader climate and development policies and goals. Second, a range of global- and national-level data tools and sources is increasingly available. It is important that World Bank project teams become more aware of the existence of these resources and that they learn how to include them, often in combination with other primary data, being able to improve the quality of the results in an efficient way.

4. **More effort is needed to value the other benefits of NBS.** It is clear from these case studies (and other reviewed projects that have not been included in the final document) that quantifying the economic benefits of NBS continues to be an active area for research at the World Bank and provides an opportunity to build capacity and develop new strategies for implementation. Reviewed projects typically focus on the biophysical layer and ecological outcomes and they invest limited resources in the valuation process, providing limited data on the economic benefits policy makers, communities, and other stakeholders hope to achieve. Although some projects invest in valuing one or two central risk reduction benefits, there is an even clearer gap in assessing other important benefits generated by NBS such as climate regulation, biodiversity, water quality, or health. Failure to incorporate these broader impacts into the CBA causes an important underestimation in the project benefits relative to its costs. The identification and estimation of the whole range of economic and social impacts together with an improved application of the appropriate valuation methods can help project teams and government clients better understand the multiple benefits of NBS and thus better support the design, funding, and cost-effective implementation of appropriate interventions.

5. **Incorporating NBS or ecosystem resilience to climate impacts remains a key knowledge gap.** Because the climate is changing rapidly, typical climatic conditions at the beginning of a project design may not serve as a realistic baseline by the end of the project. Even if uncertainties driven by both climate and socioeconomic conditions play an important role in the assessment of benefits and costs of NBS, many projects do not apply them in their valuation methods or decision frameworks. The application of climate scenario modeling to NBS cost-benefit analysis can support project design, identifying expected changes in local climate that may affect project implementation and impact as well as evaluation, serving as a baseline scenario against which the effects of the intervention can be compared. Equally important is to take into consideration the long-term nature of these green interventions and the fact that benefits may take time to be fully realized. There is a general need to strengthen the calculations of benefits and costs over time and to incorporate recommendations for addressing future projections of benefits and costs into the analysis. However, these require rigorous data collection, before and after project implementation, as well as appropriate comparison groups, which may not be feasible or desirable for every project.

Case Studies

Photo by Cosima Qin on Unsplash

CASE STUDY 1 92
Coral Reef Restoration for Coastal Resilience (Seychelles)

CASE STUDY 2 104
Urban Wetlands for Heath Reduction (Haizhu, China)

CASE STUDY 3 112
Nature-Based Flood Protection (Nacala, Mozambique)

CASE STUDY 4 120
Green Infrastructure for Landslide Risk Reduction (Kali Gandaki, Nepal)

CASE STUDY 5 130
Mangroves for Coastal Protection (Jamaica)

CASE STUDY 6 138
Mangrove Restoration for Resilience (Indonesia)

CASE STUDY 7 148
Wetland Conservation in Colombo (Sri Lanka)

CASE STUDY 8 157
Coastal Resilience in Emergency Recovery (Beira, Mozambique)

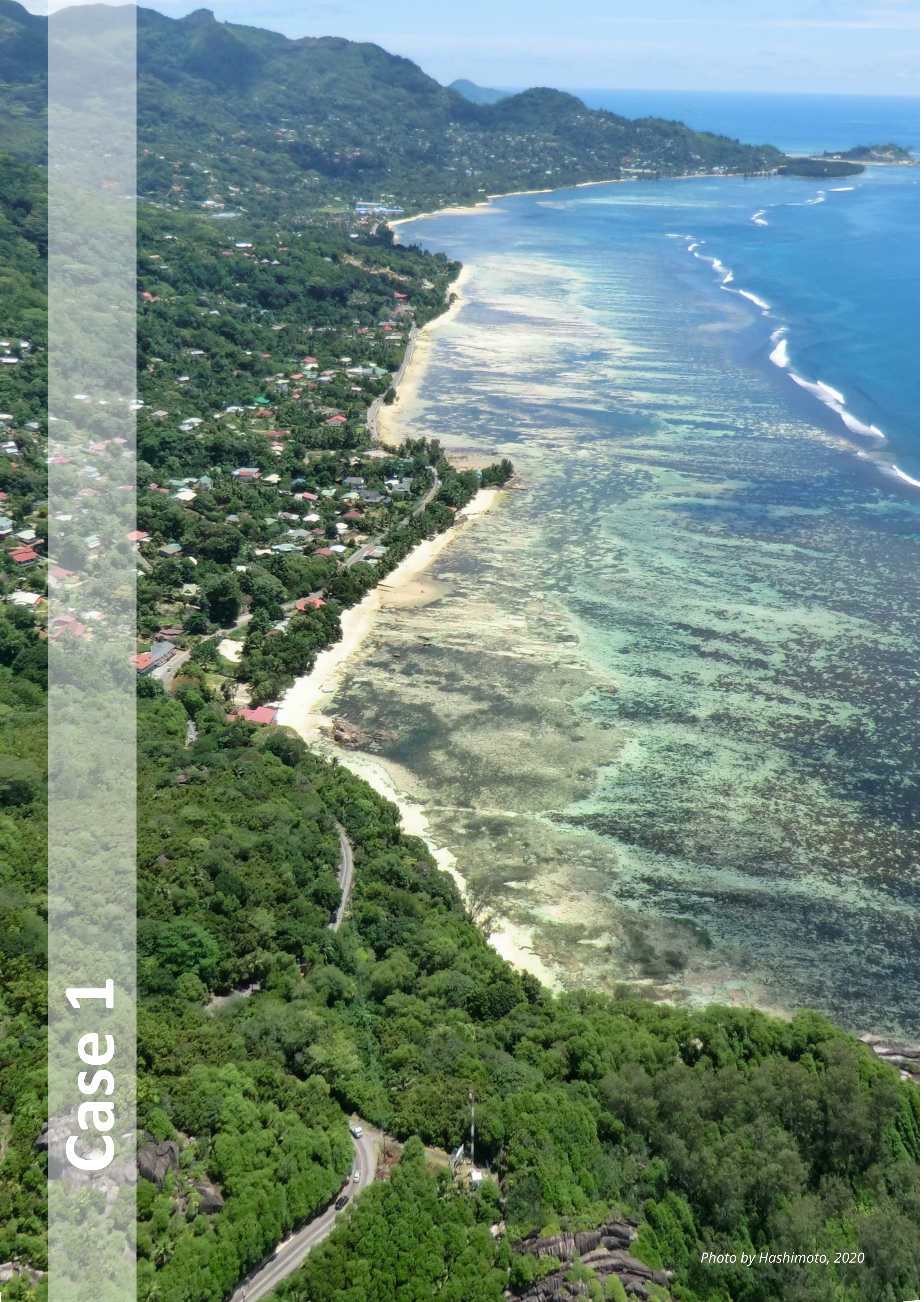


Photo by Hashimoto, 2020

Coral Reef Restoration

Coral Reef Restoration for Coastal Resilience (Seychelles)

Case study profile

NATURE-BASED SOLUTION (NBS) PROFILE

NBS TYPE

Reef Ecosystems

PRIMARY RISK REDUCTION BENEFIT (RRB)

Flooding

Erosion

NBS APPROACH

Rehabilitation, restoration, enhancement

OTHER BENEFITS

Biodiversity

Tourism and recreation

Climate regulation (only identification during scoping phase)

ECONOMIC STUDY PROFILE

PROJECT CYCLE STAGE

Upstream

ANALYTICAL APPROACH APPLIED (RRB)

MCA

Multicriteria analysis

Avoided damages and costs (only partial)

SCALE OF PROJECT

National (scoping phase)

Site-specific (pre-feasibility phase)

STUDIED SITE

Islands of Mahé, Praslin, and La Digue (Scoping) / Côte d'Or (Pre-feasibility study for the Blue Barrier)

STUDY YEARS

2018–2021

WORLD BANK PROJECT PROFILE

PROJECT NAME

Disaster Risk Management Development Policy Loan with Cat DOO (World Bank 2020)

REGION

Sub-Saharan Africa

GLOBAL PRACTICE AREA

Urban, Disaster Risk Management, Resilience and Land

PROJECT REPORTS

Quick-Scan Runup Reduction through Coral Reef Restoration in the Seychelles (Deltares 2020)

Strategies for Large Scale Coral Reef Restoration for Coastal Resilience in the Seychelles (BMT 2020)

Coastal modeling and assessment of potential solutions for coastal defense and adaptation measures at priority sites (eCoast 2022) [Report not published.]

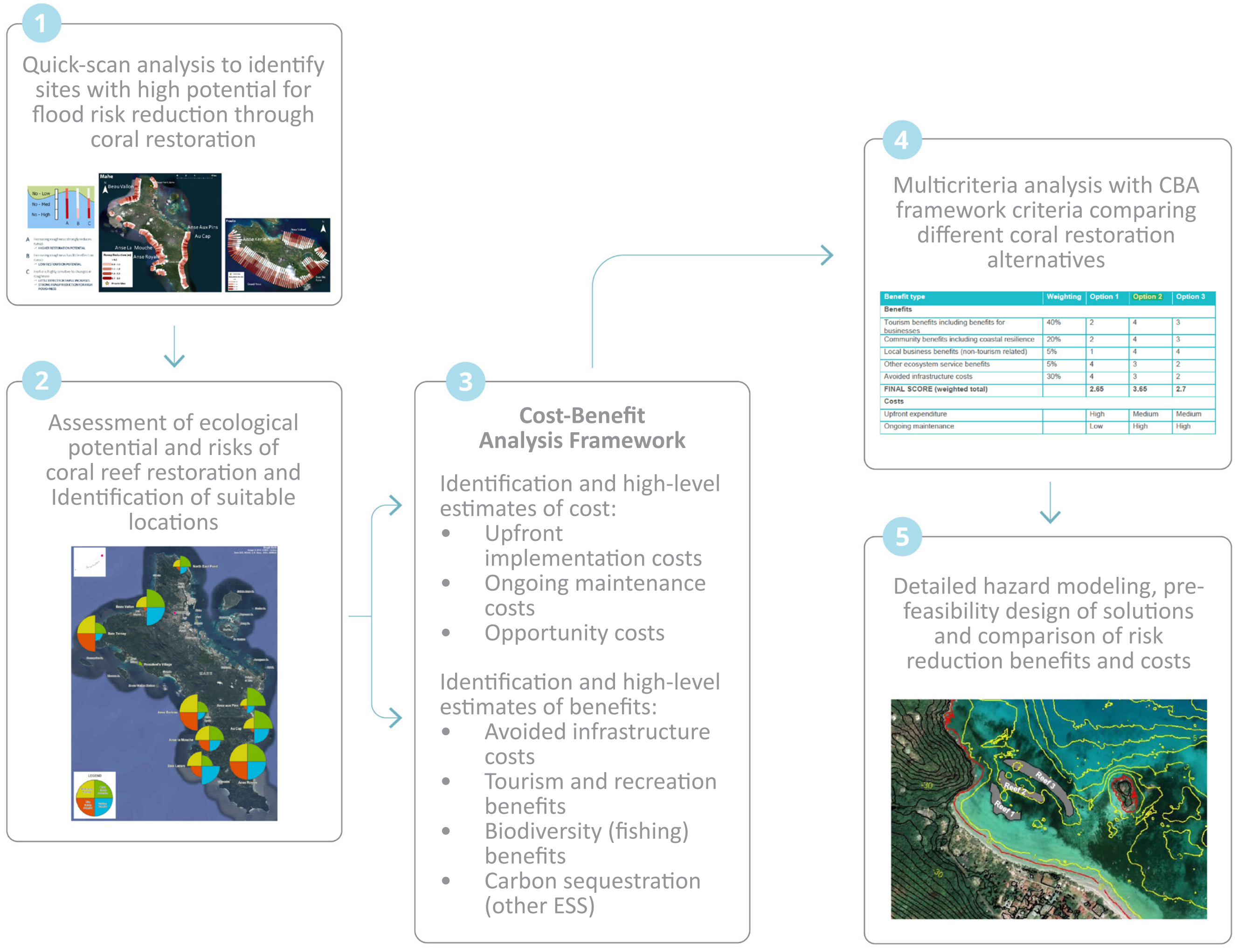
Background

The small island state of Seychelles has seen an increase in flooding, coastal erosion, and ecosystem degradation, causing damage to infrastructure, beaches, and property across the main islands. Unplanned development in the coastal zone, climate change–induced increases in sea level, and extreme rainfall are expected to further exacerbate the impacts of disasters. In 2014, a Disaster Risk Management Development Policy Loan with Catastrophe Deferred Drawdown Option (Cat DDO) was put in place to provide liquidity in the event of a disaster. As part of the technical assistance provided under the operation, the *Seychelles Coastal Management Plan 2019–2024* (World Bank and MEECC 2019) was developed as the first government-endorsed strategy and investment plan for coastal resilience in the country. This plan outlines the key risks to the coastal zone and proposes an implementation plan, which includes required investments in coastal protection, nature-based solutions (NBS), and risk-based land planning. The Coastal Management Plan (CMP), supported by previous World Bank studies, identified coral reefs as a key natural infrastructure and highlighted the primary role that coral reef restoration plays in the coastal protection that is critical to local communities and the economy. The World Bank is currently providing technical assistance on various priorities identified in the plan including the development of a pilot "Blue Barrier" approach (Jongman et al. 2021) through the use of hybrid coral reef restoration for risk reduction.

Analytical approach

The analytical approach of this case study included several phases and various studies (figure CS1-1). An initial exploratory coastal modeling study (Deltares 2020) showed that healthy coral reefs could reduce coastal flood levels in different areas of the country. A subsequent ecological and economic assessment (BMT 2020) provided a tailored framework for the economic assessment of coral reef restoration projects that included the identification and qualitative assessment of costs and benefits. That study also conducted a multicriteria analysis assessing the expected benefits of three restoration techniques at different sites, which enabled the selection of the most appropriate intervention approach. Taking into consideration these previous results, a detailed coastal modeling study (eCoast 2022) contributed to a better understanding of coastal flood and erosion causes and impacts at priority sites; it also assessed the suitability and potential of the Blue Barrier options.

Figure CS1-1. Analytical approach of the Seychelles study



Source: Original figure for this publication.

Methods and data

In the scoping level, costs and benefits were first identified and estimated with data extracted from secondary sources through literature review and surveys from Seychelles and other areas as well as a close collaboration with local experts (table CS1-1).

Table CS1-1. Methods and data of the coral reef restoration economic framework (scoping phase)

Costs

Cost/benefit type	Description	Method	Data source(s)
Upfront implementation costs	Estimation of nursery costs (land and ocean based), transplantation costs, artificial reef structure, and algae removal activities	Literature review and local stakeholder consultation	Edwards 2010; dela Cruz and Harrison 2017; Edwards and Gomez 2007; Al-Horani and Khalaf 2013
Ongoing maintenance costs	Monitoring of coral growth and percentage loss at transplanted sites	Literature review and local stakeholder consultation	Edwards 2010
Opportunity costs	Potential conflicts with other economic activities affecting coral restoration: aquaculture, fishing, and diving activities	Stakeholder consultation	*Not quantified*

Benefits

Cost/benefit type	Description	Method	Data source(s)
Avoided infrastructure costs	Improved beach protection outcomes as a result of coral reef restoration. This would reduce the cost of implementing new beach or flood protection measures such as sea walls or groins, or replacing damaged infrastructure due to flooding.	Literature review and local stakeholder consultation	*Not quantified*
Tourism and recreation benefits	Tourism benefits are delivered through increased visitation and beach use value for tourists and local residents due to (1) reduced erosion; (2) increased snorkeling, diving, and fishing recreation; and (3) non-use value of the coral reef as a result of its existence, bequest, and cultural values.	Literature review	Phillips 2011; Christie et al. 2015
Biodiversity (fishing) benefits	Coral reefs are biodiverse ecosystems that support artisanal fishing, which is an important activity in Seychelles. The volume and value of the fish catch may increase as a result of reef restoration. This will create value for local businesses both directly and indirectly involved in artisanal fishing.	Literature review	World Bank 2017
Carbon sequestration	Coral reefs stabilize the surrounding environment, making it more conducive for seagrass and mangrove growth. These ecosystems sequester carbon and serve as carbon sinks, mitigating global climate change.	Literature review	Conservation International 2019

Source: Original table for this publication.

In a second phase, a more detailed study at the pre-feasibility level was conducted. This focused on the erosion and flood risk reduction potential of the selected approach (offshore Blue Barrier) in one specific site (Côte d'Or) (table CS1-2).

Table CS1-2. Methods and data of the pre-feasibility study

Costs

Cost/benefit type	Description	Method	Data source(s)
Upfront implementation costs	Offshore Blue Barrier reef: patch of ~6,354 m² area to be covered with approximately 1,300/1,700 artificial reef units to promote coral attachment for hybrid coastal defense	Interviews with project developers	—
Ongoing maintenance costs	Reef rehabilitation activities (area of 500–600 m²): generating nursery coral stock, coral transplantation, capacity building and monitoring	Budget provided by a local coral restoration nongovernmental organization	—

Benefits

Cost/Benefit Type	Description	Method	Data source(s)
Risk reduction benefit	Coastal flood exposure of vulnerable assets (exposed buildings and roads)	Spatial analysis of intersection property polygons and road vectors with the flood outlines to determine counts of buildings and length of roads over the range of flood footprints (10-year, 50-year, 100-year, and 500-year scenarios).	Local data sets provided merged with Open StreetMap (OSM) data to provide updated coverage of building polygons.
Risk reduction benefit	Wave energy reduction	Comparison of wave transmission (Kt) for a 50-year ARI under present conditions (no reef) and with the offshore reef options.	Quantified using the average wave height from along the studied transects and using the formulation of Buccino, Del Vita, and Calabrese 2014 for a similar Reef Ball configuration.
Risk reduction benefit	Sediment mobility reduction (leading to sand accumulation)	Measurement of the longshore sediment transport rates under a range of conditions in the lee of the reef.	Quantified using the modified Kamphuis method, which is used to calculate longshore transport rates (Kamphius 1991).

Source: Original table for this publication.
Note: ARI = average recurrence interval; Kt = transmission coefficient; m² = square meters; — = not available.

Results

The development of a tailored economic evaluation framework in the scoping phase was fundamental to identifying and understanding the relative costs, benefits, and risks of undertaking activities to implement coral reef restoration and to understanding how different project options compare. In addition to providing guidance for current and future economic assessments of coral reef restoration, it also supported the idea of combining coral restoration with engineered options to ensure outcomes could be achieved at scale addressing both environmental and resilience issues.

Although the Blue Barrier case was not focused on developing a detailed economic analysis, it included estimated costs, different conceptual designs, sketches, and provided implementation recommendations for reducing coastal flooding and erosion risk (table CS1-3).

Table CS1-3. Summary of results from the Blue Barrier pre-feasibility study

Costs

Cost/benefit type	Description	Method
Upfront implementation costs	Offshore Blue Barrier (~6,354 m² area to be covered)	**Range of $1,500 to $2,000 per unit reef (installed cost)**
Ongoing maintenance costs	Reef rehabilitation activities (area of 500–600 m²)	**$100,000 (18 months of activity)**

Benefits

Cost/benefit type	Description	Method
Risk reduction benefit	Coastal flood exposure of vulnerable assets (exposed buildings and roads)	**50-year flood event + sea-level rise: 174 properties exposed**
Risk reduction benefit	Wave energy reduction (offshore Blue Barrier)	**Additional 28% wave reduction with Blue Barrier**
Risk reduction benefit	Sediment mobility reduction (leading to sand accumulation)	**Reduction in longshore sediment transport rates of up to 74% during a 50-year ARI event**

Source: Original table for this publication.
Note: ARI = average recurrence interval; m² = square meters.

Operational use of results

In this scoping phase assessment, the intervention concept evolved informed by high-level estimates of coral restoration costs and benefits before a more detailed assessment focusing on flood and erosion risk reduction potential was conducted in subsequent phases of the project. Risk reduction benefits and other co-benefits played a crucial role in the pre-selection of suitable sites, the type of technical intervention, the prioritization of the objectives of the project, and the preliminary identification of potential financing options.

The World Bank team created and maintained a coalition of key local stakeholders that have been engaged throughout the process and have supported the development of the Blue Barrier concept and ensured its alignment with the Seychelles' Blue Economy Roadmap (Government of Seychelles 2018). As a result, the National Policy and Strategic Action Plan on Coral Reef Conservation and Management included the implementation of Blue Barrier pilots as a short-term objective. The Seychelles Conservation and Climate Adaptation Trust (SeyCCAT), which is the national environmental trust fund, is also currently exploring implementation opportunities; other potential investors (from the private sector and from international NGOs) have also recently shown interest in co-financing a first pilot in the country.

Practical considerations

A Scoping Phase for Coral Reef Restoration for Coastal Resilience

Budget range and timeline: **$150,000–$300,000 (7 months)**

Note: Key tasks included (1) quick scan analysis to identify sites where the potential is high for the reduction of wave runup through coral reef restoration; (2) identification of causes of degradation and evolution of coral reefs; (3) assessment of the technical, economic, and institutional opportunities and risks of large-scale coral reef restoration; and (4) the identification of private sector engagement potential.

Key expertise requirement:

Transdisciplinary team that brings together a strong understanding of the marine and coastal natural systems, economic valuation methods, and the local coral restoration context. Recommended profiles are:

- An ecologist or marine biologist with knowledge of international best practices and cutting-edge technologies for coral reef restoration;
- An environmental economist with demonstrated experience in coastal and marine ecosystems valuation and private sector financing engagement;
- Local experts with experience in coral restoration projects in the field and the capacity to develop benthic habitat data; and
- A team member with coastal engineering experience in risk assessment and coastal management.

Replicability:

The economic assessment approach is highly replicable for other reef restoration projects in the Seychelles or elsewhere, as most of the estimations used secondary data sources. However, the incorporation of input from local experts is always required.

Data requirement:

The study was mostly developed through a desktop review of the literature, tested and refined with a small group of local experts, and validated through stakeholder consultation. The initial quick-scan analysis used remote sensing and existing data sets.

B Hazard modeling and pre-feasibility assessment of solutions

Budget range and timeline: **$150,000–$300,000 (11 months)**

Note: Key tasks included (1) collection and development of baseline data for modeling coastal processes at five selected site, (2) modeling of coastal processes at the focal site to understand flooding and erosion, and (3) conducting an assessment and pre-feasibility analysis of a portfolio of suitable coastal protection solutions.

Key expertise requirement:

Recommended profiles to assess risk reduction benefits of these types of hybrid solutions are:

- A coastal engineer with demonstrated experience in coastal protection measures;
- A coastal engineer with experience in assessing coastal flooding and erosion analyses and modeling studies;
- An expert in nature-based and hybrid solutions in coastal areas, preferably with experience in multipurpose or living reefs; and
- An ecologist or marine biologist with knowledge of international best practices and cutting-edge technologies for coral reef restoration, preferably using artificial structures to create new substrate.

Replicability:

The hazard modeling and valuation methodologies are replicable for different projects and coastal contexts, as most of them are based on global data sets. However, direct measurement and the collection of local data were fundamental to calibrate models at regional scale (beach scale).

Data requirement:

The data and information used in this study fall into three main categories:

- Instrumentally recorded or numerically modeled hindcast data: These data cover the fundamental met-ocean characteristics of the ocean environment (waves, wind, air pressure, air temperature, sea levels, sea temperature and salinity). For this study, a mix of global data sets (numerically modeled estimates of past conditions) and local data for specific sites and a short period of time (used for calibration of numerical models) were used.
- Data describing the physical environment: These data include bathymetric and topographic data and information on the seabed characteristics and sediment grain sizes at the study sites. For this study, detailed bathymetric data were collected offshore of each of the study sites and detailed ground truthing was undertaken to validate an automated process for determining bottom types.
- Scientific and technical literature: A large amount of information was gathered from reports and studies previously conducted for sites in the Seychelles and other sites with similar issues.

Areas for improvement

- This case study is an excellent example of a strong initial identification of NBS costs and benefits and a rigorous and detailed modeling of coastal hazard intensity and the effects of the NBS project. However, the risk reduction economic valuation is only partial and limited to the number of buildings currently at risk and the estimated percentage of wave reduction of the proposed intervention (see boxes CS1-1 and CS1-2 for a comprehensive risk reduction benefit valuation example).
- A detailed cost-benefit analysis would be useful to estimate all the benefits and compare them with potential alternatives.

- The valuation of other important co-benefits at Côte d'Or—such as biodiversity (fisheries) and tourism and recreation—could also be included in the study to get a complete picture of the economic advantages provided by the Blue Barrier.
- It is recommended to conduct a comprehensive decision support framework engaging with the local community and key stakeholders and integrating economic, biophysical, and socio-cultural elements before making any implementation decision.

Box CS1-1: Valuing risk reduction benefits of coral reef conservation in the United States

The US Federal Emergency Management Agency (FEMA) used a methodology combining engineering, ecologic, geospatial, social, and economic tools to provide a rigorous valuation of the coastal protection benefits of coral reefs in the State of Hawaii. Building from a previous study assessing the risk reduction benefits of coral reefs across the region (Storlazzi et al. 2019), FEMA's team completed a detailed structure-level flood analysis using the Hazus Flood Assessment Structure Tool (FAST) (available at https://github.com/nhrap-hazus/FAST/releases/tag/0.0.7) to identify areas where coral reef conservation would lead to the highest economic benefit for the five main islands of Hawaii. To develop the input structure data, the US Army Corps of Engineers' National Structure Inventory (NSI v2, available at https://github.com/HydrologicEngineeringCenter/NSI) was combined with tax assessor data.

Other communities protected by coral reef habitats can combine the methods used by FEMA with more accurate local building information to significantly improve the accuracy of these types of risk assessment results.

Source: FEMA 2021.

Box CS1-2: Valuing the potential coastal hazard risk reduction provided by coral reef restoration in Florida and Puerto Rico

In an attempt to justify the potential implementation of large-scale coral reef restoration in areas impacted by recent hurricanes, the US Federal Emergency Management Agency (FEMA), supported by other organizations, assessed and quantified how the potential restoration of coral reefs of Florida and Puerto Rico could reduce the threats to, and increase the resiliency of, their coastal communities.

The study applies the same risk reduction benefit valuation approach (based on avoided damages) described in this guideline:

- It uses a standardized approach to "place" potential restoration projects throughout the whole extent of reefs bordering Florida and Puerto Rico to identify where coral reef restoration could be useful for meeting flood reduction benefits.
- It applies risk-based valuation approaches to map flood zones along Florida and Puerto Rico's reef-lined shorelines for three different coral reef restoration scenarios and compares them to the flood zones without coral reef restoration.
- It quantifies the social and economic benefits from coastal flood risk reduction (provided by coral reef restoration) using data from the US Census Bureau, FEMA, and the Bureau of Economic Analysis for return-interval storm events.
- Using the damages associated with each storm probability, it also calculates the change in annual expected damages.

This assessment provided stakeholders and decision-makers with a spatially explicit, rigorous valuation of how, where, and when potential coral reef restoration could increase critical coastal storm flood reduction benefits for coastal communities in Florida and Puerto Rico.

Source: Storlazzi et al. 2021.

Photo by Hashimoto, 2020

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Photo by Ilee Wu on Flickr

Urban Wetlands for Heat Reduction

The Value of Key Ecosystem Services Provided by the Haizhu Urban Wetland Park (China)

Case study profile

NATURE-BASED SOLUTION (NBS) PROFILE

NBS TYPE

Inland wetlands

Urban green

NBS APPROACH

Protection

PRIMARY RISK REDUCTION BENEFIT (RRB)

Extreme heat reduction

OTHER BENEFITS

Health

Climate regulation

ECONOMIC STUDY PROFILE

PROJECT CYCLE STAGE

Upstream

ANALYTICAL APPROACH APPLIED (RRB)

Cost-benefit analysis

Avoided damages and costs (morbidity, productivity, and cooling costs)

SCALE OF PROJECT

City level

STUDIED SITE

Haizhu National Wetland Park, Guangzhou (China)

STUDY YEAR

2021

WORLD BANK PROJECT PROFILE

PROJECT NAME

Piloting Nature-based Urban Cooling Solutions for Urban Regeneration and New Town Development in Guangzhou, China: Building a Cooler Guangzhou (World Bank 2022)

REGION

East Asia and the Pacific

GLOBAL PRACTICE AREA

Urban, Disaster Risk, Resilience and Land

PROJECT REPORT

Assessment of Key Ecosystem Services Provided by the Haizhu National Wetland Park in Guangzhou, China (World Bank 2022)

Background

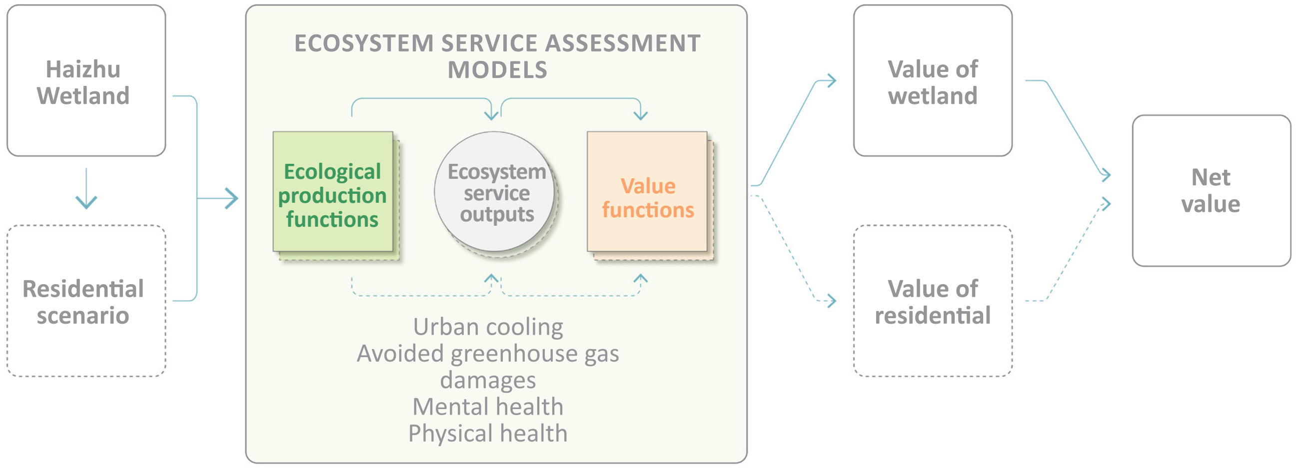
This analysis provided general information about the value of an existing urban wetland in Guangzhou, China. In 2020, the World Bank explored some of the important benefits provided by the Haizhu National Wetland Park. The goal was to quantify key benefits provided by the wetland—in biophysical, monetary, and other metrics—to make those benefits explicit to decision-makers and help protect the wetland from future development. This was part of a broader effort to pilot urban cooling projects in Guangzhou supported by the World Bank.

The Haizhu National Wetland Park is 11 square kilometers and is the largest wetland in the downtown core of any Chinese megacity. The surrounding Guangdong–Hong Kong–Macao Greater Bay Area had a population of 72 million as of 2019, and Guangzhou itself has nearly tripled in population since 1980 to 15 million residents (World Bank 2022). With the development pressure that comes with population growth, this analysis asked what value would be lost if the Haizhu wetland were urbanized.

Analytical approaches

Haizhu Wetland Park would most likely be developed into residential housing should it lose its protected status, according to local planners in Guangzhou (figure CS2-1). A cost-benefit analysis (CBA) was undertaken to estimate the value of the wetland, comparing the existing state to an alternative state where the wetland was developed in a way similar to the surrounding urban area. CBA was used to evaluate alternatives, as the planning perspective in this study is a social welfare assessment of citizens' well-being associated with the wetland in the broader Guangzhou area. Ecosystem service models were employed to estimate human well-being changes that resulted from changes in urban cooling, mental health, physical health, greenhouse gas emissions, and damages. The analysis used existing and in-development models that are part of the Natural Capital Project's open-source InVEST ecosystem service modeling platform (Natural Capital Project 2022). Because of data limitations both at the domestic and global levels, other ecological services provided by the wetland, such as biodiversity and stormwater management, were not assessed.

Figure CS2-1. Conceptual model of an ecosystem service assessment as applied to Haizhu Wetland Park



Source: Original figure for this publication.
Note: This figure compares the existing wetland to an alternative state where the wetland is replaced with urban development.

Alternative scenarios in a CBA need to be well articulated to be estimable, and they need to be designed so they can inform a decision process, serve heuristic purposes, or illuminate future conditions. The complexity of ecosystems makes this especially important in the context of ecosystem service assessments, where incomplete articulation of the geospatial changes in the environment will challenge estimation methods or produce unusable estimates (McKenzie et al. 2012). In this study, the alternative development scenario in Haizhu Wetland Park was created by "wallpapering" land cover from adjacent developed areas over the Haizhu wetland, creating a seamless land cover map for geospatial modeling (Lonsdorf et al. 2021). Land use maps were derived from an array of products, including global land cover maps, open street maps, and normalized difference vegetation index maps.

Methods and data

Urban cooling. This modeling investigated several valued end points for the urban cooling effect of Haizhu wetland area. The physical modeling employed the InVEST urban cooling model to calculate the net effect of the change in scenarios on the local urban heat island. Changes in cooling and heating to maintain temperatures in affected buildings were measured using outputs from the InVEST model and local data on energy costs and buildings. The change in air temperature from the scenario increased cooling energy demand during the summer months but decreased demand for heating energy during the winter months, so the net effect was measured. Changes in productivity and avoided mortality were measured using globally derived empirical relationships, in the absence of local data, and were reported as percentage changes (table CS2-1).

Avoided greenhouse gas damages. The InVEST carbon storage and sequestration model was used to estimate the change in greenhouse gas emissions between scenarios and to value this using a social cost of carbon approach. This is a bookkeeping model of carbon change across land use types and carbon pools. For carbon accounting in urban areas, it is more important to include human impacts on the carbon cycle, including flux carbon—in the form of annual emissions from land management and energy—and embedded emissions, which is the CO2 generated during the construction and manufacture of built infrastructure (Kuittinen, Moinel, and Adalgeirsdottir 2016). The biophysical carbon modeling was linked to a social cost of carbon modeling approach, which estimates social welfare change through the avoided climate damage from carbon emissions. This was chosen rather than a market price approach because of the social welfare perspective of the project, in consultation with local partners (table CS2-1).

Mental and physical health. Both of these models were adapted from existing literature, principally Vivid Economics (2017), for this project. They rely on empirically derived relationships between urban greenspace and physical and mental health, and they link these changes to the change in health treatment costs associated with these effects. The empirical relationships were established in secondary sources through surveys in the study area and elsewhere, and local/regional treatment cost data were also derived from existing databases or studies (table CS2-1).

Table CS2-1. Ecosystem services and valuation methods

Ecosystem service	Supply metric	Value metric(s)	Valuation modeling approach
Urban cooling	Air temperature	Productivity (percent change)	Loss of workplace productivity as a result of temperature and humidity
		Private cost of cooling	Cost of cooling (and heating) as a function of temperature
		Mortality risk (percent change)	Relative risk of mortality or morbidity as a function of temperature and region
Avoided greenhouse gas damages	Carbon stored or sequestered	Social cost of carbon	Net present value of change in damages from carbon emissions
Physical health	Access to urban nature (for example, distance to parks, tree-lined streets, urban gardens, trails, and so on)	Avoided cost of treatment	Change in costs associated with treatment to restore original physical health level
Mental health	Access to urban nature (for example, views of greenery, distance to parks, number of trees in neighborhood)	Avoided cost of treatment	Change in costs associated with treatment to restore original mental health level

Source: Adapted from World Bank 2022.

Results

The value provided to Guangzhou by the Haizhu wetland is at least $146.8 million over the next 30 years, in addition to reduced mortality risk and increased workplace productivity in the surrounding landscape and excluding other potentially valuable services that were not estimated (table CS2-2).

All value estimates were calculated at the individual, household, or neighborhood level and aggregated over the affected parties, which vary geospatially depending on the model. Value estimates were presented separately, as not all estimates were monetized and some of the estimated services may overlap, so summing them would double count different aspects of recreational benefits.

Table CS2-2. Estimated ecosystem service values
2020 US dollars, millions

Ecosystem service	Value metric(s)	Current landscape	Residential scenario	Marginal value of the Haizhu Wetland	
				Subtotal	Total
Urban cooling	Private cost of cooling	**$90.9**	**$93.5**	**$2.6**	**$1.9**
	Private cost of heating	**$9.3**	**$8.5**	**–$0.7**	**n.a.**
	Productivity	**n.a.**	**n.a.**	**2.5%** to **16.1%** increased workplace productivity within 600 meters (May and October)	
	Mortality risk	**n.a.**	**n.a.**	**1.23%** to **1.27%** decreased risk of monthly mortality within 600 meters (June through September)	
Avoided greenhouse gas damages	Sequestered carbon (SCC)	**$2.16**	**$2.21**	**–$0.05**	
	Embedded emissions (SCC)	**$2.9**	**$13.6**	**$10.7**	**$77.8**
	Annual emissions (SCC)	**$1.9**	**$69.0**	**$67.2**	
Physical health	Health expenditures	**$212.5**	**$216.7**	**n.a.**	**$4.2**
Mental health	Health expenditures	**$1,634**	**$1,704**	**n.a.**	**$70.1**

Source: Adapted from World Bank 2022.
Note: n.a. = not applicable; SCC = social cost of carbon.

Operational use of results

In this case study, the NBS was already in place and the country counterpart (planning agency) was interested in better understanding the ecosystem services provided by this urban wetland to enable city officials to make ecologically informed decisions in the future. The study was also a way for the country counterpart to expand their human capital with NBS assessments and gain familiarity with the InVEST ecosystem service modeling software, with a tentative plan to use it in assessments in other parts of the city. From a World Bank perspective, some of the methods may be useful for lending operations in other cities in China.

Practical considerations

Budget range and timeline: **$150,000–$300,000 (10 months)**
Note: Main tasks of the whole activity included (with four reports): (1) modeling and valuing the ecosystem services provided by the Haizhu wetland area complex; (2) comparing the baseline ecosystem services provided by the wetland to an alternate development scenario; and (3) producing a report documenting results and methods. Use of the wallpapering tool for scenario analysis made scenario development considerably less involved than other types of scenario generation (that is, probabilistic alternatives, or significant co-development with end-users or stakeholders).

Key expertise requirement:
For this analysis type, recommended experience and qualifications are:

- Recognized expertise and hands-on experience in the ecosystem service modeling and geospatial analysis. Familiarity with the InVEST ecosystem service models is highly desirable;
- Expertise in advising and supporting municipal governments on urban planning, especially in similar Chinese cities;
- Ability to present technical concepts clearly to both technical and nontechnical experts, including through the use of appropriate graphical elements; and
- Advanced academic background and professional experience in economics, environment, ecosystem service, urban planning, and policy field related to urban sustainability.

Replicability:
The services estimated and the scenario development approach in this project have generally high replicability potential in other areas, as many of them are based on global data sets and rely on ecosystem service modeling workflows in the open source InVEST software or are documented elsewhere, such as the wallpapering tool. The mental and physical health models, while similar in structure, had different levels of locally available data and demonstrated the feasibility of value transfer for these models.

Data requirement:
Data availability, both global and local, is crucial for this type of study. Connections to local stakeholders and scientists within the project enabled data collection that would have otherwise not been possible within the scope of the project, both because of language barriers and because of the data knowledge limitations of the project team.

Areas for improvement

The avoided greenhouse gas damages and urban cooling ecosystem service assessment models included in this project rely on reasonably well-established science and modeling frameworks, making estimate uncertainty the result more of data availability than of model uncertainty. The health models are less well-understood structurally. For example, the mental health model is a dose-response relationship where mental health outcomes, and changes in expenditures on those outcomes at the population level, are derived as a linear function of natural area within a fixed distance from urban populations. Using a linear functional form and a fixed distance are strict assumptions that may not conform to local conditions; however, the state of the science does not currently support any generalizable assumptions about the structure of this model, and hence the only alternative is to conduct primary surveying.

In addition, the value of the wetland provided to Guangzhou estimated by the study would most certainly be higher if other important ecosystem services, such as water purification and flood mitigation, were included in this analysis.

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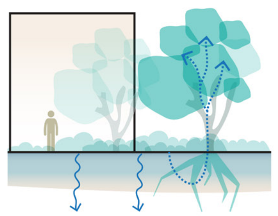
Nature-Based Flood Protection

Upscaling Nature-Based Flood Protection in the City of Nacala (Mozambique)

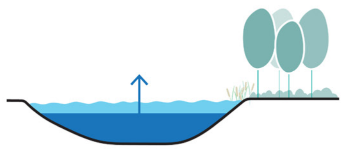
Case study profile

NATURE-BASED SOLUTION (NBS) PROFILE

NBS TYPE



Urban green



Ponds, lakes, and small water bodies

NBS APPROACH

Rehabilitation, restoration, enhancement

Creation

PRIMARY RISK REDUCTION BENEFIT (RRB)

Flooding

Erosion

OTHER BENEFITS

Provisioning of food and raw materials (agriculture)

Climate regulation

ECONOMIC STUDY PROFILE

PROJECT CYCLE STAGE

Upstream

ANALYTICAL APPROACH APPLIED (RRB)

Cost-benefit analysis

Avoided damages and costs

SCALE OF PROJECT

City level

STUDIED SITE

13 catchment areas across Nacala city (Mozambique)

STUDY YEAR:

2018–2019

WORLD BANK PROJECT PROFILE

PROJECT NAME

Cities and Climate Change (Mozambique) (World Bank 2020a)

REGION

Sub-Saharan Africa

GLOBAL PRACTICE AREA

Urban, Disaster Risk, Resilience and Land

PROJECT REPORT

Upscaling Nature-Based Flood Protection in Mozambique's Cities: Cost-Benefit Analyses for Potential Nature-Based Solutions in Nacala and Quelimane (World Bank 2020b)

Background

The Mozambican coast has seen intense cyclones, a rise in sea levels, and substantial heavy rainfalls, which are all threatening the livelihoods and health of its communities and limiting their economic development. One example is Nacala, a coastal city with several areas prone to flooding, located in Nampula Province. The poor state of its gullies and their inability to withstand the rainfall that is ever-increasing as a result of climate change have resulted in substantial erosion across multiple areas in the city, directly affecting and putting the houses and communities living closer to the gullies at risk (World Bank 2020c).

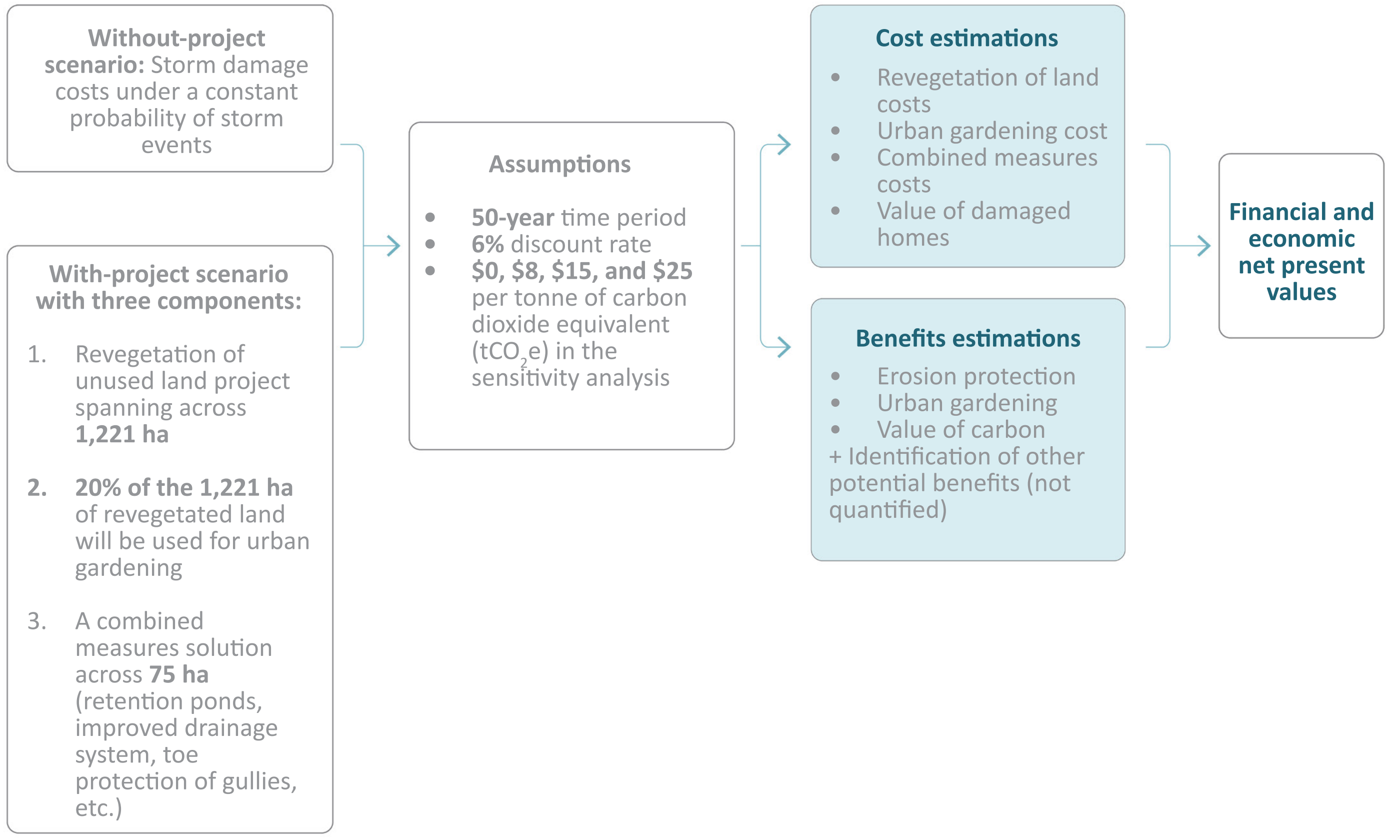
As part of technical assistance support to the government of Mozambique to enhance and upscale the use of nature-based solutions (NBS) for urban flood risk management in coastal cities financed by the multidonor partnership Program on Forests (PROFOR), the Africa City Coastal Resilient Program funded by the Global Facility for Disaster Reduction and Recovery (GFDRR), and the GFDRR Innovation Labs, the World Bank commissioned a cost-benefit analysis (CBA) to identify and understand the benefits of nature-based flood protection solutions in the coastal city of Nacala (World Bank 2020b).

Analytical approach

This study integrated the data and adopted the methodology of a previous evaluation prepared for the United States Agency for International Development (USAID) (Narayan et al. 2017), allowing the consideration of ecosystem services such as carbon sequestration and storage estimations, natural hazards, and agricultural production. The study area included 13 catchment areas in Nacala that focused on the communities' surrounding gullies, erosion channels, and unused lands (figure CS3-1).

This CBA quantified the potential costs and benefits of revegetation of land and a combined measure alternative, which included retention ponds, improved drainage systems, toe protection of gullies, and small-scale revegetation in monetary terms to help determine whether one particular adaptation option would be preferable in the study areas. The analysis used data on the economic and environmental costs and benefits of the with-project scenario and evaluated it against the cost and benefits of a without-project scenario.

Figure CS3-1. Summary of the economic assessment of nature-based flood protection in Nacala



Source: Original figure for this publication.
Note: ha = hectare; tCO2e= tonne of carbon dioxide equivalent.

Methods and data

The economic analysis considered all financial costs and benefits within the communities studied as well as the value of the carbon sequestered by the growing vegetated land (table CS3-1). However, the analysis did not consider important economic benefits such as human mortality and injury reduction, or the possible benefit transfer of biodiversity, existence value, water purification, and waste treatment. As a result, the total value is considered to be a lower bound estimate of the total benefits.

Table CS3-1. Data, assumptions, and estimations of the CBA

Costs

Cost/benefit type	Description	Quantification
Revegetation costs (CAPEX)	Costs of buying the seedlings, labor for planting and hydrological restoration	**$943 per ha (year 1) to $0 (year 6)**
Revegetation costs (OPEX)	Costs of maintenance, support staff, and non-surviving plantings	**$0 per ha (year 1) to $147 per ha (year 6)**
Urban gardening costs (OPEX)	Costs of the tools and materials needed, labor per hour, and water for the plants	**$105 per ha (year 1) to $77 per ha (year 6)**
Combines measures costs (CAPEX)	Construction of 99 ponds, 45.171 m of gullies protected, 27.118 m of drainage system	**$10,193 per ha (year 1) to $0 (year 6)**
Combines measures costs (OPEX)	Maintenance and replacements of combined measures after storm events	**$1,932 per ha (year 1) to $19.32 (year 6)**
Value of damaged homes due to storm events (CAPEX)	Annual house damage compensation calculated per ha per year considers the total resettlement cost of $13,000 and the probable number of resettlements per year in the with-project scenario	**$8,446 per ha (year 1) to $172 (year 6)**
Other costs (OPEX)	Enforcement and travel costs for support	**$17.52 per ha (year 1) to $18 (year 6)**

Benefits

Cost/benefit type	Description	Quantification
Erosion protection	Value of rebuilding or repairing the houses damaged or destroyed and compensation costs for potential resettlements (number of homes affected multiplied by cost of resettlement for 16 years)	**Annual cost of damages: Without-project scenario $2,976,800/year; With-project scenario $274,785/year**
Urban gardening	The share of crop per ha was determined (maize, cassava, etc.). For each crop type, an estimated amount of crops produced per household in kg/year/ha was then multiplied by the market price of each crop in $/kg.	**Agricultural benefit: 5,925.80 ($/ha/year)**
Value of carbon	Sensitivity analysis with four different carbon prices	**$0, $8, $15, and $25 per tCO_2e**

Source: Original table for this publication.
Note: CAPEX = capital expenditures; ha = hectare; kg = kilogram; OPEX = operating expenses; tCO_2e = tonne of carbon dioxide equivalent.

Results

The economic (and financial) benefits accumulated over the period of 50 years for the total number of hectares of the study area (1,296 hectares) and were calculated at a 6 percent discount rate (table CS3-2). The base case used a discount rate of 6 percent for economic analyses, but sensitivity analyses used discount rates of 0 percent, 3 percent, and 12 percent.

Table CS3-2. Summary of financial and economic net present values of intervention

With-project scenario	Net benefit	Annualized value
Financial results	**$7,932,270**	**$503,262**
Economic results ($0 carbon price)	**$116,936,556**	**$7,418,961**
Economic results ($8 carbon price)	**$116,936,556**	**$7,418,961**
Economic results ($15 carbon price)	**$204,304,823**	**$12,961,978**
Economic results ($25 carbon price)	**$329,116,632**	**$20,880,574**

Source: Original table for this publication.
Note: Results from a carbon price of zero are shown underlined.

Although results are sensitive to the carbon price assumption, the intervention assessed still has a positive net present value (NPV) at a carbon price of zero. The results show that both the economic benefits and the financial benefits have a positive result, with the financial benefits reaching around $7.9 million and the economic benefits resulting in around $17 million at $0 carbon price.

Operational use of results

The whole activity contributed to reducing the knowledge gap and extending the knowledge base on the implementation of NBS for urban flood and erosion management. Lessons learned have been feeding into the implementation and preparation of World Bank–financed projects in Mozambique. Specifically, these lessons have contributed to fine-tuning the remaining activities related to the green urban infrastructure in Beira under the Mozambique Cities and Climate Change Project (P123201) and are informing the design and preparation of additional nature-based interventions in Beira that will be financed under the Cyclone Idai & Kenneth Emergency Recovery and Resilience Project (P171040).

In particular, the assessments and analyses carried out for the city of Nacala provided knowledge about local conditions and local flood and erosion risks, identified suitable nature-based and hybrid measures, and assessed their potential costs and benefits to inform decision-makers' choices for future investments in drainage and flood mitigation. The findings enabled an existing general dialogue on NBS in Mozambique to evolve into a more concrete conversation with local and national government partners around specific technical solutions and their application in cities, as well as their costs and benefits.

Practical considerations

Budget range and timeline: **$150,000–$300,000 (15 months)**
Note: The budget and timeline of the whole technical assistance included (1) identification and analysis of lessons learned from previous projects, (2) assessment of the enabling environment to mainstream nature-based approaches to urban flood risk management in Mozambique focusing on the legal and institutional framework, (3) assessment of urban flood and erosion risk and potential NBS to mitigate this risk in the two pilot cities of Nacala and Quelimane, (4) cost-benefit analysis of different investment scenarios for the two cities, and (5) knowledge sharing and dissemination.

Key expertise requirement:
For this type of analysis, recommended experience and qualifications are:
- Demonstrable experience in conceptualizing and carrying out urban flood risk modeling and CBA of urban flood risk and drainage solutions;
- Knowledge of best practices and methodologies to model NBS risk assessments and assess co-benefits;
- Capacity to provide an interdisciplinary/transdisciplinary team that brings together traditional engineers and economists with ecologists or other specialists with a strong understanding of the natural systems; and
- Knowledge of the local context and language. A strong local presence in the studied region is a decisive advantage to obtain quick access to local data to determine accurate estimates and assumptions.

Replicability:
The CBA is replicable for other flood protection projects, especially in other cities in Mozambique (or similar contexts). It should be noted that the identification and estimations of benefits are based on previous assessments conducted by the World Bank.

Data requirement:
- Spatial flood risk model that quantifies the expected annual structural damages, affected population and erosion impacts—geographical information, vector data, usage of satellite imagery and unmanned aerial vehicles (UAVs), soil conditions, meteorological and hydrological data, and literature review;
- Field data verification that identifies flooding/erosion zones with participation of local technicians; and
- Detailed local costing of NBS and non-NBS design alternatives (obtained in study).

Areas for improvement

Although they were identified during the scoping stage, this analysis did not value in monetary terms important possible benefits such as reduced mortality and health and safety impacts from storms, biodiversity, water purification, or waste treatment resulting from revegetation of land. Considering these factors in the CBA would increase the benefits accrued from revegetation of land in Nacala, which means that the analysis is calculated at a lower bound estimate of the total benefits. Regarding human mortality and injuries reduction, a benefit transfer method could be used to estimate the value of statistical life based on differences in income in various developed and developing countries. However, it is often difficult to obtain this type of data for countries in Sub-Saharan Africa.

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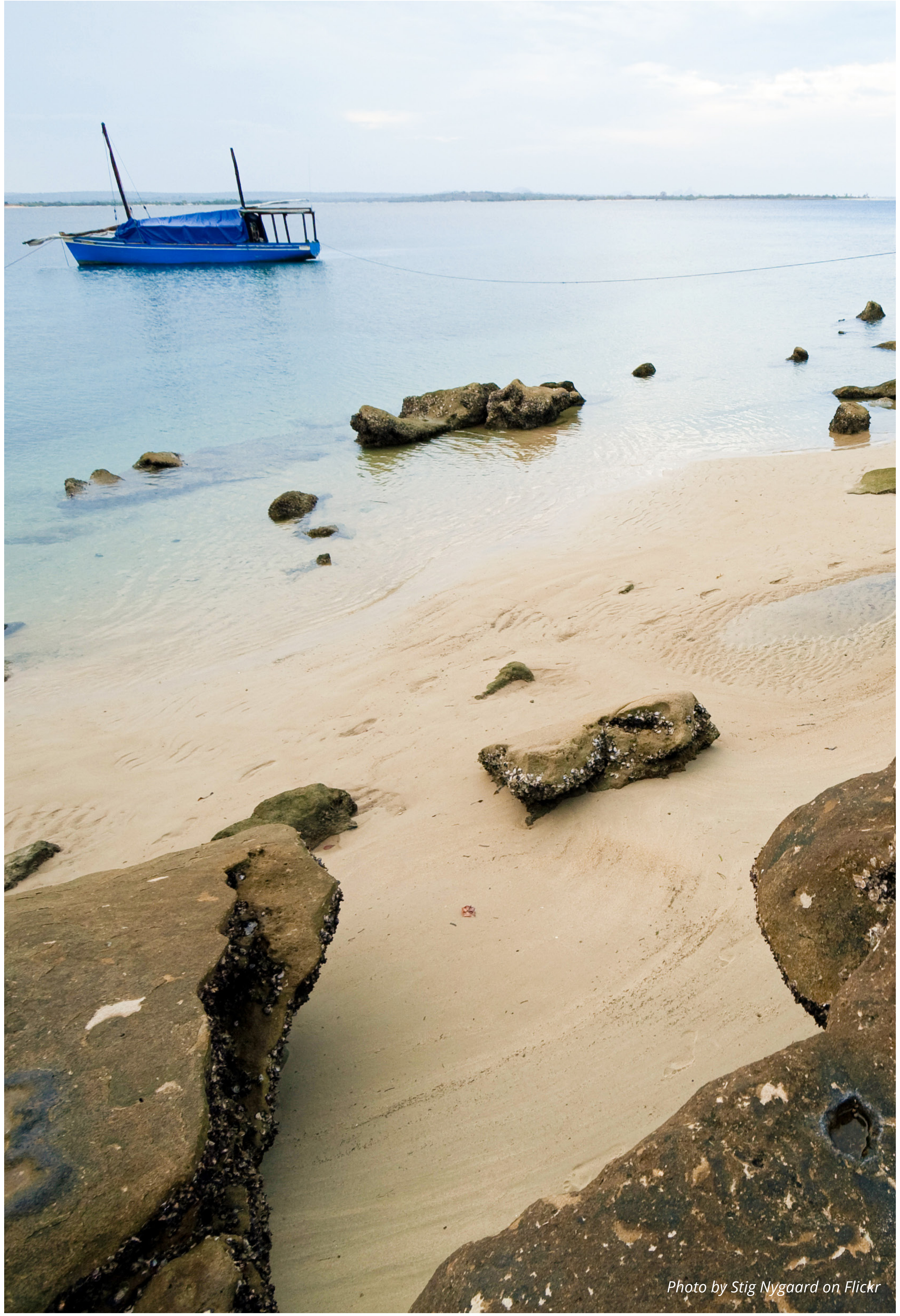

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Green Infrastructure for Landslide Risk Reduction

Economic Valuation of Watershed Management Practices for Erosion and Sediment Reduction in the Kali Gandaki Watershed (Nepal)

Case study profile

NATURE-BASED SOLUTION (NBS) PROFILE

NBS TYPE

Urban and upland forests

Terraces and slopes

Rivers and floodplains

NBS APPROACH

Restore

Create

PRIMARY RISK REDUCTION BENEFIT (RRB)

Landslide risk reduction

OTHER BENEFITS

Provisioning of food and raw materials (on-farm benefits and hydropower)

Climate regulation

ECONOMIC STUDY PROFILE

PROJECT CYCLE STAGE

Upstream / Project identification and preparation

ANALYTICAL APPROACH APPLIED (RRB)

Cost-benefit analysis

Avoided lives lost

Avoided damages and costs

SCALE OF PROJECT

Watershed

STUDIED SITE

Kali Gandaki Watershed (Nepal)

STUDY YEAR

2019

WORLD BANK PROJECT PROFILE

PROJECT NAME

Advisory Services and Analytics (ASA) linked to the Forests for Prosperity Project (Nepal) (World Bank 2023b).

REGION

South Asia

GLOBAL PRACTICE AREA

Environment, Natural Resources and the Blue Economy

PROJECT REPORT

Valuing Green Infrastructure: Case Study of Kali Gandaki Watershed, Nepal (World Bank 2019b)

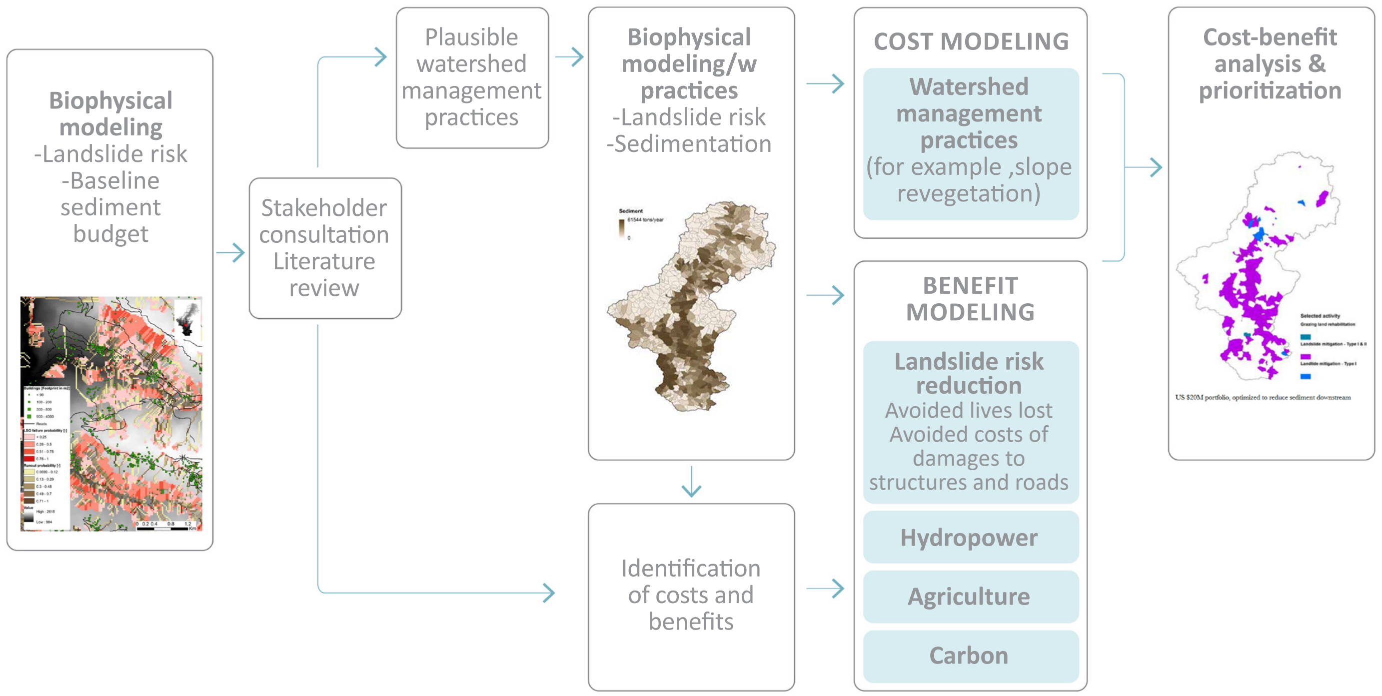
Background

As part of an Advisory Services and Analytics (ASA) project on Integrated Catchment Management for Sustainable Hydropower, the World Bank conducted a study to value watershed management practices for erosion and sediment reduction in the Kali Gandaki watershed (Nepal). The study focused on developing methodologies to value a range of ecosystem services that come from watershed management in the form of investments in green infrastructure, and to prioritize their application in the Kali Gandaki watershed. Given that sediment retention is one of the most immediate and visible impacts of watershed management activities, the study focused on the benefits that result from avoided erosion and sedimentation and looked secondarily at some of the co-benefits that arise from activities employed to control sediment.

Analytical approach

The micro-economic modeling approach employed in the study relied on biophysical modeling of erosion and sedimentation processes in the Kali Gandaki watershed (figure CS4-1). Watershed and region-specific data were used in the analysis, rather than a transfer of area-based estimates from other watersheds and regions. The study incorporated a landslide risk assessment as the project team realized from early sediment modeling that landslides are a significant source of sediment in the Kali Gandaki watershed and result in numerous social, environmental, and economic costs in the area, including loss of life and property and damage to infrastructure.

Figure CS4-1. Analytical approach of the Kali Gandaki watershed study



Source: Original figure for this publication.

Biophysical modeling for this study leveraged the InVEST modeling suite and included both a sediment delivery model and a novel landslide hazard model developed by the project team. These models established a baseline sediment budget against which interventions could be evaluated. Nature-based solution (NBS) practices were grouped together into watershed management intervention categories identified through stakeholder engagement and desk review as plausible to reduce sediment in the Kali Gandaki watershed. In addition to hill terrace improvement and degraded land restoration/rehabilitation, three landslide mitigation categories were developed to reflect NBS practices appropriate for increasing landslide depths. Biophysical models were then used to estimate the impact of these activities on the physical landscape. For impacts on landslide risk, the landslide hazard model assessed the risk of structures and roads at specific landslide object (LSO) locations (the immediate area where the landslide occurred) and along the landslide's runout pathway.

The model developed failure probability classes for each LSO and associated runout pathways and presented results at the sub-watershed level. The percentage of structures and road segments in different failure probability classes were then estimated and used in the economic analysis to estimate monetary losses resulting from lives lost and damaged structures. The study calculated the net present value (NPV) of several benefit streams that result from the watershed management practices modeled using a 10 percent discount rate. The monetized benefit streams were (1) the value of landslide risk reduction, (2) on-farm benefits of reductions in soil erosion, (3) the value to hydropower from sediment reductions, and (4) carbon value.

Methods and data

Costs

Costs of watershed management interventions were derived from a literature review of the costs of similar activities in Nepal and other Himalayan countries (India and Bhutan) (table CS4-1). The project team sought studies that included detailed and well-documented cost estimates. Cost estimates presented reflect gross costs and are not net of labor or other landholder costs. The cost-share of landholders is estimated to be 84 percent of gross costs, which brings the net cost of the interventions down to levels reported for similar World Bank projects.

Table CS4-1. Estimation of NBS cost data

Modeled intervention (Implementation locations)	NBS practices	Estimated average gross cost and range (US$/ha)
Hill terrace improvement Croplands > 5% slope	Slope correction on existing terraces, planting nitrogen-fixing hedgerow species along the terrace margins in single or multiple rows, agroforestry	**$2,230 ($50–$8,750)**
Soil and water conservation practices Croplands ≤ 5% slope	Hedgerows, hedgerow inter-cropping, crop residues, mulches, cover crops, no tillage, reduced tillage, minimum tillage, windbreaks/ shelterbelts, buffer strips/greenbelts, conservation trenching, agroforestry	**$1,100 ($140–$2,200)**
Landslide mitigation (class I) Areas with high risk of landslide failure at a depth of <1.5 m and in the topsoil only	Revegetating denuded slopes and/or bioengineering for slope stability	**$3,850 ($1,260–$8,030)**
Landslide mitigation (class II) Areas with high risk of landslide failure at a depth of >1.5 m, but deeper than topsoil and with failure plane in the range of deep rooting trees	Revegetating denuded slopes, bioengineering for slope stabilization, slope correction, and/or excavation of sub-soil drains	**$3,850 ($1,260–$8,030)**
Landslide mitigation (class III) Areas with high risk of landslide failure in the bedrock (that is, below rooting depth), but with a failure plane < 3 m deep	Bioengineering for slope stabilization, revegetating denuded slopes, sub-soil drainage, and/or retaining walls *Green-gray integrated solutions are reflected in the higher costs for class III*	**$39,480 ($19,450–$59,520)**
Reclamation/rehabilitation of degraded land (forest) Degraded forest lands (defined using data from Hansen et al. 2013)	Planting fuel and fodder tree species, conservation trenching, eyebrow pits, revegetation, hedgerow planting across the slope to regenerate degraded areas	**$1,690 ($1,080–$2,310)**
Reclamation/rehabilitation of degraded land (grasslands) Grasslands	Greenbelts, buffer strips, rotational grazing, fodder planting, silvopasture improvement	**$880 ($730–$1,030)**

Sources: Cost data for modeled interventions have been compiled from the WOCAT Sustainable Land Management Database (https://qcat.wocat.net/en/wocat/) and Dahal and Dahal 2017; Das and Bauer 2012; Devkota et al. 2015; FAO 2005.

Benefits and valuation approaches

Watershed management interventions in this study produced multiple benefit streams in the watershed. In addition to the reduction in landslide risk benefit—most relevant to the current guidance as it focuses on NBS for disaster risk reduction—the study estimated the benefits associated with reductions in sediment flowing to the Kali Gandaki A hydropower plant: hydropower efficiency benefits, facility, on-farm benefits of the practices, and carbon sequestration benefits. Table CS4-2 summarizes the valuation approach followed for each element and the data sources used. The complexity of the methods employed varied: the valuation of impacts of reduced sediment at the hydropower facility was treated in more detail than the other benefits. The benefit of reductions in landslide risk were valued as avoided lives lost, avoided costs of replacing destroyed structures, and avoided costs of road repairs pursuant to reduced landslide events in the Kali Gandaki watershed.

Table CS4-2. Valuation approaches

Ecosystem service benefit	Valuation approach and detail	Data source(s)
Reductions in landslide risk	Avoided lives lost Value of statistical life (VSL) × estimated lives at risk	VSL was estimated from a World Bank study on the costs of air pollution to be $34,565 (Narain and Sall 2016). Lives at risk was estimated from Nepal landslide data (UNISDR 2015) on number of structures destroyed and lives lost over 40 years. The ratio of lives lost to structures destroyed (1 to 4) and the average area of structures in landslide risk areas (45 m) were used to estimate lives at risk/m^2 = one life for every 180 (= 4 × 45) m^2 of structure at risk.
	Avoided cost of replacing structures Value of a structure at risk from destruction by landslide is estimated as the earnings that could be attained from owning it in the current year (rental value) plus the expected present value in the following year	Rental rates data are from the Nepal Central Bureau of Statistics' Annual Household Survey (Government of Nepal 2018). In rural areas, the household expenditures on rent average 27,180 Nepalese rupees (NPR) (US$243). Average rent is divided by average footprint of structures at risk (45 m^2) to estimate a rental value of 604 NPR ($5.39) per square meter.
	Avoided cost of road repairs Cost of new road construction used as proxy for road repair	Averaged road data from Nepal are from Starkey, Tumbahangfe, and Sharma (2013). Reported costs (3.9, 4.6, and 5.9 million NPR per kilometer to construct 4.5-meter-wide earthen roads in three different locations) are averaged and adjusted for inflation to yield a cost of 6.35 million NPR ($56,670) per kilometer of road damaged.
Reductions in soil erosion	Revealed preference based on reported cost-share from similar programs Cost share as a proxy for on-farm cost savings realized through implementing watershed management practices	WOCAT database (available at https://qcat.wocat.net/en/wocat/) NPV of costs estimated; cost-share paid by practice implementers used as proxy for benefit (84%) under the assumption that cost-share implementers are willing to pay is at least the benefit they would realize, or they would not take on the cost.
Reduced sediment arriving at Kali Gandaki A hydropower plant	Reductions in damage to equipment, in efficiency loss, and in need for repair; reduced costs of desanding and preventative measures; maintenance of storage capacity for peaking Avoided costs associated with changes in hydropower operations pursuant to reduced sediment loads	Estimates are based on Bishwakarma (2012); Karki, Mishra, and Shrestha (2010); Morris (2014); Nepal Electricity Authority Annual Reports (various years); Shrestha and Shrestha (2016); Shrestha (2011); Timilsina and Toman (2016); and personal communication with NEA personnel.
Improving or preserving vegetation cover and enhancing soil carbon	(1) Additional carbon stored through vegetation and soil management, and (2) avoided loss of carbon through mitigating landslide risk	Carbon stock estimates from InVEST carbon (C) model (Sharp et al. 2014). Aboveground carbon stock data from Ruesch and Gibbs (2008) for non-forest classes and the Ministry of Forests and Soil Conservation National Forest Reference Level study (MoFSC 2016) for forest classes. Soil carbon stock data from Dahal and Bajracharya (2012). Value of carbon benefit from estimates of social cost of carbon from 2017 report of the High-Level Commission on Carbon Prices (Stiglitz et al. 2017): midrange estimate of $60.

Source: Original table for this publication.
Note: NEA = Nepal Electricity Authority; NPR = Nepalese rupees; VSL = value of a statistical life.

Results

The results of the study (table CS4-3) are spatially explicit, optimal portfolios of interventions (built to maximize objectives at minimal cost) based on the objective to be realized (reduced landslide risk, reduced sediment at Kali Gandaki hydropower facility, on-farm benefits, carbon) at different budget levels ($500,000 to $50 million). These portfolios are achieved by running watershed management interventions through the relevant model (sediment delivery ratio or landslide) and estimating the change for each objective in each of 821 sub-watersheds. The Stanford Natural Capital Project ROOT tool (Stanford University, no date) is used for the optimization exercise. Because the study includes different objectives, which watershed management activities are targeted can change based on the objective selected. Increasing benefits are realized with increasing budget levels, driven by landholder benefits and avoided lives lost by reductions in landslide risk. The study develops benefit-cost ratios (BCR) for each portfolio budget level; for example, the $3 million portfolio yielded a BCR of 2.28

Table CS4-3. Values of investment in watershed management and benefit-cost ratios for portfolio budgets

Budget (US$, millions) [a]	Values to hydro-power from sediment reduction to KGA (US$, thousands)	VALUE OF LANDSLIDE REDUCTION						On-site benefits based on % cost-share (US$, thousands)	Carbon value based on social cost of carbon (US$, thousands)	TOTAL VALUE	
		Avoided costs of replacement and repair				Avoided lives lost, mean per year	Value of avoided lives lost (VSL, US$ millions)				
		Avoided structures at risk *(n)*	Avoided loss of structures value (US$, thousands)	Avoided roads at risk (km)	Avoided costs of road repairs (US$, thousands)					US$ (mil-lions)	BCR
$0.5	$76	17	$42	3.3	$189	4.20	$1.4	$420	$12	$2.19	4.38
$3.	$415	40	$126	5.2	$296	9.88	$3.4	$2,500	$75	$6.8	2.28
$10	$1.6	66	$242	6.8	$385	16.54	$5.7	$8,400	$289	$16.6	1.66
$50	$4.4	78	$290	9.4	$530	19.51	$6.7	$42,000	$3,800	$58	1.15

Source: Original table for this publication.
Note: This table provides only a selection of the budget values for illustrative purposes. BCR = benefit-cost ratio; KGA = Kali Gandaki A Hydropower Plant; VSL = value of a statistical life.
a. Budget values were provided at multiple levels from $0.5 million to $50 million.

Operational use of results

This ASA provided a proof-of-concept of how local data and multiple benefit streams can be valued through economic approaches to underscore the value of NBS for landslide risk reduction and other objectives using spatially explicit ecosystem services modeling and CBA. The study notes that, except for landslide risk reduction benefits, the value of watershed management practices to other sectors on their own were not enough to justify the costs of the investments; therefore, an assessment of multiple benefits can help teams to make the business case for NBS investment.

While detailed results are provided at the sub-watershed level of decision-making, uncertainties in the analysis (for example, uncertainty in data on topography, climate, sediment, costs, and valuation assumptions) led the study to state that ". . . the results of this study should be taken as demonstrative, rather than definitive" for guiding investments at a local scale (World Bank 2019b). In other words, although the study provides evidence that the watershed management activities modeled can be justified on a cost-benefit basis, additional detailed feasibility studies would likely be required to design specific watershed investments within the priority areas identified.

This proof-of-concept study was included in an online guidance tool on Nature-Based Solutions for Landslide Risk Reduction (World Bank 2019a) and was then featured in a World Bank online Watershed Management Knowledge & Learning Platform and associated live learning event developed in concert with the World Bank's Open Learning Campus (OLC) in October 2021.

The study was originally devised to inform the World Bank's forestry engagement in Nepal, where watershed management was a planned component. However, the component did not materialize and therefore the study was not used operationally for its original purpose. However, the novel methodologies developed in this study for identifying landslide hazard areas were subsequently used in a World Bank engagement in Burundi, where the models are informing the on-going Additional Financing for the Burundi Landscape Restoration and Resilience Project (P171745) (World Bank 2023a) and engagement to scale-up landscape management investments in landslide risk reduction.

Practical considerations

On the spectrum of time and resources required for economic analysis, the Kali Gandaki case study reflects a more intensive (tier 3) undertaking.

Budget range and timeline: **$150,000–$300,000 (2 years approximately)**
Key tasks included in the budget:
- Detailed biophysical modeling of sediment and landslide processes,
- Site-specific sediment collection to inform and validate model results,
- Development of novel landslide risk assessment model and implementation for the Kali Gandaki basin, and
- An economic valuation study.

Key expertise requirement:
This study required the following experience and qualifications:
- Geospatial/biophysical modeler,
- Data analyst with experience in hydrology and geomorphology/engineering, and
- Environmental economist.

Replicability:
This study has developed a novel landslide risk reduction model. This model and the associated valuation methods can be replicated in other landslide-prone areas using global data; ideally, they would have some observed landslide data from local inventories or remote sensing. The sediment model would also ideally be run with observed sediment data from monitoring activities.

The valuation methodologies employed could be useful for several World Bank practice areas: for payments for ecosystem services schemes in the agriculture, forestry, water, and energy sectors to control upstream sedimentation; for landscape-scale risk mapping for roads and other infrastructure for the transportation and disaster risk management sectors; and for identifying ecosystem service impacts and mitigation opportunities for environmental and social safeguards.

Data requirement:
The study leveraged both open-access global data sets and local data procured through mission visits to Nepal and the Kali Gandaki watershed and a stakeholder engagement process:
- Biophysical data (general landscape data; hillslope, glacial, and road erosion data; landslide data; data on elements at risk; carbon data);
- Site-specific field data with the participation of local researchers; and
- Detailed local costing of NBS and non-NBS design alternatives.

Areas for improvement

- Assessment of non-monetized benefits of the watershed management practices and landslide risk reduction, such as water quality and flow for consumption and fisheries, and biodiversity.
- More time on calibration of the landslide risk model.

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Mangroves for Coastal Protection

Economic Valuation of Risk Reduction Services and Other Benefits Provided by Mangroves (Jamaica)

Case study profile

NATURE-BASED SOLUTION (NBS) PROFILE

NBS TYPE
Mangrove forests

PRIMARY RISK REDUCTION BENEFIT (RRB)
Flooding
Erosion

NBS APPROACH
Protection

OTHER BENEFITS
Climate regulation (blue carbon)
Provisioning of food and raw materials (fisheries)

ECONOMIC STUDY PROFILE

PROJECT CYCLE STAGE
Upstream / Project identification and preparation

ANALYTICAL APPROACH APPLIED (RRB)
Avoided damages and costs

SCALE OF PROJECT
National
Site-specific

STUDIED SITE
Montego Bay, Saltmarsh, and Portland Bay (Jamaica)

STUDY YEAR
2019

WORLD BANK PROJECT PROFILE

PROJECT NAME
Jamaica Disaster Vulnerability Reduction Project (World Bank 2016)

REGION
Latin America and the Caribbean

GLOBAL PRACTICE AREA
Environment, Natural Resources and the Blue Economy (Program on Forests, or PROFOR)

PROJECT REPORT
Forces of Nature: Assessment and Economic Valuation of Coastal Protection Services Provided by Mangroves in Jamaica (World Bank 2019)

Background

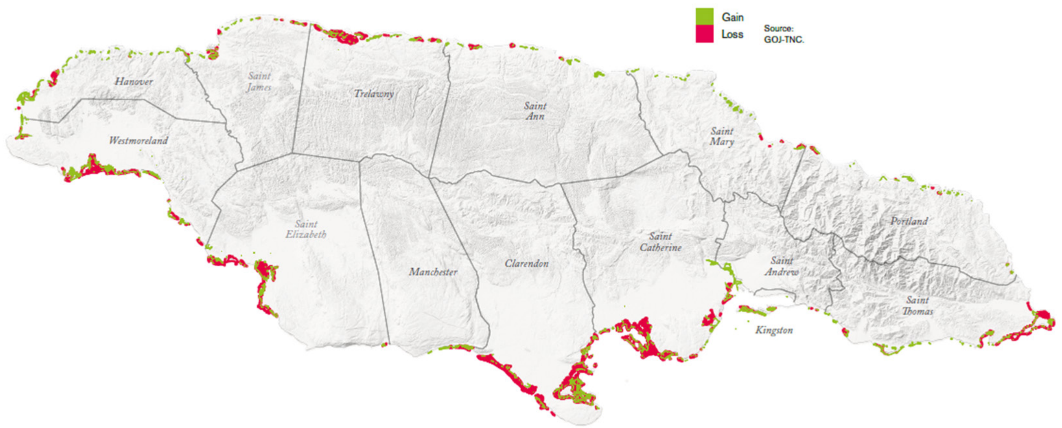
In small island developing states (SIDS), a growing number of people, industries, and critical assets to national economies are located in low-lying coastal zones that are increasingly challenged by climate hazards. Jamaica, like many other island states, is at high risk from coastal hazards because of its exposure to tropical storms, high levels of coastal development, vulnerable coastal communities, degradation of coastal ecosystems, and the predicted impacts of climate change. Tropical coastlines are, however, protected by ecosystems such as sandy shorelines, reefs, and mangroves that serve as natural infrastructure to provide flood and erosion protection. Yet, competing interests of conservation relative to development, and the need for removal/clearance of such storm buffers, in some instances have been challenging for government regulators and natural resources managers.

This project quantified the contribution of mangrove forests to flood protection and reduction of climate vulnerability in Jamaica. The project responded to the need to account not only for the ecological value but also for the disaster risk reduction benefits of coastal resources such as mangroves as part of Jamaica's National Vision 2030 objectives. The project comprised four different studies: a national assessment of the flood protection benefits and restoration costs for mangroves; a local scale assessments of mangrove ecosystem status; a monitoring and evaluation manual; and a valuation of selected ecosystem services (co-benefits) beyond coastal protection.

Analytical approaches

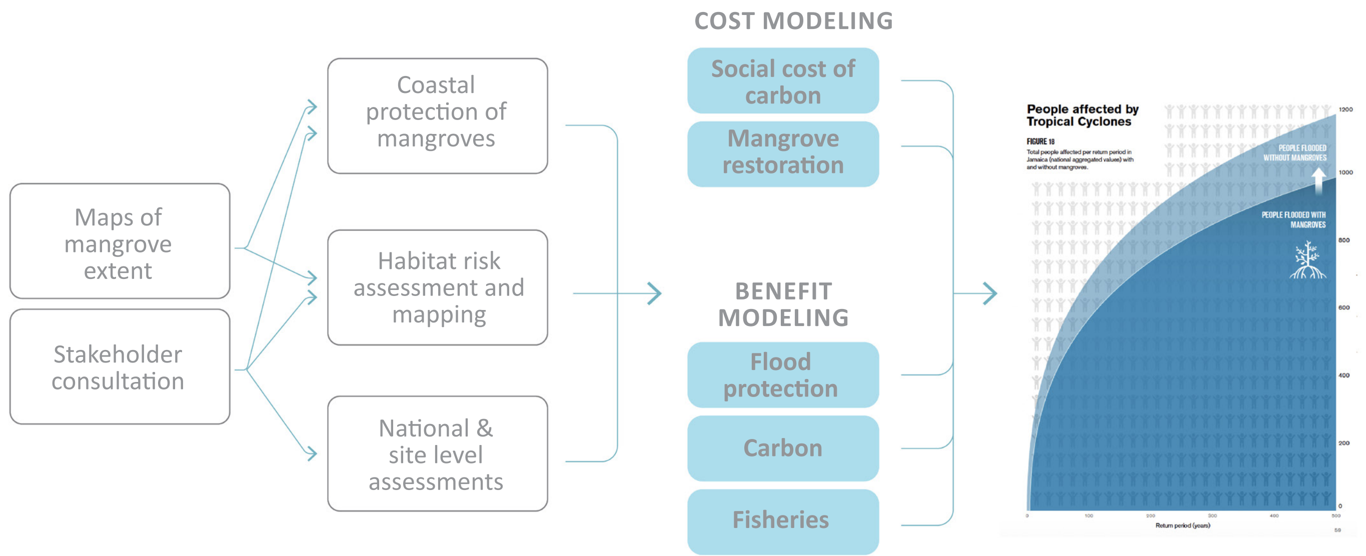
The study combined global and local data to assess the services of mangroves for flood risk reduction at a national scale. First, an assessment of historical changes and mangrove status, based on mangrove cover data from 2005 to 2013 (see map CS5-1), served to determine historical mangrove loss and current mangrove extents to inform where future restoration may be most feasible. Based on global results, 770 hectares of mangroves were estimated to have been lost in Jamaica between 1996 and 2016, whereas more than 70 percent of these mangroves could be potentially restorable. Second, three local sites were surveyed to determine mangrove species and composition, spatial variation, vegetation biometrics, ecosystem services (fisheries), sediment sampling, wave height and wind speed attenuation, soil, water quality, social perception and willingness to participate in restoration, and carbon stocks. Third, the additional economic values of mangroves for blue carbon and nearshore fisheries co-benefits (additional services) were estimated based on literature and benefit transfer approaches (figure CS5-1). Other co-benefits, such as ecotourism, were acknowledged through sightseeing, boating, swimming, and sport fishing, but these were not quantified in the study.

Map CS5-1. Change in mangrove extent in Jamaica from 2005 (baseline) to 2013



Source: 2005 data from government of Jamaica data; 2013 data from World Bank 2019.

Figure CS5-1. Summary of the analytical approach for the economic assessment



Source: Original figure for this publication.

Methods and data

The flood risk reduction benefits of mangroves were quantified following the method described in this guideline, calculating the flood damages avoided by mangroves. The results, presented in number of people and the value of property flooded with and without mangroves, provide a "conservation value" and can also inform restoration projects.

The methodology described in this guideline (section 4.3) was applied to coastal flood hazards in a tropical cyclone–prone area taking sequential steps. First, the offshore conditions of water levels and waves were determined using meteorological and hydrodynamic models that simulated 462 tropical cyclones, generated from 46 historical tropical cyclones within a 100-kilometer radius around the coastline of Jamaica. Next, hydrodynamic models were used to estimate how the offshore waves and water levels for each of these storm events transformed as they approached the shoreline, and how the presence (or absence) of mangroves affected flooding. These effects were modeled through changes in friction in the flood model. The results provide flood zones, with and without mangroves, associated with a certain frequency of occurrence.

To calculate the exposure of people and built capital within these flood zones, the study used global data sets on population and built capital (residential and industrial property) at 1 square kilometer grids. The assessment also used regional depth-damage functions (European Commission 2023; FEMA 2022). The avoided damages were determined based on the differences in numbers of people and amount of built capital value damaged by comparing the results with and without mangroves. The results for different storm probabilities were integrated into an "annual expected benefit." The annual prevention of property damages was estimated at more than 23 percent, for an annual value of more than $32 million across the country. Following a similar method, the study also evaluated a local case study, with more granularity and through local flood modeling.

The other ecosystem services and their economic valuation of fisheries and carbon sequestration were defined using literature review, benefit transfer methods, and the social cost of carbon. The site-based information at three sites (local surveys) were used in some instances to scale up or impute estimated values from other locations with similar physical and socioeconomic characteristics.

Blue carbon

On average, mangroves contain three to four times the mass of carbon typically found in boreal, temperate, or upland tropical forests. Much of this carbon storage, however, could be lost if mangroves continue degrading. The studies used the local sites to determine correlations between the presence of mangroves and the amount of carbon stored in the soil (the soil organic carbon, or SOC) and the vegetation. For the economic assessment, the study uses a tier-1 assessment of a carbon stock within a project area by multiplying the area of an ecosystem by the mean carbon stock for that ecosystem type (see table CS5-1). However, the site surveys found more carbon in the soil and the vegetation than the tier-1 approach used at the national scale. The site-specific economic social cost of carbon (SCC) values were higher than the global average, confirming the high value of the surveyed mangroves for carbon sequestration.

Fisheries

The fisheries benefits were derived from two sources: (1) primary productivity from the mangrove trees, and (2) productivity from secondary producers that use the physical structure (habitat). These two mechanisms make mangroves particularly effective as nursery grounds for juveniles of species that later move offshore or to adjacent habitats such as coral reefs. In addition to nursery services, mangroves also support commercial harvest of fin and shellfish species, including mullets, crabs, oysters, and other estuarine species. Annual commercial fish harvests from mangroves have been valued from $6,200 per square kilometer in the United States to $60,000 per square kilometer in Indonesia. However, estimates vary between regions, habitat characteristics, and seaward location. There are studies with a broad range estimates of mangrove-associated fisheries economic values, but, in general terms, such benefits can be considered in excess of $1,000 per hectare per year.

Table CS5-1. Data, assumptions, and estimations of the approach

Benefit	Description of approach	Result
Flood protection	Avoided damage to people and built capital from tropical cyclone flooding	Mangrove forests in Jamaica provide $32.65 million in annual flood reduction benefits to built capital Average risk reduction benefits per unit of surface = $2,500 per hectare per year Note: The value is a national average, estimated over the entire coastline; the value per hectare can vary widely, depending on asset concentration.
Blue carbon	The study applied a tier-1 assessment of a carbon stock by multiplying the area of an ecosystem by the mean carbon stock for that ecosystem type: • Blue Carbon (t) = mean carbon (MgC ha − 1) × area (ha) • Potential CO_2 emissions per ha ($MgCO_2$ ha) = MgC × 3.67 (carbon equivalent) • Carbon sequestration value = MgC × SCC	Area of mangroves: The total estimated area covered by mangroves according to the Land Use and Land Cover (LULC) categorization reported in the 5th National Green House Gasses (GHG) report was 9,715 hectares. Mean value of carbon sequestered by mangroves per surface area (global review) = 386 MgC per hectare Total carbon sequestered: 3.7 t C; or 13.7 million tonnes of CO_2 equivalent Social cost of carbon (SCC), Latin America = $48 per tonne Net present value for carbon sequestration over 100 years, at 3% discount rate = $180 million per year Note: The site surveys estimated more carbon in the soil and the vegetation that the tier 1 approach used nationally. The site-specific economic SCC values were higher than the global average, confirming the high value of the surveyed mangroves for carbon sequestration.
Fisheries (primary and secondary production)	The estimates of value per site were based on a review of related literature and subsequent benefit (value) transfer. The global median value is $77 per hectare per year for (fin) fish, and $213 per hectare per year for mixed species fisheries. The median values were used in value transfer estimates for the Jamaican mangrove sites.	National nearshore fishing (fin fish) = $0.7 million (global median value of $77 per hectare per year) National nearshore fishing (mixed species) = $2 million ($213 per hectare per year) for mixed species fisheries

Source: Original table for this publication.
Note: ha = hectare; MgC = tonnes of carbon; t = tonne.

Results

- Average risk reduction benefits against tropical cyclones from mangrove forests across Jamaica are around $2,500 per hectare per year (this is the national average—over the entire coastline, it can vary widely depending on asset concentration).
- The economic value for carbon sequestration of conserving mangroves forest is $180 million per year (3 percent discounting). *It is important to note that local site surveys estimated more carbon in the soil and the vegetation than the tier 1 approach used nationally.*
- Net present value for carbon sequestration over 100 years, at 3 percent discount rate, is $180 million per year.
- National nearshore fishing at a total estimated value for the country is $0.7 million (fin fish) plus $2 million (mixed species fisheries).

Operational use of results

This technical assistance provided support to the government of Jamaica on promoting cost-effective coastal protection measures through mangrove ecosystems enhancement. The focus was on assessing the conservation value of mangroves to inform national environmental management of coastal zones in mangrove coastlines, restoration, and conservation actions. The results also provide baseline information for carbon offset mechanisms and national accounting of natural capital.

The project was an element of World Bank disaster risk management (DRM) initiatives as part of the Disaster Vulnerability Reduction Project. The project also complements the National Coastal Guidelines and Beach Restoration Guidelines (GFDRR 2017) and the ecosystem-based measures for coastal protection in site selected areas (World Bank 2016).

The project was developed after numerous meetings with the client related to coastal erosion control and DRM through the enhancement of natural infrastructure such as coral reefs, seagrass beds, mangroves, and beach vegetation. The departments most involved were the National Environment and Planning Agency (NEPA), the National Works Agency (NWA), and the Office of Disaster Preparedness and Emergency Management (ODPEM), which provided in-kind support through the Disaster Vulnerability Reduction Project. The secondary audiences were organizations of civil society and academia since these stakeholders expressed both their concern about the impacts to mangrove forests and the opportunity to work on those ecosystems for the enhancement of coastal protection.

The project is aligned with Jamaica's Resilience Agenda, as it builds on World Bank operation efforts (CIF, no date; World Bank 2016) and provides on-the-ground insight to guide and inform Jamaica, other SIDS, and continental countries on the potential for introducing forestry actions into disaster risk reduction strategies. The close links between environment and disasters also present an opportunity for scientists and policy makers.

Practical considerations

Budget range and timeline: **$300,000–$500,000 (24 months)**
Note: Main tasks involved in the technical assistance included (1) assessment of mangroves natural capital that supports coastal protection, including data collection and modeling; (2) socioeconomic analysis on the role of mangroves in coastal resilience; (3) habitat risk assessment and mapping; and (4) costs associated to mangrove conservation, restoration, and replanting efforts.

Key expertise requirement:

This type of analysis requires a multidisciplinary team, which should include flood modelers, engineers, ecologists, and economists, as well as others with an understanding of the management of natural resources and local issues. The involvement of the government and the local university was also an important aspect. The project involved the local university, which helped enhancing local capacity while also generating long-term sustainability and collaboration between the government and the university in the monitoring and evaluation of mangrove areas. The work also provided practical experience to undergraduate and postgraduate students. Two workshops with government agencies improved knowledge and analytical capacity.

The recommended experience and qualifications include:

- Modeling experience: Experience in flood risk modeling and the role of ecosystems in coastal risks. This requires expertise in computational modeling of hurricane dynamics, coastal processes, and flooding;
- Ecosystem service expertise: Knowledge of methodologies to model ecosystems co-benefits;
- Mapping expertise: Capacity to understand flood maps and analyze spatial data for management objectives;
- Economics: For the socioeconomic assessment, assessment of flood damages and cost studies; and
- Understanding of local context and historic conditions: Local presence is an important factor for obtaining access to local data and use results that are based on large-scale approaches (for example, global reviews of co-benefits).

Replicability:

The approach for flood modeling and co-benefit analysis is replicable for other island states. The project can also inform similar initiatives across the Latin American and the Caribbean region. The risk reduction valuation can be replicable in tropical cyclone–prone areas. It can be adapted in other regions with other contributors to flooding (for example, extratropical storms) by modifying the climatic forcing conditions. The valuation of ecosystem services is replicable in any other context, and it is valid for regional to national scales. However, it may present significant differences with local estimates.

Areas for improvement

- Local socioeconomic information could be included to improve the risk analysis. The risk analysis could also include the effects of historical changes in development (the built-up area).
- Using similar approaches, the assessment could include an evaluation of the effects of historical changes in mangrove cover to determine the changes in flood risk.
- While the assessment provides a direct valuation of the risk reduction benefits of existing mangroves, it does not include an explicit identification of restoration opportunities. The approach could be used to identify potential NBS projects and benefits in specific sites, associated with historical changes and the existing/loss value for coastal protection.
- The analysis could also include the effects of climate change, to assess the risk reduction benefits over time.

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Photo by Agung Hidayat on Unsplash

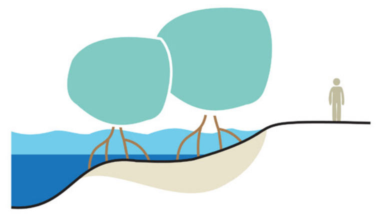
Mangrove Restoration for Resilience

Spatial Cost-Benefit Analysis of Mangrove Restoration at National Level (Indonesia)

Case study profile

NATURE-BASED SOLUTION (NBS) PROFILE

NBS TYPE



Mangrove forests

PRIMARY RISK REDUCTION BENEFIT (RRB)

Flooding

Erosion

NBS APPROACH

Protection

Rehabilitation, restoration, enhancement

OTHER BENEFITS

Climate regulation

Provisioning of food and raw materials (fisheries)

Tourism and recreation

ECONOMIC STUDY PROFILE

PROJECT CYCLE STAGE

Project identification and preparation / Project appraisal

ANALYTICAL APPROACH APPLIED (RRB)

Spatial cost-benefit analysis

Avoided damages and costs

SCALE OF PROJECT

National

STUDIED SITE

Provinces of East Kalimantan, North Kalimantan, North Sumatra, and Riau (Indonesia)

STUDY YEAR

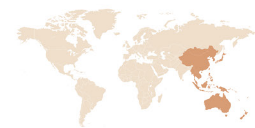
2021

WORLD BANK PROJECT PROFILE

PROJECT NAME

Mangroves for Coastal Resilience Project (World Bank 2022b)

REGION



East Asia and Pacific

GLOBAL PRACTICE AREA

Environment, Natural Resources and the Blue Economy

PROJECT REPORT

The Economics of Large-Scale Mangrove Conservation and Restoration in Indonesia (World Bank 2022a)

Background

The government of Indonesia has set an ambitious target to rehabilitate 600,000 hectares of mangroves by 2024—equivalent to the total amount of mangrove lost since 1990. This case study seeks to inform the policy dialogue on how to reach this target by providing spatially disaggregated estimates of the costs and benefits of mangrove restoration and conservation at a national scale. The analysis has supported the preparation of the World Bank's Mangroves for Coastal Resilience Project, a $419 million investment project to support the government of Indonesia rehabilitate 75,000 hectares and protect an additional 400,000 hectares of mangroves across four provinces of the country (World Bank 2022b).

Analytical approach

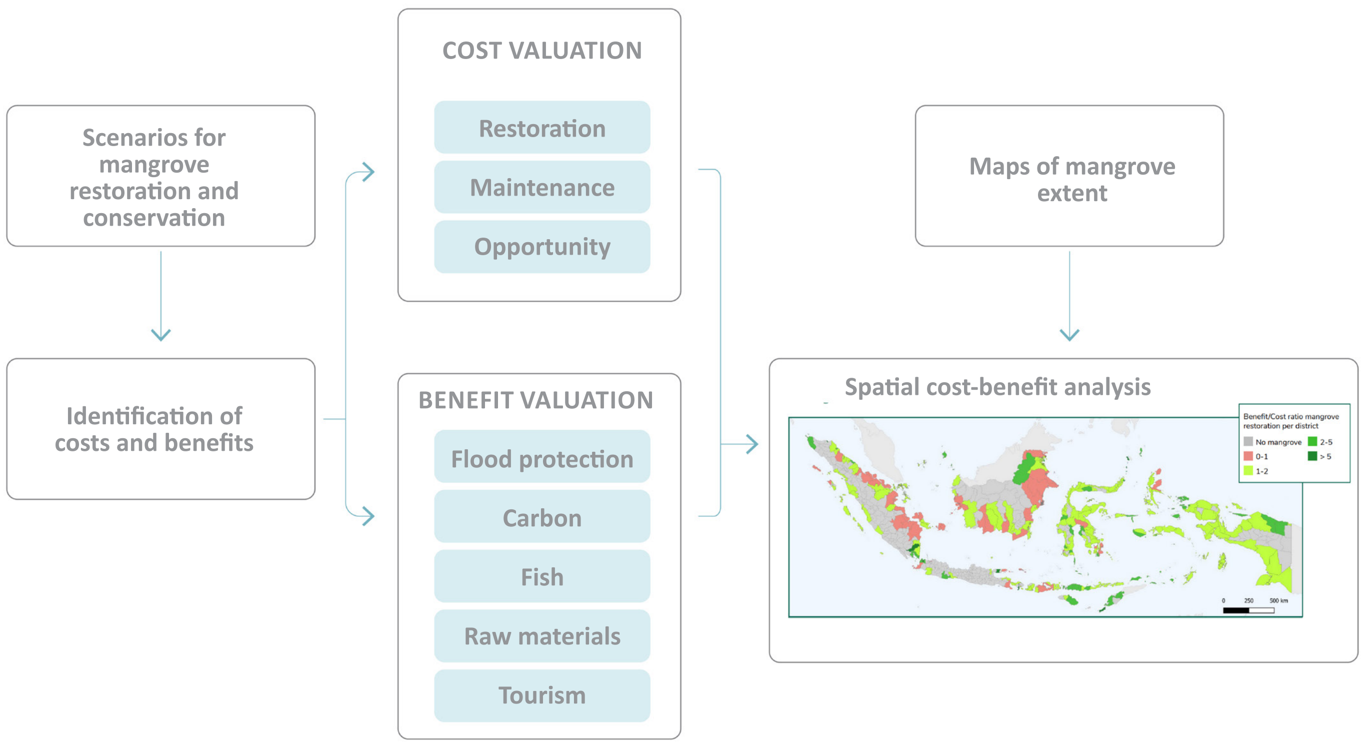
The analytical approach used in this case study is a national-level spatial cost-benefit analysis (CBA) to measure the net benefits of mangrove restoration and conservation. The overall approach is represented in figure CS6-1 and combines several analytical tools: stakeholder consultation to define scenarios and identify key costs and benefits; value transfers to quantify spatially variable costs and benefits; and CBA to identify locations with potentially high net returns from investment in mangrove restoration or conservation.

Spatially explicit values are extracted for Indonesia from a detailed global analysis (Menéndez et al. 2020) that uses an avoided damage costs method. This method models nearshore conditions (waves and tides) to estimate the land area flooded with and without healthy mangroves. This information is combined with land and property values to determine expected avoided losses.

Annual unit costs and benefits (per hectare) are estimated and then extrapolated to the extent of targeted mangroves in each coastal district. The results are presented as benefit-cost ratios for each district.

The main advantage of this analytical approach is that it provides a rapid comparison of costs and benefits under different scenarios and in different geographic areas to inform national-level programs, strategies, and investment plans for mangrove interventions, and identifies priority areas and interventions for follow-up studies. The main limitation of this analytical approach is that it does not provide sufficient granularity for (pre-)feasibility-level studies or project design as it is conducted at the district level. This approach may also require additional on-site economic studies using primary data and reliable spatial (mapped) values.

Figure CS6-1. Summary of the analytical approach for the economic assessment



Source: Original figure for this publication.

Methods and data

Stakeholder consultation

The stakeholder consultation process, including various ministries that are part of the decision-making process, was used to define the scope of the study and to identify relevant benefits (or ecosystem services) and appropriate data sets.

Mangrove extent and condition

Two different mangrove extent data sets have been used to map the location of Indonesian mangroves. These are the mangrove extent data from the Indonesia Coastal Capital Accounts prepared by the Department of Forestry Planning and Environmental Management of the Ministry of Environment and Forestry with support of the World Bank; and the Global Distribution of Mangroves from the US Geological Survey (Giri et al. 2011), which is the source data for the coastal protection model (Menéndez et al. 2020).

Cost valuation

The costs of restoration, conservation, and forgone land use (opportunity cost) are drawn from a variety of secondary sources (summarized in table CS6-1).

Table CS6-1. Cost estimates and data sources

Cost category	Valuation method	Cost estimate	Source
Restoration costs	Based on secondary data of costs for techniques applied, capital expenditures, and operating costs. Based on joint estimation with the government of Indonesia of capital costs.	Restoration cost per hectare of $3,900 constant across all districts.	Estimations of cost of techniques based on Hashim et al. (2010); Motamedi et al. (2014); Narayan et al. (2016); Primavera and Esteban (2008). Estimations of capital expenditures based on Bayraktarov et al. (2016); Flint et al. (2018). Operating costs based on Bayraktarov et al. (2016). *Note: Data completed in 2020 by the Ministry of Marine Affairs and Fisheries (Government of Indonesia).*
Conservation costs	Based on secondary data of maintenance costs.	Proxy indicator: Management cost of marine protected areas per hectare from the government of Indonesia	Estimations based on Flint et al. (2018) and consultations with the government.
Opportunity costs of land	Opportunity costs were estimated at a 5 km resolution based on the average productivity of agriculture and pastures for all mangrove-holding countries.	Modeled and spatially explicit estimate of land opportunity cost at 5 km resolution. In the analysis, per hectare opportunity costs are considered district-level averages.	Estimations based on Jakovac et al. (2020); Richards and Friess (2015); Strassburg et al. (2020).

Source: World Bank 2022a.

Benefit valuation

The five key benefits of mangrove restoration or conservation that are included in the analysis are quantified using individually applicable value transfer methods and underlying data (summarized in table CS6-2).

Table CS6-2. Benefit categories, valuation methods, and data sources

Mangrove benefit	Valuation method	Source
Coastal protection	Avoided damage costs.	Menéndez et al. (2020).
Climate regulation	Voluntary market price estimate for avoided emissions and carbon sequestration.	Estimations based on; Cameron, Hutley, and Friess (2019); Cameron et al. (2019); Jakovac et al. (2020); on Mudiyarso et al. (2015).
Support to fisheries	Value transfer using meta-analytic value function. Primary studies applied production function approach.	Estimations based on methodology presented in Brander et al. (2012).
Raw materials provision	Value transfer using meta-analytic value function. Primary studies applied production function approach.	Estimations based on methodology presented in Brander et al. (2012).
Cultural services	Value transfer in areas where mangroves are used for tourism activities.	Estimations using the median of meta-data set of mangrove tourism estimates in SE Asia (data from ESVD 2021). Mangrove tourism use areas are depicted by Spalding and Parret (2019).

Source: World Bank 2022a.

Spatial cost-benefit analysis

CBA (see section 4.2) is used to estimate the net benefits of mangrove restoration and conservation. The advanced feature of the CBA conducted in this case study is that costs and benefits are estimated at a spatially disaggregated level (individual districts), which enables decision-makers to see how costs, benefits, and net returns of mangrove restoration and conservation vary across locations. This allows them to gauge the relative viability of such interventions across districts and prioritize those that yield the greatest benefits and the lowest costs.

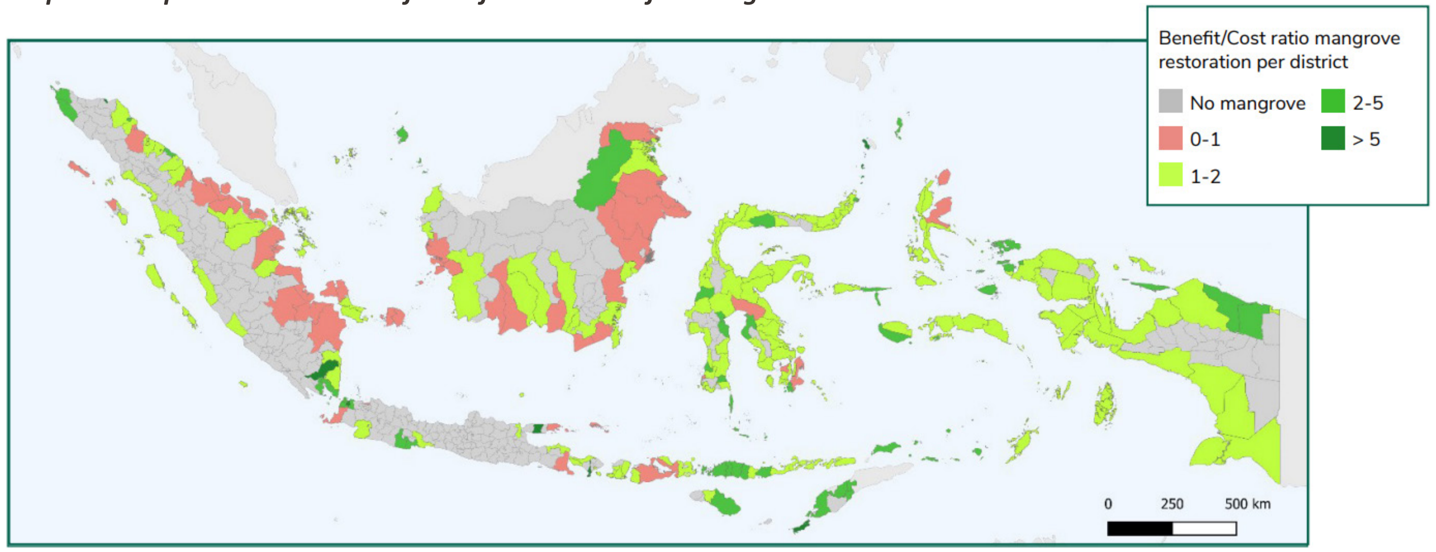
In addition, this method can also be customized via different scenarios to assess different restoration and/or conservation strategies with more accurate estimates than other national averages but at lower costs than using primary data collection.

In this CBA, the costs and benefits are estimated over a 30-year project lifetime. A discount rate of 5.5 percent is applied to convert costs and benefits that occur in future time periods to present values to allow aggregation over time. A sensitivity analysis with a 0 percent and 10 percent discount rate is used to examine the robustness of the results to variation in the discount rate.

Results

- Mangroves provide valuable ecosystem services that contribute to human well-being in Indonesia. On average, these sets of services yield $15,000/hectare/year in benefits, but some provide benefits totaling nearly $50,000/hectare/year.
- The extent and value of mangrove-related ecosystem services vary sharply across regions and types of services. Average financial benefits for protecting coastlines and fisheries are the largest.
- Average restoration cost in Indonesia are estimated to be $3,900/hectare.
- The opportunity costs of conservation and restoration are high and variable, showing a need for differentiated investment strategies. Net present opportunity costs average $3,400/hectare, but these are higher in areas with higher depletion rates.
- Restoration net benefits are generally higher than restoration net benefits, but regional differences should still be considered when making investment decisions. For example, benefit/cost ratios for both conservation and restoration vary from less than 1 to more than 5. See map CS6-1 for mapped benefit-to-cost ratios at the district level for mangrove restoration.

Map CS6-1. Spatial distribution of benefit-cost ratios for mangrove conservation



Source: World Bank 2022c.

Operational use of results

The new information that this case study brings to the table, based on spatially explicit cost-benefit analysis, has informed the policy dialogue and preparation of the Mangroves for Coastal Resilience Project (World Bank 2022b). The task team utilized results in the dialogue with the government to stress the differences in economic viability between mangrove restoration and conservation across the country. Moreover, the framework was used to distribute 75,000 hectares of mangrove restoration and conservation across districts and provinces and to conduct cost-benefit analysis for the project appraisal document (PAD) of the Mangroves for Coastal Resilience Project (World Bank 2022b). The main findings and related policy messages are particularly useful for government officials from the Ministry of Marine Affairs and Fisheries, the Ministry of Environment and Forestry, the Peat and Mangrove Restoration Agency, the Ministry of Finance, and other line ministries that are part of the decision-making process.

Practical considerations

Budget range and timeline: **Less than $150,000 (3–6 months)**
Note: The economic assessment benefited from a set of global values already published.

Key expertise requirement:
This study required the following experience and qualifications:
- Geographic Information System (GIS) expertise to prepare digital maps and spatially defined variables;
- Understanding of underlying biophysical and economic models for quantifying coastal protection, carbon sequestration, provisioning services, and tourism benefits of mangroves;
- Experience formulating and conducting a CBA; and
- Experience conducting value transfers using value functions.

Replicability:
The spatial CBA is replicable for other national- or regional-scale strategic assessments of the economic viability of NBS that require information on the return on investment across multiple potential sites. Applications for mangrove conservation/restoration for other countries can utilize similar cost and benefit data and models developed by this case study. Applications for other NBS and ecosystems can potentially replicate the analytical approach to produce spatially explicit evaluation of costs and benefits.

Data requirement:
- Digital maps of mangrove extent and condition. A global map of mangrove extent is available from the US Geological Survey (USGS 2011).
- Data on mangrove conservation, restoration, and opportunity costs from literature or obtained from local stakeholders. Globally available data sets include Bayraktarov et al. (2016), which provides information on restoration costs for coastal ecosystems globally.
- Data and models on mangrove benefits from literature. There are several published meta-analyses of mangrove ecosystem service values, including Brander et al. (2012), Getzner and Islam (2020), and Salem and Mercer (2012). Globally available data sets on ecosystem service studies and values include the Environmental Valuation Reference Inventory (EVRI, no date) and the Ecosystem Services Valuation Database (ESVD 2021), which covers all regions, biomes, and ecosystem services.

Areas for improvement

The valuation of cultural services from mangroves in this case study is limited to tourism at a relatively small number of sites identified through social media data. This valuation could be expanded to include local recreational use and improved with data on actual visitor numbers. Such data, however, are currently unavailable and would require an extensive survey.

The data and models, including climate scenarios, used in the analysis are characterized by varying levels of uncertainty. Further analysis could examine the sensitivity of the results to plausible variation in the underlying parameters and assumptions to test the robustness of the results.

Photo by Bayu Setiawan on Unsplash

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Wetland Conservation in Colombo

Metro Colombo Wetland Conservation: Decision-Making under Uncertainty (Sri Lanka)

Case study profile

NATURE-BASED SOLUTION (NBS) PROFILE

NBS TYPE

Inland wetlands

NBS APPROACH

Protection

PRIMARY RISK REDUCTION BENEFIT (RRB)

Flooding

Erosion

Extreme heat reduction

OTHER BENEFITS

Climate regulation

Tourism and recreation

Wastewater treatment

ECONOMIC STUDY PROFILE

PROJECT CYCLE STAGE

Project identification and preparation / Project implementation and support

ANALYTICAL APPROACH APPLIED (RRB)

Cost-benefit analysis

Decision-making under uncertainty

Avoided damages and costs

SCALE OF PROJECT

City level

STUDIED SITE

Colombo Metropolitan Region (Sri Lanka)

STUDY YEAR

2014–2015

WORLD BANK PROJECT PROFILE

PROJECT NAME

Metro Colombo Urban Development Project (World Bank 2012)

REGION

South Asia

GLOBAL PRACTICE AREA

Urban, Disaster Risk, Resilience and Land

PROJECT REPORTS

Wetlands Conservation and Management: A New Model for Urban Resilience in Colombo (Rozenberg et al. 2015)

Background

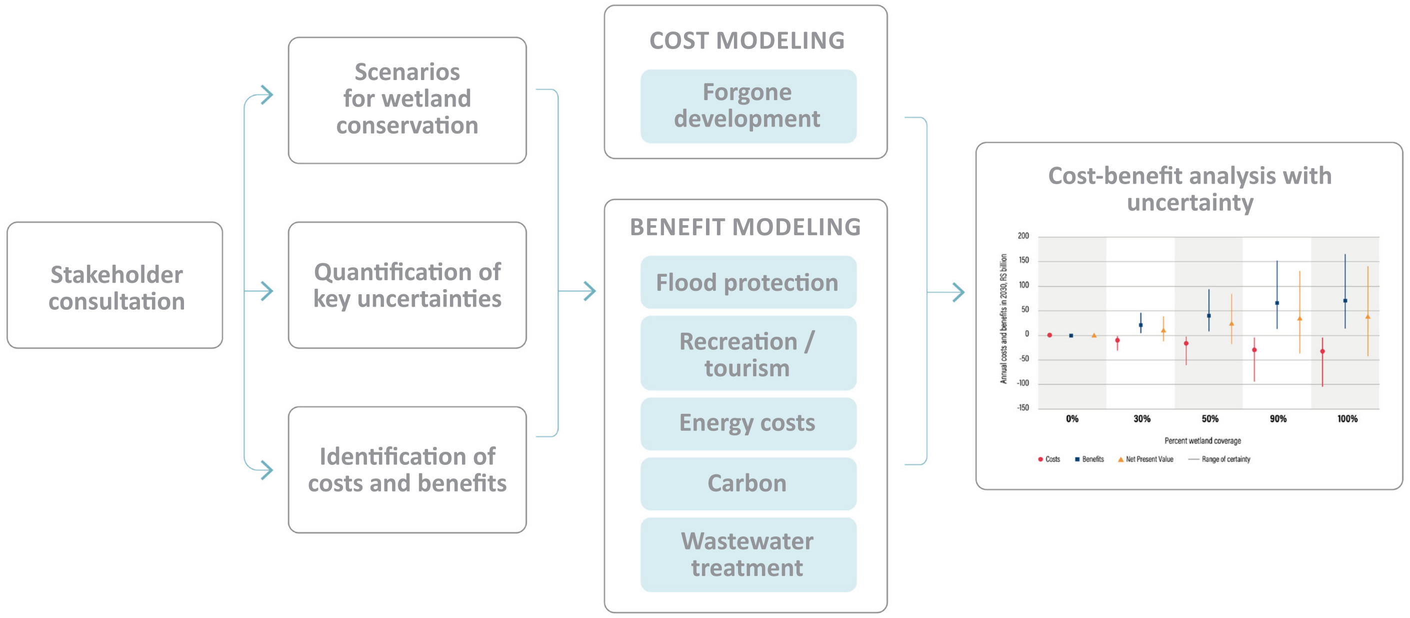
Flooding in Colombo has been occurring with worrying frequency. As the city expands in size, population, and aspirations, it must address its vulnerability to flooding to realize a high quality of life for its residents. The Metro Colombo Urban Development Project (World Bank 2012) is helping reduce the risk and impacts of flooding while making the city more livable and competitive through investments in public spaces and infrastructure. However, policy options that were under scrutiny regarding the future of the Colombo wetlands carried several economic and social consequences and trade-offs impacting land value, housing rents, and real estate prices.

The project was considering the use of wetlands as green infrastructure to complement a gray infrastructure investment package. This particular case study provided an additional economic analysis to advocate in favor of supporting the conservation and management of these critical wetlands as natural flood retention areas.

Analytical approach

The analytical approach is to quantify the economic costs and benefits of conserving wetlands using state-of-the-art decision support tools for complex problems under deep uncertainties. The process involved workshops with representatives of the government and civil society, along with the use of scenario analyses incorporating uncertainties over future urban development and changes in climate and hydrological conditions in the Colombo basin. The results are presented as annual net benefits for five wetland conservation scenarios. The overall approach is represented in figure CS7-1.

Figure CS7-1. Summary of the analytical approach for the economic assessment



Source: Original figure for this publication.

The main advantage of this analytical approach is that it explicitly accounts for deep uncertainties in multiple factors underlying the performance of the nature-based solution (NBS) intervention; it also quantitatively and visually represents the range of possible outcomes. A key feature of this approach is the possibility of running hundreds of scenarios, but more than anything, decision-making under uncertainty (DMU) methodologies promote an interactive and iterative analytical framework, where collaboration and continuous exchange with the client is fundamental. This type of analytical approach is technically complex to implement and requires a quantitative understanding of underlying uncertainties.

Methods and data

Stakeholder consultation

The economic analytics were embedded in an intensive and structured participatory process with stakeholders through a series of four workshops. This consultation used a "deliberation with analysis" process in which stakeholder discussions provide instructions to an analytical team, which then provides results, trade-offs, and materials for further stakeholder deliberation. The consultation process was used to identify key questions that the analysis should address as well as policy levers, exogenous uncertainties, and metrics for project performance. Moreover, the consultation process served to inform and engage stakeholders in the potential of wetland conservation.

Cost valuation

The opportunity cost of wetland conservation is estimated as the forgone value of commercial and residential development (table CS7-1). This cost was estimated using secondary data on similar areas of development in the country. The residual value method was used to compute economic surplus as the value of completed commercial and residential development minus the costs of development (including initial land purchase and developers' profit).

Table CS7-1. Cost categories

Cost	Description	Quantification
Construction and maintenance	Construction is not required as the wetland already exists. The maintenance cost of wetlands is low because they are largely self-maintained.	**−0.07 million SL Rs/ha/year**
Opportunity cost of commercial and residential development	Residual value method used to estimate forgone economic surplus from development. Urban economic model used to measure effects on housing rents and land prices.	Housing rents and land values are respectively **0.82%** and **3.75%** higher than without wetland conservation.

Source: Rozenberg et al. 2015.
Note: ha = hectare; SL Rs = Sri Lanka rupees.

Benefit valuation

The benefits of wetland conservation that are included in the analysis are quantified using individually applicable valuation methods and underlying data (summarized in table CS7-2).

Table C7-2. Benefit categories

Benefit	Description	Quantification
Moderation of extreme events	Avoided damage costs were estimated using flood damage data from Greater Colombo Flood Control Project and Environmental Improvement Project (JICA 2009).	**1–1.3% of GDP**
Recreation	Value transfer based on past studies on economic valuation of wetlands in Sri Lanka and other countries (for example, Emerton and Kekulandala 2003).	**5.53 million SL Rs/ha/year**
Reduction of energy costs (mainly electricity cost)	Market-based method using secondary data on use of air conditioners/fans, electricity consumption levels, electricity bills, etc.	**0.03 million SL Rs/ha/year**
Carbon sequestration	Value transfer using carbon benefits estimated Emerton and Kekulandala (2003).	**0.02 million SL Rs/ha/year**
Regulation of water flows (hydrological regimes)	Replacement cost estimated using secondary data on local water users, types of water use, required water-related infrastructure, and costs published by the Department of Census & Statistics, National Water Supply and Drainage Board.	**0.01 million SL Rs/ha/year**
Nutrient retention and wastewater treatment	Replacement cost estimated using secondary data on sources, volume, and treatment costs of wastewater.	**2.03 million SL Rs/ha/year**

Source: Rozenberg et al. 2015.
Note: GDP = gross domestic product; ha = hectare; SL Rs = Sri Lanka rupees.

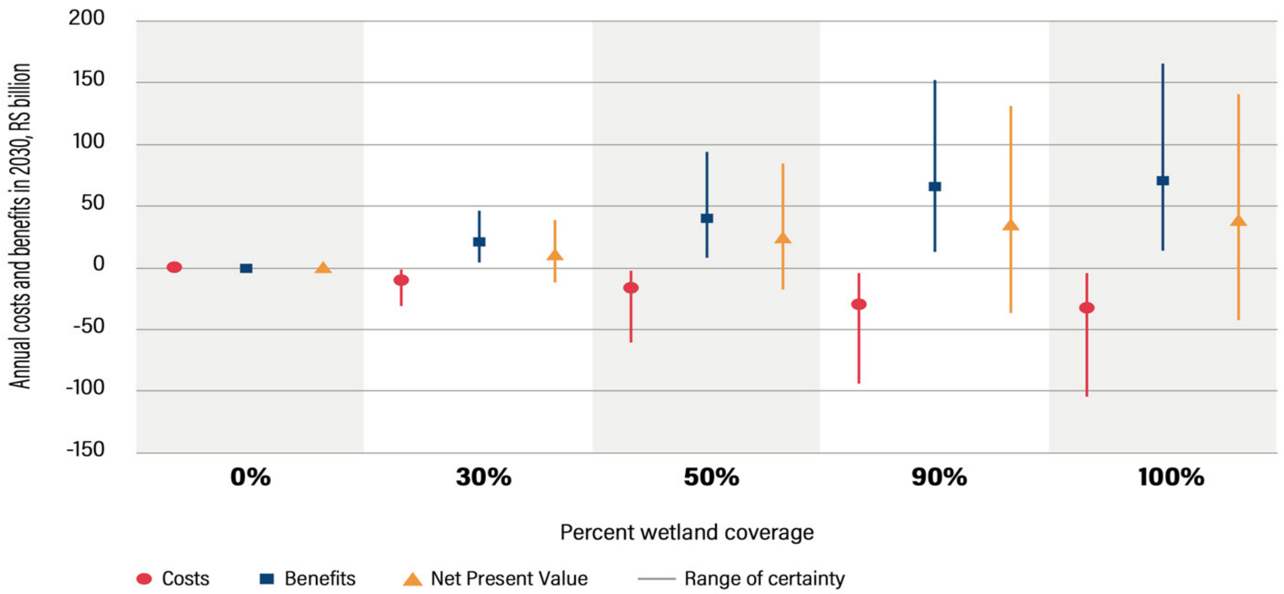
Decision-making under uncertainty

Cost-benefit analysis (CBA) is used to estimate the net benefits of wetland conservation. The sophisticated feature of the CBA conducted in this case study is that it uses an advanced approach to incorporate uncertainties regarding underlying factors and parameter values in the analysis. The analysis identifies a broad range of potential outcomes given the underlying uncertainties, but it then identifies the most important uncertainties and the thresholds for these variables that would lead to a net negative or positive outcome. Finally, it indicates whether there is a higher or lower likelihood of being on the right side of the threshold. This information can provide planners with some degree of confidence to proceed to a decision.

Results

Figure CS7-2 represents the annual costs, benefits, and net present value of preserving the wetlands in the year 2030 (chosen as a middle-term target by which a master plan for the Colombo basin should be completed). For each scenario of wetland conservation, the cost, benefit, and net present value (NPV) is represented as a point with a range of uncertainty, indicating that the large majority of potential outcomes will deliver net benefits.

Figure CS7-2. Cost-benefit analysis results for wetland conservation scenarios



Source: Browder et al. 2019.

Operational use of results

Although the project was already in the implementation phase, this economic analysis shed light on the magnitude of the impacts of wetland conservation contributing to decision-makers' guidance. The results were used to advocate for including and strengthening wetland conservation in the project design. The study also contributed to the establishment of a Wetland Management Unit within the country's Land Reclamation Agency and to the implementation of a detailed follow-up study on wetland potential and values.

Practical considerations

Budget range and timeline: **Less than $150,000 (12 months)**

Note: The activity included: (1) workshop facilitation and a comprehensive data collection process; (2) the development of probabilistic flood maps, based on different scenarios of climate change and urbanization; (3) a vulnerability assessment; and (4) a strategy to increase resilience identifying a list of specific solutions.

It is important to note that the client already had a flood model that they had calibrated to design the gray components of the project.

Key expertise requirement:

For this type of analysis, recommended experience and qualifications are:

- Demonstrated experience in carrying out studies similar to robust decision-making, decision scaling, adaptation pathways, and/or other decision-making under (deep) uncertainty (DMDU) methods;
- Knowledge of Python or R software for DMU modeling;
- Demonstrated experience in probabilistic flood risk modeling, spatial analysis, and risk assessment; and
- Experience working on NBS.

Replicability:

DMU methodologies are highly recommended when a close collaboration and continuous exchange with the client and key stakeholders is possible. Besides a required interactive and iterative process, it is important to understand that the implementation of this methodology entails a degree of technical complexity that requires support from specific experts and a quantitative understanding of underlying uncertainties.

Data requirement:

The study relied on the following local data sets to determine the benefits of wetland conservation:

- Area of interest and the population it hosts,
- Location and size of the studied wetlands,
- Average income and expenditure distribution (transport and housing),
- Transport costs (the monetary costs and the opportunity costs of time spent commuting), and
- Construction costs.

Areas for improvement

One area for improvement in this analysis is the flood risk assessment. A flood risk model was developed for the project as a whole, but it was not designed to assess the flood mitigation benefits of urban wetlands. Wetlands were loosely represented by their water retention capacity and were not modeled differently from lakes. In addition, the exposure and vulnerability data were quite crude and could be refined with better vulnerability curves and exposure data. Further analysis could therefore refine the modeling of wetlands for flood risk reduction. This highlights the need to incorporate NBS into project design at an early stage.

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Photo by Yunesh Shalika on Unsplash

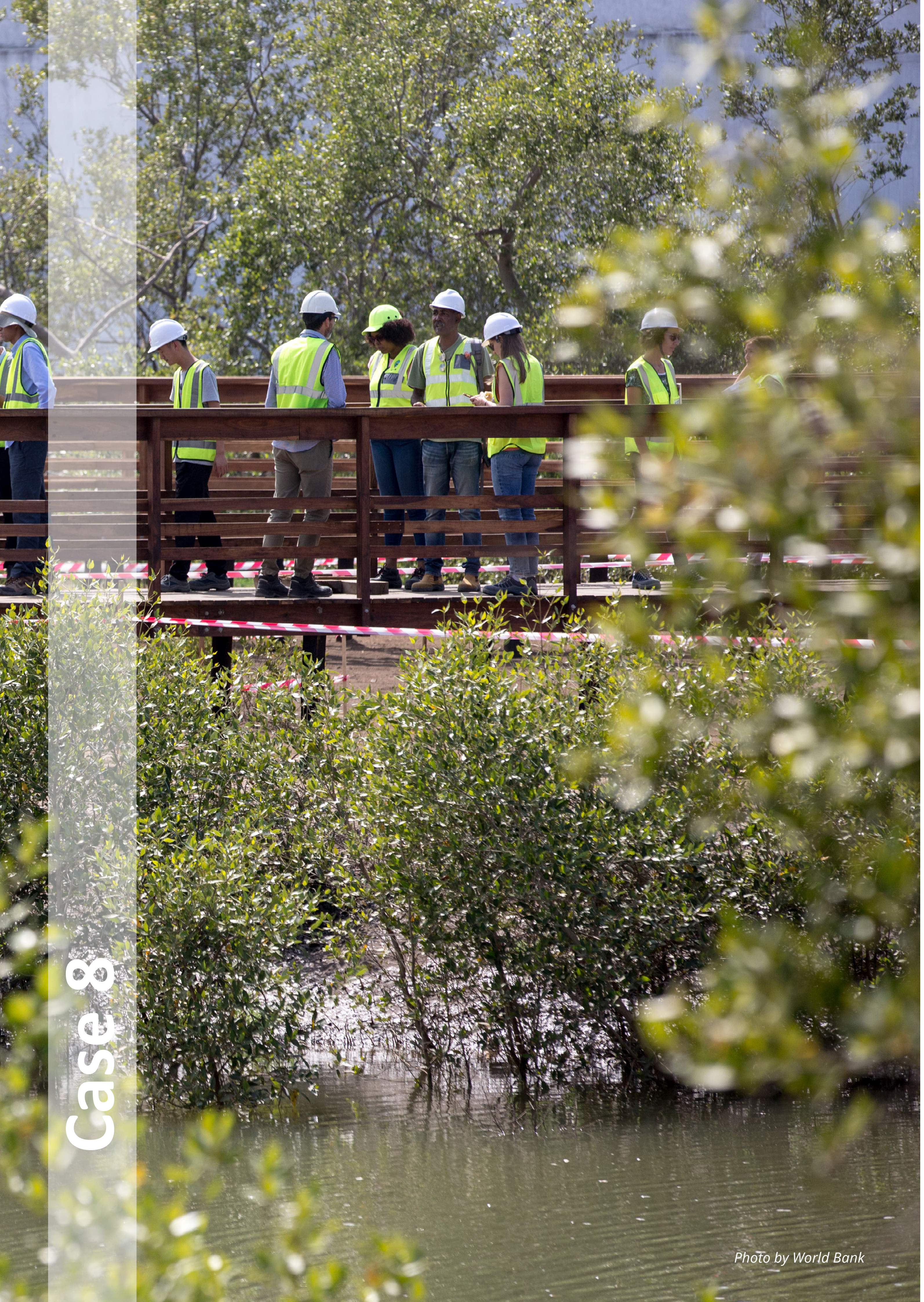

Photo by World Bank

Coastal Resilience in Emergency Recovery

Cost-Benefit Analysis to Assess the Feasibility of NBS for Coastal Protection in the City of Beira (Mozambique)

Case study profile

NATURE-BASED SOLUTION (NBS) PROFILE

NBS TYPE

Mangrove forests

Sandy shores and dunes

Rehabilitation, restoration, enhancement

PRIMARY RISK REDUCTION BENEFIT (RRB)

Flooding

Erosion

OTHER BENEFITS

Tourism and recreation

Biodiversity

Job creation

Health

ECONOMIC STUDY PROFILE

PROJECT CYCLE STAGE

Project implementation and support

ANALYTICAL APPROACH APPLIED (RRB)

Cost-benefit analysis

Avoided damages and costs

SCALE OF PROJECT

Site specific

STUDIED SITE

4 coastal sections in the city of Beira (approximately 5 km)

STUDY YEAR

2020–2022

WORLD BANK PROJECT PROFILE

PROJECT NAME

Mozambique: Cyclone Idai & Kenneth Emergency Recovery and Resilience Project (World Bank 2020)

REGION

Sub-Saharan Africa

GLOBAL PRACTICE AREA

Urban, Disaster Risk Management, Resilience and Land

PROJECT REPORT

Coastal Protection Project Preparation Studies for Beira Mozambique: Feasibility Report (Royal Haskoning DHV, unpublished)

Background

In March and April 2019, Mozambique was struck by two consecutive major cyclones with significant impacts on local populations, business, and core infrastructure. Flooding has been a primary hazard in areas affected by the cyclones, resulting in loss of life and damage to infrastructure, housing, and productive sectors. The city of Beira is particularly exposed to flooding because of its low-lying setting in a delta area. Beira was affected by widespread rainfall-induced flooding in January 2019 and faced both fluvial and coastal flood hazard during Cyclone Idai.

Under the banner of the Cyclone Idai & Kenneth Emergency Recovery and Resilience Project (World Bank 2020), the World Bank, the government of Mozambique, and development partners from the Netherlands (Invest International) and Germany (Kreditanstalt für Wiederaufbau, or KfW) are building coastal resilience in the most vulnerable areas of the city of Beira. The project includes $60 million of planned investment in coastal protection measures, co-financed by the development partners. The planned measures include a combination of nature-based and gray solutions, such as beach restoration and conservation, seawalls, and levees. This case study describes the cost-benefit analysis (CBA) of the feasibility study conducted for the coastal resilience component of the Cyclone Idai & Kenneth Emergency Recovery and Resilience Project. The objective of the study is the definition and evaluation of design alternatives for four coastal sections (also called *stretches*) to select the preferred alternative. The feasibility study, including the economic analysis, was financed and overseen by Invest International.

Analytical approach

A CBA was undertaken to assess and evaluate the economic viability of design alternatives for the four coastal sections in the city of Beira. Three design alternatives were evaluated (map CS8-1). In some cases, the CBA was conducted for specific interventions at the sub-section level. Per coastal section, three design alternatives were evaluated, and for each section, locally relevant benefits were included.

Map CS8-1. Design alternatives and coastal stretches

Source: Royal Haskoning DHV, unpublished.
Note: Stretch 1, protecting the port of Beira on the western side of the city, interventions consider an early warning system in combination with other measures. Along stretches 2, 3, and 4, combinations of seawalls and dune restoration are proposed and evaluated.

The CBA assumed a 30-year project lifetime (2021–51), assuming implementation to be completed in year 6 of the project. As the lifetime of the civil engineering investments (except sand buffer suppletion) is estimated at 50 years, residual cost and benefits are added in the CBA in year 30 for the remaining 20 years. Three cost components were specified for three design alternatives per coastal section: total capital investment cost, annual maintenance cost, and—for investments in beach restoration and conservation—a periodic cost to maintain sand buffers (table CS8-1). Risk reduction benefits considered in the analysis include avoided flooding and erosion damages. In addition, relevant ecosystem services and avoided indirect effects are quantified for each individual section.

Table CS8-1. Categories of cost and benefit included in the study

	Costs	Benefits
Description	Total capital investment cost Periodic investment to maintain sand buffers Annual maintenance cost	Annual avoided damages of coastal flooding Annual avoided damages of temporal beach erosion Damage to assets due to structural erosion Gain in ecosystem services Health effects Avoided indirect flood damages

Source: Original table for this publication.

Methods and data

Cost

In this feasibility study, full preliminary designs were developed for the different alternatives across the four coastal stretches (table CS8-2). These designs included a detailed bill of quantities of the construction materials and associated capital expenditures (CAPEX) and operating expenses (OPEX). Unit costs for materials were estimated based on international experience by the consultant and by engaging the client and local stakeholders. The rates of the most important material cost components, such as sand and rock, are based on a survey of the market prices in Beira and Mozambique. In this analysis, the price of sand is $5.50/cubic meter based on interaction with a local stakeholder. For rock, a unit rate of $65/cubic meter is used, which is the upper limit of the collected information.

Table CS8-2. Cost estimates per stretch and cost category
US dollars, millions

Coastal stretch	Alternative and project	Total capital investment cost	Periodic sand buffer	Maintenance
STRETCH 1	**Alt. 1** EWS and land use regulation	**0.69**	**n.a.**	**0.05**
	Alt. 2 EWS and land use regulation and evacuation by road	**1.52**	**n.a.**	**0.11**
	Alt. 3 EWS, evacuation by road and levee	**2.22**	**n.a.**	**0.11**
STRETCH 2 NORTH	**Alt. 1** Strengthen seawall	**4.42**	**n.a.**	**1.02**
	Alt. 2 New seawall seaward at same location	**11.62**	**n.a.**	**0.31**
	Alt. 3 New seawall seaward of existing location	**11.95**	**n.a.**	**0.31**
STRETCH 2 SOUTH	**Alt. 1** Dune with 10-year buffer	**12.85**	**6.3**	**0.54**
	Alt. 2 Levee/floodwall with 10-year buffer	**32.12**	**6.3**	**1.25**
	Alt. 3 Dune with 10-year buffer and elevation for urban development	**26.87**	**6.3**	**0.54**
STRETCH 3	**Alt. 1** Dune with 50-year buffer	**25.52**	**13.4**	**0.11**
	Alt. 2 Levee with 10-year buffer	**155.34**	**2.7**	**1.09**
	Alt. 3 Dune with 10-year buffer	**14.79**	**2.7**	**0.56**
STRETCH 4	**Alt. 1** Dune with 10-year buffer	**27.78**	**18.5**	**1.31**
	Alt. 2 Levee with 10-year buffer	**228.96**	**18.5**	**2.47**
	Alt. 3 Inland levee with road without buffer	**42.52**	**n.a.**	**1.03**

Source: Royal Haskoning DHV, unpublished.
Note: Alt. = alternative; EWS = early warning system; n.a. = not applicable.

Benefits

The CBA adopts the per-unit damage estimations of a Global Facility for Disaster Reduction and Recovery (GFDRR)-funded coastal flood modeling study (GFDRR and World Bank 2019). Considering the annualized impacts of a 50-year return period event, the CBA estimated the avoided structural flood damages and the reduced annual erosion damages. These damages were estimated for 2020 and 2070 climate change scenarios (map CS802); for the years in between, annual avoided damages were interpolated. The coastal flood modeling study also considered that increasing development in coastal areas in Beira might lead to higher flood damages in the future: land use change projections were adopted from the Beira masterplan and a 4 percent annual increase in erosion damages was assumed to account for projected economic growth. This growth is expected to result in higher-quality and more multistory buildings along the coast.

Map CS8-2. Flooding of the industrial port for a 1/50-year event

a. In 2020 ***b. In 2070***

Source: Royal Haskoning DHV, unpublished.

In addition to the risk reduction benefits, the CBA estimates indirect flood damages, loss of wages in the flooded areas, and the avoided cost of beach loss for the tourism economy. Assumptions are made to value these benefits: based on a review of empirical studies globally, indirect flood damages are estimated at 50 percent of structural damages to properties; avoided loss of wages is estimated proportional to the annual affected population by flooding (50 percent of the annual affected population is assumed to be working and business interruptions are assumed at one day on average); and the avoided damage to the tourism economy as a result of beach loss is estimated by valuing the tourism value of touristic beaches at $50/square meter/year.

Results

For each coastal section, a CBA was conducted comparing three alternative interventions. As an example, we will have a closer look at the results of stretch 4. Table CS8-3 shows the summary of CBA results for stretch 4, with a 0 percent, 6 percent, and 10 percent discount rate. Alternative 1 proposes dune conservation with a sand suppletion buffer, which is required to be replenished every 10 years. The other alternatives for this coastal section are alternative 2, a levee with sand suppletion buffer (also creating a beach); and alternative 3, an inland levee with a road on top. Along this coastal section, the expected damages from flooding are comparatively low and the preservation of the beach for the local economy is very important. Therefore, alternative 1, which preserves the beach, comes out as most economically viable with a benefit-cost ratio (BCR) of 2.6 (6 percent discount rate). Alternative 2 has a BCR of 0.68, and alternative 3 has a BCR of 0.06.

Table CS8-3. Summarized CBA results for the three design alternatives
US dollars, millions

	Alternative 1			Alternative 2			Alternative 3		
Discount rate	0%	6%	10%	0%	6%	10%	0%	6%	10%
Total cost	**102.4**	**50.7**	**39.4**	**243.3**	**203.9**	**173.3**	**51.2**	**43.2**	**31.2**
Direct benefits	**14.4**	**5.1**	**1.8**	**14.4**	**5.1**	**2.9**	**5.5**	**2.6**	**2.1**
Indirect benefits	**437.8**	**126.7**	**61.6**	**446.5**	**133.2**	**67.0**	**0.4**	**0.1**	**0.4**
BCR	**4.42**	**2.60**	**1.61**	**1.89**	**0.68**	**0.40**	**0.11**	**0.06**	**0.08**
ENPV	**349.8**	**92.5**	**55.2**	**217.6**	**−65.6**	**−103.5**	**−45.4**	**−38.1**	**−32.4**
EIRR	17.0%			3.5%			−6.7%		

Source: Royal Haskoning DHV, unpublished.
Note: BCR = benefit-cost ratio; EIRR = economic internal rate of return; ENPV = expended net present value.

As shown in table CS8-4, along stretch 4 the potential "beach income" is high and the expected avoided flood damages are comparatively low. Alternative 1 is therefore economically viable, also because the upfront investment costs are low compared to the other alternatives.

Table CS8-4. Economic CBA for stretch 4, alternative 1 (dune with 10-year buffer)
US dollars, millions

STRETCH 4	2022	2023	2024	2025	2026	2027	2030	2034	2044	2051
Alternative 1: Dune and buffer										
Costs	**0.00**	**0.00**	**9.26**	**9.26**	**9.26**	**1.66**	**1.66**	**20.11**	**20.11**	**-2.07**
1 Investment cost excl sand buffer			**3.11**	**3.11**	**3.11**					**-3.73**
2 Investment cost, sand buffer			**6.15**	**6.15**	**6.15**			**18.45**	**18.45**	
3 Maintenance cost						**1.66**	**1.66**	**1.66**	**1.66**	**1.66**
Direct benefits - Flood and erosion protection	**0.00**	**0.00**	**9.26**	**9.26**	**9.26**	**0.20**	**2.34**	**0.31**	**0.61**	**0.99**
1 Flood protection level benefits						**0.14**	**0.17**	**0.21**	**0.39**	**0.58**
2 Structural erosion assets (one time)							**2.11**			
3 Storm erosion damage (temporal)						**0.05**	**0.07**	**0.10**	**0.23**	**0.41**
4 Other										

STRETCH 4 (table part 2)	2022	2023	2024	2025	2026	2027	2030	2034	2044	2051
Indirect benefits	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.10**	**4.45**	**10.26**	**24.76**	**34.92**
1 Avoided wages lost						0.00	0.00	0.01	0.01	0.01
2 Other indirect benefits						0.0	0.0	0.0	0.0	0.0
3 Loss of beach income						0.1	4.5	10.3	24.8	34.9
Benefits–Costs	**0.00**	**0.00**	**−9.26**	**−9.26**	**−9.26**	**−1.36**	**5.14**	**−9.54**	**5.27**	**37.99**
NPV 2022–2051 (6%)	**81.1**									
IRR	**17 %**									

Source: Royal Haskoning DHV, unpublished.
Note: Blank cells indicate no costs and no benefits. IRR = internal rate of return; NPV = net present value.

Operational use of results

The objective of the Cyclone Idai & Kenneth Emergency Recovery and Resilience Project for Mozambique is to support the recovery of public and private infrastructure and livelihoods while strengthening climate resilience in the areas most affected by the cyclones. The CBA, part of the feasibility study, supported the government of Mozambique, the World Bank, Invest International, and KfW with the selection of economically viable design alternatives. Financing in the amount of $60 million has been allocated for investments in the four coastal sections, and the CBA can help ensure the economic returns of these investments. The CBA, combined with stakeholder engagement and implementation planning, demonstrated that a combination of green and gray interventions was the right approach for the coastal sections covered by the project. The feasibility study and the CBA together led to the identification of preferred alternatives, which were then further elaborated in a detailed design study.

Practical considerations

This feasibility study developed full preliminary design alternatives for four pre-identified coastal sections along the Beira coastline. The preliminary designs were developed in consultation with local stakeholders and included a detailed estimation of needs and costs of materials. As part of the assessment, a cost-benefit analysis evaluated the NPV and benefit-cost ratio of the specified alternatives to inform detailed design of the actual investment.

Budget range and timeline: **More than $500,000 (12 months)**

Note: This budget was used for the full feasibility studies of investments along the four coastal stretches, including preliminary designs, cost estimations, stakeholder engagement, and CBA. The quantification of risk reduction benefits (avoided damage from flooding and erosion) benefited from an existing flood risk assessment conducted previously with other funding.

Key expertise requirement:
For this type of analysis, recommended experience and qualifications are:
- An engineering firm with strong international experience and expertise in coastal protection projects and coastal hydrology/hydrodynamics;
- International experience with the scoping, evaluation, and design of NBS projects;
- An ecologist or marine biologist with knowledge of international best practices and cutting-edge technologies for beach and dune restoration and mangroves;
- An environmental economist with expertise in natural capital/ecosystem services valuation; and
- Expertise in modeling coastal risk and adaptation.

Replicability:
The CBA is highly replicable as part of a feasibility study for other coastal resilience projects in Mozambique or elsewhere. The study takes an integral approach to assessing a range of green and gray measures, including dune restoration, sand nourishment, and embankments. It also used a combination of data sets and approaches, both from existing risk assessments and from the analyses conducted under this feasibility study, to conduct the economic analysis.

Data requirement:
- A spatial flood risk model that quantifies the expected annual structural damages, affected population, and erosion impacts of a 50-year return period coastal flood;
- Detailed local costing of NBS and non-NBS design alternatives;
- Unit benefits from ecosystem services and avoided indirect flood impacts; and
- Stakeholder engagement to identify preferred alternative strategies.

Areas for improvement

- Integrated evaluation of NBS and non-NBS alternatives in the feasibility study. A multicriteria analysis and a CBA are conducted separately from each other in the same report and present different results.
- Scoping of other benefits, stakeholder engagement, and primary valuation of other ecosystem services benefits of NBS and non-NBS alternatives would be needed. A more sophisticated valuation of other benefits would enable mapping beneficiaries and potentially create opportunities to—for example—leverage tourism revenues to fund the operation and maintenance of beaches.

References for case study 8

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World Bank. 2020. Mozambique: Cyclone Idai & Kenneth Emergency Recovery and Resilience Project. https://projects.worldbank.org/en/projects-operations/project-detail/P171040.

Photo by DougSunBeams on Flickr

Appendix A

Table A1: Overview of primary valuation and value transfer approaches that are applicable to NBS benefits

Valuation method	Approach	Data requirements	Application to NBS	Limitations
Market prices	Prices for ES are directly observed in markets.	Prices of some ES can be obtained from markets or surveys of businesses and households.	ES that are traded directly in markets (for example, water, carbon).	Market prices can be distorted (for example, by subsidies). Most ES are not traded in markets.
Defensive expenditure	Expenditures are needed for the protection of ES.	Data on public or private expenditure can be obtained from government reports, key informants, or surveys of businesses and households.	ES for which there is public or private expenditure for its protection (for example, protection of urban forests used for recreation).	Applicable only where direct expenditures are made for environmental protection related to provision on an ES. Provides lower bound estimate of ES benefit.
Replacement cost	Estimate the cost of replacing an ES with an artificial service.	Estimates of construction costs can be obtained from experts or based on past investments.	ES that have artificial equivalents (for example, water quality regulation provided by inland wetlands replaced by water treatment facility).	No direct relation to ES benefits. Overestimates value if society is not prepared to pay for artificial replacement. Underestimates value if artificial replacement does not provide all of the benefits of the original ecosystem.
Restoration cost	Estimate the cost of restoring degraded ecosystems to ensure provision of ES.	Estimates of restoration costs can be obtained from experts or based on past investments.	Any ES that can be provided by restored ecosystems (for example, recreational use of urban ponds).	No direct relation to ES benefits. Overestimates value if society is not prepared to pay for restoration. Underestimates value if restoration does not provide all of the benefits of the original ecosystem.
Avoided damage cost	Estimate damage avoided due to ES.	Data on past damage costs and frequencies can be obtained from government reports and household surveys.	Ecosystems that provide storm, flood, or landslide protection to houses or other assets.	Difficult to quantify changes in risk of damage to changes in ecosystem condition.
Social cost of carbon (SCC)	Estimate the monetary value of damages caused by emitting 1 tonne of CO_2 in a given year. The social cost of carbon (SCC) therefore also represents the value of damages avoided for a 1 tonne reduction in emissions.	Estimates of the SCC can be obtained from Integrated Assessment Models of climate-economy impacts and published summaries of model results.	NBS that result in increased carbon sequestration and storage.	SCC is a specific application of the "damage cost avoided" method. SCC is characterized by high modeling uncertainties and partial coverage of climate change impacts.
Net factor income (residual value)	Estimate the revenue from sales of a marketed good with an ES input minus the cost of other inputs.	Revenues can be obtained from markets; costs can be obtained from business surveys.	Ecosystems that provide an input in the production of a marketed good (for example, wetlands and mangroves that support fisheries).	There is a tendency to overestimate values since all normal profit is attributed to the ES.
Production function	Provide a statistical estimation of production function for a marketed good with an ES input.	Data on production, inputs, costs, and revenues can be obtained from business surveys.	Ecosystems that provide an input in the production of a marketed good (for example, wetlands and mangroves that support fisheries).	Technically difficult to implement. Data requirements are high.
Hedonic pricing	Estimate the influence of environmental characteristics on the price of marketed goods (usually residential property).	Data on house prices and characteristics can be obtained from estate agents or public records. Data on environmental characteristics can be observed or modeled using biophysical methods.	Environmental characteristics that vary across goods (usually houses)—for example, flood risk reduction and recreation provided by urban forests.	Technically difficult to implement. Data requirements are high. Limited to ES that are spatially related to property locations.
Travel cost	Estimate demand for ecosystem recreation sites using data on travel costs and visit rates.	Data on travel costs and visit rates can be obtained through visitor surveys.	Recreational use of NBS ecosystems.	Technically difficult to implement. Data requirements are high. Limited to valuation of recreation. Complicated for trips with multiple purposes or to multiple sites.

Valuation method	Approach	Data requirements	Application to NBS	Limitations
Contingent valuation	Ask people to state their WTP for an ES through surveys.	Data can be collected through public surveys.	All ecosystem services.	Expensive and technically difficult to implement. There is a risk of biases in design and analysis.
Choice modeling (choice experiment)	Ask people to make trade-offs between ES and other goods to elicit WTP.	Data can be collected through public surveys.	All ecosystem services.	Expensive and technically difficult to implement. There is a risk of biases in design and analysis.
Unit value transfer	Select appropriate values from existing primary valuation studies for similar ecosystems and socioeconomic contexts. Adjust unit values to reflect differences between study and policy sites (usually for income and price levels).	Primary valuation results can be collected from literature or databases.	All ecosystem services.	Unlikely to be able to account for all factors that determine differences in values between study and policy sites. Value information for highly similar sites is rarely available.
Value function transfer	Use a value function derived from a primary valuation study to estimate ES values at policy site(s).	Value functions are published in primary valuation studies.	All ecosystem services.	Requires detailed information on the characteristics of policy site(s).
Meta-analytic function transfer	Use a value function estimated from the results of multiple primary studies to estimate ES values at policy site(s).	Meta-analytic value function can be gotten from literature.	All ecosystem services.	Requires detailed information on the characteristics of policy site(s). This is analytically complex. Value information for highly similar sites is rarely available.

Source: Original table for this publication.
Note: ES = ecosystem services; SCC = social cost of carbon; WTP = willingness to pay.


Photo by Deepak Kumar on Unsplash

Appendix B

EXAMPLES OF STUDIES ASSESSING THE BENEFTIS OF NBS FOR CLIMATE RESILIENCE

STUDY	Country	NBS Type	Scale	Risk reduction benefits (RRB)	Other benefits	Main analytical approach applied for RRB
Valuing Green Infrastructure: Case Study of Kali Gandaki Watershed, Nepal http://hdl.handle.net/10986/32757	Nepal	Forests, Terraces and slopes, Rivers and floodplains	Watershed	Landslide risk reduction	Provisioning of food and raw materials, Climate regulation	Cost-benefit analysis, Avoided lives lost, Avoided damages and costs
Wetlands Conservation and Management: A New Model for Urban Resilience in Colombo https://collaboration.worldbank.org/content/usergenerated/asi/cloud/attachments/sites/collaboration-for-development/en/groups/research-partnership-for-sustainable-urban-development/groups/urbanization-reviews/documents/jcr:content/content/primary/blog/wetlands_conservatio-c0LE/Wetlands-Conservation-and-Management-a-New-Model-for-Urban-Resilience-in-Colombo..pdf	Sri Lanka	Inland wetlands	City	Flooding and erosion, Extreme heat reduction	Climate regulation, Tourism and recreation, Wastewater Treatment	Cost-benefit analysis; Decision-making under uncertainty
Tam Phu Park, Thu Duc City – A multi-functional urban wetland and eco-social housing scheme. Case Study Report https://watersensitivecities.org.au/wp-content/uploads/2022/03/HCMC-case-study-report-ENG.pdf	Vietnam	Inland wetlands, Terraces and slopes	Site specific	Flooding and erosion, Drought (water flow regulation)	Tourism and recreation, Biodiversity	Cost-benefit analysis, Avoided damage costs
Project Assessment Document to the People's Republic of Bangladesh for a Coastal Embankment Improvement Project Phase-I May 29, 2013 (PAD) https://documents1.worldbank.org/curated/en/748531468209052823/pdf/744820PAD0P1280disclosed060701300SD.pdf	Bangladesh	Mangrove forests	Large coastal area	Flooding and erosion	Provisioning of food and raw materials, Health	Cost-benefit analysis, Avoided damages and costs
Forces of Nature: Assessment and Economic Valuation of Coastal Protection Services Provided by Mangroves in Jamaica http://documents.worldbank.org/curated/en/357921613108097096/Forces-of-Nature-Assessment-and-Economic-Valuation-of-Coastal-Protection-Services-Provided-by-Mangroves-in-Jamaica	Jamaica	Mangrove forests	National and Site specific	Flooding and erosion	Climate regulation (blue carbon), Provisioning of food and raw materials	Avoided damages and costs

STUDY	Country	NBS Type	Scale	Risk reduction benefits (RRB)	Other benefits	Main analytical approach applied for RRB
The Economics of Large-scale Mangrove Conservation and Restoration in Indonesia https://www.worldbank.org/en/country/indonesia/publication/the-economics-of-large-scale-mangrove-conservation-and-restoration-in-indonesia	Indonesia	Mangrove forests	National	Flooding and erosion	Climate regulation, Provisioning of food and raw materials, Tourism and recreation	Spatial cost-benefit analysis, Avoided damages a nd costs
Indonesia- Mangroves for Coastal Resilience Project (PAD) https://documents.worldbank.org/en/publication/documents-reports/documentdetail/793041653404341879/indonesia-mangroves-for-coastal-resilience-project	Indonesia	Mangrove forests	National	Flooding and erosion	Climate regulation, Provisioning of food and raw materials, Tourism and recreation	Spatial cost-benefit analysis, Avoided damages and costs
Cost-Benefit Analysis of Mangrove Restoration for Coastal Protection and an Earthen Dike Alternative in Mozambique https://www.climatelinks.org/resources/cost-benefit-analysis-mangrove-restoration-coastal-protection-and-earthen-dike	Mozambique	Mangrove forests	Site specific	Flooding and erosion	Provisioning of food and raw materials, Climate regulation	Cost-benefit analysis, Avoided damage costs
Mangroves as Protection from Storm Surges in Bangladesh https://openknowledge.worldbank.org/server/api/core/bitstreams/0b903252-3907-5905-8a07-c1fce695e705/content	Bangladesh	Mangrove forests	Large coastal area	Flooding and erosion	n.a.	Only benefit scoping
Strong Roots, Strong Women: Women and Ecosystem-based Adaptation to Flood Risk in Central Vietnam https://www.wocan.org/resource/strong-roots-strong-women-women-and-ecosystem-based-adaptation-to-flood-risk-in-central-vietnam/	Vietnam	Ponds, lakes, and small water bodies	City	Flooding and erosion	Provisioning of food and raw materials, Tourism and recreation	Cost-benefit analysis, Discrete choice experiment

STUDY	Country	NBS Type	Scale	Risk reduction benefits (RRB)	Other benefits	Main analytical approach applied for RRB
Strategies for Large Scale Coral Reef Restoration for Coastal Resilience in the Seychelles https://naturebasedsolutions.org/knowledge-hub/46-strategies-large-scale-coral-reef-restoration-coastal-resilience-seychelles	Seychelles	Reef ecosystems	National (scoping phase)	Flooding and erosion	Biodiversity, Tourism and recreation, Climate regulation (only identification)	MCA
Mapping the Risk Reduction Benefits of Coral Reef Conservation https://www.fema.gov/case-study/mapping-risk-reduction-benefits-coral-reef-conservation	United States	Reef ecosystems	Large coastal area	Flooding and erosion	n.a.	Avoided damages and costs
Quantifying Flood Risk and Reef Risk Reduction Benefits in Florida and Puerto Rico: The Consequences of Hurricane Damage, Long-term Degradation, and Restoration Opportunities https://www.usgs.gov/centers/pcmsc/science/quantifying-flood-risk-and-reef-risk-reduction-benefits-florida-and-puerto	United States	Reef ecosystems	Large coastal area	Flooding and erosion	n.a.	Avoided damages and costs
International Bank for Reconstruction and Development Project Appraisal Document on a Proposed Loan in the Amount of UA$150.00 million to the People's Republic of China for a Qinghai Xining Water Environment Management Project (PAD) https://documents1.worldbank.org/curated/en/956941468220182643/pdf/PAD6970PAD0P13010Box385316B00OUO090.pdf	China	River and floodplain	City	Flooding and erosion, Drought (water flow regulation)	Water quality	Cost-benefit analysis
Coastal Protection Project: preparation studies for Beira,Mozambique. Feasibility Report (Unpublished report)	Mozambique	Sandy shores and dunes, Mangroves forests	Site specific	Flooding and erosion	Tourism and recreation, Job creation	Cost-benefit analysis; Avoided damages and costs
Comparing the cost effectiveness of nature-based and coastal adaptation: A case study from the Gulf Coast of the United States https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0192132	United States	Sandy shores and dunes, Reef ecosystems, Coastal wetlands,	Large coastal area	Flooding and erosion	n.a.	Cost-benefit analysis based on Avoided damages and costs

STUDY	Country	NBS Type	Scale	Risk reduction benefits (RRB)	Other benefits	Main analytical approach applied for RRB
2017 Coastal Master Plan https://coastal.la.gov/our-plan/2017-coastal-master-plan/	United States	Sandy shores and dunes, Reef ecosystems, Coastal wetlands	Large coastal area	Flooding and erosion	Provisioning of food and raw materials, Tourism and recreation, Job creation	Cost-benefit analysis based on Avoided damages and costs
Vietnam- Mekong Delta Integrated Climate Resilience and Sustainable Livelihoods Project https://documents.worldbank.org/en/publication/documents-reports/documentdetail/840701467996680631/vietnam-mekong-delta-integrated-climate-resilience-and-sustainable-livelihoods-project	Vietnam	Terraces and slopes, Mangrove forests	Watershed	Flooding and erosion, Drought (water flow regulation)	Provisioning of food and raw materials, Water quality	Cost-benefit analysis, Discrete choice experiment
Burundi hotspots mapping: climate and conflict. Diagnosing Drivers of Climate and Environmental Fragility in Burundi's Colline Landscapes – Climate & Conflict Risks https://p-phung.github.io/Burundi_hotspots/	Burundi	Terraces and slopes, River and floodplains, Urban and upland forests	National	Landslide risk reduction	Provisioning of food and raw materials, Transport	Only benefit scoping
Proposed Credit in the Amount Of SDR 124.9 Million to the People's Republic of Bangladesh for a Sustainable Forests & Livelihoods (SUFAL) Project (PAD) https://documents1.worldbank.org/curated/en/395741538969430897/pdf/P161996-PAD-post-rvp-147pm-09182018.pdf	Bangladesh	Urban and upland forests	National	Flooding and erosion, Landslide risk reduction (only identification)	Climate regulation, Provisioning of food and raw materials	Cost-benefit analysis
Urban Climate, "Urban heat in Johannesburg and Ekurhuleni, South Africa: A meter-scale assessment and vulnerability analysis https://www.sciencedirect.com/science/article/pii/S2212095522002498	South Africa	Urban green	City	Extreme heat reduction	Health, Productivity, Transport	Only benefit scoping
Economic Assessment of Heat in the Phoenix Metro Area https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_EcoHeatAssement_AZ_Report.pdf	United States	Urban green	City	Extreme heat reduction	Health, Productivity, Transport	Cost-benefit analysis, Avoided lives lost, Avoided damages and costs

STUDY	Country	NBS Type	Scale	Risk reduction benefits (RRB)	Other benefits	Main analytical approach applied for RRB
Making the Case for Investing in Nature-Based Solutions: A Case Study from Tshwanf https://wwfint.awsassets.panda.org/downloads/making_the_case_for_investing_in_nature_based_infrastructure.pdf	South Africa	Urban green	Site specific	Flooding and erosion, Extreme heat reduction	Climate regulation	Value transfer, Market prices
Assessment of Key Ecosystem Services Provided by the Haizhu National Wetland Park in Guangzhou, China https://www.thegpsc.org/sites/gpsc/files/haizhu_wetland_report_fin.pdf	China	Urban green, Inland wetlands	City	Extreme heat reduction	Health, Climate regulation	Cost-benefit analysis, Avoided damages and costs
Upscaling Nature-Based Flood Protection in Mozambique's Cities: Cost-Benefit Analyses for Potential Nature-Based Solutions in Nacala and Quelimane https://naturebasedsolutions.org/knowledge-hub/31-upscaling-nature-based-flood-protection-mozambiques-cities-cost-benefit-analyses	Mozambique	Urban green, Ponds, lakes, and small water bodies, Mangroves forests	City	Flooding and erosion	Provisioning of food and raw materials, Climate regulation	Cost-benefit analysis, Avoided damage and costs
Towards a Circular Island Economy – Duong Dong Freshwater Wildlife Conservation Park, Phu Quoc. Case Study Report. Valuing the Benefits of Nature-based Solutions for Integrated Urban Flood Management in the Greater Mekong Region https://watersensitivecities.org.au/wp-content/uploads/2022/03/PQ-case-study-report-ENG.pdf	Vietnam	Urban green, Ponds, lakes, and small water bodies, Rivers and floodplains	Site specific	Flooding and erosion	Water quality, Biodiversity, Tourism and recreation	Cost-benefit analysis, Avoided damage and costs
The Economic Benefits of Green Infrastructure: A Case Study of Lancaster, PA https://www.epa.gov/green-infrastructure/economic-benefits-green-infrastructure-case-study-lancaster-pa	United States	Urban green, Ponds, lakes, and small water bodies, Upland and urban forest	City	Drought (water flow regulation), Extreme heat reduction	Water quality, Climate regulation	Avoided damages and costs

Source: Original table for this publication.
Note: MCA = multicriteria analysis; n.a. = not applicable.

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GLOSSARY

Baseline (scenario): The starting point from which the impact of a project, policy or investment is assessed. In the context of ecosystem service valuation, the baseline is a description of the level of ecosystem service provision in the absence of the intervention under consideration. The baseline describes both the current and future provision in the absence of the intervention.

Benefits: "Goods and services that are ultimately used and enjoyed by people and society" (UN 2022).

Biodiversity: The "variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (Convention on Biological Diversity 2006).

Biophysical models: Simulation of a biological/physical system using mathematical formalizations of the physical properties of that system. Such models can be used to predict the influence of biological and physical factors on complex systems.

CAPEX (capital expenditure): Funds used by the project to acquire, upgrade, and maintain major physical assets providing benefits in the long term such as property, plants, buildings, technology, or equipment.

Climate adaptation: The process of adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. These changes in processes, practices, or structures aim to moderate potential damage or to benefit from opportunities associated with climate change.

Climate mitigation: Interventions aiming to make the impacts of climate change less severe by preventing or reducing the emission of greenhouse gases (GHG) into the atmosphere. Mitigation is achieved either by reducing the sources of these gases or by enhancing the storage of these gasses.

Climate resilience: The ability to anticipate, prepare for, and respond to hazardous events, trends, or disturbances related to climate change.

Disaster: "Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery" (IPCC 2014).

Disaster risk reduction: "Denotes both a policy goal or objective, and the strategic and instrumental measures employed for anticipating future disaster risk; reducing existing exposure, hazard, or vulnerability; and improving resilience" (IPCC 2014).

Discount rate: "A mathematical operation making monetary (or other) amounts received or expended at different times (years) comparable across time. The discounter uses a fixed or possibly time-varying discount rate (>0) from year to year that makes future value worth less today" (IPCC 2014).

Disservices (ecosystem disservices): These "arise in contexts in which the outcomes of interactions between economic units and ecosystem assets are negative from the perspective of the economic units" (UN 2022).

Economic value: The value that a person places on an economic good/service based on the benefit that they derive from the good/service. It is often estimated based on the person's willingness to pay for the good/service, typically measured in units of currency. The economic value should not be confused with market value, which is the market price for a good or service, which can be higher or lower than the economic value that any particular person puts on a good. The economic value is then subjective and difficult to measure, though there are approaches to estimating it.

Ecosystem services: "The benefits people obtain from ecosystems" (IPBES, no date).

Ecosystem service assessment: Simulation of how an action (that is, an NBS project) translates into impacts on valued ecosystem services. It relates the action to valued environmental outcomes through an ecological/physical production function and measures how the change in those outcomes affects people.

Exposure: "The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected" (IPCC 2014).

Externalities: A positive or negative consequence (benefits or costs) of an action that affects someone other than the agent undertaking that action and for which the agent is neither directly compensated nor penalized (**Dasgupta 2021**).

Green infrastructure: Natural or semi-natural systems including forests, floodplains, wetlands, and soils that provide additional benefits for human well-being, such as flood protection and climate regulation.

Gray infrastructure: Human-engineered structures such as water and wastewater treatment plants, pipes, dams, seawalls, and roads.

Hazard: " The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources" (IPCC 2014).

Hybrid infrastructure: Adaptation interventions that combine engineered (gray), nature-based (green), and/or indirect actions.

Mitigation hierarchy: A set of guidelines, established through the International Finance Corporation's Performance Standard 6, meant to help development projects prepare for impacts and aim to achieve no net loss of biodiversity. The hierarchy follows avoidance, minimization, restoration, and offsets in order to reduce development impacts and control any negative effects on the environment.

Monetary value: The amount of currency that would be exchanged for the sale of a resource, product, or service.

Natural capital: The stock of renewable and nonrenewable natural assets (for example, ecosystems) that yield a flow of benefits to people (that is, ecosystem services). The term *natural capital* is used to emphasize that it is a capital asset, like produced capital (roads and buildings) and human capital (knowledge and skills) (**Dasgupta 2021**).

Nature-based solutions: Defined by the United Nations as "actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits" (UNEP 2022).

Net present value: This applies to a series of cash flows occurring at different times. The present value of a cash flow depends on the interval of time between now and the cash flow and the discount rate applied. It provides a method for evaluating and comparing capital projects or financial products with cash flows spread over time.

OPEX (operating expenses): A project's ongoing day-to-day expenses such as salaries, rent, utilities, taxes, and monitoring costs.

Opportunity cost: The benefits of an activity forgone through the choice of another activity.

Other benefits: The other relevant society benefits derived from positive ecosystem services of an NBS for resilience project in addition to reducing climate and disaster risk. This guideline addresses an inexhaustive selection of six main types of other benefits (also known as *co-benefits*) provided by NBS: provisioning of food and raw materials, tourism and recreation, carbon storage and sequestration, biodiversity, water quality, and health.

Primary valuation methods: Valuation methods and studies that produce a new or original value estimate for a specific ecosystem.

Resilience: The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure while also maintaining the capacity for adaptation, learning, and transformation (Arctic Council 2013).

Risk: "The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard" (IPCC 2014).

Risk assessment: "The qualitative and/or quantitative scientific estimation of risks" (IPCC 2014).

Risk reduction benefits: The positive contribution to people derived from an NBS project aiming at reducing socioeconomic vulnerabilities to disaster as well as dealing with the environmental and other hazards that trigger them. This guideline focuses on five major processes underpinning change in risk: flooding, erosion, water provision and droughts, heat, and landslides.

Uncertainty: Any situation in which the current state of knowledge is such that the order or nature of things is unknown; the consequences, extent, or magnitude of circumstances, conditions, or events is unpredictable; and credible probabilities to possible outcomes cannot be assigned (**Dasgupta 2021**).

Urban heat island: Urban or metropolitan area that is significantly warmer than its surrounding rural areas as a result of human activities, notably the replacement of natural land cover with dense concentrations of pavement, buildings, and other surfaces that absorb and retain heat.

Value transfer methods: This refers to applying quantitative estimates of ecosystem service values from existing studies to another context (from similar ecosystems and socioeconomic contexts). Value transfer methods are usually applied when time and/or resource constraints preclude the possibility of doing a primary valuation study.

Vulnerability: "The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC 2014).

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Key references

GLOBAL PROGRAM ON
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